DEVELOPMENT OF GESTURE AND SPEECH IN TYPICALLY DEVELOPING INFANTS

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CERTIFICATE

This is to certify that the thesis entitled ***"Development of Gesture and Speech in Typically Developing Infants"*** submitted by Ms. Mili Mary Mathew for the award of degree of Doctor of Philosophy (Speech and Hearing) to the University of Mysore, Mysore, was carried out at the All India Institute of Speech and Hearing, Mysore.

Place: Mysore
Date: 02.03.2016

Director
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CERTIFICATE

This is to certify that the thesis entitled ***"Development of Gesture and Speech in Typically Developing Infants"*** submitted by Ms. Mili Mary Mathew for the award of degree of Doctor of Philosophy (Speech and Hearing) to the University of Mysore, Mysore is the result of original work carried out by her at the All India Institute of Speech and Hearing, Mysore, under my guidance.

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DECLARATION

I declare that this thesis entitled ***"Development of Gesture and Speech in Typically Developing Infants"*** submitted herewith for the award of degree of Doctor of Philosophy (Speech and Hearing) to the University of Mysore, Mysore is the result of work carried out by me at the All India Institute of Speech and Hearing, Mysore, under the guidance of Dr. R. Manjula, Professor, Dept. of Speech Language Pathology, All India Institute of Speech and Hearing, Mysore. I further declare that the results of this work have not been previously submitted for any other degree.

Place: Mysore
Date: 02.03.2016

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ABSTRACT

ABSTRACT

The faculty of communication in humans is special; it is complex, systematic, and is context-bound (Berko-Gleason, 1997). Communication is also multi-faceted, in that, the linguistic code is enhanced through paralinguistic (suprasemental aspects), nonlinguistic (facial expressions, hand gestures etc.) and metalinguistic (analytical skills) codes (Owens, 2012). It is often suggested that human communication has evolved from other primate communication which is essentially nonlinguistic in nature (Tomasello, 2008). Therefore, vocal communication is hypothesized to have emerged from conventional gestures.

Kelly, Ozyurek & Maris (2010) consider speech and gesture as two sides of the same coin, because both gestures and speech mutually enhance comprehension in either of the two modalities. Moreover, there never is a true distinction between speech and gestural communication, since speech is universally accompanied by gestures and the synchrony between the two behaviours is hypothesized to be controlled by a single system (McNeill, 1985). However, both these modalities are not well integrated right from birth in children; it is only by 10 months that children begin to produce meaningful gestures, which precedes the acquisition of meaningful words (Bates, 1976; Bates, Benigni, Bretherton, Camaioni & Volterra, 1979; Veena, 2010; Veena & Rajshekar, 2015). Further, children as young as 3 months old are found to systematically sequence vocalizations with facial actions, hand gestures etc. (Ejiri, 1998; Fogel & Hannan, 1985; Iverson & Fagan, 2004; Murillo & Belinchon, 2012; Yale, Messinger, Cobo-Lewis, Oller & Eilers, 1999). However, we still know little about the origins of manual and non manual gestures, and the co-development of these

gestures with speech in infants. This is because gestures have most often been studied as independent behaviours at an age below or above 12 months and not as parts of the same communication system. Also many of these studies in infants have used different methodologies and have been done across different age groups, and therefore do not provide a comprehensive picture. And, it is necessary that the development of multimodal behaviours in children is documented in order to facilitate the understanding of communication breakdowns in children with atypical development. This is especially true in the Indian context, and it is with this understanding that the present study was conducted.

Therefore, this study aimed to document the development of gestures and speech across age and observe for patterns of emergence, the growth trends of these behaviours as well as the coordination patterns between gestures and speech in typically developing infants from Kannada speaking families, from 3 months till 12 months of age. The objectives of the study were threefold so as to investigate and compare the following across age; (1) Gestural behaviours of face, gaze, head, leg, torso, whole body as well as hands, (2) Speech behaviours of pre-speech, vocalic, syllabic and verbal utterances, and (3) Emergence of gesture - speech coordination.

The data was analyzed in order to test two hypotheses. The first hypothesis was that, both gestures and speech would demonstrate similar growth patterns, within the first year of life, as they are components of the same communication system. The second hypothesis was that speech and gestures would co-occur from the age of 3 months and with age, there would be differential patterns of coordination exhibited by various behaviours within each modality. Nine typically developing infants (three girls and six boys) participated in the study. They were followed for a period of 10 months, with the first recording taken at the age of 3 months and the last recording taken at 12 months of age. Each infant and the mother were videotaped at their home, during naturally occurring interaction/play, once a month. Gesture and speech behaviours observed in the infants were annotated using ELAN software, based on a *key* that consisted of the operational definitions for each of the behaviours studied. Apart from the investigator, who coded all videos, two other coders (speech language pathologists) annotated 13 % (10 videos; 1 video per month of study) of the data in order to estimate inter-coder reliabilities. Additionally, intra-coder reliability was also calculated. Further, instances in which the speech and gestural behaviours co-occurred in time were noted, in order to understand the coordination patterns of behaviours across modalities. These were studied for three time frames, namely, >3 months to ≤ 5 months, 29 days (initial pre-linguistic phase), >6 months to ≤ 7 months, 29 days (middle pre-linguistic phase) and >8 months to ≤ 12 months (final pre-linguistic phase). Measures such as percentage frequency of occurrence/co-occurrence and rates of occurrence/co-occurrence were calculated.

The results suggested that gestures and speech shared both common and different characteristics of growth, not entirely supporting our first hypothesis. Further, there were significant differences seen in the rates of occurrence of most behaviours within both modalities across the months of study, suggestive of differences in the patterns of acquisition of these behaviours. It was seen that behaviours either demonstrated positive or negative correlations with age, and behaviours within each developing system demonstrated coordinated patterns of growth. Most behaviours exhibited non-linear patterns of growth, with only few behaviours within the gestural modality exhibiting linear patterns. Behaviours in the gestural modality (except movements of torso and symbolic hand movements) showed significant changes in the patterns of occurrence of behaviours at certain ages, however, this trend was not exhibited by behaviours in the speech modality.

Further, speech and gestural behaviours co-occurred with each other from the age of 3 months, and with age, there were differences observed in the patterns of co-occurrence for behaviours in both modalities. This satisfied the assumption of the second hypothesis. Moreover, hand movements were found to co-occur with speech at highest frequencies across the developmental timeframes that were studied. There were significant developmental influences seen in the co-occurrence of pre-speech and syllabic utterances with gestures, with these behaviours co-occurring at higher rates in the initial pre-linguistic phase of development. There was wide variation observed in the co-occurrence of various behaviours within both modalities, and interestingly, novel behaviours in both modalities (such as symbolic hand movements and true words) did not co-occur with each other or with other well practiced behaviours.

The findings of this study suggest that infant development is indeed a multimodal phenomenon. Additionally, a large number of factors such as biological maturation, neuro-muscular development, environmental factors and even interaction styles of caregivers seemed to determine the occurrence of these behaviours. These highlight the need for studying the role of communication as a multifaceted skill even in atypically developing children.

INTRODUCTION

INTRODUCTION

Human beings are multimodal while speaking: they move their hands, head, arms and whole body during the process of communication. Gesturing constitutes the nonverbal aspect of communication. It is common to note that people of all ages, cultures and backgrounds gesture when they speak (Kelly, Manning & Rodak, 2008). Contrary to earlier observations that gestures are movements produced by hands in a human being, it is now affirmed that gesture is not only performed with hands, but by other parts of body, such as the head, the face or the arms. Thus, gestures are defined as manual [e.g., waving arms to say goodbye], facial [e.g., pouting of lips to show displeasure], or other body movements [e.g., miming/mimicking an object or person] (Capone, 2010).

Gestures are clearly not random movements; rather these movements are used to communicate some meaning. They are visual and spatial phenomena that are influenced by contextual and socio-psychological factors that are closely tied to complex speaker-internal, and linguistic processes (Gullberg, deBot, & Volterra, 2010). According to Kendon (2004), gestures are the imagistic portion of a linguistic utterance. Other investigators have also observed that gestures are highly integrated with speech and that they aid in language production and comprehension (Goldin-Meadow, 2003; McNeill, 1992). Moreover, speech and gestures are reported to share the same neural structures in both perception and production (Bernardis & Gentilucci, 2006; Dick et al., 2014; Holle & Gunter, 2007; Xu, et al., 2009; Yang, Andric & Mathew, 2015). It is also assumed that, like verbal language, gestures are acquired from exposure to the gestures used by a linguistic or cultural community.

There are several lines of support which suggest that human language originated from a manual mode and not from vocal mode (Corballis, 2012), and these include evidences both from findings on human and non-human primates. One excellent observation that provides support to this construct is that hands provide a natural medium to communicate regarding the world since its contents are arrayed in space and time. Therefore, as primates, humans are said to have evolved with pre-adaptations for the production and perception of movements of the hands and arms, which was further enhanced by the appearance of the bi-pedal posture in the early human ancesters (Corballis, 2012).

Donald (1991) proposed that verbal language probably emerged from pantomime, as it uses the body to convey meaning, and they most often represent what one refers to. On the other hand, the verbal system of language uses arbitrary symbols (words for sentences) which may not be directly representing the idea/thought that it refers to. Ramachandran and Hubbard (2001) express that since communication is vision-centric, manual gestures offer flexibility for the labeling of objects. On similar lines, Gentilucci and Corballis (2006) reported that the origins of vocal production might be linked to gestural movements based on studies that relate ‘mouth opening’ to ‘manual grasping’.

Studies on non-human primates have shed valuable insights on the evolution of language, as there are similarities reported in the communication systems of humans and other primates (Hauser & Konishi, 1999; Snowdon, Brown, Petersen, 1982). Studies addressing vocalization patterns of non-human primates have observed that they have distinct alarm calls in response to different predators, as well as for organizing different escape responses, suggesting that these vocalizations are used for referential communication (Cheney &

Seyfarth, 1990). A good number of studies have also revealed that there is limited flexibility in their call morphology and usage (Corballis, 2002; Lieberman, 2007). Few other investigators have put forth evidences to show that some primate species show audience effects on vocalizations; categorical perception of vocalizations; acoustic typicalities to regulate vocal exchange; flexibility in vocal production, vocal learning and the ability to combine calls into higher-order sequences in order to reflect a meaningful exchange (Arnold & Zuberbuhler, 2006; Caine, Addington & Windfelder, 1995; Crockford et al., 2004; Masataka, 1983; Mitani & Nishida, 1993; Sugiura, 1993; Sugiura, 1998). In addition to these vocalizations, non-human primates have also been found to use hand/manual gestures in their communication (van Hoof, 1967). Dunbar (1998) reported that chimpanzees are capable of intentional use of hand and arm movements and also have the abilities to learn manual skills. Bogart and Pruetz (2008) also observed that chimpanzees possess the ability to make and use tools, mainly for hunting. Attempts to teach apes to speak have remained largely unsuccessful, although there have been instances where these non-human primates have been able to learn and use sign language, develop pointing skills and even invent gestures to communicate (Gardner & Gardner, 1969; Savage-Rumbaugh, Shanker & Taylore, 1998).

Taken together, these findings suggest that since the vocal system in non-human primates is not well developed, language would have initially evolved within the visuo-manual modality followed by the development of vocal modality in human primates. Such an observation derives additional support from studies on human infants and children, which suggest that gestures precede speech in the process of development of communication (Corballis, 2012). Luria (1959,1960), for example, theorized that children develop skills with the interactions of two cognitive systems, namely, the nonverbal and verbal systems; that the nonverbal system heralds the development of the verbal, and children interact with their environment using both these systems. Further, recent understanding of the developmental processes also hints at the communication process occurring in a dynamic context, with the influence of intrinsic (neuro-biological maturation of various systems) and extrinsic (mother-infant relationship, perception, environment etc.) processes relevant to a given child (Gerhskoff-Stowe, 2002; Gogate, Walker-Andrews & Bahrick, 2001; Rohlfing, 2008).

Research on the development of hand gestures, in particular, provides a window into the understanding of the influences of multimodality in the development of communication. From birth, infants are found to move their hands and these movements seem to be integrated with vocal productions and possibly reflect the beginnings of the gesture-speech relationship as seen in adults (Iverson & Thelen, 1999; Goldin-Meadow & Iverson, 2010). Although hand movements and speech appear to be integrated from an early age, it is only by 10 months that children begin to produce meaningful gestures, which precedes the acquisition of meaningful words (Bates, 1976; Bates et al., 1979). By the age of 16 months, gestures are used for communication more frequently than words, and by 20 months of age this trend gets reversed (Caprici & Volterra, 2008). It has also been documented that the initial two-word utterances are most often a gesture combined with a single word which paves way for future utterances composed of two spoken words. Iverson and Goldin-Meadow (2005) have also suggested that early manual gestures in childhood can predict language development till the two-word level. Moreover, it has been documented that hand gestures can predict language learning, in terms of vocabulary size and the ability to produce complex sentences. and therefore it can be considered an index of communicative competence (Caprici, Iverson, Pizzuto & Volterra, 1996; Goodwyn & Acredolo, 1998; Goldin-Meadow et al., 2007). As they grow older, children begin to depend more on verbal symbols than gestures, although their use of abstract, metaphoric and beat gestures develops with their ability to use discourse as well as prosodic structures in their spoken utterances (McNeill, 2005).

It is therefore reasonable to suppose that since hand gestures precede and support the development of verbal communication skills, these gestures may have an important role in the evolution of language in humans, as evidenced from early hominin ancestors. One has to also consider the presence of other forms of gestures or motor behaviours as an important aspect of human communication process. This is evidenced in both adult and child expressive communication, as well as in the expression of emotions (Ludtke, 2012). In infants, early expressive actions occur in the form of facial actions, and other bodily actions (legs, gaze etc.) which are produced either in isolation or in combinations to represent a message. As development unfolds, each of these modalities undergo changes while the ability of the child to synchronize and combine behaviours from these different modalities also develop (Parlade & Iverson, 2011).

There are few evidences to support the temporal relationship seen between manual gestures and speech in children and these are majorly taken from two sources:

a) From the relationship between vocal and motor activity in early infancy which suggests that very young infants between the ages of 2 to 20 weeks structure their hand actions with vocalization or other movements related to the mouth (e.g. mouth opening) (Fogel & Hannan, 1985; Lew & Butterworth, 1997; Trevarthen, 1977) and,

b) From the relationship between production of rhythmic manual movements and the emergence of babbling in later infancy, which suggests that there is an increase in the production of upper limb rhythmicities at the onset of babbling (Ejiri, 1998; Iverson and Fagan, 2004).

Few other studies have supported the coordinated occurrences of non-manual/body behaviours and speech in children. One such study examined the temporal relationship between facial actions (e.g. smile and frown) and vocalizations in 12 infants at the ages of 3 and 6 months (Yale, Messinger, Cobo-Lewis, Oller & Eilers, 1999). It was found that infants were sequencing vocalizations and vocal expressions within the first 6 months of life across interactive contexts. They also observed two patterns of coordination; one pattern in which infants temporally embedded one communicative event in another and a second pattern, in which they were seen to end vocalizations before ending facial actions. Murillo and Belinchon (2012) studied 11 Spanish children from 9 to 15 months of age. They coded vocalizations, gestures (any motor action) and gaze behaviours in these infants and concluded that the rate of use of multimodal behaviours increased significantly with age for the observed periods. They also suggested that the rate of use of multimodal behaviours at the age of 12 months seemed to predict the development of vocabulary at the age of 15 months. It was also documented that pointing gestures were the best predictors of lexical outcomes; especially the pointing gestures that accompanied vocalizations and the social use of gaze at 12 months of age in these children.

Taken together, these studies suggest that gestures, both manual and non-manual, play a role in language acquisition and possibly even during later stages of language learning, and that gesture-speech relationship changes at different stages of development and in different interactional contexts. At around one year of age, gestures play a crucial role in the creation and expression of meaning. In the following years, gesture develops together with speech. At later years, gesture production appears to decrease in some linguistic contexts (e.g., naming tasks) although it is frequently used with speech in others (e.g., narratives); but gesturing never disappears and continues well into adulthood. Studies have also suggested that adult pattern of gesture-speech temporal synchrony is evident by the time children transit to two-word utterances (Butcher & Goldin-Meadow, 2000; Kelly, 2014).

Currently, however, we know little about the origins of manual and non manual gestures, and the co-development of these gestures with speech in infants, especially in the Indian context, when compared to the plethora of information that is available on the acquisition and development of speech in infants and children (Anjana & Sreedevi, 2008; Oller, 1980; Reeny & Sreedevi, 2013; Rupela & Manjula, 2006; Stark, 1980). The development of communicative hand and few other whole-body gestures (e.g. facial gestures) in typical and atypical children from few linguistic backgrounds has been documented, including that of children from Kannada speaking backgrounds (Bates, 1976; Camras, Holland & Patterson, 1993; Owens, 2012; Savithri, 1988; Thelen, 1981; Veena & Rajashekar, 2015). However, in these studies, gestures have most often been studied as independent behaviours at an age below or above 12 months and not as parts of the same communication system. For example, the study on Kannada speaking children documented the development of symbolic hand gestures, the pragmatic context in which they occurred, as well as the gesture-speech combinations in infants from 8 to 18 months (Veena, 2010; Veena & Rajashekar, 2015). This study reported that deictic gestures were observed from 8 months; ‘reach’ from 8 months, ‘points’ from 13 months, ‘give and take’ between 11-14 months, and ‘show’ between 12-13 months. However, there were variations observed in the ages of acquisition of these gestures based on the communicative functions that the gestures served, for example, ‘request for object’ was seen around 8-9 months, whereas ‘request for action’ was seen around 11-12 months. Representational gestures were reported to emerge between 9 and 10 months of age, and children were found to use more complex gestures as their age increased. It was also established that combinations of hand gestures and speech (both vocalizations and verbalizations) that represented a single message developed around the age of 1 year and the children frequently produced supplementary (gesture and speech refer to different aspects of the linguistic unit) combinations than complementary (gesture and speech refer to the identical aspects of the linguistic unit) ones. Veena and Rajashekar (2015) concluded that Kannada-speaking children use communicative hand gestures of ‘point’, ‘reach’, symbolic and representational gestures around the same age as children from American English speaking backgrounds. However, this study did not focus on the analysis of other behaviours, such as facial gestures, that simultaneously develop within the motor modality which contribute to the development of communication, in order to understand the coordinated patterns of emergence of these behaviours in infancy. Moreover, the study followed an ‘elicited-response approach’, in that parents were informed regarding the target behaviours and were encouraged to elicit the same during their recorded interactions.

Similarly, few studies have documented that the beginnings of gestural forms are often connected with vocal forms, and can be seen very early in human infants (Bower, 1974; Fogel, 1981; Fogel &Hannan, 1985; Hannan, 1987; Thelen, Kelso & Fogel, 1987). For example, a longitudinal study on 8 infants, between the ages of 9 to 15 weeks explored the relationship between manual actions, vocalizations, gaze, and facial expressions, while these infants were interacting with their mothers (Legerstee, Corter & Kienapple, 1990). When the mothers were active, it was seen that ‘pointing’ followed ‘smiling’, ‘neutral expressions’, ‘gazing’, and ‘vocalizations’, and these were significantly more than what would be expected by chance. While during the passive-mother condition, it was observed that ‘pointing’ followed ‘neutral’, ‘distressed expressions’, ‘gaze aversion’, ‘gazing’ and ‘vocalization’, whereas in the active and passive object condition no such patterns were seen. Thus, the results showed that young infants produced discrete hand actions that followed specific facial expressions during interactions. These links are said to resemble adult-like patterns as children grow older (Butcher & Goldin-Meadow, 2000; Esteve-Gibert & Prieto, 2014; Kelly, 2014). However, many of these studies in infants have used different methodologies and have been done across different age groups.

There is also growing number of evidence which points out that gesture development is affected in children with communication disorders. It has been suggested that gestures may play a compensatory role (use of gestures to compensate for their deficits in verbal communication) in children with SLI (Evans, Alibali & McNeill,2001; Mainela-Arnold, Alibali, Hostetter, Evans, 2014) and Down syndrome (Caselli et al., 1998; Os, Jongmans, Volman & Lauteslager, 2015) while gestures are found to be equally delayed as that of verbal language in children with unilateral perinatal early brain lesions (Ozcaliskan, Levine & Goldin-Meadow, 2013) and autism spectrum disorders (So, Wong, Lui &Yip, 2014). There is also increasing interest to examine whether interventions focusing on increasing manual gestures will facilitate the use of language in children with communication disorders, similar to what has been observed in adults with aphasia (Rose, Attard, Mok, Lanyon & Foster, 2013).

Therefore, it is necessary that the development of multimodal behaviours in children is documented in order to facilitate the understanding of communication breakdowns in children with atypical development. Moreover, if mature speech derives its roots from early pre-speech behaviours, the same might be the case even for manual and non-manual gestures, since speech and gestures share a close relationship in adults. Thus, it would be interesting to understand if early gestures and speech behaviours in infants show a coordinated developmental pattern that paves way for mature communication.

This study aimed to document the development of gestures and speech across age and observe for patterns of emergence, the growth trends of these behaviours as well as the coordination patterns between gestures and speech in typically developing infants from Kannada speaking families, from the age of 3 months till 12 months of age.

Aim of the study

This study aimed to investigate and compare the development of gestures and speech in infants during play/interaction with mothers using a longitudinal design. The objectives of the study were to investigate and compare the following across age (3 to 12 months):

1) Gestural behaviours of face, gaze, head, leg, torso, whole body as well as hands

2) Speech behaviours of pre-speech, vocalic, syllabic and verbal utterances

3) Emergence of gesture - speech coordination

Two hypotheses were proposed:

1) Both gestures and speech will exhibit similar growth trends within the first year of life as they are parts of the same multimodal system.
2) Speech and gestures will co-occur with each other from the age of 3 months and they will demonstrate varied patterns as the infants grow older.

Method

Participants

The participants in the study were selected from two hospitals in the city of Mangalore in Dakshina Kannada district, following ethical clearance obtained from AIISH Ethics Committee for Bio-Behavioural research. Informed consent was obtained from the parents prior to the inclusion of their infants in the study. Nine infants (3 girls and 6 boys) from Kannada speaking families participated in the study which began when the infants were 3 months and ended when they were 12 months old.

All the participants had to fulfill the inclusion criteria. Apart from this, the parents also filled a questionnaire developed by the investigator to rule out problems during the gestational period, birth history and familial history of communication disorders. The infants also passed a screening test for hearing and visual acuity, a pediatric and neurological examination. Further, the infants were also found to have adequate receptive and expressive skills at the age of 3 month based on the test 'Assessment of Language Development' (Lakkanna, Venkatesh

& Bhat, 2008). The infants included in the study were from either upper or lower middle class families and the mothers had a minimum qualification of 10^{th} grade.

Procedure

Age-appropriate toys (2 for each month of observation) were selected and provided by the investigator for the mothers to interact with their infants. They were encouraged to speak and play with their infant in a natural manner and this interaction was video and audio recorded by the investigator. Play with the infant included both semi-structured (play with specific toys) and unstructured naturalistic (play without toys) contexts, which randomly and naturally occurred throughout the recording. Both audio and video recordings were made once a month in each of the infant's homes using a high definition handycam, at those times when the infant was most playful and alert. Each recording was done well within +/- 3 days of the previous months recording for each infant. However, there were instances when an infant could not be recorded for a particular month due to illness or other reasons.

The recordings were edited and analyzed in EUDICO Linguistic Annotator (ELAN) software (Lausberg & Sloetjes, 2009). The investigator annotated specific gestural and speech behaviours of interest from all the samples that were collected, based on a *key* (Appendix 2) that was developed for this purpose. These included spontaneous behaviours which occurred during mother-child interactions. The following behaviours were annotated:

a) *Gestures:*

1. Facial gestures- facial expressions and other movements of the facial structures, such as smile, frown, tongue play, mouthing etc.
2. Gaze behaviours- patterns of looking behaviours, such as gaze at object or person etc.
3. Head movements- movements of the neck, such as turn, extension etc.
4. Torso movements- movements of the trunk, such as rock and bounce.
5. Leg movements- movement of either one or both legs, such as foot rub, kicks etc.
6. Whole body movements: movements that involve the displacement of the whole or-mid half of body, such as walking, leaning etc.
7. Hand movements: pre-symbolic and symbolic movements of either one or both hands, such as reach, grasp, show, point etc.

b) *Speech:*

1. Pre-speech utterances: vocal productions that include cooing and vocal play
2. Vocalic utterances: vocal productions that include vowelizations and hums
3. Syllabic utterances: vocal productions that include syllabic shapes of marginal babbles or canonical babbles, and variegated babbles
4. Verbal utterances: vocal productions that include jargon, verbalizations and true words

5. Prosodic alterations: syllabic, vocalic and verbal utterances with distinct intonation patterns.

c) ***Coordinated bouts:*** Instances in which the speech and gestural behaviours co-occurred in time were noted, and this was defined as occasions where there was considerable overlap in the occurrence of two or more gestural and vocal units (Caprici et al., 1996). E.g. A hand gesture and a facial expression that were either produced simultaneously, after or before the onset of a vocalic utterance was considered as a coordinated bout.

Coding

The investigator annotated all the samples (76 videos) and identified the various gestural and speech behaviours exhibited by all the nine infants. Additionally, two speech language pathologists with a minimum of 3 years of experience in the field and with good background knowledge of nonverbal communication were also selected as coders for the study. These coders were trained and familiarized with the behaviours that needed to be identified in the samples based on the *key* (Appendix 2) which included a list of all the behaviours with their operational definitions. The investigator trained the second and third coders using a sample video of an infant, who was not included in the study. They were provided with 10 randomly chosen samples from the pool of data (13% of samples), one sample each for every month of study. They independently observed the sample and annotated the behaviours in ELAN. Inter- and intra- judge reliability measures were carried out for these annotated samples, and the mean percentage of agreement was calculated. For those instances in which there were disagreements between the coders, the behaviours in question were not included for further analysis. After the reliability measures were calculated, the investigator identified the speech and gestural behaviours that co-occurred in each of the samples in order to calculate the number of coordinated bouts of behaviours that occurred in all the samples.

Statistical analysis

A measure called *rate of occurrence per minute* (Locke, Young, Service & Chandler, 1990) was computed and this was calculated for every behaviour that occurred for each month, and it represented the total number of a single behaviour divided by the duration of the observational segment for that month. Also, *rate of co-occurrence per minute* (Iverson & Fagan, 2004) was computed and this represented the total number of co-occurred gesture and speech behaviours divided by the duration of the observational segment for that month. Further, the co-occurrence patterns were studied for three time frames, namely, >3 months to ≤ 5 months, 29 days (initial pre-linguistic phase), >6 months to ≤ 7 months, 29 days (middle pre-linguistic phase) and >8 months to ≤ 12 months (final pre-linguistic phase). Additionally, percentage frequency of occurrence and co-occurrence were also calculated. The different non-parametric statistical tests that used for the analysis of this data, in order to test the hypotheses, were Friedman test, Wilcoxon signed rank test, Spearman's rank-order correlation, Quadratic regression equations and Change point analysis.

Results

The results were presented under two sections that comprised of a) development of gestures and speech, and b) patterns of co-occurrence of speech and gestures.

Implications

The findings of this study suggests that infant development is indeed a multimodal phenomenon which is influenced by a large number of factors such as biological maturation, neuro-muscular development, environmental factors and even interaction styles of caregivers. The strong links between both modalities within the first year of life might explain the semantic, temporal and pragmatic synchrony seen between gestures and speech later in life; with the nonverbal mode being a more frequent phenomenon in infants in the first year of life. The results point to the need for simultaneously documenting verbal and non-verbal behaviours in children, as well as establishing normative ranges for the emergence as well as co-development of these behaviours in order to understand differences in typical and atypical development. The findings also suggest that development is marked by variability and stability within the first year of life and this has to be taken into account while making diagnostic and therapeutic decisions in the case of children with communication disorders. Since both modalities complement and supplement each other during communication, non-verbal modes should be considered equal to verbal modes of communication, and this will have an important bearing for therapeutic decisions.

Limitations

The study included nine participants in order to analyze the multimodal behaviours in infancy. The lack of uniformity in the number of infants representing both genders limits the understanding of gender effects on the development of these behaviours. Since the observations were made only once a month, it is possible that the actual age of emergence or co-emergence of these behaviours has been missed out. This should be factored in while considering further studies and could be substantiated by obtaining records of parental observations or by obtaining frequent observational data recordings, such as having recordings once a week. It would also be interesting to expand this study in order to better understand the influence of various environmental factors and caregiver interactional styles that were observed in infants from Kannada speaking families and even compare the results across data obtained from infants belonging to other linguistic backgrounds in India.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Human communication is considered the hallmark of humanity and is hailed as the ability which differentiates humans from animals (Berko-Gleason, 1997). It is a complex, systematic, collaborative and context-bound skill used for social action. Communication is usually accomplished through use of linguistic and para-linguistic codes with various means of transmission (speech, gestures, and whole body language). Language or linguistic code is a socially shared code or conventional system which represents concepts through the use of arbitrary symbols and rule-governed combinations of these symbols (Owens, 2012). On the other hand, speech is the verbal means of communication, which is the result of precise neuromuscular coordination.

It is important to acknowledge that both speech and language are only parts of a communication act. There are other aspects of communication that may enhance the linguistic code and are these are classified as paralinguistic, nonlinguistic and metalinguistic codes (Owens, 2012). Paralinguistic or suprasegmental components of communication include intonation, stress, pause and rate of delivery, which are superimposed on the speech signal. Nonlinguistic cues are composed of hand gestures, facial expressions, body movements, body postures, head movements and proxemics. Metalinguistic skills are those abilities that enable an individual to analyze, judge and talk about language, thus signalling the success of communication.

There have been numerous accounts of how human communication emerged from other primate communication, and most researchers conclude that human communication is fundamentally cooperative and requires socio-cognitive skills of shared intentionality (Tomasello, 2008). This cooperative nature controls the cooperative structure of human social interaction and culture. Tomasello (2008) has also suggested that the early forms of communication were gestural in nature and included pantomimes and pointing which were cooperative in nature and differed qualitatively from other forms of primate communication. The type of communication that emerged could have resulted from a biological adaptation during collaborative activities, such as fear of hunger or survival. Although chimpanzees demonstrate individual intentionality, they do not have shared intentionality or joint goals for cooperative communication. Additionally, Kita (2003) has suggested that human gestures and pantomimes are universal to humans alone.

Many consider language as only the tip of the iceberg phenomenon of human communication, with all the complexities below the surface yet to be discovered (Liszkowski, 2008). Since human communication is an inferential process, it involves two main psychological components namely, attributes of social-cognition and motivation (Sperber & Wilson, 1986). From the social-cognition point of view, speakers need to have an intention of self and others and comprehend the epistemic states to transmit and infer referential content. On the other hand, motivation in human communication helps build cooperation since humans provide others with relevant information which is not just meant for immediate gain. This is in stark contrast with animal communication, which is least referential and lacks communicative intent (Call & Tomasello, 2008).

Vocal communication is also reported to have emerged from conventional gestures. It has been hypothesized that the early vocal accompaniments were emotional vocalizations or imitated animal sounds. The need for vocal communication would have further paved the way for meaningful vocalizations. While gestures convey meaning in a context, they may be insufficient to communicate about something other than the present (Goldin-Meadow, 2005). At the same time, development of vocal communication would have proved useful, since it freed the hands for other purposes.

There never is a true distinction between speech and gestural communication, since speech is universally accompanied by gestures and the synchrony between the two behaviours is hypothesized to be controlled by a single system (McNeill, 1985). Kelly, Ozyurek & Maris (2010) consider speech and gesture as two sides of the same coin, because both gestures and speech mutually enhance comprehension in either of the two modalities. Although speech and gesture emerged simultaneously in the evolution of language, the dominance of manual actions over vocalizations in the repertoire of non-human primates suggests that the priority lay with manual gestures in non-human primates. At behavioural and neural levels, there is abundant evidence that gestures and speech function as an integrated system and are tightly coordinated in adults and children (Balog & Brentari, 2008; Dick et al., 2014; Esteve-Gibert & Prieto, 2014; Holle & Gunter, 2007; Kelly, 2014; Loehr, 2012; McNeill, 1992; Xu, et al., 2009).

The ability to learn verbal language by non-human primates is rare and only few species show some modification of vocal output (Hopkins, Taglialatela & Leavens, 2007). Language is always considered intentional, and the intentional control of vocalization is restricted to humans and some birds, and is largely absent in other primates (Ploog, 2002). Since humans have evolved with a special disposition for both vocal and gestural communication, a child learning the nuances of the linguistic code of his/her culture will need to develop the necessary verbal and nonlinguistic cues.

Acquisition of the Linguistic Code

The study of language or communication development in children provides a window of opportunity into the understanding of normal and atypical development. There are numerous theoretical accounts which have been proposed and these suggest that acquisition of language takes place due to various processes that are active in a given child; for example, the generative approach assumes that language is acquired since children are born equipped with innate rules related to the their native language (Chomsky, 1965; Lenneberg, 1967; Yang, 2002); the constructionist approach suggests that children derive linguistic knowledge from the environmental input that they are exposed to (Christiansen & Charter, 1999; Goldberg, 2006; Tomasello, 2005); the behaviourist approach proposes that language is a behaviour that is acquired through principles of learning and is similar to any other skill that is learned by a child (Skinner, 1957; Watson, 1913); social interactionist approach suggests that development occurs as an outcome of social interactions that a child engages in (Vygotsky, 1962); and the cognitive approach proposes that language is a part of larger cognitive development (Piaget, 1954).

Elaborating on the social interactionist approach, Luria (1959) conceptualized that language in humans plays an important role in regulating sequential behaviour. He suggested that this regulation is possible through the interactions of two 'signaling' systems even in children; the nonverbal system, which precedes the development of the verbal system.

According to Luria (1960), children are able to interact with their physical and social environments through these two cognitive systems. The nonverbal system is said to develop from the physical attributes of the environment and is seen from a very young age and allows the infant to integrate environmental representations at a visual, spatial and motor level. The verbal system is said to begin by the end of the first year of life, although it does not have the same symbolic characteristics of the adult language system. The verbal system is said to arise from the nonverbal system, and it then participates in the mediation of newer experiences along with the nonverbal system. However, as development continues the verbal system is said to become more autonomous and will herald the child's cognitive capacities in a better fashion that what is possible with the nonverbal system alone.

It can be understood that these various approaches indicate that language acquisition is generally seen as the milestones achieved in succession by each learner. This is then attributed to a genetically programmed and pre-existing mental structure trapped in an immature body, which contains the latent capabilities for communication that are revealed as the infant matures by developmental psychologists (Smith & Thelen, 2003). But at the same time, it may not be appropriate to view the learning process as a step-by-step process, since that would mean one milestone has to be achieved by the child before he/she learns the next (Rohlfing, 2008). This is important because variations are seen in the milestones achieved, both in an individual child and between children. Some children may achieve a particular milestone early, some may achieve the same milestone a little later and others may even skip that milestone. Therefore, an alternate view has been suggested to document the development of any skill, including that of communication, in children.

Smith and Thelen (2003) suggested that the developmental process should be viewed as a change within a complex dynamic system, since it is better understood as the emergent product of many decentralized and local interactions that happen in real time. Development is understood as creating something more from something less; i.e., the coming into existence of new forms through ongoing intrinsic processes within the system. From this perspective, language acquisition is not limited to speech but also includes multimodal communication and the influence of the environment on the same (Rohlfing, 2008). It encompasses different domains such as imitation, mother-infant relationships, language, social relationships, perception, action and even atypical patterns of developmental change (Gerhskoff-Stowe, 2002; Gogate, Walker-Andrews & Bahrick, 2001).

According to the *dynamic system theory* (Thelen & Smith, 1994), there are two main tenets that applies to the self-organization of human development. One assumption of this theory is that the developing organism is a complex system which is composed of numerous embedded individual elements, which are also open to a complex environment. As a complex system, these elements are coordinated in the absence of a programme which may produce this organized pattern. Therefore, this coherent behaviour is manifested by the relationships between these components and the constraints and opportunities of the environment. This would then mean that no single element within the system has causal properties, rather it works on *multicausality* principles (Figure 1).

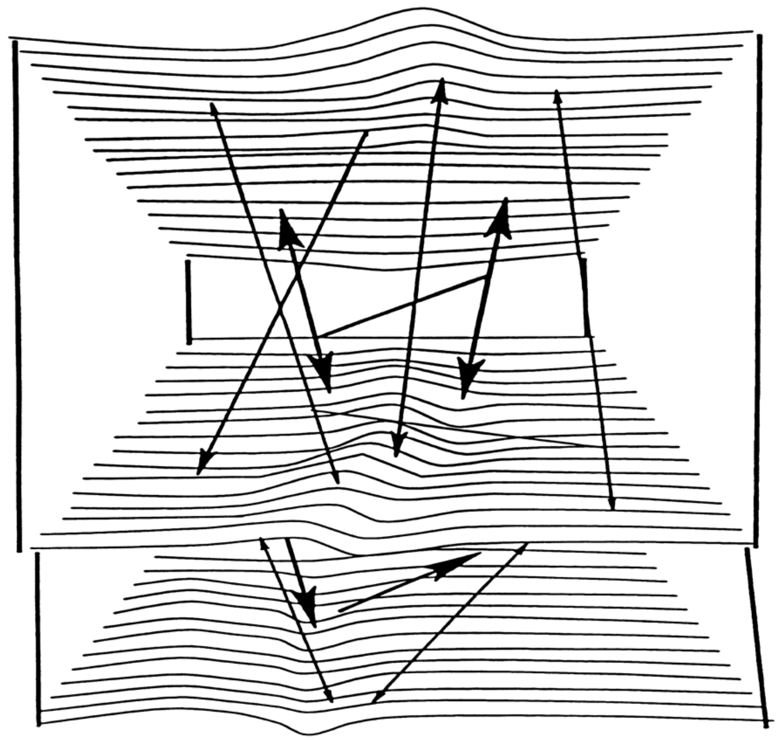


Figure 1. The landscape of a multilayered system whose components mutually influence each other in changing patterns by Thelen & Smith (1994).

Further, Smith and Thelen (2003) hypothesize that when such complex systems self-organize they would be characterized by the comparative stability or even instability of their states. Thus, development can be envisioned as a series of evolving and dissolving patterns of varying dynamic stability, than as a linear path achieving maturity. This assumption was explained using the example of infant crawling, a coherent behaviour which helps an infant locomote when he/she has adequate strength and the coordination to assume a hands-and-knees posture. At this stage, the infant is neither sufficiently strong nor balanced to start walking, but in a few months when walking is achieved, crawling pattern destabilizes. This self-organization occurs to provide an efficient solution to the problem of locomotion for the infant, and is not wired by a programme within the system.

The second assumption of the approach by Smith and Thelen (2003) is that changes in behaviour are observed over different timescales. For example, a neural excitation can happen in milliseconds, while people learn a skill after hours, months or even years of practice. In a developing organism, time is presumed to be unified and coherent, along with the collaborating elements of the system. Thus, every event at a given time is the base for the next skill that is yet to be achieved. The coherence of time and levels of complex system implies that the dynamics of one time-scale (neural activity) is continuous with and *nested* within the dynamics of the other time-scales (learning). Therefore, it is the interaction of different timescales within an organism that paves way for its development.

Smith and Thelen (2003) also propose that there is considerable indeterminacy within processes that have globally similar outcomes. It suggests that complex systems can self-organize to produce cohesive patterns that are highly non-linear. This could imply that small changes in one or more elements of the system can lead to reorganization and larger changes in the behaviour. Such non-linearities explain the stage-life shifts in skills seen within a child as well as create individual differences during development. Therefore, it is important to understand the processes by which everyday activities of children will create the developmental change towards individual pathways and universal attainments.

DST fosters the understanding that infants assemble skills that enable them to perceive and subsequently act (Smith & Breazeal, 2007; Thelen & Smith, 2006). Therefore, in order for them to develop a skill, infants need to *perceive* things in the environment that will *motivate* them to *act*, and then they can use these perceptions to help guide their movements; thus, skills represent the means to achieve an infant’s goals. This view of development has garnered support through studies done on infant motor development such as crawling, walking, reaching etc. (Adolph & Robinson, 2015; Thelen & Smith, 2006). For example, Adolph & Joh (2007) suggest that infants learn to walk when their nervous system permits them to control leg muscles, when their legs are capable of supporting their weight and when they have the desire and opportunity to move. Therefore, DST proposes that development is not just the passive unfolding of sequences of a skill, but rather, an infant actively integrates a skill in order for it to achieve a goal that is within the limitations set by the infant's body and its dynamic environment.

Based on the above theory, Rohlfing (2008), suggests that language acquisition is a multimodal avenue for each child, and that one should be mindful of the contributions of various cognitive and motoric abilities. Consequently, development should be envisioned as interactions at both internal (multimodality) and external (environmental support) levels.

Gestures/Multimodal behaviours

Language in human beings is considered special since it is at the highpoint of the mind's ability and is most notably what differentiates the minds of human beings from that of thinking animals (Kelly, Iverson, Terranova, Niego, Hopkins & Goldsmith, 2002). Language is a hallmark of modern human communication, but language is best understood as an evolving property over historical time of more basic and non-linguistic, yet unique forms of human communication. Language, whether in the spoken or signed mode, is a conventional code, but it is clear the code alone is not a sufficient basis for communication (Liszkowski, 2010).

Many researchers have argued that there is a designated language device built into the human brain at birth and that language is encapsulated within the device (Chomsky, 1965). According to this view, language develops as a special neurocognitive ability which is different from other abilities of a human being. However, it can be counter argued that though such an approach is useful in understanding many aspects of language, it is not sufficient to explain other attributes associated with language.

Kelly et al. (2002) have suggested that language should be understood as a part of its original habitat, that is, *the body*. This approach is guided by the notion that cognition in human is determined by the physical make-up and functioning of the body (Thompson & Varela, 2001). They also propose that humans are not wired to process information in a precisely uni-modular manner. This implies that humans are capable of integrating and producing information across modalities, that is, both verbal and nonverbal modalities. This has also been supported by studies in children and adults, wherein, nonverbal actions shape the language development in children and also play a role in adult language (Kuhl & Meltzoff, 1984; McNeill, 1992).

Nonverbal communication refers to a variety of gestural activities, namely, expressions of the face, gaze, voice and other bodily expressions (Feyereisen & de Lannoy, 1991). People use gestures when they talk. Contrary to the earlier observation that gestures are movements constructed by hands in a human being, it is now affirmed that gesture is not just performed with hands, but by other parts of body, such as head, face or arms. Thus, gestures are defined as manual [e.g., waving in order to say goodbye], facial [e.g., lip pouting to show displeasure], or other movements of the body [e.g., miming an object or person] (Capone, 2010).

Gestures are often not considered as random movements, rather, they are spatio-visual constructs influenced by contextual and sociopsychological factors, and are also tied to sophisticated speaker-internal, linguistic processes (Gullberg, de Bot & Volterra, 2008). Thus, gesture is an action related to ongoing speech and has the features that manifest deliberate expressiveness (Kendon, 2004). It has also been suggested that the act of gesturing is inherent to the act of speaking (Goldin-Meadow, Butcher, Mylander & Dodge, 1994). This would again imply that these movements can communicate meaning or simply accompany the forward flow of speech.

Several observations support the hypothesis that the processes underlying verbal and nonverbal behaviours may be analogous. First, gestures, like spoken languages, vary according to place, time, and socioeconomic factors. Second, body movements, like speech sounds convey symbolic meanings, and some conventional gestures belong to a given language as that of lexical items. Third, regularities in gestural performances while speaking resemble the syntactic rules.

Researchers have argued that gestures, language and speech are intimately linked forming an ‘integrated system’ (Kendon, 2004; McNeill, 2005). These arguments come from studies of both language production and comprehension. Studies on language production have reported that gestures provide referential content, fill structural slots in an utterance, and act as or modify speech acts (Kendon, 1995; Slama-Cazacu, 1976). There are also observations on the semantic-pragmatic and temporal coordination between speech and gesture (Loehr, 2004). Although the precise relationship between the two modalities is not straightforward, there has been a consensus that gesture and speech express closely related meanings selected for expression (de Ruiter, 2007; Kendon, 2004).

It has also been recorded that speakers often distribute information across both modalities depending on the spatial and visual properties of the interaction (Melinger & Levelt, 2004; Ozyurek, 2002). The synchronized development of gestures and speech during language acquisition (Volterra, Caselli, Caprici, & Pizzuto, 2005) and their breakdown in language disorders (Feyereisen, 1987) provides further confirmation regarding the intimate link. Also, studies on language comprehension have provided considerable evidence that gestures affect the perception, th einterpretation of and the memory for speech (Kelly, Barr, Breckinridge Church & Lynch, 1999).

Factors that determine the use of gestures. Every human being belongs to a certain community that will influence both his/her development. Like language, gestures are acquired from being exposed to gestures used by a community. McNeill & Duncan (2000), studied the gestures of speakers of English, Spanish and Chinese and observed that just as these speakers differed in the way they verbally described motion events, so did their gestures. It was suggested that a combination of factors help to shape gestures even within a community. In a recent study that looked into cross-linguistic differences between English and Turkish speakers, it was seen that co-speech gestures produced by English speakers was different from that of those produced by Turkish speakers (Ozcaliskan, Lucero & Goldin-Meadow, 2016) while representing motion elements in spoken language productions. However, the authors found no cross-linguistic differences in the gestures that were produced minus the spoken component, suggesting that speakers do not rely on language-specific gestural patterns when they are not required to speak.

According to Tellier (2009), gender is a factor in development of gestures, since studies on nonverbal communication have shown differences between males and females, such as the way arms and legs are displayed, the way people sit, stand or walk (Rekers, Sanders & Strauss, 1981). Feyereisen & de Lanoy (1991), have observed that nonverbal behaviours can even reflect the personality of an individual. Verbal skills and levels of proficiency have also been hypothesized to have an effect on the way someone gestures, both in first and second language acquisition (Gullberg, 1998; Sherman & Nicoladis, 2004; Yoshioka, 2006). Professional skills are also said to have an influence on the gesture style of an individual (Calbris, 2003).

Functions of gestures. Traditionally, gestures are said to function as communicative devices. Though research has been directed towards the contribution of gestures to communication and types of information that gestures convey, there is inconclusive evidence. Kendon (1994) observed that gestures produced by people when they talk plays a part in communication and provides information to co-participants about the semantic content of the utterances, but there are variations depending on when and how the gestures are used.

Dittmann & Llewelyn (1969) suggested that sometimes gestures may be used as random movements to dissipate tension during lexical search, because people often gesture while having difficulty retrieving an elusive word from memory and hand movements provide a means for reducing this tension. Other investigators have observed similar functions but they have not attributed this to tension management (Butterworth, 1975).

Since gestures are common when speakers try to access words from their lexicon, it has been suggested that they play a direct role in retrieval of lexical units (Freedman, 1972; Werner & Kaplan, 1963). However, support for this notion is again inconclusive. Graham & Heywood (1975), analyzed the speech of five speakers who were prevented from gesturing as they were required to describe abstract line drawings, and concluded that exclusion of gestures did not have any particular effect on speech. On the other hand, Rime (1982) and Rauscher, Krauss and Chen (1996) reported that restricting gestures adversely affected speech.

The relationship between gesture and speech. There are still unanswered questions as to the nature of relationship between gesture and speech during the act of spontaneous expression. Nevertheless, there are various hypotheses proposed to explain the possible nature of this relationship.

a) The 'independent-systems' framework hypothesis holds that gesture and speech are autonomous and separate communication systems (Butterworth & Beattie, 1978; Feyereisen & deLannoy, 1991). In this hypothesis, gestures are assumed to function as a backup or auxiliary system for the temporary absence or failure of speech, such as in the act of coughing, or being unable to put words to thoughts. In other words, speech has to fail in order that a gesture has to appear in the speech stream. This implies that there are feedback links between speech production and gesture such that when there is a problem in speech, gesture emerges. Therefore, according to this view, gestures form a supplementary 'support system' whose primary role is to compensate for speech when verbal expression is temporarily disrupted. The production of gesture is thus assumed to have no effect on speech production or the cognitive processes that guide it.

b) The second view proposes that gesture serves a compensatory role for speech, as exemplified by the home sign gestures of deaf children and the related phenomenon of sign languages (Goldin-Meadow, McNeill & Singleton, 1996). This view, as opposed to the independent – systems hypothesis, focuses on the compensating role that gestures play in the complete absence of speech.

c) The third view differs from the second in that it assumes that there exists reciprocal links between gestures and speech (Krauss & Hadar, 1999). These links are argued to be located within the process of speech production; at the phonological encoding stage (Levelt, 1989). So, while speech and gesture are viewed as a linked system, the connection is highly limited in scope, with gesture influencing the processing of speech to an extent that it provides for activation of cross-modal concepts at a moment of difficulty in word form retrieval.

d) A fourth hypothesis that has been proposed based on the concept of 'integrated- systems' framework, considers that both speech and gesture together form an integrated communication system for the purpose of linguistic expression (Kendon, 1980; McNeill, 1992). According to the concept, gesture is linked to the structure, meaning and timing of spoken language. Thus, speech and gesture would always be co-expressed. And when gesture and speech are tightly connected to one another, there are links between gesture and speech throughout the process of speech production, which occurr at various levels of semantics, morpho-syntax, discourse, and prosody. While speech is conventionalized and arbitrary, gesture is idiosyncratic and imagistic. Speech and gesture are two different modalities that capture and reflect different aspects of a unitary underlying cognitive process.

From this latter perspective, gesture and speech co-occur during production because they are linked to each other and to the same underlying thought process. Any disruption in speech production would have an influence on gesture, and vice versa. The strength of this link has been demonstrated in gesture suppression experiments and in studies of communication among blind individuals. Congenitally blind speakers, who have never seen the gestures of others, not only gesture while speaking, but do so even when talking to a blind listener (Iverson & Goldin-Meadow, 2001). Rauscher, Krauss, & Chen (1996) reported that narratives produced when gestures are prohibited are more verbally dysfluent than those produced when gestures are permitted.

Kendon (1985) also posits that gestures and speech stem from a single conceptual structure, since both of these outputs are meant to express meaning. He suggests that the structuring of discourse in paragraphs, sentences and 'prosodic phrases' is paralleled by the organization of bodily expressions, in that, the larger the size of speech units, the greater the number of limb segments involved in movement when there is a transition between units. It has also been observed that a single gesture is sometimes associated with several speech units, and that these different units express a single idea (Kendon, 1975).

According to this view, nonverbal behaviours accompanying speech seems to be intended to make the organization of discourse more visible. But, the two modes of expression, verbal and gestural, are not equivalent. There are several reasons for the same. Firstly, both modes are used in different contexts. Secondly, gestures and speech do not obey similar constraints in the turn-taking system. Finally, gestures are particularly adapted to convey information about spatial relations.

In summary, there is considerable agreement on the existence of close links between gestures and speech production, yet there are variations in the explanations proposed by different researchers.

Theoretical considerations in the production of gesture and speech

It is generally agreed that processes of speech are sequential consisting of three stages: a) conceptualization, b) formulation, and c) articulation (Levelt, 1989). Levelt (1989) proposes that, in the conceptualization stage, the speaker conceives an intention, selects relevant information to be expressed and orders that information to be expressed. At the formulation stage, the pre-linguistic message is given a linguistic form through the selection, ordering and appropriate combinations of lexical items and syntactic frames. Finally, at the articulation stage, the information reaches the articulators for the production of the desired utterance.

Human beings intuitively combine language and spontaneous gesture to form multimodal utterances. Words as well as gestures, in such utterances, appear highly coordinated and closely intertwined or aligned to each other. These alignments concern the meaning that the verbal and nonverbal behaviours convey and the form they take up in doing so, the way in which they are executed, their relative temporal arrangement, as well as their coordinated organization in a phrasal structure of language. There have been a couple of theoretical accounts that have attempted to explain either one of many of the above observed phenomenon.

One such account is called the ***Lexical Retrieval/Level Hypothesis***, which holds that gestures are involved in generating the surface form of an utterance. Many researchers propose that gesture facilitates speaking by aiding in the process of lexical retrieval, during formulation stage of speech production. This accentuates the claim that a gesture serves as a cross-modal prime to boost the activation of a particular lexical entry. This specifies that gestures play an active role in lexical access especially for words with spatial content (Butterworth & Hadar, 1989; Krauss, 1998; Rauscher et al., 1996). Support for this view comes from studies which report that speech including spatial content were adversely affected when production of gestures was restricted (Rauscher et al., 1996). Studies have also shown that when production of gesture was restricted, there was increase in the number of failure to retrieve tip-of-the-tongue productions (Frick-Horbury & Guttentag, 1998).

One version of this hypothesis holds that iconic gestures derive from spatially encoded knowledge, and facilitates access to lexical entries that incorporate syntactic and semantic information (Krauss, Chen, & Chawla, 1996). An alternative version holds that iconic gestures are derived from lexical representations (Butterworth & Hadar, 1989) or from non-propositional representations in working memory (Krauss, Chen, & Gottesman, 2000), and assist in the retrieval of the relevant phonological forms.

These observations also led to the proposal of the ***Process model*** (Figure 2), which is based on the speech production model by Levelt (1989). The process model assumes that a spatial and dynamic feature selector transforms information stored in spatial or dynamic formats into a set of spatial and dynamic specifications, especially abstract properties of movements. These abstract specifications are in turn translated by a motor planner which converts it into a motor program, which in turn that provides the motor system with a set of instructions for executing the lexical gesture. The output of the motor system is then a gesture, which is monitored kinesthetically. This model suggests that lexical gestures provide input to the phonological encoder via the kinesic monitor. The input consists of features of the source concept represented in motoric form. Thus, these features may facilitate retrieval of the word form by a process of cross-modal priming. The model also specifies a path from the auditory monitor to the motor planner which is necessary in order to account for gesture termination.

Another interpretation of the same data is that prohibition of gestures can also affect the conceptual process involved in constructing a pre-linguistic message rather than in lexical retrieval processes per se. So, if one assumes that gestures aid in the activation of conceptual representations, this activation will then spread to the lexical level. Supporters of this view argue that gestures help in the activation of imagistic and conceptual information at a pre-lexical level (de Ruiter, 1998) and help to map the imagistic information to the propositional information (Alibali, Kita & Young, 2000). This is considered the ***Conceptual Level Hypothesis***.

An alternate account is ***the Information Packaging Hypothesis***, which is based on the observations that gesture along with language helps constitute thought and that gestures reflect the imagistic mental representation that is activated at the moment of speaking (McNeill, 1992). This view posits that gesture help speakers organize knowledge that is spatio-motoric in nature and puts it into units appropriate for verbalization (Kita, 2000). Gesture is thus a mode of thinking, an aid in interpreting spatial and motoric knowledge into linguistic output. More specifically, speakers use gesture to explore alternate ways of encoding and organizing spatial and perceptual information. This opens the possibility that gesture may play a role in speech production, as well as in other cognitive activities such as reasoning and problem solving (Alibali & DiRusso, 1999).

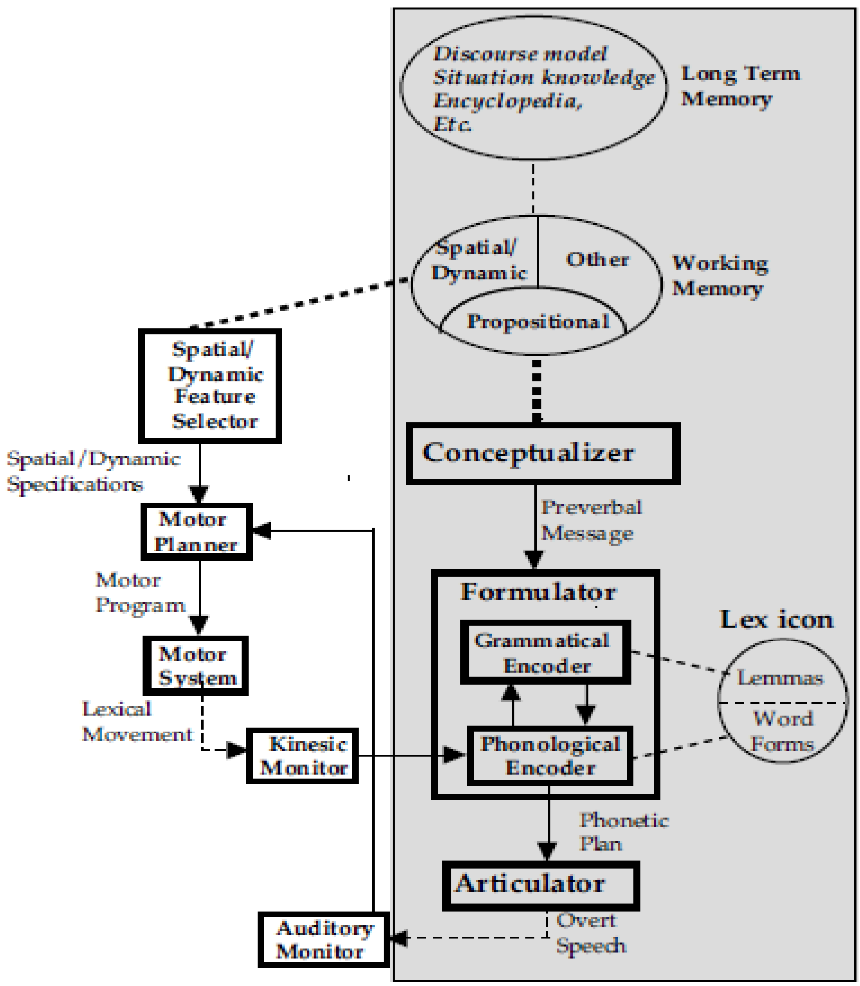


Figure 2. The Process Model which is based on the speech production model by Levelt (1989).

Evidence for this hypothesis comes from studies which have manipulated the difficulty of conceptualization while holding the difficulty of lexical access constant. Alibali, Kita and Young (2000), studied children engaged in a conservation task, and reported that children used more representational gestures when they were asked to explain why two items were different than when they were asked to describe how the items looked different. They observed that children used highly similar words across the two tasks, however, the explanation task was more complex when compared to the description task. The authors argued that the frequent use of representational gestures by children in the explanation task was possibly due to the increased demands on the conceptualizer.

Melinger and Kita (2007) also found that adults were more likely to gesture in instances where there was a greater choice of selecting what to say, inspite of the fact that the words spoken in both situations were identical. This again was assumed to be the result of taxing the conceptualizer rather than the formulator. Thus, according to this hypothesis, gestures play a role in speech production since it plays a role in the process of conceptualization.

Based on this hypothesis, Kita and Ozyurek (2003), developed a ***model of speech and gesture production*** (Figure 3). According to this model, a *Communication Planner* is sadi to generate ‘communicative intentions’ which is a rough decision on the information to be expressed and includes deciding the modalities that should be involved. This planner has access to a discourse model, and hence can process additional information. The specifications of intent are then sent to an *Action Generator* and a *Message Generator*. The action generator then produces a spatio-motoric plan for the gesture to be performed. It is assumed to have access to the part of working memory where relevant spatial imagery is active (action schemata based on features of imagined or real space). The message generator then formulates a propositional preverbal message which is sent to the Formulator.

Both these generators are considered to constantly exchange information, which also involves transformations between the two formats. Additionally, the message generator is said to obtain feedback from the Message Generator regarding whether an intention should be readily verbalized. The interactions between the three components continue till a state of equilibrium is reached. Then the verbal formulation begins and the spatio-motoric plan generated by the Action Generator is sent to the motor control for execution. With these posited interactions, this model explains the influences of verbal encoding problems, the overall communicative goals and the coexpressivity of speech and gesture.

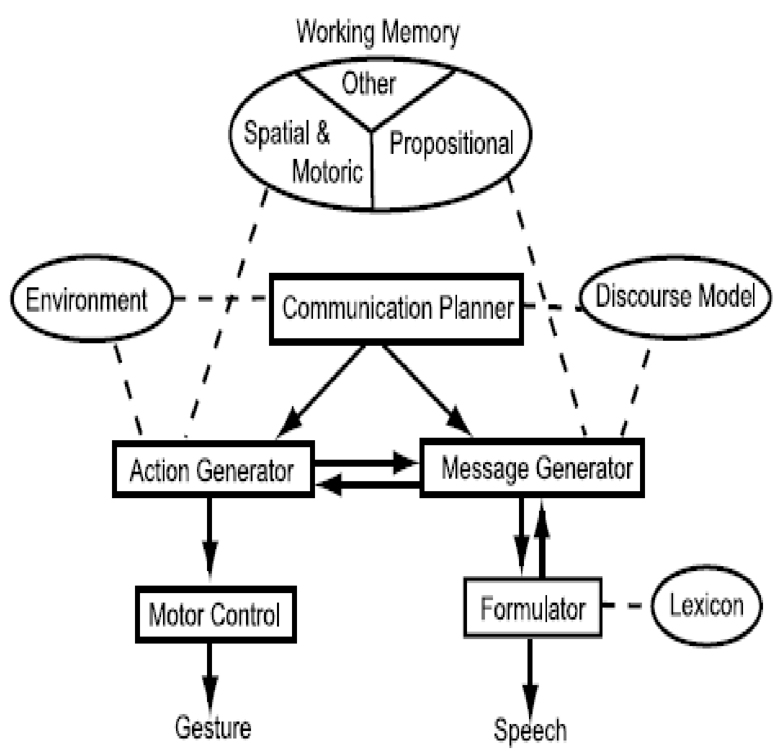


Figure 3. Model of speech and gesture production by Kita & Ozyurek (2003).

Similar to the process model of speech and gesture production, de Ruiter (2000) proposed the ***Sketch Model*** (Figure 4). This model is based on the assumption that gestures are generated before the linguistic formulation process takes place, and that both speech and gesture production are largely independent processes. This model also relies heavily on Levelt's model but considers that gesture is a communicative device. The argument for this view is derived from the fact that people gesture both, when there is no visual contact between speaker and listener, as well as when there is visual contact (de Ruiter, 1995).

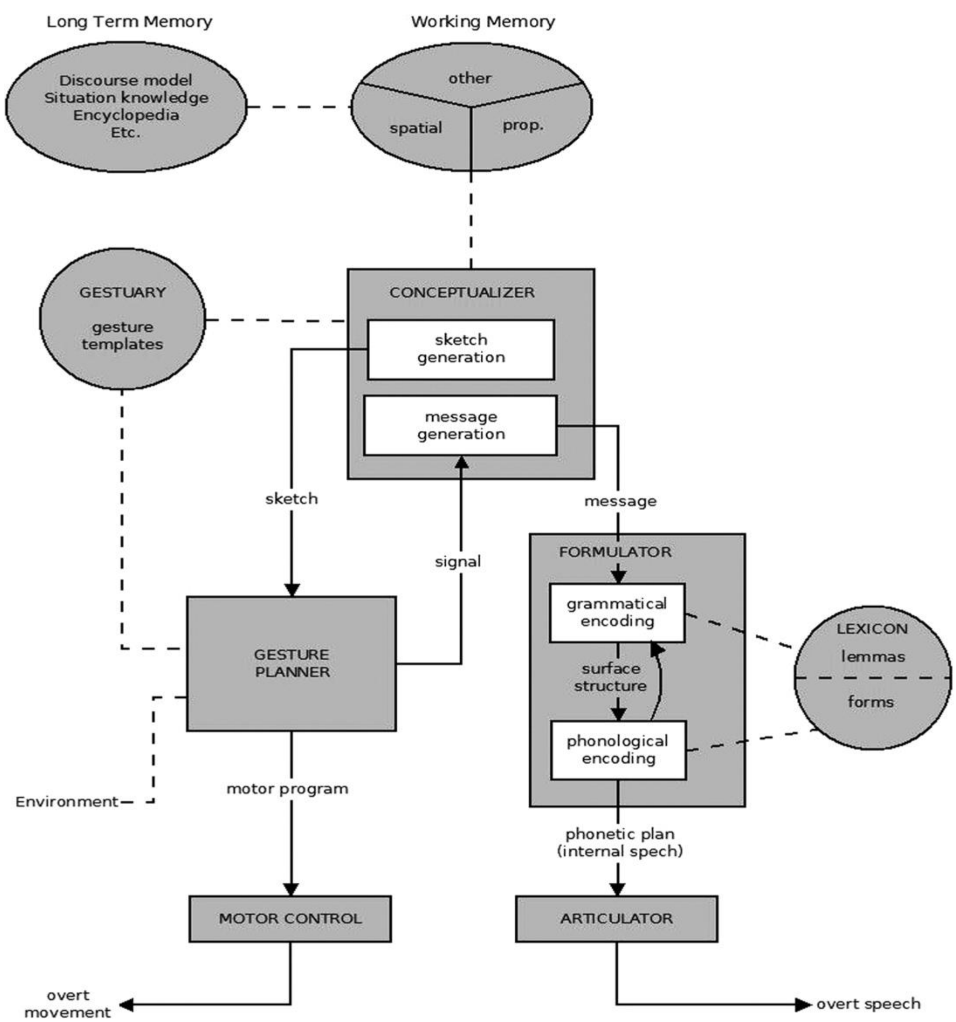


Figure 4. The sketch model by de Ruiter (2000).

According to this model, the final output of the conceptualizer is a sketch which can encode iconic gestures, deictic gestures, emblems and pantomimes. This sketch will be then sent to the gesture planner whose task is to build a motor program out of the received sketch. The planner has access to the gestures, motor procedures (schemata), and information about the environment. It also allocates the body parts required for the execution of gesture, encode the sketch entries into the gesture, as well as assess potential physical constraints posed by objects in the environment. Once the planner has finished building a motor program, it is sent to the lower-level motor control units, which results in a movement.

Further, to account for the integration of verbal language and of the imagistic thinking such as gesturing, McNeill and Duncan (2000) proposed a theory of ***Growth-Points (GP)***. According to this theory, an utterance is the product of an 'unpacking' process that originates from an ideational complex in which global, synthetic, imagistic thought and thought in terms of categories that can be expressed in spoken language are inseparably intertwined. The growth point is the name given to the analytic unit combining imagery and linguistic categorical content. A GP is assumed to be the minimal psychological unit that retains the essential properties of a whole.

This concept counters the idea that an utterance is built up, piece by piece, in a linear fashion, as proposed by information processing models like that of Levelt (1989). It assumes that what is expressed in an utterance is present right from its beginning and the final form is what one observes in a speaker. The end product of a particular gesture-speech combination is the product of a micro-genetic process in which imagistic thinking and linguistic categories engage together in a dialectic process.

The psychological reality of GP has been considered in the fact that it strongly resists forces trying to divide it. Evidences for the same are derived from studies that have demonstrated that though delayed auditory feedback grossly disrupts speech timing, the gesture-speech synchrony remains intact (McNeill, 1992). It was also observed that individuals with stuttering did not have interrupted gesture-speech synchrony, despite the massive disruptions seen in their speech (Mayberry & Jacques, 2000). Thus, it can be gathered that in each of the cases, the meaningful linkage of gesture and speech resists division

Gesture - Speech System in Adults

Hand Gestures. Hand or manual Gestures in adults have been classified based on many criteria; voluntary or involuntary, natural or conventional, of literal or metaphorical significance, its relationship to speech and such. It has also been observed that a given gesture, when understood in the context of its use, may be located on several of these dimensions simultaneously. Kendon (1988) proposed a classification, which is now called *Kendon's continuum*, which has four kinds of gestures on the continuum: gesticulation, pantomime, emblems and sign language.

Gesticulations are referred to as idiosyncratic spontaneous movements of the arms and hands that accompanying speech (McNeill, 1992). They are also known as co-speech gestures. *Pantomime* is used to define those gestures that mime an action or object and are mainly used when it is impossible to speak or in games of miming. *Emblems* are conventionalized gestures used in a specific community and they have a specific meaning. These are most often associated with a fixed expression but can also be used without speech, and are understood by individuals who belong to the same cultural community. *Sign-languages* are considered full-fledged linguistic systems with segmentation, lexicons, syntax, distinctiveness, arbitrariness, standards of well-formedness, and a community of users. These are languages that stand on their own and are mainly used without speech.

McNeill (2000), has further supplemented this continuum by dividing it into four continua to highlight the differences among these different kinds of gestures.

a) Continuum 1: Relationship to speech

Gesticulation ⇨	Emblems ⇨	Pantomime ⇨	Sign language
Obligatory presence of speech	Optional presence of speech	Obligatory absence of speech	Obligatory absence of speech

b) Continuum 2: Relationship to Linguistic Properties

Gesticulation ⇨	Pantomime ⇨	Emblems ⇨	Sign language
Linguistic properties absent	Linguistic properties absent	Some linguistic properties present	Linguistic properties present

c) Continuum 3: Relationship to Conventions

Gesticulation ⇨	Pantomime ⇨	Emblems ⇨	Sign language
Not conventionalized	Not conventionalized	Partly conventionalized	Fully conventionalized

d) Continuum 4: Character of the Semiosis

Gesticulation ⇨	Pantomime ⇨	Emblems ⇨	Sign language
Global and synthetic	Global and analytic	Segmented and synthetic	Segmented and analytic

McNeill (1992) has described four main types of co-speech manual gestures, namely, iconic, metaphoric, deictic, and beats. *Iconic* gestures share a close relationship to the semantic content of speech. These gestures imagistically represent object attributes, actions of objects/events as well as spatial relationships (e.g. when one mimes the holding of a steering wheel while saying 'drive'). Iconics are said to represent body movements, movements of objects or people in space, and shapes of objects or people. *Metaphoric* gestures are very similar to iconic gestures except that they depict abstract concepts and not concrete objects (e.g. when one cups their hands while saying the word 'concept'). The gesture acts as symbolic images for the idea of a concept.

Deictic gestures refer to things as indicated by pointing with one's hand, finger or even chin. They can be concrete (such as pointing to someone, something or somewhere) or even abstract (for example, pointing to something/someone who is not present or a place or even a moment in time). Abstract deictics can be shaped by geographical and time references which differ across languages and culture. *Beat* gestures are rhythmic movements that bear no semantic resemblence to the accompanying speech. They rather stress important words or phrases expressed while speaking. An example of a beat would be a flick of the hand or finger. McNeill (1992) explains that the critical factor distinguishing beats from other gestures is that it has two phasic movements – in/out, up/down etc.

McNeill (1992) also pointed out that manual gestures are not just movements and can never be explained in purely kinesic terms. Researchers have also noted that hand gestures can depict, demonstrate or re-enact (Kendon, 1985; Streeck & Knapp, 1992). They have also stressed that there is a difference between a hand action, which serves a practical function (e.g.

holding a telephone) and a hand gesture which serves a communicative function (e.g. telling a person you will call them later). Therefore, on the one hand practical and material considerations shape hand actions, however, on the other hand social and communicative considerations shape hand gestures. Ozyurek (2002) showed that speakers made a gesture depicting the same motion differently which depended on the spatial relationship to their addressees. Other experiments have also shown that linguistic principles unique to the dialogue could shape hand gestures. It has been observed that individuals made sketchier gestures to depict objects when the participants shared knowledge about the object, than in those instances when it was new to them (Grewing & Bavelas, 2004).

McNeill (1992) maintains that gesture and speech are part of the same conceptual structure and that they share a computational stage. He documented few major characteristics of the adult gesture-speech co-production:

a) First, although gesture and speech often convey complementary aspects of an underlying message, as they are temporally linked within the bounds of a single utterance. It is argued that gestures and speech appear together 90% of the time during active speech output and 10% of the time during silence which is followed by more speech.

b) Second, when adults gesture while speaking, gestures consist primarily of manual gestures, i.e., hand, arm, and finger movements, and it is relatively uncommon for mature speakers to produce gestures that involve non-manual movements of legs, feet or whole body.

c) Third, among right-handed speakers (majority of all speakers), coexpressive gestures tend to be unimanual and are produced primarily with the right hand (Kimura, 1973).

d) Fourth, gestures and speech have a constant relationship in time, with the manual movements of gesture either slightly anticipated or occurring in synchrony with co expressive speech.

e) Fifth, *iconic* gestures bear some semantic relationship to the content of speech. These gestures are distinguished from beats, which are stress-time movements with no apparent semantic content and also from self- and object- adaptors (e.g. while saying zoom fingers touch the body doing the movement for 'zoom' from the body). The semantic argument is that iconic gestures exhibit the meaning relevant to simultaneously expressed linguistic meaning, in their form and manner of execution.

f) Sixth, class of gestures called *beats* are movements with no propositional content, instead they fulfill a discourse-oriented function, like some elements and structures of language itself. The pragmatic argument is that there are certain pragmatic similarities between language and certain categories of gesture.

g) Seventh, gestures and speech are affected in comparable ways by damage to the nervous system, particularly in the case of Broca's and Wernicke's aphasia. In Broca's aphasia, there is a relative ability to refer, and McNeill (1985) argues that gesturally these patients can still use iconic gestures. However, there is a marked inability to combine these referring terms into larger grammatical wholes and they show few or no beats. Therefore, there is a breakdown in the overall structure of discourse with a breakdown in the discourse oriented gestures. On the other hand in Wernicke's aphasia, there is a disruption in the ability to formulate semantic plans, but preserved ability to construct sequences of words. McNeill (1985) has observed that there is a parallel breakdown in gesture use, with few or no iconic gestures, but beats are intact. Thus, since discourse is intact, the discourse-oriented gestures stay intact.

h) Eighth, gestures and speech pass through very similar stages in development with an early emphasis in speech on denoting concrete objects and situations which are parallelly denoted using iconic gestures, which then progresses to the eventual emergence of discourse and the parallel emergence of beats.

Facial Expressions. There is often a strong tendency to equate a facial expression with an emotional expression. Facial expressions of emotion are nonsymbolic involuntary acts that reveal information about an individual's intra psychic state (Ekman, 1997). They are understood to occur during conversation, but their location in the speech flow is related not to the discourse structure, but to the semantics, and thus revealing an emotional reaction. While, conversational signals are part of the structure of conversation and are governed by the rules of the production of speech. There are three systematic descriptions of communicative facial displays in literature, namely,

a) Eyebrow movements (Ekman, 1979)

b) Smiles as back-channels (Brunner, 1979)

c) Conversational displays like smiles, facial portrayal, and eyebrow movements that represent a variety of syntactic and semantic functions (Chovil, 1992).

In adults, multimodal communication is essentially expressed through manual gestures and facial expression, while whole body gestures and leg movements are less frequently expressed during conversation. However, there is evidence that head (Wang, 2007), torso (Yasinnik, Renwick & Shattuck-Hufnagel, 2004), and eye brow movements (Swerts & Krahmer, 2006) are aligned with either accented syllables or the following weak syllables; i.e. the temporal synchrony is not as closely timed with spoken prosodic accents similar to what is observed for the hands. There is also consensus in the observation that there are wide cultural variations seen in the gestures exhibited by adults across the world.

Gesture - Speech System in Children

Repetitive motor activities of young infants towards the end of the first year, especially of the hand, begins to pave the way for mature and articulated control, which eventually leads to better directed communication. Infants begin to communicate intentionally, initially through hand gestures, then vocalizations and even later with words. Gestures and speech are considered equal partners, since most often the symbols produced by children are expressed in both modalities, i.e. gestural and vocal (Gullberg, de Bot & Volterra, 2010). Some studies indicate that the gestural and vocal modalities are semantically and temporally integrated from the earliest stages (Caprici, Contaldo, Caselli & Volterra, 2005), while others report that asynchronous combinations of gestures and speech are frequently produced than synchronous ones, in an initial development period (Butcher & Goldin-Meadow, 2000).

Functions of hand gestures accompanied with speech in children. It has been hypothesized that infants, toddlers, and even children with spoken language impairments use gesture to compensate for limitations or immaturities in articulatory or language skills (Acredolo & Goodwyn, 1988; Iverson & Thelen, 1999). In addition, the retrieval and formulation of spoken language to convey what the child knows seems to rely on a rich mental representation whereas gesture taps into the still evolving mental representation (Capone & McGregor, 2004; Capone, 2007). Further, it has been suggested that gestures allow the child to express ideas that are still forming because gestures represent knowledge visually without the demand of formulating a verbal description (Goldin-Meadow, 2003). Research has also shown that adults can glean information from a child's gesture, and they often tailor their instruction to the child according to what they believe is the childs' understanding (Goldin-Meadow & Singer, 2003). In the same vein they report that, the child's gesturing sets up opportunities for the adult to model the spoken language that labels what the child is gesturing.

Several studies also suggest that the gestures children produce while speaking reveal much more about what they are thinking than what is reflected solely in their speech (Alibali & Goldin-Meadow, 1993). Investigations on gesture production in school-aged children in problem-solving tasks, reasoning about balance or mathematical equivalence, problem-solving strategies etc. indicates that children convey a substantial proportion of their knowledge through speech-accompanying gestures (Alibali & Goldin-Meadow, 1993; Beaudoin-Ryan & Goldin-Meadow, 2014; Church & Goldin-Meadow, 1986; Pine, Lufkin, & Messer, 2004). In some other instances, children's gesture-speech 'mis-matches' may predict learning. Children whose speech and gestures mismatch are more likely to benefit from instruction than children whose speech and gesture match. This interesting finding suggests that speech and gesture can serve as an index of transitional, implicit knowledge in a topic, and may help determine a child's 'readiness to learn'. This claim that gestures may reflect implicit knowledge and readiness to learn agrees with research done in education, which suggests that teachers can better interpret a student's work by taking note of that student's underlying understanding of a topic (Carpenter, Fennema & Franke, 1996). Gestures have also been suggested as an effective learning tool in the classroom to help children understand mathematical concepts (Novack, Congdon, Hemani-Lopez & Goldin-Meadow, 2014).

Even in language comprehension, infants and children are able to interpret and integrate information conveyed in the gestural mode. For example, even before they start producing pointing gestures, infants are able to respond to others' points and direct their attention to an indicated object (Allen & Shatz, 1983; Leung & Rheingold, 1981; Murphy & Messer, 1977). Children have also been shown to glean meaning from multimodal information, i.e. when they encounter gesture-speech combination at both single-word and conversation levels (Kelly & Church, 1997, 1998; Morford & Goldin-Meadow, 1992). These findings are also corroborated with evidences of gesture processing in children using neuroimaging studies (Bakker et al., 2015; Gredeback et al., 2010; Melinder et al., 2015; Sheehan et al., 2007).

As can be seen, most of the studies have indicated that the role of gesture in spoken language acquisition and development, changes in different stages and depends on the communicative/interactional contexts. By one year of age, gestures aid in the construction and expression of meaning. In the following stages, gestures and speech develop together. At later stages still, gesture production appears to decrease in certain contexts (e.g., naming), although it is frequently used with speech in others (e.g., narration); however, gesturing never disappears and continues well into adulthood.

Research on children with brain injury has led to the understanding that there remains a tight link between gestures and speech production. For example, Ozcaliskan, Levine and Goldin-Meadow (2013) compared 11 children with prenatal unilateral brain lesions with their typically developing peers in their second year of life. They observed that children with brain lesions showed similarities to their typical peers in the production of simple sentences and not for complex sentences. Children with brain lesions exhibited parallel delays in the speech and gesture-speech combinations and they also initially produced simple sentences in both modalities before producing them entirely in the spoken modality. Another interesting feature seen was that these children produced complex sentence types in the spoken modality alone. Based on these findings they concluded that the gesture-speech system appears to be a robust feature of language learning for simple sentence constructions and acts as a harbinger of change in language development in an injured brain. The above evidences lend support to the ground that the communication system in a typically developing child is a multi-modal system.

Multi-faceted Development during Infancy

As outlined earlier, communication development is not just the language skills a child acquires, but also the simultaneous development of other motor and cognitive abilities. This perspective not only links the different abilities together, but suggests that they develop in a symbiotic manner.

Development of cognition. According to Nicolosi, Harryman and Kresheck (1989), cognitive development is the progressive growth of perception, memory, imagination, conception, judgment and reasoning. It also involves the mental activities of comprehension of information, and the process of paying attention, acquiring, organizing, remembering and using knowledge (Owens, 2008). Cognitive development in infants is suspected to be related to increase in memory and to the ability to acquire symbols in areas such as language and gestures, and this correlation seems to be very strong, especially during the first two years of life (Owens, 2012).

Many theories have been proposed on how cognitive development proceeds, and amongst these, a significant one is the theory by Piaget (1954). According to this theory, a child is viewed as an active participant in the learning process, and learning takes place when the child interacts with his/her environment and other people. It is proposed that maturation, physical experience, social interaction and a general progress towards equilibrium are the factors that aid in the development of cognition. Although this theory is not uniformly accepted, it still provides a framework for understanding development (Bartolotta, 2010).

Cognitive development begins with a cognitive structure (way of thinking), which is based on what the child currently knows, and when the child encounters a new experience, it creates a disequilibrium. It has been suggested that the child will then try to compensate for the disturbance and solve the conflict by means of *adaptation*, which will help in the integration of new information. Right from birth, an infant is learning from his/her interactions with the environment, with each interaction building upon a previous interaction, and the interactions that share similar features get organized as a *scheme*. Schemes are considered as cognitive structures that help the infant analyze and act upon an incoming sensory information, which become complex as the child learns new experiences (Bartolotta, 2010).

Piaget (1954) explained that assimilation and accommodation were two key aspects of the adaptation process. Assimilation is understood as the process of incorporating new stimuli into existing cognitive schemes, while accommodation refers to the process of integrating new information to develop new schemes. With each adaptation being made in cognition, the child is trying to maintain equilibrium with the environment. Based on the observation of patterns in the responses of children to intellectual tasks, Piaget (1954) categorized four definitive developmental periods, namely, sensorimotor, preoperational, concrete and formal stages. These stages are illustrated in Table 1.

The sensorimotor period of cognitive development is regarded with special interest since the foundations of communication behaviours are formed in this period, and it provides an opportunity to examine the links between aspects of linguistic, cognitive and motor development. This period is further divided into six stages and is as shown in Table 2. It is also assumed that by the end of this period a child is fully capable of using different types of behaviours including verbal, gestural and multi-step motor movements.

Table 1

The Periods of Cognitive Development (Piaget, 1954)

Stage	Age range	Summary of behaviours seen
Sensorimotor	Birth-2 years	Begins with a reflexive state, progresses to motor action related to sensory input, and ends with child's action becoming more purposeful
Preoperational	2-7 years	Close link between the development of language and cognition, complex social and play skills, storytelling, sense of time, and imagination.
Concrete	7-11 years	Develops abstract thoughts and ability to make judgments, and simple problem solving.
Formal	11-15 years	Complex problem solving, abstract thinking and logic. Development is considered complete.

Table 2

The Stages of Sensorimotor Period. (Piaget, 1954)

Stage	Age Range	Features
Reflexive	Birth-2 months	Child interacts through reflexive behaviours
Primary circular reactions	2-4 months	Child coordinates sensory input and new motor patterns, develops object concepts.
Secondary circular reactions	4-8 months	Complex input-output patterns develop (schemes); searches briefly for objects and child may imitate familiar behaviour.
Coordination of reactions	8-12 months	Child begins to combine schemes to achieve desired effect; achieves intentional behaviours; imitates new behaviours; recognizes qualities of objects (shaking a rattle) and achieves object permanence.
Tertiary circular reactions	12-18 months	Explores new ways to achieve purposes; begins to walk; words emerge; searches for objects.
Early representational thought	18-24 months	Child talks to control environment; repeats an imitated behaviour in the absence of a model; shows evidence of symbolic thought.

Development of motor skills. Motor development encompasses both gross motor and fine motor skills. Gross motor skills refer to movements which involve larger muscles (sitting upright), while smaller muscles are used for fine motor skills (writing). WHO (2006) has provided data on the major gross motor skills achieved during the first 18 months of life. This was based on a longitudinal study conducted on 800 healthy children in the age range during which the skills are expected to emerge (see table 3). The study suggests that there is a wide variation in the ages of acquisition of these skills, even among typically developing children, which is consistent with accounts that suggest development is marked by variability (Thelen & Smith, 1994).

Table 3

Gross Motor Skills in Infants (WHO, 2006)

Sl No:	Age Range	Motor Milestone
1.	4-9 months	Sitting without support
2.	5-11 months	Standing with assistance
3.	5-14 months	Hands and knees crawling
4.	6-14 months	Walking with assistance
5.	7-17 months	Standing alone
6.	9-18 months	Walking alone

Development of social and emotional behaviours. To be an effective communicator, a child needs to have the ability and interest in socializing and communicating with others and therefore, difficulties with social interaction can impair communication (Gerber, 2003). In early infancy, a child connects with his world mainly through nonverbal means, such as eye gaze and facial expressions. The infant might reflexively exhibit a behaviour that usually elicits a reaction from the environment, and in turn the infant will respond to this reaction, thereby aiding in learning. Infants also have a preference for faces, which helps them establish the foundations for early social relationships.

Another key behaviour that is achieved by children is the ability to maintain self-regulation. Regulatory capacity evolves as a control of physiological responses that controls an individual's emotional state and attention (National Research Council & Institute of Medicine, 2000). At infancy, the child has very limited regulatory capacity, which matures as the child grows older. Consequently, as adults they have better control over their emotions and attention. A strong social and emotional foundation paves way for the development of communication behaviours.

Development of Oral Language. The study of how children acquire language has been a core concept of enquiry for a very long time. There have been numerous accounts which have suggested the role of various mechanisms which aid in the development and use of language in a child.

Verbal skills are reported to develop and mature right from infancy through adulthood. During the first 2 months of life, infants produce a limited variety of sounds, which also serve limited purposes, like fulfilment of primitive needs such as hunger or pain. They also make pleasure sounds when they are calm, which resemble vowels (quasi-resonant nuclei), but are not true speech sounds (Bartolotta, 2010). Around 3 to 4 months of age, the infant produces cooing sounds, which are considered to approximate a single syllable consisting of a consonant and vowel. During this period, the production of vowels increases and diversifies.

After the age of 4 months, the child starts babbling and this consists of strings of consonant-vowel productions. These vocalizations begin as repeated strings of the same sound pattern (da-da-da) and as the child matures, babbles become more complex (ba-da-bi). Non-linguistic features of intonation, loudness and pitch are also found in their productions. Vocal patterns of jargon also set in after the age of 9 to 10 months. Often, jargon is accompanied by gestures, body movements and changes in facial expressions. As the child approaches 10 to 12 months of age, true words usually emerge which also marks the emergence of intentional verbal communication (Owens, 2012).

Development of mutually dependant cognition and action systems. Cognition and action are assumed to be mutually dependent and form functional systems which are driven by motives that facilitate the development of adaptive behaviours (von Hofsten, 2004). From this point of view, development does not begin with a set of reflexes triggered by external stimuli, but by a set of action systems activated by an infant. During the developing years, dynamic systems are formed when the nervous system and the actions of the infant mutually influence each other through activities and experiences. As development progresses, the action systems become further oriented and integrated with each other and each action will also engage multiple coordinated action systems.

While the infant is interacting in the environment, it gains prospective control as it starts foreseeing the ongoing stream of events in the surrounding and the unfolding of its own actions. All events are controlled by rules and regularities; some rules are general (e.g. laws of gravity) while others are more task specific (e.g. rules for grasping an object). There are also socially determined rules that facilitate social behaviour and enable us to communicate with others. Gaining knowledge of these rules, which are accessible through our cognitive and sensory systems, enables smooth and skilful actions (von Hofsten, 2007).

Based on the problem that needs to be solved and the goals to be attained, the knowledge needed to control actions varies. Thus, actions are organized by goals and not the trajectories they form, which imply that motives are the core of these cognitive processes (Poggio & Bizzi, 2004). Hence, while an action is being performed, the child will fix the goals and sub-goals of movements before they are implemented, which provides proof that these goals are represented in the planning phase itself (Johansson, Westling, Backstrom & Flanagan, 2001).

Early abilities in any organism develops with a built-in base, and these can be observed from the morphology of its body, the design of its sensorimotor system, and the abilities to perceive and conceive the world. Some of the core abilities are present at birth, and although infants have a restricted behavioural repertoire, the behaviours performed by them are prospective and goal directed actions and not just primitive reflexes. As an example, Rochat and Hespos (1997) reported that the rooting reflex is not seen when the infant touches his/her own cheeks or when they are not hungry.

von Hofsten (2007) suggests that these built-in skills not only enables the child to act, but also provides activity-dependent input to the cognitive and sensorimotor systems. Consequently, using this perception-action loop, infants begin to explore the relationship between movements, commands, vision, proprioception and even get a feedback on the constraints of their own actions. According to Spelke (2000), these core knowledge systems are limited in many ways since they are domain specific (each system represents a small subset of what infants perceive), task specific (each system solves a limited set of problems) and encapsulated (each system operates independently from other cognitive systems).

Motives also play a crucial role in the development of an organism, as these define the goals for each action and provide the energy for achieving them. Social and explorative motives are the two most important motives that govern the development of an infant. Social motive places the infant in the context of other humans and this helps the infant learn, seek comfort, and exchange information. This motive is expressed right from birth as it can be observed in the tendency to fix on social stimuli, imitate gestures and engage in interactions. Exploratory motive aids the infant in learning about their surrounding environment, as well as about their own action capabilities (Gibson & Pick, 2000).

It is hypothesized that prospective control develops simultaneously with the emergence of all new forms of behaviour in an infant, such as, locomotion, gazing, manual actions and other social behaviours. A few of these are elaborated below.

Development of posture and locomotion. An important pre-requisite for purposeful activity is the body's orientation in space and time. The body should be balanced in relation to gravity and maintain a stable orientation in relation to the environment. When there is an imbalance or threat to stability, the body should be able to counteract the same in a quick and automatic manner. An infant is born with postural reflexes which serve the purpose, but these are insufficient to maintain continuous balance during action and may even interrupt action. Such disturbances are better handled in a prospective manner because if the disturbance can be foreseen, then the need for reflexive reactions will not arise. It has been suggested that infants develop such anticipations in parallel with their mastery of different modes of postural control (Witherington et. al., 2002).

Development of gaze behaviours. One of the earliest appearing skill is the development of oculomotor control and this marks a profound improvement in the abilities of an infant. It is important for the extraction of visual information from the environment, for establishing attention and social communication. This control involves both head and eye movements and is guided by visual, vestibular and proprioceptive information. An infant is required to master two tasks to achieve this control, when they move the eyes to the visual target and also stabilize the gaze on the target.

Rosander and von Hofsten (2002) reported that from 4 weeks of age, compensatory eye movements are present that anticipate upcoming body movements, and from 6 weeks of age, tracking abilities improve rapidly. von Hofsten and Rosander (1997) also recorded that smooth head and eye movements develop around 6 weeks and reach adult-like form at around 14 weeks of age, and from 4 months of age, infants are able to attend to a moving object despite interruptions from other objects in the visual field. Infants were able to demonstrate this behaviour over larger occlusion intervals, suggesting that infants are able to track the object in their 'mind's eye' and that this is not an expression of the notion of object permanence (von Hofsten, Kochukhova & Rosander, 2006).

Development of hand action for reaching. While reaching for a mobile or immobile object, the hand needs to adjust to the orientation, form, and size of the object and the timing needed to anticipate the closing of fingers around the object is subject to good visual control. Infants have been observed to exhibit these anticipations from around 4-5 months of age and infants who were 5 and 9 months old moved their hand to the vicinity of the object and then only grasped it, while 13 month old children exhibited the grasping action during their approach towards the object, meaning that older children exhibited a mature and continuous reach-and-grasp action (von Hofsten & Ronnqvist, 1988).

Development of Social abilities. Interacting with other humans often creates a dynamic situation for infants than while interacting with and manipulating objects. Emotions and intentions are conveyed using elaborate and specific movements, gestures, and verbal productions which are important in perception and gaining control. A good number of these abilities are present at birth and reflect the preparedness of an infant for social interaction. It has been demonstrated that neonates are attracted to the human face, due to the sounds, movements and features of the face (Maurer, 1985; Johnson & Morton, 1991). Their ability to imitate facial gestures may be considered a reflection of their participation in social interaction and turn-taking. They also seem to perceive and express emotions such as that of pain, hunger or disgust through their innate abilities (Wolff, 1987). These innate dispositions probably provide a window of opportunity in order to learn more mature and intricate social behaviour.

Thus, cognitive development does seem to influence and expand the attainment of soon-to-be control of an infants' own actions as well as helps the infant perceive the goals and motives of the actions of another person in his/her environment.

Support for Ontogeny of Multimodal Communication in Infants

Infant communication is considered as a good example for models of human communication. It is widely believed that the since human communication is distinctive, the core foundation of communication will be present before the development of language and will be evidently different from that of other species. It has been suggested that the pre-linguistic gestures exhibited by an infant may throw some light into the origins of human communication.

Hand gestures in infants. From the age of 10 months, infants first communicate intentionally by using *deictic* gestures (Bates et al., 1979). They begin to *show* objects in order to participate in an interaction; although the infant may not hand over the object. Shortly thereafter, the infant will *give* the object to an adult to communicate. During the 10- to 12-month age range, they also produce ritual *request* gestures. These convey the infant's want for an object by reaching with open hand or moving from an adult's hand to the referent of interest (Bates et al., 1979). Just before the emergence of the first true words infants begin to show pointing (Bates, 1976). Pointing may to grow out of a child's use of index finger to explore objects, very early in infancy, while he is either alone or he is with others; but this action does not demand adult attention (Locke et al.,1990). But, later in infancy these pointing gestures are well coordinated with social interaction.

The sequence of deictic gesture development has been suggested to reveal the gradual distancing of self from objects which underlies symbolic development (Capone & McGregor, 2004). Among the other gestures, pointing is considered the hallmark in communication development because it is understood to predict the emergence of language symbols. In fact, this pre-naming behavior alone is said to predict the emergence of language symbols (Butcher & Goldin-Meadow, 2000). Children begin to produce deictic gestures and culturally rooted gestural routines such as waving goodbye, before they begin to talk (Bates, 1976; Butcher & Goldin-Meadow, 2000). These behaviours are also referred to as prelinguistic gestures (or performatives) because their acquisition is often seen prior to spoken language. However, pointing is used throughout the period of development. Showing, giving, pointing and requesting emerge in a predictable sequence, mostly from the age of 10 months (Bates et al., 1979). These show a marked increase in occurrence after 11 months as more primitive gestures (e.g. reaching) and emotive gestures decline (e.g. moving body up and down).

Pointing gesture has always been the subject of special attention for many researchers. Murphy (1978) observed this gesture in infants aged 9, 14, 20 and 24 months, while they were looking at books and found that pointing emerged at 9 months, but was not integrated with vocal activity until 14 months. Another study traced the emergence and development of three object-related gestures, namely, pointing, extending objects, and open-hand reaching in infants aged 9 to 18 months (Masur, 1983). It was reported that pointing was the last among these gestures to emerge between 12 to 14 years.

Representational gestures are said to emerge at around 12 months of age, which coincides with the emergence of first words (Bates et al., 1979). These are not considered as instrumental gestures since the infant does not manipulate objects but rather represents referents symbolically (eg. child flapping arms to represent a bird). Goodwyn and Acredolo (1993) have reported that infants are better equipped to express using gestures than using spoken language, in that, a child's gesture depicts the knowledge represented in memory. The early stages of vocabulary development are marked by a relatively slower pace of word learning. During this time, many children heavily rely on representational gestures to expand their communicative potential (Fenson et al., 1994).

Acredolo & Goodwyn (1988) have further proposed that initially children use words and gestures for the same communicative functions, such as referring, requesting, commenting and replying. The words and gestures are used in similar contexts and refer to the same semantic domains. Then with an increase in age, it reaches a stage where there is little or no semantic overlap between individual verbal and gestural items (Caselli & Volterra, 1990; Iverson, Caprici & Caselli, 1994). Between 12 and 18 months, children are observed to communicate with gestures or words in isolated ways, which means that they either gesture or speak, but not at the same time. The child is thus said to choose between the two modalities, i.e. verbal and gestural communication (McNeill, 1992). This was also further supported by Butcher & Goldin-Meadow (2000), who observed children longitudinally during the one- to two- word transition periods. Their data uncovered that during the early period, children produced majority of their gestures without speech and then there was a decline in the proportion of gestures produced without speech, and by the end of this period they began to produce gesture-speech combinations.

After a period of relatively slow-paced word learning, most children begin to acquire words at a rapid rate. At this point, children begin to make greater use of speech relative to gestures when communicating and the acquisition of new gestures slows substantially. By 18 months of age, children produce iconic or representational gestures along with their speech

(Bates et al., 1979; Butcher & Goldin-Meadow, 2000; Iverson, Caprici, & Caselli, 1994). During this period, complementary and supplementary gesture-speech combinations are seen, which are said to reliably predict the onset of two-word combinations, marking the robustness of gestures as an indicator of language development (Butcher & Goldin-Meadow, 2000). A study on Kannada-speaking children between 8-18 months has suggested that gesture-speech combinations begin by early months of the second year of life in these children (Veena, 2010; Veena & Rajashekar, 2015). It was also observed that children frequently produced supplementary gesture-speech combinations than when compared to complementary combination.

Children's first gesture-speech combinations are complementary because the gestures and spoken elements convey similar or redundant information. The second type of supplementary combinations emerge somewhat later, and in these combinations, the gestured and spoken elements convey a different piece of information about the same referent. Thus, they demonstrate the ability to coordinate production of two communicative elements as well as convey two different pieces of information in a single integrated message. Both these skills are reported to predict the transition to two-word speech. This shift toward two-unit productive combinations in communication also develops in parallel with gesture-gesture combinations in symbolic play, which have no obvious communicative purpose, for example, stirring and then drinking from a cup in a single uninterrupted action sequence (Iverson & Goldin-Meadow, 1998).

On the other hand, studies have also shown that language development is associated with neither an increase nor decrease in gesture production. Dobrich and Scarborough (1984) found no difference in form and frequency of pointing gestures between two groups of 2-year-old children with high and low mean length of utterances respectively. A study on children between 2 and 4 years of age reported the usage of fewer gestures and more verbal imperatives in a task where children were pretending to ask an object from a doll (Wilkinson & Rembold, 1981). Also, when 2-year-old children with superior verbal competence were compared with a group of children of the same age and normal verbal abilities, it was documented that there were no significant differences seen in the frequency of use of deictic gestures.

It has also been reported that 4-year-old children frequently use pointing gestures in their conversations (Elmslie & Brooke, 1982). Pechman and Deutsch (1982) stimulated deictic gestures in 2- to 9-year-old children and found that the older children relied on the verbal channel when gestures were likely to elicit ambiguity. But when confusion was unlikely, these children used gestures as often as the younger children did. In another study in which children of three different age groups were instructed to explain the rules of a game to adults, no differences were noted with increase in age (Evans & Rubin, 1979).

Emblem gestures seem to appear early in toddlerhood and are most often routine-based gestures at this point in development (Capone, 2010). During this period, children also come to prefer verbal expressions to gestural expressions as they are learning more and more words. Children still use gestures and there is even a certain increase in the use of deictics (Iverson, Caprici, & Caselli, 1994). As speech develops, gestures become elaborated especially in their relation to speech. Iconic gestures appear often with verbs and adjectives, rather than with nouns and the link between gesture and language extends to the domain of morphosyntax as children advance in age (Capone & McGregor, 2004). This also, coincides with the emergence of *beat* gestures, which are reported to emerge as a child becomes competent in the morphological and syntactic domains of language development (McNeill, 2005; Nicoladis, Mayberry & Genesse, 1999).

From the third to the fifth year of age, iconic gestures are found to increase significantly in children's productions. But, their co-speech gestures do not refer to abstract ideas. After the age of 5 years, *metaphoric* gestures as well as abstract *deictic* gestures are seen in their productions (McNeill, 1992). Colletta (2004) has provided support to this finding in a study on children from 6 to 11 years of age, wherein multi-modal story telling skills (inclusive of linguistic, prosodic and gestural modalities), developed together and simultaneously in these children with increase in age. Another study on referential communication studying pointing gestures observed that 4-year-old children point to designate a distant object surrounded by other objects, but by 9 years of age, children preferred to name the target object, like adults (Pechman & Deutsch, 1982).

Jancovic, Devoe, and Wiener (1975), addressed the question of evolution of gestures across stages of speech development and they recorded the occurrence of deictic, pantomimic and more complex speech-accompanying (semantic modifiers and relationals) hand movements among children aged 8 to 18 years. There was no evidence of developmental change for deictics, though pantomimics showed a strong linear decrease with age, and a significant corresponding increase was recorded for more complex speech accompanying gestures. Thus, the developmental data showed a shift in the types of gestures displayed as age increased, which suggests that gestures do not disappear with age and are not just compensatory movements used by young children during the stages of poor verbal fluency.

In summary, hand gestures emerge as a natural course of development in children. Deictic gestures emerge during the pre-linguistic period before 12 months of age, while representational gestures and emblems are seen during the first word period. Metaphoric gestures and beats are observed once morpho-syntactic development begins. Furthermore, deictic gestures are considered as predictors of the emergence of first words, and then gesture-speech combinations conveying different but related information precedes the first two-word utterances (Iverson & Goldin-Meadow, 2005). However, many observations also refute such predictions. It has been observed that not all types of hand gestures contribute towards further language development. In a recent study on children in the age range of 14 to 34 months, it was observed that children produced iconic gestures for actions after a 6-month period, following the development of the verbal production of the same verb categories (Ozcaliskan, Gentner & Goldin-Meadow, 2013). This finding could suggest that, although children use gestures to expand their repertoire, these gestures selectively precede or follow the development of spoken language.

The two salient characteristics of an adult's production of speech and hand gestures are the synchrony of both modalities and the semantic coherence. Butcher & Goldin-Meadow (2000) suggest that children's productions of speech and gestures bear the same characteristics as adults. They also reported that gesture and speech do not form a completely integrated system from the beginning and aligns with each other as the child's communicative range expands. A recent study longitudinally documented children from 12 to 30 months of age during interactions with caregivers and peers and has concluded that there are several phases that children pass through before they achieve synchronous use of gesture-speech combinations (Kelly, 2014). The children in this study were found to use 'gesture + single word indicating same element' asynchronously from a mean age of 13 months, while these modalities were synchronously used from a mean age of 16 months to convey the same elements of a message. Soon after this phase, by the age of 17 months' children were seen to produce synchronous 'gesture + single word indicating different elements' units. The result of this study suggests that temporal synchronization of gestures with accompanying speech elements is seen only from the second-half of the second year of life, while semantic synchronization of both modalities is seen from the first-half of the second year.

Dynamic development of language from gestures. It has been recognized that infants communicate using a variety of gestures involving various parts of the body, but it has also been often concluded from accounts of human communication that language evolved from manual actions and gestures (Armstrong & Wilcox, 2007; Tomasello, 2008). Social/pragmatic theories of human communication often emphasize that language usage and acquisition rely on prior social, cognitive and cooperative abilities, and so, an infants' gestural communication is nothing but a reflection of these abilities. Therefore, it is anticipated that infants' gestural abilities will reflect the presence of these social-cognitive and symbolic skills before the acquisition of verbal language. But there is also a view proposed by Liszkowski (2010) that, only certain pre-linguistic gestures, especially hand gestures, may precede language acquisition and although some key cognitive rudiments are revealed through gestures, many of these pre-requisites only emerge after language begins to develop.

Two perspectives have evolved with regard to the origins of gestural communication in infants. From a classic point of view, infant gestures have been described as either imperative or declarative, eventually building infants' emerging intentionality (Bates et al., 1979). This intentionality is assumed to stem from the infants' sensorimotor schemes towards the environment. Liszkowski (2008) argues that it is highly unclear as to what extent these gestures reflect intentions of the child towards others' intentional states and cooperative motives, and the need to achieve mutual understanding of the benefits for the other. The other view emphasizes that the social nature of human communication is what triggers the origin of infant gestures (Bruner, 1983). Since infants are exposed to interactional contexts with competent communicators (caregivers) from the beginning, it is said to provide the basis for cooperative human communication. Yet again, this account of origin does not explain the extent to which gestures are under the infants' control, nor does it elaborate on the existance of intentionally directed towards others (Liszkowski, 2010).

Communicative or symbolic hand gestures have been classified as deictic and representational gestures (Bates et al., 1979). Deictic gestures indicate a referent in the environment, the most prominent one being pointing; while non-deictic gestures represent a referent, either in a conventionalized arbitrary form or in an iconic manner. Thus, both these gestures are available for use as a referential means. But there have been both 'lean' and 'rich' views that look at these gestures as different sides of the same coin.

Among the deictic gestures, showing and placing have been considered as good candidates for intentional and referential communication and are said to reflect the foundations of human communication (Bates et al., 1979). But, it is not very clear as to how these gestures work from the point of view of the infant. It has been proposed that these gestures might originate from individualistic object-directed actions, as a way of interacting with others using objects in a non-referential manner, although they do afford and establish social contact

(Liszkowski, 2008). Thus, though these gestures can be explained through motives, the underlying cognitive complexities are unknown.

Franco and Butterworth (1996) have observed that pointing does not originate from object-directed actions and is used communicatively with cooperative motives and a social-cognitive understanding from the infant. Therefore, the ability to refer might originate in interpersonal contexts due to the emergence of the motive to share objects with others together as 'objects-of-regard' (Werner & Kaplan, 1963). However, it is still not apparent whether this form of pointing emerges through imitation or from a biological basis (Puccini & Liszkowski, 2012). A study on 12 month old infants across seven different cultures has however revealed that deictic gestures can be considered uniform across cultures (Liszkowski, Brown, Callaghan, Takada & de Vos, 2012). There is also evidence that pointing gesture continues to get integrated in later language skills learnt by the child while there is a decrease in the use of non-deictic gestures (Vallotton, 2010). Based on the above arguments, Liszkowski (2010) concludes that deictic gestures may be viewed as a developmental achievement and not just as a precursor to referential communication.

Non-deictic gestures have been further classified as ritualized and representational gestures. According to Tomasello (2008), ritualized gestures involve simpler forms of communication as well as cognition and are similar to that used by non-human primates. Though these gestures may resemble meaningful symbolic codes, they have been dismissed as symbols as they are not acquired and are not used with an understanding of embodying anything apart from its current usage. Representational gestures are conceptualized as forms of symbolic communication unique to humans and involving complex representational processes when compared to other gestures (Bates et al., 1979). This would then imply that gestures represent a referent and are often socially constructed.

An issue, however, with these gestures is that there is poor evidence as to whether infants can spontaneously create gestures to represent a referent. Therefore, Liszkowski (2010) prefers to consider that infants in the pre-linguistic period are organizing only the usage of an object through their representational gestures. This would imply that, infants ‘present’ and do not ‘re-present’ through their gestures. A support for this assumption is found in the cognitive argument that symbolic usage of representational gestures can be challenging than using words since infants can comprehend the iconic depiction of an action only after the age of 26 months (Namy, 2008).Therefore, Liszkowski (2010) concluded that there is solid evidence that deictic gestural communication precedes language development, but also that this communication is fully dependent on visually shared situations between the infant and others. In view of the findings that representational gestures play a minor role in the transition to higher language, it is suggested that deictic gestures play a participatory role in infant communication, and contributes to the development of language. Thus, from an ontogenetic point of view, deictic gestures are the stepping stones to acquiring unique symbolic forms of communication.

The study on Kannada speaking children between the ages of 8 and 18 months has also suggested that the use of pointing gestures was a good indicator of behaviour regulation and joint attention and that the children used these gestures to fulfill both imperative and declarative functions (Veena, 2010; Veena & Rajshekar, 2015). It was also observed that children combine pointing behaviours with vocalizations as well as verbalizations in order to either ‘request’ or ‘inform’; ‘pointing to request’ was also seen to emerge earlier than ‘pointing to comment’.

There is an alternate account proposed by Southgate, van Maanen and Csibra (2007) which suggests that describing infant pointing as either declarative or imperative may be premature. They suggest that infant pointing should be interpreted as an ‘interrogative act’ and not declarative communication, since engaging in declarative communication leaves no scope for further dialogue. Dialogues are possible when communication is very interrogative and so the infant points in order to obtain information about objects or events. Thus, gestures might only serve the infants’ needs to learn about his/her environment through a unique way of communication. But, the authors have not put forth further evidence to substantiate their hypothesis.

Facial gestures in infants. It is now being recognized that most facial components of human expressive repertoire can be observed shortly after birth (Camras, Holland & Patterson, 1993). Facial expressions are nothing but social signals. It is understood that an infant can provide cues regarding its emotive status through facial expressions combined with crying, vocalization or even body movements (Sullivan & Lewis, 2003). This in turn makes the caregiver alert and helps in the interpretation of the infant’s emotions, be it pain or satisfaction. This interpretation is important to parents personally and helps in promoting interactions.

Facial expressions may also serve as signals to the neurological and cognitive status of a child, since these expressions are controlled through the facial cranial nerve and are also assumed to be linked to cognitive development (Lewis & Michalson, 1983). Although, the initial appearance of these expressions may be controlled at the subcortical level, however, as the child develops higher-order cognitive and motivational systems get integrated with cortical control. Thus, infant expressions may also be assumed to have some clinical significance.

The differential emotions theory (DET), which is a highly influential theory of emotion, suggests that when infants experience basic emotions that are motivational associations of expressive, neurophysiological and phenomenological responses, these assemblies are realized through facial expressions (Izard & Malatesta, 1987). This theory was developed on the principles of innate concordance, and this has led to the use of facial expressions as the sole measure of infant affect.

Izard and Malatesta (1987) have made several assertions in order to support DET, which are as follows:

1. The morphology of infant expression is the same as that of adults for the same discrete emotions.
2. Infant's facial expressions are identified as discrete emotional expressions by adults.
3. There is covariance between infant expressions and emotion-appropriate incentive events.
4. There is covariance between infant expressions and non-facial emotional behaviours.

Based on DET, few of the common infant facial expressions have been categorized as those having either a 'positive' or a 'negative' affect. *Interest* is one expression that is considered as a sign of positive approach, although many researchers may not consider it an emotional expression (Sullivan & Lewis, 2003). This expression is characterized with raised brows, wide open eyes, relaxed and open or close mouth (Sullivan & Lewis, 1989). Camras (1992) has also reported a 'knit-brow' interest expression, where the brows stand out more prominently and eyes are narrowed, and this is often accompanied by a vocalization or a momentary stillness and is seen when the infant appears to be extremely interested (Sullivan & Lewis, 2003). Interest is recognized as the most common expression seen in infants and is reported to follow a specific developmental trajectory (Lewis, Alessandri & Sullvian, 1990). It is found to be frequent in young infants, decreasing between 2 and 8 months and again appearing by 10-12 months. At these ages, knit-brow interest is suggestive of problem solving in challenging situations.

Surprise, which is characterized by raised and arched brows, widened eyes, gaping mouth and sometimes momentary stopping of ongoing activity, is an expression that is rarely seen in young infants (Sullivan & Lewis, 2003). It is said to appear in the context of exposure to a sudden and unexpected audiovisual event. It also appears to be brief and is found to resolve into some other expression like interest or a negative expression. Bennett, Bendersky and Lewis (2002) have also reported that infants may begin to show mild expressions of surprise by the age of 6 months.

Enjoyment is easily recognized and is acknowledged as the milestone of social behaviour and is expressed as facial actions of *smile* and *laughter*/*play* face (Sullivan & Lewis, 2003). Both these expressions appear universally, although cultural and environmental differences have been observed (Kisilevsky et.al., 1998). *Smile* is identified by narrowed eyes and a widened mouth with raised corners. It is reported to be present from birth and is said to be state-dependent within the neonatal period. By 6 to 8 weeks of age, smile is observed in response to both auditory and visual stimulation, especially for stimuli with face-like quality (Vine, 1973). Social expression of smile is reported to increase by the age of 16 weeks, after which many infants are aware of whom they will smile for. It has also been documented that after the age of 12 months there can be many variants of social smile (Fogel, Nelson-Goens, Hsu & Shapiro, 2000). As the infant matures, he/she is capable of self-referential and self-evaluative behaviours which leads to the integration of enjoyment along with other postural and gestural behaviours.

Painful stimulation to the infant results in the expression of a strong negative emotional response, which is characterized by drawing together and lowering of brows, deep nasolabial furrow and squinting of eyes (Sullivan & Lewis, 2003). The expression of *pain* is reported to be seen from the new born period till 18 months of age, after which the frequency of facial displays reduce and other variations of anger occur (Izard, Hembree & Heubner, 1987). This could be the result of enhanced behavioural coordination and maturation of motor skills in the child. These expressions of pain are seen both in physically painful and distress situations (Oster, Hegley & Nagel, 1992).

Anger appears to be depicted by brows lowered and drawn together, with deep nasolabial folds and an open mouth (Sullivan & Lewis, 2003). This negative expression is often accompanied by crying in infants. It is understood that the central nervous system responds intensely for a negative than a positive stimulus, which could explain the co-occurrence of multiple negative and blended expressions with anger face (Peters & Cazapinski, 1990). This expression is observed to remain stable throughout childhood.

Sullivan and Lewis (2003) have documented that a *sad* expression is recognized by raised and angular brows, narrowed eyes with turned down mouth corners. The nasolabial folds are also prominent and some infants may even raise their chin. Sad pouts are not reported to be a response to a specific stimulus or context and have low frequencies of occurrence both during social interactions and during episodes of learning (Lewis, Alessandri & Sullivan, 1990). Camras (1992) has also suggested that when this expression occurs in an infant or a young child, it either manifests into an expression of anger or into a regulatory movement which eventually inhibits the anger.

Although there are many researchers who support DET, there are others who have argued that infant facial expressions are initially not tied to discrete emotions, rather they are tied to diffuse indistinguishable hedonic states (Campos & Barrett, 1984). Campos & Barret (1984) assume that it is only during development that facial configurations become associated with specific emotions. Despite these different viewpoints, it is clear that infant facial expressions are present from birth and these are well organized and similar in form to that of an adult (Camras, Malatesta & Izard, 1991; Sullivan & Lewis, 1989).

Thelen, Kelso and Fogel (1987) have suggested that infant facial expressions can be considered within the framework of coordinated structures. This implaies that, infant facial action may be a component of a larger assembly of motoric and physiological variables that are obliged to cooperate and to form patterns according to the rules of the system's dynamics.

These coordinated structures emerge as a product of the dynamics of action, and arise because the movement of one set of muscles employs other muscles (Michel, 1991). The pattern of recruitment, however, may depend on the effort needed to move the muscle and the closer proximity of this muscle's neural control to that of other muscles.

Thus, infant's facial expressions maybe components of motoric and physiological variables that are compelled to cooperate and form different patterns on which these variables are operative (Fogel & Reimers, 1989). This would also mean that these expressions can occur without a link to the emotional states of the infant (Michel, Camras & Sullivan, 1992). Moreover, a study by Legerstee, Corter and Kienapple (1990) on 9 to 15 week old infants reported that there were specific facial and hand movements that were associated with states of distress or pleasure, in both social and non-social contexts. A study on 5- and 7- month old infants demonstrated that brow movements occurred as a coordinated motor pattern involving actions of head and eyes in both the age groups, during the expression of interest (Michel, Camras & Sullivan, 1992). It was noted that when eyes and head were raised, the muscles that raised eyebrows were also involved. Another study in the same age group of infants for the expression of surprise documented that mouth opening was accompanied by brow raising and in some instances by even raising of eyelids (Camras, Lambrecht & Michel, 1996). These findings are consistent with the dynamic systems perspective on the recruitment of motor actions and tend to disregard the notion that facial expressions are controlled by a discrete program for emotion. However, it is difficult to speculate how many of these facial expressions exhibited during infancy may be part of these larger coordinative motor structures.

Gaze behaviours in infants. Eye gaze is considered an important element of human social interactions, and can reflect the individuals' feelings or attitudes towards the interaction partner and the goal behind his/her interaction (Kleinke, 1986). Eyes suggest the person's attention and intention and often serve as dependable signals to infer mental states (Baron-Cohen, 1995). It also helps us identify and share a topic during communication and social learning (Bloom, 2000; Csibra & Gergely, 2006).

Infants are sensitive to eye gaze from an early age and are invariably attracted to open eyes (Rigato, Menon, Johnson, Faraguna & Farroni, 2011). They prefer to look at faces that have a direct gaze than an averted gaze (Bakti, Baron-Cohen, Wheelwright, Connellan & Ahuluwalia, 2000; Farroni, Csibra, Simion & Johnson, 2002). Murray & Trevarthen (1985) suggest that infants also use their social partner's gaze to guide social interactions, just like that seen in adults. Subcortical mechanisms are said to be responsible for newborn gaze behaviours, like that which helps draw attention to face-like stimuli, while after about 4 months of age cortical mechanisms are assumed to be responsible for the development of eye contact (Caron, Caron, Roberts & Brooks, 1997; Johnson, Grossmann & Farroni, 2008).

Zeifman, Delaney & Blass (1996) reported that 4-week old infants maintained eye contact during episodes of nursing, and it has been found that this also potentiates the effect of sucrose delivery to help calm the infant. An infant is able to fix visually on its mother's eyes and holds this fixation with widened eyes (Owens, 2012). This infant might also begin to look and continue to look if the caregiver is also looking at the infant. By 9 weeks of age, an infant can fixate consistently on an adult's eyes when addressed to than when the adult is silent (Haith, Bergman & Moore, 1977).

From the age of 3 months, an infant can smile in response to eye contact, but there is a decrease in this behaviour when the adult's gaze is averted (Hains & Muir, 1996). At this age, the infant has a visual range that almost similar to its mother's, and this enables the infant to be an interactional partner using this modality (Owens, 2012). By 4 months of age, eye contact aids in face recognition and by 6 months, direct gaze is said to determine the rate of subsequent gaze-following behaviours (Farroni, Massaccesi, Menon & Johnson, 2007; Senju & Csibra, 2008).

Akhtar and Gernsbacher (2008) have pointed out that gaze plays a significant role in the social cognitive development of typically developing sighted infants. Mutual gaze, gaze following and gaze alternation are considered the milestones that may mark the development of social interactions in infants. Gaze between infants and caregivers is considered as a sign of mutual engagement (Gergely, Egyed & Kiraly, 2007). Engaging in mutual gaze is reported to calm distressed infants and infants avert their gaze when they are over-aroused (Blass, Lumeng & Patil, 2007). It has been suggested that since maintaining mutual gaze consumes resources in processing, gaze aversion might be a mechanism that will help reduce the cognitive load (Doherty-Sneddon & Phelps, 2005).

It has been demonstrated that a 1-year-old child follows an adult's gaze to locate an object of interest and older children use gaze to determine which of the two objects an adult is referring to, during interactions (Baldwin, 1993). Thus, gaze following can be considered as an index of understanding another person's attention. Brooks and Meltzoff (2008) suggest that the gaze following ability in 10- to 11- month old infants can be an index of their vocabulary development. Gaze following is further interpreted as an ability to represent what another person can or cannot see, which is in turn a precursor to the development of theory of mind (Tomasello, 2004). However, during an interaction, changes in gaze direction are also accompanied by changes in body posture, head orientation and voice direction (Kita, 2003), possibly suggesting a coordinated pattern of development.

Joint attention is possibly indexed by gaze alternation between caregiver and object (Kasari, Freeman & Paparella, 2006). Infants are assumed to demonstrate their awareness of the adult's eye gaze and visual focus when exhibiting this behaviour (Brooks & Meltzoff, 2008). However, there are many researchers who do not agree with this viewpoint. This is because in such a scenario, the infant is expected to initiate eye contact with an adult so as to engage the adult, and this might not be an easy task that can be executed (Carpenter, Nagell & Tomasello, 1998). Many others have also reported proto-declarative points enable an infant to direct and share attention to objects as it requires maintenance of eye contact with an adult (Tomasello, Carpenter & Liszkowski, 2007). However, this view of pointing in infants for sharing of attention is again not universally accepted (D'Entremont & Seamens, 2007).

Despite these conflicting viewpoints, there is a common consensus that towards the end of the first year there is considerable improvement in infants' abilities to understand and use gaze both as a social and goal-directed action. Brooks & Meltzoff (2008) have suggested that individual differences in following gaze and pointing can a measure of language development, since without the ability to follow gaze a child would miss the point of access into language and the mental states of others.

Body movements in infants. Rhythmical stereotypes are part and parcel of the behavioural repertoires of insects, fish, and birds, but not so in mammals (Schleidt, 1974), and these stereotyped behaviours are often considered pathological. Among non-human primates these have not been observed in free animals, but they can be produced by animals caged in small enclosures or when they are raised in social isolation (Berkson, 1968). Even in humans, stereotypy is usually associated with not-so-typical populations, like children with autism, individuals who are blind, or those who are emotionally disturbed (Berkson & Davenport, 1962).

However, stereotypy is the hallmark of typically developing human infants during one stage in the lifecycle (Kravitz & Boehm, 1971). Infants are reported to produce large amounts of rhythmical behaviours, like kicking, banging, rocking, waving, bouncing, swaying and such. These behaviours occur very frequently when they are young and infants seem to enjoy and absorb these acts, though it is difficult to assign a purpose for these movements.

There has been considerable debate regarding the functions of these stereotypical behaviours seen in infants. Psychoanalysts, for example, have proposed that stereotypy could be a sign of emotional development; either an attempt to recreate rhythmical prenatal experiences or as a result of an infant being confined to a small space (Kris, 1954; Levy, 1944). Piaget (1954) described repetitive movements as 'secondary circular reactions' since an infant only repeats an activity that has an interesting effect on the environment. He claimed that this was a sign of cognitive development. It has also been noted that certain rhythmical behaviours may be associated with particular stages of neuromuscular maturation, and this therefore suggests that rhythmic patterns are indicators of motor development (Kravitz & Boehm, 1971).

Schleidt (1974) proposed that repetition of a signal could increase its potency for communication, since caregivers may consider these behaviours as intentional. For example, a study on 'fussy' infants reported that increased levels of arousal in a baby facilitated the release of rhythmic motor output, which in turn accentuated their cry for distress which was reciprocated with a hastened response from the caregiver (Thelen & Fisher, 1982). This suggests that rhythmic movements may communicate infant affect.

Thelen (1979) observed 20 infants between the ages of 28 and 52 weeks and concluded that there seemed to be multiple contexts that elicited rhythmical behaviours in the infants. These were categorized as interactions with caregivers, other people, interest in objects, feeding times, passive or active kinesthetic changes and non-alert states like that of drowsiness. She also observed developmental trends in the interactions of these contexts and rhythmic movements. It was observed that in 3-5 month old infants, interactions with caregivers were stronger elicitors of stereotypy, whereas this was frequent in object related interactions in older infants. It was also seen that all categories of contexts elicited stereotypy during the middle months (6-7 months) and showed a decline when the infants were approaching 12 months of age. The same study by Thelen (1979) documented a wide range of rhythmical stereotypies that involved various parts of the body such as legs, head, torso, arms and face of infants. Among the movements of legs and feet, rhythmical kicking was observed an early age and was found to be persisting for a number of months. These bouts were often seen when the infants were either in prone or supine position and they began when the infants were between 6 and 14 weeks of age. The rhythmic movements seen were alternate-leg kicking, single-leg kicking, foot rubbing, both-legs-together kicking, foot flexion, foot stomping and foot rotation.

In the same study (Thelen, 1979), movements of torso observed included bouncing, swaying, rocking, hand-and-knees rock, hands-and-feet rock, rocking and bouncing while sitting, kneeling and standing. These stereotypies were observed while the infants were in prone, sitting, kneeling or standing positions as well as when they were supported on hands, knees and feet. These movements were observed in infants at various ages; abdomen movements by 16 to 34 weeks, hands and knees movements by 18 to 44 weeks, sitting movements by 18 to 48 weeks, kneeling movements by 30 to 50 weeks and standing movements by 22 to 44 weeks.

It was also documented that infants performed many bouts of stereotyped movements of the arms, hands and fingers (Thelen, 1979). These were often found to incorporate objects as part of the movement itself. Arm waving, arm banging, hand clapping, push-pull movement of elbow (bend), ear/hair rub, flexing of hands, rotating of hands and flexing of fingers were observed in the infants. It was also noted that flexing of fingers was not seen in all infants. Rhythmical movements of arms began by 6 to 22 weeks, movements of hands by 22 to 46 weeks and movements of fingers were seen by 4-16 weeks. Movements of head and face were reported to be infrequent when compared to the rest of the body. Head shake and head nod were seen along with tongue protrusions, tongue swipes, non-nutritive sucking and small rhythmic mouthing movements.

From the observations of rhythmic strerotypies, Thelen (1981) concluded that these behaviours appeared to be under strong neural control, based on the regularity seen in the onset ages of these behaviours and the close association of these ages to other aspects of neuromuscular maturation. Therefore, the production of these behaviours seems dependent on the maturation levels of the nervous system and these events are intrinsic to the infant. But this does not rule out the variable developmental course of these behaviours, which might reflect the influence of factors extrinsic to the infant. However, it can be understood that even in the face of this variability, these behaviours develop in an orderly manner.

Evidence that also supports this view can be found in the appearance of these behaviours before the infant gains postural control. For example, rhythmical kicking may precede both the ability to support weight on legs as well as the use of legs for crawling or walking. This might suggest that such behaviours actually reflect some degree of functional maturity of a neuromuscular pathway, inspite of the lack of complete voluntary control and imperfect goal-correction.

Thelen (1981) also suggested that these stereotypies could also be the result of an overload in the neural processing capacity, since the available pathways are immature to process heavy demands. This would imply that, when maturation enhances the processing capacity of the system, these behaviours will be replaced by variable and goal-corrected activity. This might hold good for human infants, since their neuromuscular maturation is much slower when compared to infants of non-human primates. However, these behavioural ‘by-products’ are often used opportunistically and may serve a variety of functions when the complex and mature behaviours of the functions are not available to infants.

Speech in infants. The development of vocalic behaviours of an infant is a widely researched area. Earlier claims of acquisition have proposed that infants are capable of producing the phonemes of all languages which are often acquired in a universal order and that there is a discontinuity between babbling and subsequent word development (Jakobson, 1968). But these claims have now been rejected and the importance of prelinguistic foundations of verbal behaviours is being recognized. It is now documented that the simplified sounds produced by infants as young as 6 months of age pave way for more complex vocal productions (Nathani & Oller, 2001).

During the first year of life, it has been demonstrated that there are rapid quantitative and qualitative changes occurring in an infants' vocal production (Hsu & Fogel, 2001). With the frequency of crying reducing by the end of the second month, speech-like vocalizations becomes more frequent in the infants' vocal repertoires (Oller, 1980). During the second half of the first year, the emergence of canonical babbling is said to mark the beginning of complexity and paves the way for development of mature speech (Nathani & Oller, 2001).

Infant vocal production has been viewed as (i) a response to gravity; as (ii) a response to social stimulation; as (iii) a discovery of vocal capacity; and also as (iv) a result of active learning (Oller, 1981). Some of these views draw support from the Piagetian perspective, which purports that infants explore the sound-making abilities of their anatomical system with little need for adult shaping. But there are other viewpoints which suggest that vocal production, interactions and communication may be interrelated processes and that these shape the speech production abilities of the child (Stark, Bernstein & Demorest, 1993).

Oller (1980) created a hierarchy of widely accepted prelinguistic speech development, i.e. a five-stage model, to characterize the patterns seen during the period of development. This model comprises of the following stages: phonation stage, primitive articulation stage, expansion stage, canonical stage and variegated babble stage. In the *phonation* stage, which extends till the second month of life infants produce quasivowels, and these are produced during normal phonation. These sounds are separate from the vegetative sounds (coughing, sneezing) and fixed vocal signals (laughter, cry). During the *primitive* articulation stage, which is around 2-3 months, infants are reported to produce normal phonation and simultaneously move the supraglottalic vocal tract to produce protophones which are called gooing. In the *expansion* stage, which is around 4-6 months, infants are noted to produce full vowel-like sounds in which the vocal tract is postured such that vowel contrasts are created. Infants also articulate consonant-like sounds while phonating. This sequence of actions produces marginal babbling. During the *canonical* stage, which is around 7-10 months, infants are found to produce well-formed syllables, where the transition between vowel-like and consonant-like elements occurs rapidly, just like in speech. In the *variegated babble* stage, which is around 11-12 months, repetitive sound clusters diminish and infants produce a variety of consonants and vowels, as well as jargon which resembles the ambient language (Elbers, 1982).

But, many researchers do not agree with Oller's hierarchy as they feel that emerging speech behaviours in infants cannot be easily categorized. Stark (1980) demonstrated that speech development could be logically divided into four stages, which include the phonation, primitive articulation, and expansion stages as suggested by Oller (1980). However, stage four was described as a combination of the canonical and variegated babble stage, wherein, the infant is making use of CV patterns, reduplicated and non-reduplicated babble, gibberish and intonation. She suggested that there is no one fixed point in time where one process ends and another replaces it, and that there is a transition between vocalizations and employing sounds in a speech-like manner.

Mitchell and Kent (1990) have suggested that the progression from canonical to variegated babble marks a shift from prelinguistic to linguistic behaviour. It is also at this stage that the child's productions may be perceived as words by adults (Oller, 1980). Further, parents will try and shape these vocalizations to word-like realizations (Oller, Eilers, Neal & Schwartz, 1999). There is also an increase in the variety of consonants and vowels within an utterance with changes in intonation and further a reduction in repetitive clusters. Many researchers also acknowledge that babbling may be height of development that precedes meaningful speech, since there are resemblances between the syllables of canonical babbling and early meaningful speech (Vihman, Macken, Miller, Simmons & Miller, 1985). It has also been suggested that these vocalizations reflect the emerging capacity for speech as they incorporate properties of adult-speech, such as normal phonation, articulation and various consonant and vowel combinations. There is also growth in these capacities since these properties are accumulated systematically over time (Oller & Lynch, 1992).

In the Indian scenario, few studies have focused on documenting the development of early speech production abilities in infants. Shyamala and Basanti (2003) documented the development of vowels and consonants in children from two language groups in India, namely, Hindi and Kannada. Their results revealed that there were subtle differences in the consonant and vowel repertoires, which appeared between the ages of 6 and 12 months, in these groups of children. Another study on phonotactic development in Kannada speaking children, between the ages of 0 and 5 years, reported that syllabic shapes of V, C, CV, VC and CVC were most frequently occurring and the frequency of occurrence of these shapes increased between 0-18 months of age (Rupela & Manjula, 2006). Anjana and Sreedevi (2008) also reported that V, C, CV, CVC, VC and VCV were the most common syllabic shapes seen in infants from the age of 6 months, and that there were differences in the occurrence of these various shapes towards the end of the first year.

Davis and MacNeilage (2004) proposed a *frame/content theory* of speech evolution based on the biological view of vocal-auditory medium being founded on biomechanical capacities and rooted in deep evolutionary frame. They also based the theory on the fundamental construct of embodiment considering the ability of an individual to produce rhythmic strings of syllables (Lashley, 1951). This theory suggests that consonants and vowels (‘content’ elements) are placed into a syllabic structure ‘frame’ which obeys the diverse ordering regularities of modern languages.

The ‘frame’ for an adult speaker is based on pre-motor (planning and organization) syllabic receptacle for consonant and vowel placements, whereas for infants the ‘frame’ is the actual speech movement with the onset of speech-like canonical babbling. This frame is considered as the product of rhythmic open and close jaw cycles, which is a biomechanically based operation of the speech mechanism. And as the infant develops independent control of the coordinated articulators within the time constraints, mastery of these movements will subsequently enable accurate productions of specific consonant and vowel elements. Thereby, the ‘content’ elements will eventually differentiate from the jaw-based ‘frame’ to become separate entities as the infant gains control over the coordination of articulators in vocal productions. This development is attributed to the introduction of on-line variations in the basic frame cycle and in the positioning of the articulators (e.g. tongue or soft palate).

Thus, the key construct of this theory is that sound patterns of words are a result of two conflicting forces, which are production constraints and perceptual distinctiveness. Also, as the infant matures, motor, perceptual and cognitive abilities enable the infant in increasing recognition and learning salient sounds and sequencing regularities in the ambient language (Jusczyk, 1997). These components are essential for learning the precise nature of 'content' elements specific to the infants own language across the developmental time frame. This gradual emergence of 'content' capacities is regarded as a reflection of the emergence of complexity in phylogeny and motivated by social and cultural pressures to enhance complex communication.

Research has also suggested that early infant vocal development may be continuous, and yet a non-linear process. And it has been suggested that the principles of self-organization from a dynamic systems perspective may explain the nature of development (Hsu, Fogel & Cooper, 2000). This approach proposes that vocal production is the outcome of coordination among articulatory, respiratory and anatomical elements and that the constraints imposed by the configuration of these elements helps the vocal system retain its continuity over time (Thelen, 1994). Elements of the vocal system reassemble themselves when both internal (maturation of an anatomical component) and external (social environment) changes occur and the new configuration of these elements results in a non-linear shift in the system. Thus, this phase-shift may result either in progression/increases in occurrence or regression/ attenuation in occurrence, which would explain the continuous and non-linear nature of vocal development during the prelinguistic period.

The development of prosodic features in the vocalizations of infants has also been studied, especially with regard to melodic contours. Infants are reported to imitate, discriminate and produce a large range of melodic patterns in the prelinguistic period (Kessen, Levine & Wendrich, 1979; Papousek & Papousek, 1981; Trehub, Bull & Thrope, 1984). It has also been suggested that early vocal development might be manifested in melodic contours (Tonkova-Yampol'skaya, 1973).

D'Odorico (1984) reported that infants between the ages of 4 -9 months produced vocal sounds with different melodic patterns that may serve different communicative functions. It was observed that sounds for request were characterized by flat and rising pitch contours, while sounds for discomfort were marked by flat or falling pitch contours. Another study documented associations between melodic contours and the context in which the vocalization occurred (Delack & Fowlow, 1978). They found that rise-fall contours were likely to occur when infants were interacting with their mothers, while rise and flat-rise contours were likely to occur when the infants were left alone. It has also been reported that infants as young as 3 months old produced speech-like syllabic sounds with more variable pitch contours when compared to their non-speech like vocal production (Bloom, 1993).

Another interesting observation with regard to infant vocal actions is that they can be performed even in the absence of an intended social function (Oller, 2010). Through their motoric exploration from an early age, infants may develop a repertoire of sounds that are not speech and also may develop categories of vocalizations (squeals, vowel-like sounds), which are categorized and labeled as communicative gestures by caregivers (Stark, 1980). But this communication is essentially not speech-like and is not meaningful since it does not involve reference to entities, but is interpreted as a message by parents. The functions that these categories serve also appear to be varying from one occasion to the other, even within a child or within the same day (Oller & Griebel, 2004). This is labeled as ‘functional flexibility’ and is considered as a salient feature of human infants alone. Snowdon (2004) also suggests that human infant vocal communication also has ‘signal flexibility’, as they are capable of producing a good number of vocal categories that serve varied purposes.

From the above, one can understand that both the primitive phonatory categories and later babbling stages incorporate principles of motor development, which appears to be a necessary condition for acquisition of spoken language. However, the influences of the structural aspects of language (form) and pragmatic aspects of speech (function) that shape the dyadic communication process cannot not be undermined.

Development of gestures and speech in infants. Researchers have documented that the beginnings of gestural forms associated with vocal forms can be seen very early in infants (Bower, 1974; Fogel, 1981; Fogel & Hannan, 1985; Hannan, 1987; Thelen, Kelso & Fogel, 1987). Trevarthen (1977), followed 5 children from 2 to 6 months of age, and observed that by 2 months of age, most infants demonstrated hand-waving, index-finger pointing, and fingertip-clasping movements near their faces during expressive vocalization and pre-speech facial movements such as tongue protrusion and lip contraction. These hand patterns were termed as gesticulations, which refer to gestures accompanying speech in adults (Kendon, 1994). The facial movements were also accompanied by hand, foot or trunk movements. These movements were viewed as innate forms that are not imitated but modified through exposure to adult models.

Fogel and Hannan (1985) conducted a study on a larger scale with 28 children, 9 to 15 weeks old, and reported that manual actions such as index finger extensions, which resemble 'pointing', followed vocalization or mouthing movements even. However, there was no relationship found between pointing and gaze direction. Curling action of fingers was also found to precede or follow all the other hand actions, as well as co-occur with vocalizations. They also reported that spread of fingers did not occur in sequence with vocalizations and that it occurred during facially neutral states when a baby was looking away from the mother. Grasp was found to occur incidentally and was not considered to be systematically related to any other behavior. This study also documented the laterality in hand actions and it was seen that there was right-side dominance for spread, and left-side dominance for grasp. There were differences noted in the way each hand was sequenced with non-hand actions, specifically, co-occurrence relationships with vocalizations and sequential relations with mouthing were reported to occur with actions of the right hand. Also, the co-occurrence relationships with gaze direction, mouthing and relaxed face were found with spread, and a sequential relationship with vocalization was observed to occur with actions of the left hand. This study also reported that there were no gender differences seen in this phenomenon.

In addition, Fogel and Hannan (1985) emphasized that the early appearance of discrete, articulated hand actions such as points called for a review of theories of the ontogeny of hand and finger actions. Hannan and Fogel (1987) studied one infant in interaction with the mother for the first 12 weeks of the infant's life. They reported that pointing was seen as early as 18 days of age, with 38 instances of pointing documented over 12 sessions of observation. 80% of the single occurrences of pointing and 87% of the total duration of pointing occurred for the right hand. Pointing on the right hand tended to occur with fingers curled on the left hand, and points either preceded or followed other categories of hand behavior. There was a positive co-occurrence of pointing and mouth at rest, with a negative co-occurrence with smile. They did not document any significant relationship between pointing and maternal behaviours. There was also no evidence that the mother was aware of her infant's points, though these points were observed to be related to changes in maternal body distance. But, not all researchers agree with this viewpoint. Many other accounts have proposed that pointing develops at the end of the first year through parental shaping and modeling, which stems out of simple grasps and spreads (Murphy & Messer, 1977; Leung & Rheingold, 1981).

Lew and Butterworth (1997) looked at the development of hand-mouth coordination in 14 infants between the ages of 2- to 5- months. They reported that, by 4 months of age there was an increased focus on contacts made on the mouth when compared to the rest of the face. Mouth opening in anticipation to the approaching hand was seen from the age of 5 months. They concluded that hand-mouth coordination does not develop before the age of 4 months due to the presence of reflexive actions and an immature neuromuscular system in the infant.

Considering these observations, Fogel and Thelen (1987) have offered a theoretical account for the early appearance and further development of these co-expressive actions. They suggest that early manual actions may not be direct precursors to later expressive behavior, and that there may not be a complete absence of relationship between early and late forms. Further, they propose that these early actions in infancy integrate dynamically and form subcomponents, which is related to specific infant states and eliciting contexts. For example, in early infancy, pointing may occur during face-to-face interaction with an adult; while in the first and second year it may be used as a referential act to refer to things. Mothers are assumed to decide on their responses towards their infants based on the overall status of the infant (Fogel, 1982). Thus, it may be that specific actions of the hands and fingers occurring in harmony with expressive actions of the face and mouth suggests the affective state of the infant through multiple channels.

In another study, index-finger extensions were observed to co-occur specifically with "speech like" vocalizations, but not with vocalic utterances (Masataka, 1995). Additionally, a longitudinal study on 8 infants, between the ages of 9 to 15 weeks, explored the interaction between manual actions, vocalizations, gaze, and facial expressions in interactions with their mothers (Legerstee, Corter & Kienapple, 1990). When the mothers were active, it was seen that pointing followed smiling, neutral expressions, gazing, and vocalizations significantly more than would be expected by chance. On the other hand, during the passive-mother condition it was observed that pointing followed neutral, distressed expressions, gaze aversion, gazing and vocalization. Such patterns were not seen in the active and passive object condition. Thus, the results showed that young infants produced discrete hand actions that followed specific facial expression. Other studies, however, have found that index finger extensions rarely occur with vocalizations (Blake, O'Rourke & Borzellino, 1994; Hannan, 1987).

The temporal relationship between gestures and speech in adults has received considerable attention from researchers, and the study on children in the two-word transition period has suggested that the adult pattern of gesture-speech synchrony is evident by the time children make the transition to two-word utterances (Butcher & Goldin-Meadow, 2000; Kelly, 2014). Currently however, little is known about the infant origins of this phenomenon. However, connections between the vocal and motor systems are said to be in place even in the reflexive behaviours exhibited by infants. For example, the Babkin reflex can be elicited by applying pressure to the palm and infants react to this manual stimulation by opening their mouths (Babkin, 1960).

Newborns are also found to open their mouth as their hand is moving towards the facial area, in anticipation of its arrival for sucking (Butterworth & Hopkins, 1988). Also, as noted earlier, infants between the ages of 9 and 15 weeks were reported to exhibit index finger extensions which were likely to co-occur with vocalizations or mouthing movements (Fogel & Hannan, 1985). Among older infants, increased production of upper limb rhythmicities has been shown to relate to age of onset of reduplicated babbling. Ejiri (1998) conducted a longitudinal study on 28 infants between the ages of 5 and 9 months of age. She reported that infants exhibited rhythmic activities with higher frequency at the period around the onset of canonical babbling which was consistent with another cross-sectional study on infants' manual activity at the canonical stage (Locke, Bekken, McMinn-Larson & Wein, 1995). In the same study, it was also seen that when infants began to babble they shook both audible and inaudible rattles, whereas after this period they shook audible rattles more frequently than the inaudible ones. It was hypothesized that the early shaking behaviour exhibited by infants regardless of their rattle's audibility, may be caused by infants' natural tendency to move their body parts rhythmically, and that these activities are at first motivated largely by their sensory motor feedback. While subsequently, the auditory feedback that infants happen to produce by their own movements may reinforce this sound-making activity, which helps infants learn to control their motor activities by means of auditory feedback. Ramsay (1985) also reported that infants' unimanual hand preference concerning toy contact activity, which includes hand banging, emerges following the onset of babbling. He suggested that the connection between hand banging and canonical babbling reflects the developmental change in hemispheric specialization of the brain, which is again related to speech and handedness. Increase in repetitive right-handed activity and simultaneous emergence of babbling in infants was also observed in the study by Locke et al., (1995).

Ejiri and Masataka (2001) reported the co-occurrence of vocal behaviours and motor actions in 4 infants who were studied longitudinally, from the age of 6 to 11 months of age. These infants exhibited rhythmic activities with high frequency at the period around the onset of canonical babbling. It was also noted that vocalizations frequently co-occurred with rhythmic action in infants during the pre-canonical stage, particularly before the month when infants began to babble. Consequently, it was hypothesized that infant's rhythmic activity, which occurs frequently in the transition period from the pre-canonical stage to the canonical stage may help infants learn the articulatory skills required to produce canonical babbling.

Iverson and Thelen (1999) proposed a theoretical model that helps us understand the nature of vocal-motor coordination during the pre-linguistic developmental period. According to them, a critical factor in the coproduction of speech and gesture is the ability to produce controlled, voluntary movements in the two effector systems, namely, the vocal tract and the manual system, and to coordinate these systems in time and space. Thus, this model conceptualizes the development of the gesture-speech system within the broader context of the development of motor control, and the emergence of gesture-speech coordination is viewed as a specific example of the more general problem of movement coordination. The model uses four key concepts: coupled oscillators, entrainment, elicitation threshold, and relative activation strength.

Oscillations and *rhythmicity* are characteristic behaviours of any developing motor systems. In infants, these oscillations take the form of rhythmically organized, repetitive movements (such as shaking, kicking, rocking, and bouncing) and appear to be closely associated with moments of transition from no voluntary control over a limb or body segment to adaptive and intentional control (Thelen, 1979). In the vocal system, the properties of rhythmic limb stereotypes are evident in reduplicated babbling. MacNeilage and Davis (2000) have argued that the repetitive patterns of early reduplicated babbling are the product of mandibular oscillations in combination with phonation and limited tongue control. As infants gain control of the tongue and its position during mandibular cycles, they begin to widen their repertoire of syllabic patterns. Thus, rhythmically organized repetitive activity is a hallmark of both the infant motor and vocal systems. Therefore, as part of the initial coupling between the two systems, one might expect activity in one system to influence or entrain activity in the complementary system.

When oscillators are coupled, each system will try to draw the other into its characteristic oscillation pattern. *Entrainment* occurs when one system successfully pulls in the activity of the other, resulting in an ordered patterning of coordinated activity reflected in the temporal characteristics of the entrained system. In infancy, the coupling of the vocal and manual systems exists from early in development. This suggests that when there is sufficient activation in one component of the coupled vocal-motor system, that component will pull in and entrain the activity of the complementary system. This entrainment is dynamic and flexible, such that activation of one system can have a tight temporal synchrony or more loosely coupled influence (Iverson & Thelen, 1999). Therefore, when an infant is engaged in intense bout of rhythmic limb activity, this activation in the motor system may spill over into the vocal system resulting in the production of a vocalization.

Further, the *threshold* for any behavior is presumed to be directly related to its ease of performance. For infants, a good indication of the threshold for any behavior is how often it is performed. Behaviours with a low performance threshold are seen frequently and in a variety of contexts, while behaviours with a high threshold are less frequent and more effortful. *Activation* is defined as the relative strength of any behaviour once the threshold is reached and the behaviour is subsequently performed. Relatively novel and unpracticed behaviours are assumed to have relatively low levels of activation, while more established behaviours can be said to have relatively higher levels of activation. The critical assumption that this model makes is that the dynamic coupling of the two effector systems requires relatively higher levels of activation in atleast one of the systems (Figure 5). Infants have a long history of producing rhythmic manual movements before the onset of babbling, therefore these movements are stable and should exhibit low threshold and relatively high activation strength, which will facilitate the entrainment of the vocal system.

Taken together, this model assumes that infant vocal-manual coordination is a precursor to the coproduction of speech and gesture. This model was put to test in a cross-sectional study on 47 infants in the age range of 6-to-9 months (Iverson & Fagan, 2004). The findings revealed that relative to vocalizations that do not co-occurr with rhythmic movement, a higher proportion of vocalizations with rhythmic movements consisted of CV repetitions. Also, it was noted that the majority of the CV repetitions that co-occurred with rhythmic movements occurred in coordination with rhythmic manual movements. Thus, the researchers predicted that when the infant reaches the ages of 9 to 12 months, which is the time for the onset of meaningful gestures and first word, the link between vocalization and manual activity is strong, stable, and is also available for communication.

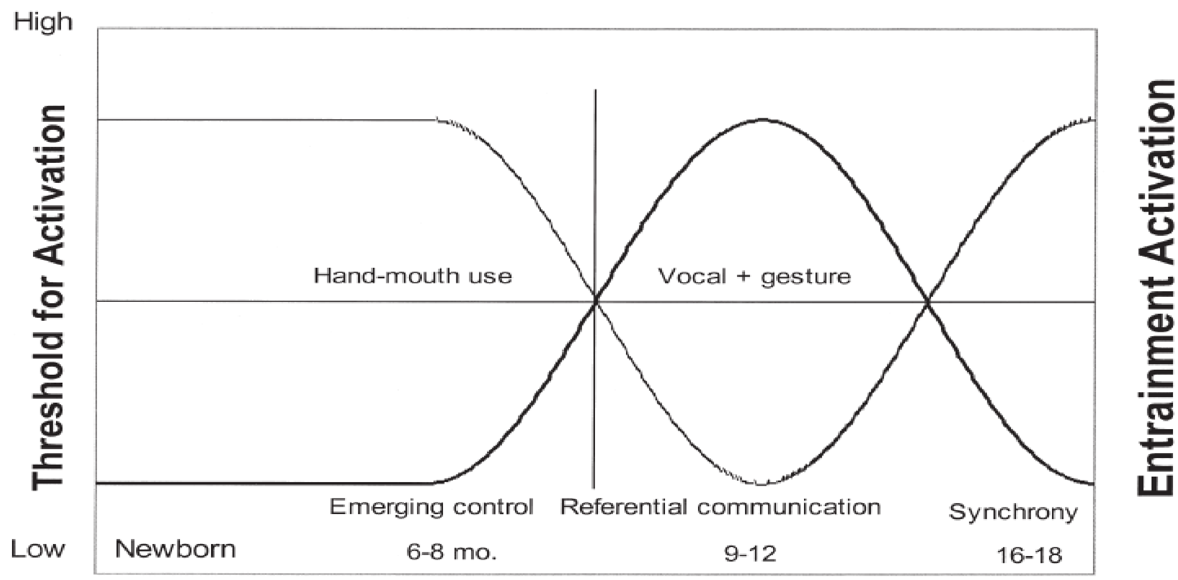


Figure 5: Activation levels for threshold and entrainment in the vocal-gesture system during the first two years of life (Iverson & Thelen, 1999).

Further, Iverson and Thelen (1999) proposed a four-phase dynamic developmental progression, based on their construct. The phases are as follows:

a) Phase of *initial* linkages; where the activities of the hand and mouth are loosely coupled from birth, as evidenced in spontaneous hand/mouth coordination

b) Phase of *emerging* control; where there is an increase in the adaptive use of hands and mouth, as evidenced in coinciding rhythmical movements of vocal and arm movements between 6 to 8 months of age.

c) Phase of *flexible* coupling; where there is the emergence of non-synchronous yet coupled gesture and speech, as evidenced by use of communicative gesture before first words, between 9 to 14 months of age

d) Phase of *synchronous* coupling; where adult-like, timed coupling of gesture and speech in seen, as evidenced by onset of meaning full word and gesture combinations, between 16 to 18 months of age.

Few studies have also looked into the coordination between vocal and non-manual gestural systems such as that of the facial movements and gaze behaviour. One such study examined the temporal relationship between facial actions (smile and frown) and vocalizations in 12 infants at the ages of 3 and 6 months (Yale, Messinger, Cobo-Lewis, Oller & Eilers, 1999). They concluded that there was evidence that infants were systematically sequencing vocalizations and expressions within the first 6 months of life across interactive contexts and that there were two principles of coordination. Infants either temporally embed one communicative event in another or were seen to end one communicative event before the cessation of the other.

Another study by Murillo and Belinchon (2012) on 11 Spanish children from 9 to 15 months of age reported similar findings. They coded vocalizations, gestures (any motor action) and gaze behaviours in these infants and concluded that the rate of use of multimodal patterns increased significantly with age for the observed periods. They also suggested that the rate of use of multimodal behaviours at the age of 12 months seemed to predict lexical development at the age of 15 months. Further, it was documented that the best predictor of lexical outcome was the use of pointing gestures with accompanying vocalizations and social use of gaze at the age of 12 months.

These findings support the idea that gestures and speech are part of an integrated and developing system that children tend to use flexibly to communicate right from birth.

Summary

There is a considerable amount of support in literature regarding the multimodal nature of communication in children; children begin to use the gestural modality and subsequently start using the verbal modality, and they continue to use both modes for communication throughout their lifespan. These evidences are from a plethora of studies targeting different age groups of children, cultures, with varied aims and methods of study, and many questions are left unanswered. One such question is the nature of emergence of gestures and speech in infants from a very early age.

In the context of language acquisition in Indian children, there have been studies which have focused on speech development and one study has targeted the development of manual gestures in children; however, these studies do not place development in a multimodal context within the pre-linguistic period. This is important to document, since both verbal and non-verbal skills are sensori-motor in nature and these early experiences during infancy shape the learning of mature skills in all modalities. The purpose of this study was to document the development of gestures (both manual and non-manual), and speech in infants from the age of 3 months till they turned 12 months of age and also to understand the nature of coordination of these behaviours. The results of this study will be useful, since it will suggest the ages of emergence as well as the nature of development of these behaviours and this will in turn form a platform upon which the concept of multimodality in the assessment and management of infants with atypical development can be incorporated in clinical practice.

METHOD

METHOD

The aim of the present study was to investigate and compare the development of gestures and speech in typically developing infants during play and interactions with parents who spoke Kannada language. The study followed a longitudinal design with 10 months of observation data, as the infants developed from 3 to 12 months of age. Therefore, the objectives of the study were to investigate and compare the following across age:

a) Gestural behaviours of face, gaze, head, leg, torso, whole body as well as hands

b) Speech behaviours including, pre-speech, vocalic, syllabic and verbal utterances

c) Emergence of gesture-speech coordination.

Further, based on the review of literature, there were two hypotheses that were tested in the study. Firstly, on the basis of evidence that gestures and speech are part of the same communication system, it was hypothesized that both modalities, i.e. gestures and speech, would exhibit similar growth trends within the first year of life. Secondly, based on the evidence that older children and adults exhibit temporal synchrony in the co-production of gestures and speech, it was hypothesized that speech and gestural behaviours would co-occur from the age of 3 months, and would demonstrate varied patterns of co-occurrence with advances in age; specifically, over three developmental timeframes (>3 months to ≤ 5 months 29 days; >6 months to ≤ 7 months, 29 days; >8 months to ≤ 12 months).

Ethical clearance for conducting the study was obtained from AIISH Ethics Committee for Bio-Behavioural research. The study was initiated in December 2010 and was completed in February 2014. Table 4 gives the time frame for the progress of the study between 2010 and 2014.

Table 4

Time frame of the study

Data collection	Data analysis	Statistical analysis
Duration: December 2010 - June 2012	Duration: April 2011 - August 2013 - Total no: of videos annotated: 76 - Video editing duration:2 hours / video - Video annotation duration: a) 3-4 hours / tier / video of average 15 minutes b) 8-9 hours / tier / video of average 30 minutes	- Duration for calculation of rate measures: 2 hours / sample - Duration for statistical analysis: October 2013-February 2014

Participants

At the beginning phase of the study, 55 parents were contacted via telephone based on birth records from two hospitals in Mangalore, Karnataka, over a period of 3 months. Only 25 parents agreed to meet the investigator and gave permission for the investigator to administer the questionnaire and answer questions regarding the selection criteria. The selection criteria were as follows.

Initially, a 7-point questionnaire was administered and this was developed by the investigator to aid in the process of selecting these infants for the study. This questionnaire focused on collecting information from the parents regarding family histories with specific reference to the pre-natal and natal history, communication disorders and health problems. The questionnaire that was developed is shown in Table 5. After administration of the questionnaire, only those families meeting the selection criteria (outlined below), and in particular those who showed negative history of communication disorders and uneventful birth histories were selected for the study.

Table 5

Questionnaire concerning medical/family history

Sl No:	Question	Yes	No
1.	Is this your first-born child?		
2.	Do you have a history of abortion prior to this child?		
3.	Did you any difficulties during your pregnancy period? (if yes, specify)		
4.	Did you suffer from any medical condition before or during your pregnancy? (if yes, specify)		
5.	Did you face any difficulties at the time of child birth? (if yes, specify)		
6.	Did your child have any ill-health soon after birth and during the days following? (if yes, specify)		
7.	Is there a history of disability in your family? (if yes, specify)		

Criteria followed for the selection of participants were as follows.

- Infants were to belong to Kannada speaking families, residing in Mangalore, Karnataka state.

- Infants were to belong to nuclear families.

- Infants were to be the first born in the family.

- The parents were to be from the middle socioeconomic strata, which was determined using the Scale for measuring the Socioeconomic Status (Aggarwal et. al., 2005).

- The education level of the parent was to be a minimum of 10th standard, with the mother either being a homemaker or on maternity leave for a large part of the study period.

- Infants were to pass a screening test for hearing (using Behavioural Observation Audiometry) and visual acuity test (using visual fixation and tracking).

(i) Behavioural observation audiometry (BOA) was done in a hospital based audiological set-up and was carried out in an acoustically treated two room set up, with two observers, who were audiologists. The infant was held in the parent/care giver's lap, with the caregiver seated on a chair which was placed at a distance of 3 feet from the loudspeakers. Loudspeakers were placed at an azimuth of 45 degrees in front of the child. The stimuli were presented through the GSI-61 dual channel audiometer in an ascending manner and minimal response level was determined. The range of stimuli included warble tones, narrow band noise (NBN), and speech. Responses such as cessation of the activity, eye widening, rudimentary head turn, and/or eye movements in search of the sound source were considered for minimal response level estimation. The responses were considered as valid only when both the observers agreed on it. Non-agreement of even one of the observers for a certain response was followed by another trial. The test was not discontinued till the responses were gathered for the frequencies of 500 kHz, 1 kHz, 2 kHz and 4 kHz. The responses of the infants were considered normal when the responses were comparable to the cut off value of 45 dB for speech, 55 dB for NBN and 65 dB for Warble tones, established for 3 month old typical infants.

(ii) Screening for visual acuity was done in the Ophthalmology department of the same hospital. *Visual fixation* was determined by presenting a small colorful object, which was placed approximately 12” in front of the infant’s nose at eye level. If the examiner (ophthalmologist) observed that both the eyes were directed towards the object for at least two seconds, the infant was declared as having passed the procedure. *Visual tracking* was determined by presenting a small brightly colored object. The examiner sat facing the child and presented the object approximately 12” in front of the infant’s nose at eye level. When it was noted that the child had fixated his/her gaze at the object, the examiner moved the object initially to the right and then brought it back to the starting point and then moved it to the left (horizontal plane). When the infant was observed to track the object in a smooth and continuous movement with the eyes in symmetrical alignment, it was established that the infant had passed the procedure.

- Infants were also tested on their age-appropriate language skills. Assessment of Language Development (Lakkanna, Venkatesh & Bhat, 2008) was used in the assessment. This test has been standardized on Kannada speaking children in Mangalore, in the age range of 0 months to 8 years. It tests both receptive and expressive language skills. The test was also re-administered after a period of 3 months, i.e. when all the infants were 6 months old, to document any deviations from normal development. All the participants included in the study had both receptive and expressive abilities that approximately matched their chronological age (+/- 2-month variation is acceptable). There were no major deviations observed at both the third and sixth month.

- Infants also had to pass a paediatric and neurological examination to rule out organic and genetic conditions, syndromes, seizures or any other medical disorders at the age of 3 months. This was done in the paediatric department of the hospital. The investigator also followed up regularly with the parents regarding the medical status of each child, to keep a track of any condition that could hamper the communication development of the infant.

Table 6

Demographic details of participants

Sl No:	Chronological age at which study began	Gender	Education level of mothers	Socioeconomic status of family
1.	3 months	Girl	Post graduate	Upper middle class
2.	3 months	Girl	12th grade	Lower middle class
3.	3 months	Girl	Graduate	Upper middle class
4.	3 months	Boy	10th grade	Lower middle class
5.	3 months	Boy	Graduate	Upper middle class
6.	3 months	Boy	10th grade	Lower middle class
7.	3 months	Boy	10th grade	Lower middle class
8.	3 months	Boy	12th grade	Lower middle class
9.	3 months	Boy	10th grade	Lower middle class

From the 25 families who had agreed to meet the investigator, the parents and infants who did not conform to the inclusion criteria were excluded from the study and this lead to the inclusion of 12 infants. Written informed consent was obtained from these parents before the study was initiated and continued for a period of 10 months, and the parents were kept blind to the objectives of the study. The 12 infants underwent hearing, communication, medical and neurological screening as detailed in the text above. Out of the 12 infants, two infants dropped out of the study within the first month as the parents expressed their desire not to continue participating in the study and a third child relocated to another city after the third month of recording. Therefore, nine typically developing infants formed the participant group for the study, and the parents and other family members of the infants spoke Kannada[1] language at home most of the time. The details of these infants are as listed in Table 6. However, it must also be noted that the mothers of participant 1 and 3 would speak in English to their children and most mothers hailed from various parts of Karnataka and therefore, the dialect of Kannada that they spoke was not entirely uniform. All the participants were living in the city of Mangalore, which is a located in Dakshina Kannada District of Karnataka.

[1]Kannada is one of the major languages of Dravidian language family spoken predominantly in the state of Karnataka in India. This language is spoken by native Kannada speakers across India. Kannada is officially recognized language of Karnataka state and is spoken by approximately 70 million people as per the Census Report of India 2011.

Procedure

The gestural and speech behaviours of these infants were audio-video recorded, longitudinally for 10 months' duration, in their homes. The first recording began when each infant turned 3 months of age and the last recording ended when they were 12 months old. The initial recording that was carried out at 3 months of age was determined for each infant based on their respective date of birth. Thereafter, the recordings were done once in a month for each infant by the investigator ensuring that the recording was carried out on/before/after 3 days every month up until 12 months of age, based on the convenience of the parents. There were also instances where a child could not be recorded for a particular month due to an illness or inconvenience to the parents and that month was not included in the analysis. This accounted for '*missing data'* in the case of all infants and these instances of lack of recording are as shown in Table 7.

Table 7

Details of the samples obtained for month of the study from each participant

	Age in months									
Participant No:	3	4	5	6	7	8	9	10	11	12
1	+	+	+	+	+	+	+	+		+
2	+	+	+		+	+		+	+	+
3	+	+	+	+	+	+		+	+	+
4	+	+	+	+		+	+	+	+	
5	+	+	+	+	+		+	+	+	+
6	+	+	+	+		+	+	+		+
7	+	+	+		+	+	+		+	+
8	+	+	+	+	+	+	+		+	+
9	+	+	+	+	+		+		+	+

Note: Shaded area represents missing data.

Materials. Toys suitable for infants were selected after a thorough literature search (Stoppard, 2009). Care was taken to include 2 toys for each age (in months) under the observation period. These toys were kept constant for all the participants. The toys that were provided by the investigator are as shown in Table 8. Apart from these toys, the interactions also included toys that belonged to the infant.

Task. Mothers were encouraged to interact with their infant by speaking and playing with the child. They were also familiarized with the use of toys provided by the investigator, when needed. They were instructed to ignore the presence of the investigator, who would be present in the room during the recording, and were persuaded to engage their infant in constant interaction, through games, songs and play.

Table 8

List of age-appropriate toys selected for the study.

Age in months	Toys/games
3	Rattle & Key ring
4	Toys with colors and sounds &Teethers (noise-makers)
5	Wobble toy & Soft toy
6	Doll & Stacking rings
7	Cuddly toys & Action-reaction toys
8	Bricks & Musical vehicle
9	Telephone & Shape sorters
10	Ball & Toy drum
11	Push and pull toy & Puppet
12	Animal farm & Kitchen/tool set

Set-up. The interaction between the mother and infant was recorded in a relatively well lit and quiet room in the infant's home. The video camera was placed on a tripod in a suitable section of the room which provided an unobstructed view of the infant. Sometimes the camera was even held by the investigator, especially while recording older infants as they moved around the room at times.

Recording. The interaction between the mother and infant was recorded using a high definition Sony HDR-CX12 handycam (with a sampling rate of 25 frames/sec in MPEG4 video format), with in-built microphone that enables audio recordings, at a sampling rate of 48KHz. The camera was placed such that the lens was focused on the child's face and body. The recordings, both audio and video, were taken at those times when the infant was most playful and alert. Whenever the child became fussy during the recording, the session was terminated and continued further when the child was calm again.

Each mother and infant interaction was recorded for a period of 40-60 minutes, once a month, by the investigator. The mothers were instructed to speak and play with their child as they normally would, in a semi-structured (play with specific toys) and unstructured naturalistic (play without toys) situation, as and when they occurred, based on the interest of infant. During this phase, there were a few challenges faced. The recordings would most often be disrupted due to interactions of the mother with the investigator although they were instructed to ignore the presence of the investigator, or even due to the presence of another family member, who would be interested in observing the infant at play. Additionally, for the infants below the age of 6 months, the recordings were done in multiple sittings on the same day since there were frequent breaks for feeding and nappy changes.

Editing. The audio-video samples of each participant were viewed by the investigator and were edited, in order to delete those segments in the interaction when; (i) an infant was very quiet, (ii) infants moved away from the line of camera focus, (iii) infants were uninterested and did not exhibit any gestural or speech behaviours or (iv) when the infants showed an interest in the investigator. Further, care was taken not to code the data for those segments in the video when the infant faced away from the camera or when toys obstructed the movements of hands/legs/torso etc. or even when there was noise present in the video (e.g. traffic noise).

This process provided a usable average sample size of 20–30 minutes per child, which also varied with the age of the child. Younger infants tended to have smaller samples (around 10-15 minutes) than the older infants (around 30-40 minutes), with respect to the duration of the usable sample. The edited version was then used for further coding and analysis.

Annotation. The edited and final version of the samples of every infant was uploaded into EUDICO Linguistic Annotator (ELAN) software (Lausberg & Sloetjes, 2009). This is a multi-media annotation tool which is widely used in gesture and sign language research, and enables the coder to identify and annotate the desired behaviours from a running audio and video sample. Appendix 1 gives a representative snap-shot view of an annotation done in ELAN for participant 3 of the present study.

The annotation of gestures and speech behaviours was done by three coders, including the investigator, who were speech language pathologists with a minimum of 3 years' experience in the field. These coders had background knowledge in Augmentative and Alternative Communication (AAC) and nonverbal communication. The investigator completed the coding for all samples and only 13% the samples were provided to the other two coders who carried out the task independently.

The following spontaneous behaviours, which were naturally elicited by the mother and not prompted by the investigator, were identified in the participants:

a) Gestures:

1. Facial gestures- facial expressions and other movements of the facial structures, such as smile, frown, tongue play, mouthing etc.
2. Gaze behaviours- patterns of looking behaviours, such as gaze at object or person etc.
3. Head movements- movements of the neck, such as turn, extension etc.
4. Torso movements- movements of the trunk, such as rock and bounce.
5. Leg movements- movement of either one or both legs, such as foot rub, kicks etc.
6. Whole body movements- movements that involve the displacement of the whole or-mid half of body, such as walking, leaning etc.
7. Hand movements- pre-symbolic and symbolic movements of either one or both hands, such as reach, grasp, show, point etc.

b) Speech:

1. Pre-speech utterances- vocal productions that include cooing and vocal play
2. Vocalic utterances- vocal productions that include vowelizations and hums

3. Syllabic utterances- vocal productions that include syllabic shapes of marginal babbles or canonical babbles, and variegated babbles
4. Verbal utterances- vocal productions that include jargon, verbalizations and true words
5. Prosodic alterations- syllabic, vocalic and verbal utterances with distinct intonation patterns.

c) ***Coordinated bouts:*** Instances in which the speech and gestural behaviours co-occurred in time were noted, and this was defined as instances where there was considerable overlap in the occurrence of two or more gestural and vocal units (Caprici, Iverson, Pizzuto & Volterra, 1996). E.g. A hand gesture and a facial expression that were either produced simultaneously, after or before the onset of a vocalic utterance was considered as a coordinated bout.

The coders were trained to recognize the gestural and speech behaviours that needed to be identified in the samples based on a *key* (as given in Appendix 2). This *key* included a list of the behaviours with their operational definitions. The list was prepared after a thorough literature search based on studies which have addressed these behaviours (e.g. Bates, et al., 1979; Fogel & Hannan, 1985; Oller, 1980). Additionally, the investigators' own observations of behaviours that could not be classified under previously established descriptions based on the videos of the participants were also included. For example, 'articulatory gesture with weak vocal element' was a term coined for a speech behaviour which could not be classified as ‘mouthing’ behaviours due to the presence of an audible voicing component, and the lack of a distinct syllabic structure.

The investigator trained the other two coders using a sample video of an infant, who was not included in the study. This infant was recorded when he was 6 months old and the coders were made to transcribe the videos on ELAN to have a better understanding of the *key*. Any doubts and questions raised at this point were clarified by the investigator and in many cases the descriptions of the behaviours were also modified based on the suggestions of the coders and used in the actual coding of sample data.

The coders were provided with 10 randomly chosen samples from the pool of data (13% of videos), representing every month of study. This ensured that a minimum of one sample each was observed by the coders from all the infants included in the study. Their task was to annotate the samples based on the *key* and the coders carried out this process independently, with minimum interaction with the investigator, except for any technical difficulties they faced while using ELAN. Later the investigator calculated the instances of agreement (score of 1) and disagreement (score of 0) based on the annotations of all the three coders. Those instances in which there was disagreement between the coders, the annotation in question was not included for further analysis. Following the establishment of reliability, the investigator identified the speech and gestural behaviours that co-occurred in each of the samples in order to identify the instances of coordinated bouts of behaviours that occurred in all the samples.

Reliability

a) *Inter-coder reliability:* The second and third coders were provided with 10 coded samples (approximately 13%), ranging from 3rd to 12th month, with one participant's data being used twice for different months, and these were annotated independently. The mean percentage of agreement was calculated for all the three coders for all gesture and speech behaviours, and these are as shown in Table 9.

b) *Intra-coder reliability:* Intra-judge reliability was carried out using one video sample of the 7th month of an infant, which was re-coded by the investigator. The re-coding was done 12 months after the same sample was initially coded by the investigator. The mean percentage of agreement was calculated and was found to be 94.80% (N=2190).

Table 9

The mean percentage of agreement between coders for all behaviours (per sample that was analyzed)

Age of infant in months	N (behaviors coded)	Mean percentage of agreement (%)
3	838	91.41%
4	1605	87.99%
5	1438	91.13%
6	1877	93.88%
7	1599	90.96%
8	1742	86.11%
9	2000	90.48%
10	2921	91.94%
11	2190	92.37%
12	1327	82.58%

Note. N= Total number of gestures and speech behaviours coded by investigator

Data analysis

All spontaneous gestural behaviours and speech utterances produced by the infants were extracted from the ELAN files. The following measures were calculated from each sample based on the objectives of the study:

a) Development of gestures and speech was analyzed using the following measures:

- Frequency of occurrence of gesture/speech: the percentage frequencies of occurrence of each category of behaviour was calculated by dividing the number of a gesture/speech type (e.g. facial gestures) by the total number of behaviours seen in the observational segment for each month of observation.
- Rate of occurrence of gesture/speech per minute (Locke, Young, Service & Chandler, 1990): the total number of a particular gesture/speech (e.g. mouthing) behaviour divided by the duration (in minutes) of the observational segment from each sample.

b) Emergence of coordinated bouts of behaviours was analyzed using the following measure:

- Frequency of co-occurrence: the percentage frequencies of co-occurrence of each category of speech behaviour with categories of gestural behaviours was calculated by dividing the number of coordination bouts of each category across both modalities (e.g. pre-speech utterances with facial expressions) divided by the total number of co-ordination bouts. This was done separately for each developmental time period that was considered in the study.

- Rate of co-occurrence of speech with gestures per minute (Iverson & Fagan, 2004): the total number of coordinated behaviours (e.g. articulatory gesture with weak vocal element and concentration) produced divided by the duration (in minutes) of the observational segment from each sample. This was done separately for each developmental time period that was considered in the study.

These measures were calculated for every infant across all the ages under study and these served as the data for further statistical analysis that were carried out.

Statistical analysis

Statistical analysis was carried out using SPSS version 17, and the data demonstrated non-normal distribution according to Shapiro-Wilk test for the data sets that did not comprise of constants (0). The study aimed to investigate and compare the development of gestures, speech behaviours and coordination patterns between both modalities in typically developing infants in the age range of 3 to 12 months. Further, the data was analyzed in order to test the hypotheses of the study.

The first hypothesis was that gestures and speech being a part of the same communication system, would exhibit similar trends during development within the first year of life. In order to examine this, the following non-parametric tests were carried out:

a. Friedman test was administered to check for differences in the rates of occurrences across the months of study along with Wilcoxon signed rank test for pair-wise comparisons
b. Spearman's rank-order correlation analysis was carried out to understand the relationship between various behaviours within each modality
c. Quadratic equation analysis was performed to help determine the growth trajectory of every behaviours studied
d. Change point analysis was done to determine if the behaviours demonstrated an age at which a reliable change in their occurrence can be detected

The second hypothesis was that speech and gestural behaviours would co-occur from the age of 3 months and with age, differential patterns would be seen in the coordination bouts exhibited across the three time periods that were studied. In order to examine this:

a. Friedman test was administered to check for differences in the rates of co-occurrences of various categories of speech and gestural modalities across the developmental timeframes, along with Wilcoxon signed rank test for pair-wise comparisons
b. Spearman's rank-order correlation was done in order to understand the relationship in the co-occurrence between various behaviours across each modality.

RESULTS

RESULTS

The aim of the study was to investigate and compare the development of gestures, speech and gesture-speech coordination in infants in the age range of 3 to 12 months during play/interaction in a longitudinal design, in order to appreciate their relevance to multimodal communication. Gestures of the face (facial movements and facial expressions), gaze, head, torso, legs, whole body, hands, and speech behaviours which comprised of vegetative, vocalic, syllabic and verbal utterances, were studied in 9 infants (6 boys and 3 girls).

The data was analyzed in order to test two hypotheses. The first hypothesis was that, both gestures and speech would demonstrate similar growth patterns within the first year of life, as they are components of the same communication system. The second hypothesis was that speech and gestures would co-occur from the age of 3 months and with age, there would be differential patterns of coordination exhibited by various behaviours within each modality. In order to test these hypotheses, the frequency, the rates of occurrences and the rates of co-occurrences of speech with gestures were computed and further statistical analyses were carried out using SPSS (Statistical Package for Social Sciences) version 17.

The number of infants whose gestural behaviors were annotated and analyzed was not the same across all the months of observation because of instances when a particular infant(s) could not be recorded in a certain month due to ill-health or other unavoidable circumstances (as demonstrated in Table 4 in the Method's section). In such cases of '*missing data*', the month(s) was not included in the analysis for that particular infant. It must also be noted that in most cases, the same infant did not exhibit all the behaviours across all the months of observation and in such cases the value was considered as a constant (0). For example, the first participant produced the gesture ‘smile’ (facial expression) only in the 3rd, 4th, 6th, 7th and 12th months. Therefore, the rates of occurrence were calculated only for these months, while for the remaining months the rate was considered and coded as ‘0’.

Apart from the investigator, two other speech language pathologists annotated 13% of the data. This consisted of 10 randomly selected videos, such that each month of observation, between the 3rd and 12th months, was included in the reliability check. The mean percentage of agreement between the coders was calculated and these are as given in Table 9 (Method’s section). Additionally, the investigator also re-coded one randomly selected video (7th month of participant 1) from the data pool. This was done 12 months post the initial annotation and the mean percentage of agreement was calculated and was found to be 94.80% (N=2190).

Since the inter-coder and intra-coder reliability scores were in the acceptable range between 82% - 94%, the data was subjected to further statistical analysis. Shapiro-Wilk test was administered to test for normality of distribution across the behaviours studied and age. The results revealed a non-normal distribution ($p<0.05$) and it may be noted that normality could not be computed for those months in which the data comprised of constants. Further, since the number of boys and girls included in the study were unequal in number, the data was not analyzed for gender differences and the following section in this chapter represents the combined data of all the nine participants.

The following non-parametric tests were used to analyze the data. Friedman test was administered in order to analyze if there were differences in the rates of occurrences of gestural and speech behaviours and their co-occurrences across the ages of study. Rates of occurrences were calculated for all the months of observation. Considering that there were only three ages (3^{rd}, 4^{th}, and 5^{th} months) in which there was complete data from all the participants, Friedman test was carried out for the data of these three months. The rates of co-occurrences were also calculated for all the months. But, the Friedman test was administered for data that was combined for three time periods (>3 months to $\leq$ 5 months 29 days; >6 months to $\leq$ 7 months, 29 days; >8 months to $\leq$ 12 months). Further, pair-wise comparisons were carried out using Wilcoxon signed rank test, to observe for differences (if any) in the rates of occurrence and co-occurrence across various months of study. Additionally, Spearman's rank-order correlation Coefficient was computed to analyze the relationship in the occurrence and co-occurrence of the various types of gestures and speech during the ages of study.

Quadratic equation analyses were used to plot the developmental trajectories, in order to determine the growth trends of each behavior documented in the study. There were three types of growth trends observed, namely, linear (depicting clear increase or decrease in the rates of occurrences with a corresponding increase or decrease in age), polynomial (depicting a curvilinear relationship between rates of occurrences across age), exponential (depicting the rate of occurrence that increased or decreased exponentially or rapidly with age). In certain instances, however, the trends were unpredictable.

Further, a Change Point Analysis was used in the study. Change Point Analysis is usually done in order to establish if changes occur in a time series data. In this study, the analysis was carried out using Taylor's method in order to determine whether statistically significant changes occurred within the first year of life, in the rates of occurrence of each of the categories of gestures and speech behaviours that were documented in the study. The change point analysis software (Taylor, 2000) uses a combination of cumulative sum charts and bootstrapping to detect changes in the data, and generates the confidence intervals which ideally should be above 90%. This procedure is also robust to the presence of outliers in any given data, which makes its application ideal for behavioural data (Abney et al., 2014), such as the one obtained in the present study.

Infants were observed to exhibit a plethora of behaviours, including various types of gestural and speech behaviours that were of interest in the study. Table 10, shows the frequency of occurrence (percentage) of each of the categories of behaviours that were studied. Across these developing systems, most behaviours exhibited non-linear growth trends, while some of them did not demonstrate a predictable trend in the ages of study. Some of these behaviours, such as facial movements, were essentially reflexive and seen during the early months; some other behaviours, such as facial expressions, leg and hand movements, seemed to provide a supportive framework during transition towards mature behaviours; while certain other behaviours, such as speech and hand movements, were clearly reflecting communicative roles. Behaviours within both modalities (gesture and speech) were also found to exhibit coordinated bouts of occurrence, which seemed to depend largely on the frequency of occurrence of the behaviours. There were also differences in coordination patterns based on the novelty of behaviours seen in the ages of study. Moreover, individual variations were seen in the frequencies of occurrences of these behaviours in infants as well as in the co-ordination patterns that they exhibited.

Table 10

Frequency of occurrence (in percentage) of gestures and speech across ages

Age of the infants in Month	Facial gestures	Gaze behaviours	Head movements	Torso movements	Leg movements	Whole body movements	Hand movements	Speech behaviours
3	14.02	14.11	8.70	12.65	0.15	0.21	43.22	6.75
4	7.25	14.53	8.60	11.76	0.07	0.54	34.00	3.83
5	6.70	24.67	16.24	12.52	1.45	2.01	50.81	7.79
6	3.90	18.69	16.06	5.59	1.40	2.28	44.90	7.16
7	2.59	18.73	18.36	4.66	1.52	2.56	45.60	5.77
8	0.72	17.58	15.79	0.58	1.46	4.26	49.39	3.52
9	1.75	19.35	17.02	0.41	1.31	5.16	51.68	3.27
10	1.97	20.96	12.35	0.14	0.83	4.61	54.08	5.05
11	1.86	22.18	16.47	0.40	1.24	6.77	46.06	5.00
12	1.52	18.58	16.94	0.30	0.71	5.22	51.35	5.35

The results of the study are presented in the following sections:

I. Development of gestures and speech

II. Patterns of co-occurrence of speech and gestures

I. Development of gestures and speech

All the samples were coded for behaviours seen under each of the types of gestures and speech (refer to Appendix 2) under study. It was observed that most of the infants produced all behaviours listed under the different types of gestures and speech that were studied, but there were variations observed in the production of few behaviors under each of the categories studied. Further, the number of behaviours produced by these infants varied both within a month of study period as well as across the ages that were studied.

1. Facial gestures

The facial gestures documented and analyzed in the study were categorized into two distinct groups: facial expressions and facial movements.

1.1. Facial expressions

The samples were analyzed for expressions of the face such as ‘attention’, ‘displeasure’, ‘discomfort’, ‘frown’, ‘interest’, ‘smile’ and ‘startle’. The means, standard deviations and medians for the rates of occurrence of facial expressions are shown in Table 11. From the table, it is seen that most of the facial expressions produced by infants, namely, ‘attention’, ‘frown’, and ‘interest’, were seen from the age of 3 months, and the rates of occurrences of these gestures seems to reduce with increasing age, especially after the 6^{th} month of age. ‘Startle’, ‘smile’ and ‘discomfort’ were also seen from an early age, although there were variations seen in the rates across all the months with a decline seen towards the end of the first year. ‘Displeasure’ was less frequently produced by all the infants throughout the study period, and was observed for only 2 months.

Friedman test revealed that there was a significant difference in the rates of occurrence for gestures ‘attention’ [$\chi^2(2, N=9) =10.66; p=0.005$], ‘displeasure’ [$\chi^2(2, N=9) =14.85; p=0.001$], ‘discomfort’ [$\chi^2(2, N=9) =15.44; p=0.000$], ‘frown’ [$\chi^2(2, N=9) =12.62; p=0.002$], and ‘interest’ [$\chi^2(2, N=9) =10.40; p=0.006$] across the three months, at 0.01 and 0.001 alpha levels of significance.The results of the pair-wise comparisons revealed that there were significant differences ($p<0.05$) in the rates of occurrence of five facial expressions, namely, ‘attention’, ‘discomfort’, ‘frown’, and ‘interest’ across the various months. It was seen that these differences were seen in the rates of all these gestures between the 3rd month with the 4th, 5th and all other months above the age of 9 months. In the case of ‘displeasure’ the difference in rates was seen between all the other months and the 5th and 6th months.

Table 11

Means, SD’s & Medians for rates of occurrence of facial expressions

Age of the infants in Months	Attention	Displeasure	Discomfort	Frown	Interest	Smile	Startle
3	0.76 (0.64); 0.74	0.00 (0.00); 0.00	0.10 (0.11); 0.08	0.43 (0.46); 0.34	0.84 (0.58); 0.64	1.13 (0.96); 0.88	0.05 (0.07); 0.00
4	0.50 (0.40); 0.27	0.00 (0.00); 0.00	0.10 (0.17); 0.04	0.31 (0.25); 0.41	0.69 (0.70); 0.32	1.16 (0.51); 1.14	0.02 (0.04); 0.00
5	0.26 (0.36); 0.17	0.04 (0.01); 0.00	0.26 (0.31); 0.17	0.44 (0.34); 0.40	0.27 (0.21); 0.20	0.86 (0.48); 0.84	0.02 (0.04); 0.00
6	0.30 (0.28); 0.20	0.08 (0.22); 0.00	0.10 (0.11); 0.07	0.3 (0.39); 0.16	0.21 (0.18); 0.19	0.67 (0.75); 0.24	0.02 (0.03); 0.03
7	0.21 (0.13); 0.27	0.00 (0.00); 0.00	0.09 (0.07); 0.07	0.25 (0.27); 0.28	0.08 (0.11); 0.07	0.71 (0.51); 0.68	0.00 (0.00); 0.00
8	0.11 (0.19); 0.05	0.00 (0.00); 0.00	0.01 (0.01); 0.00	0.12 (0.16); 0.49	0.15 (0.19); 0.09	0.55 (0.66); 0.46	0.09 (0.25); 0.00
9	0.17 (0.12); 0.18	0.00 (0.00); 0.00	0.01 (0.04); 0.00	0.05 (0.07); 0.04	0.11 (0.18); 0.07	0.42 (0.52); 0.24	0.04 (0.11); 0.00
10	0.10 (0.11); 0.09	0.00 (0.00); 0.00	0.06 (0.08); 0.08	0.16 (0.22); 0.09	0.13 (0.17); 0.04	0.48 (0.39); 0.45	0.00 (0.01); 0.00
11	0.07 (0.07); 0.06	0.00 (0.00); 0.00	0.08 (0.16); 0.00	0.13 (0.19); 0.09	0.09 (0.09); 0.08	0.86 (0.51); 0.65	0.01 (0.02); 0.00
12	0.06 (0.09); 0.00	0.00 (0.00); 0.00	0.04 (0.11); 0.00	0.08 (0.20); 0.00	0.06 (0.13); 0.00	0.50 (0.39); 0.45	0.01 (0.02); 0.00

Table 12

Correlation coefficients among facial expressions with age

Rates of occurrence	Attention	Displeasure	Discomfort	Frown	Interest	Smile	Startle
Attention		-0.07	0.01	0.52***	0.47***	0.39***	0.15
Displeasure			-0.02	0.40***	0.09	0.26*	0.04
Discomfort				0.44***	0.03	0.02	-0.04
Frown					0.35**	0.39***	0.09
Interest						0.34**	0.16
Smile							0.39***
Startle							

Note: *** p≤0.00; ** p* p≤0.01; * p≤0.05

Analysis using the Spearman's test revealed that there was a highly significant negative correlation in the rates of occurrence of 'discomfort' (r=-0.22; p=0.042), 'smile' (r=-0.30; p=0.008), 'attention' (r=-0.52; p=0.000), 'frown' (r=-0.39; p=0.000), and 'interest' (r=-0.53; p=0.000) with age at 0.05, 0.01 and 0.001 alpha levels of significance. In Table 12, a summary of the correlation values in the rates of occurrence between the various facial expressions with age is presented. As can be seen, there were highly significant positive correlations in the rates of occurrence of few facial expressions within the first year of life, namely 'frown' with 'attention', 'displeasure' and 'discomfort'; 'interest' with 'attention' and 'frown'; 'smile' with 'attention', 'displeasure', 'frown' and 'interest'; 'startle' with 'smile'.

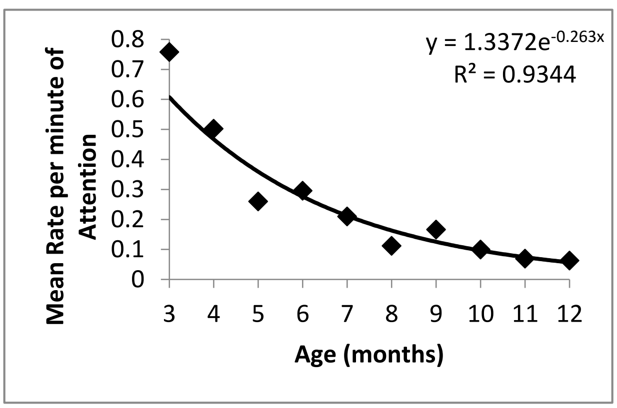


Figure 6(a): Growth trend for attention.

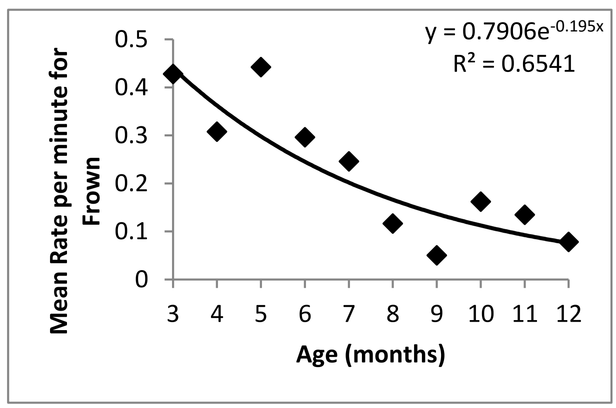


Figure 6(b): Growth trend for frown.

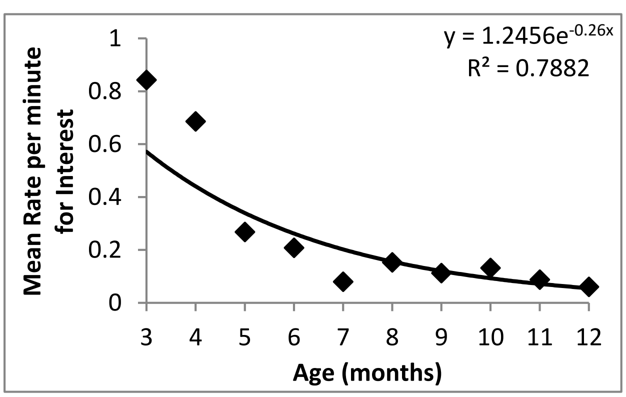


Figure 6(c): Growth trend for interest.

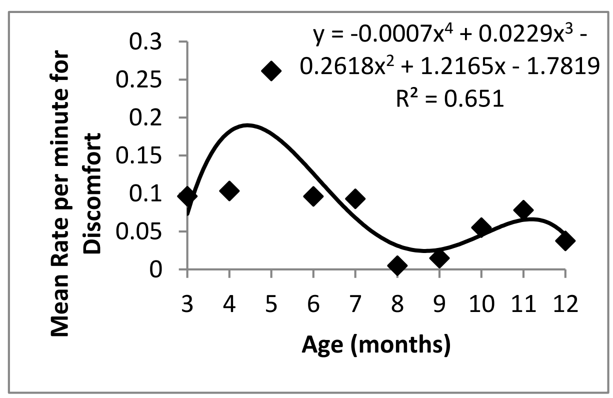


Figure 6(d): Growth trend for discomfort.

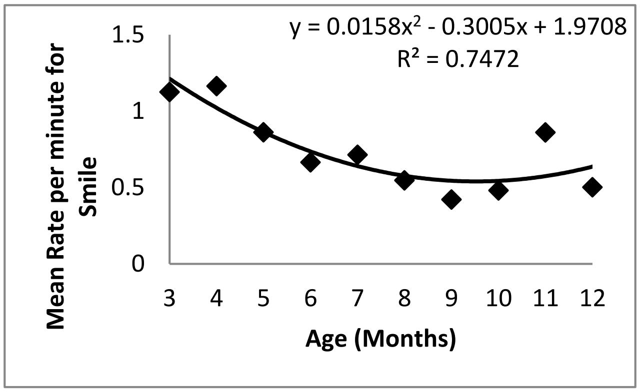


Figure 6(e): Growth trend for smile.

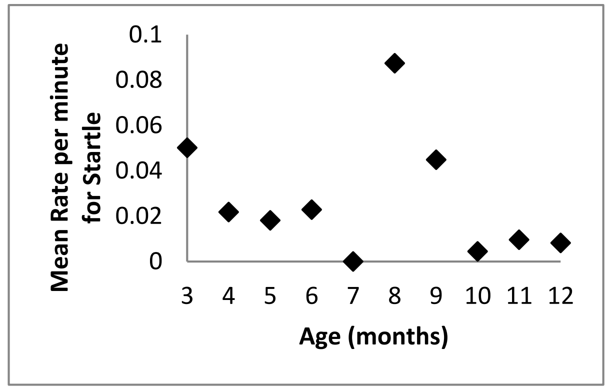


Figure 6(f): Growth trend for startle.

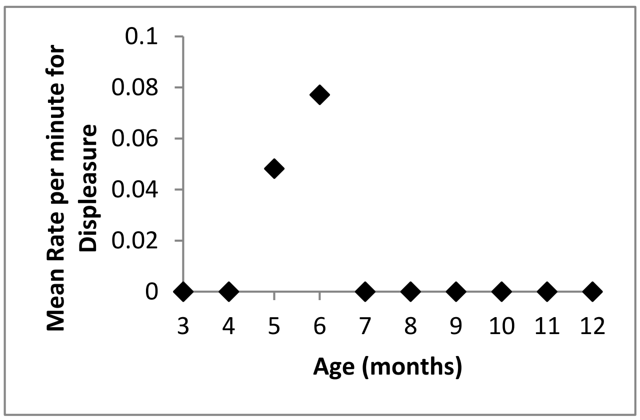
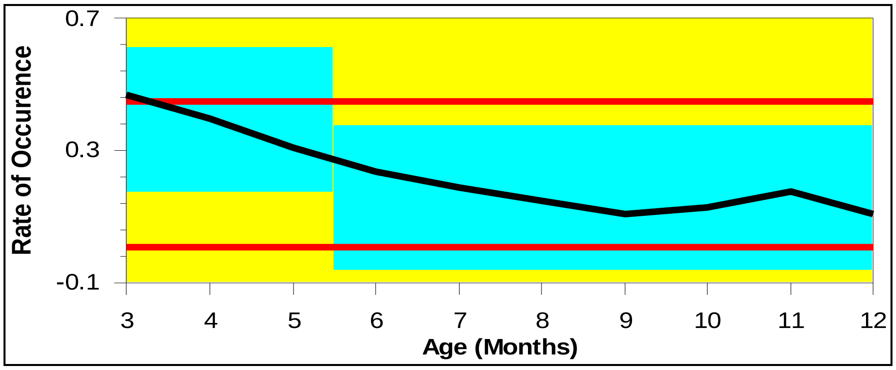


Figure 6(g): Growth trend for displeasure.

Figures 6 (a, b, c, d, e, f & g) depict the quadratic growth trends for each of the gestures studied. It was observed that the gestures 'attention' (Fig. 6(a); R^2=0.93), 'frown' (Fig. 6(b); R^2= 0.65) and 'interest' (Fig. 6(c); R^2=0.78) exhibited exponential trajectories. Gestures 'discomfort' (Fig. 6(d); R^2=0.65) and 'smile' (Fig. 6(e); R^2=0.74) demonstrated polynomial growth trajectories, while 'displeasure' (Fig. 6(f)) and 'startle' (Fig. 6(g)) exhibited unpredictable growth trajectories.



Note: In the figure, blue shaded region-region expected to contain data points; red lines-upper & lower control limits; black line-rate of occurrence

Figure 7: Change point analysis for facial expressions.

Figure 7 shows the results of the change point analysis which reveals a significant change in the rate of occurrence of facial expressions in the 6th month of age (96% confidence interval). Further, the analysis suggests that the rates of occurrence of this gesture decreased beyond this age at which change was observed.

1.2. Facial movements

The facial movements that were analyzed included movements of lips and tongue, namely, 'lip protrusion', 'mouthing', 'lip pout', 'puckered lips', 'tongue protrusion' and rhythmical movements of 'lip play' and 'tongue play'. The means, standard deviations and medians for the rates of occurrence of facial movements are shown in Table 13. The result in this table shows that all the facial movements were seen from the 3rd month of age, and in most cases there seemed to be a decrease in the production of these gestures with an increase in age. 'Mouthing', 'tongue play' and 'tongue protrusion' were noted to show this trend, whereas 'lip play', 'lip protrusion', 'pout', and 'puckered lips' were produced with varying rates across all the months.

Table 13

Means, SD's & Medians for rates of occurrence of facial movements

Age of the infants in Months	Lip Play	Lip Protrusion	Mouthing	Lip Pout	Puckered Lips	Tongue Play	Tongue Protrusion
3	0.18 (0.44); 0.00	0.18 (0.25); 0.06	1.12 (0.70); 0.90	0.02 (0.06); 0.00	0.04 (0.12); 0.00	0.10 (0.29); 0.00	2.20 (1.72); 2.06
4	0.02 (0.03); 0.00	0.16 (0.16); 0.14	0.84 (0.96); 0.45	0.01 (0.02); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	1.32 (1.22); 0.91
5	0.05 (0.05); 0.04	0.03 (0.03); 0.00	0.35 (0.63); 0.19	0.02 (0.05); 0.00	0.00 (0.00); 0.00	0.00 (0.01); 0.00	0.61 (0.65); 0.20
6	0.02 (0.02); 0.00	0.01 (0.03); 0.00	0.35 (0.68); 0.07	0.00 (0.00); 0.00	0.00 (0.01); 0.00	0.02 (0.06); 0.00	0.37 (0.43); 0.16
7	0.01 (0.02); 0.00	0.00 (0.00); 0.00	0.04 (0.05); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.01 (0.02); 0.00	0.31 (0.30); 0.11
8	0.02 (0.04); 0.00	0.02 (0.05); 0.00	0.35 (0.79); 0.05	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.38 (0.45); 0.20
9	0.02 (0.03); 0.00	0.01 (0.02); 0.00	0.08 (0.12); 0.00	0.01 (0.02); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.18 (0.15); 0.20
10	0.00 (0.00); 0.00	0.04 (0.08); 0.00	0.09 (0.09); 0.09	0.01 (0.02); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.15 (0.10); 0.18
11	0.01 (0.03); 0.00	0.19 (0.35); 0.00	0.04 (0.04); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.01 (0.02); 0.00	0.11 (0.08); 0.09
12	0.00 (0.00); 0.00	0.04 (0.04); 0.05	0.03 (0.04); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.09 (0.17); 0.00

The results of the Friedman test revealed that there was a significant difference in the rates of occurrence for gestures 'lip protrusion' [$\chi^2(2, N=9) = 8.32; p=0.016$], 'mouthing' [$\chi^2(2, N=9) = 6.88; p=0.032$], and 'tongue protrusion' [$\chi^2(2, N=9) = 16.22; p=0.000$], at 0.05 and 0.001 alpha levels of significance. Pair-wise comparisons indicated that there were significant differences ($p<0.05$) in the rates of occurrence of three facial movements across months, namely, 'lip protrusion', 'mouthing', and 'tongue protrusion'. These differences were seen in the rates of these gestures between the 5th month with all other months above the age of 6 months in the case of ‘lip protrusion’ and ‘mouthing’; while for ‘tongue protrusion’ these differences were seen between all the months.

The Spearman’s correlation analysis revealed that with age, there was a highly significant negative correlation in the rates of occurrence of ‘mouthing’ (r=-0.48; p=0.000) and ‘tongue protrusion’ (r=-0.55; p=0.000), at 0.001 alpha level of significance. Table 14 summarizes the relationship between the occurrences of various facial movements with age. As can be seen, there were significant positive correlations in the rates of occurrence of few facial movements within the first year of life, namely, ‘lip play’ with all other facial movements except ‘lip protrusion’; ‘mouthing’ with all facial movements except ‘lip play’ and ‘lip protrusion’, ‘pout’ with ‘puckered lips’ and ‘tongue play’.

Table 14

Correlation coefficients among facial movements with age

Rates of occurrence	**Lip play**	**Lip protrusion**	**Mouthing**	**Pout**	**Puckered lips**	**Tongue play**	**Tongue protrusion**
Lip play		0.03	0.29**	0.71***	0.96***	0.95***	0.22*
Lip protrusion			-0.00	-0.09	-0.06	-0.03	0.12*
Mouthing				0.27**	0.25*	0.22*	0.31**
Pout					0.70***	0.67***	0.13
Puckered lips						0.97***	0.19
Tongue play							0.20
Tongue protrusion							

Note: *** p≤0.00; ** p* p≤0.01; * p≤0.05

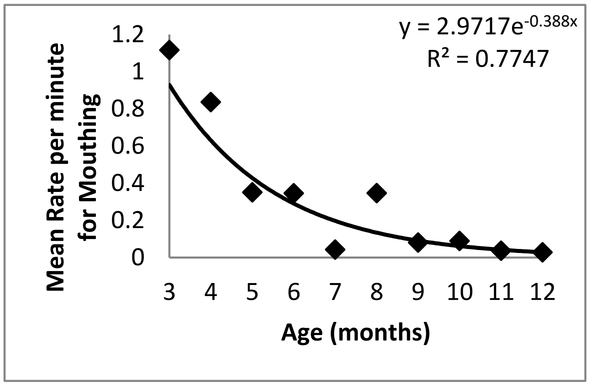


Figure 8(a): Growth trend for mouthing.

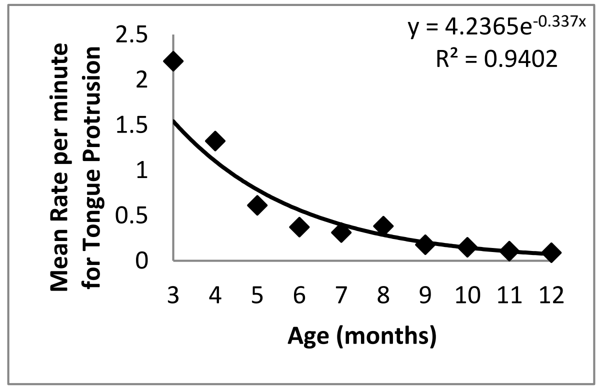


Figure 8(b): Growth trend for tongue protrusion.

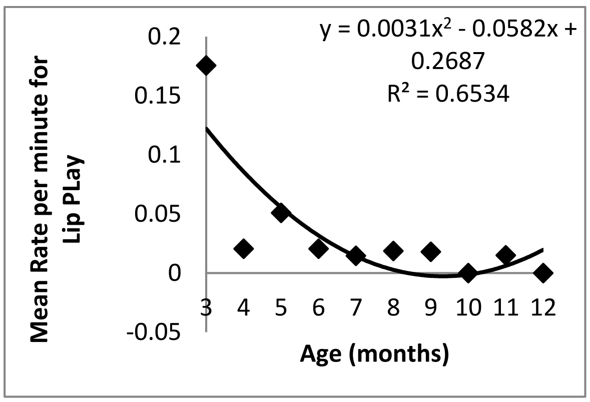


Figure 8(c): Growth trend for lip play.

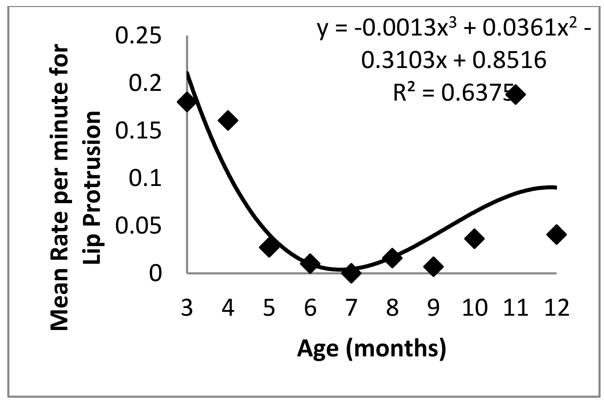


Figure 8(d): Growth trend for lip protrusion.

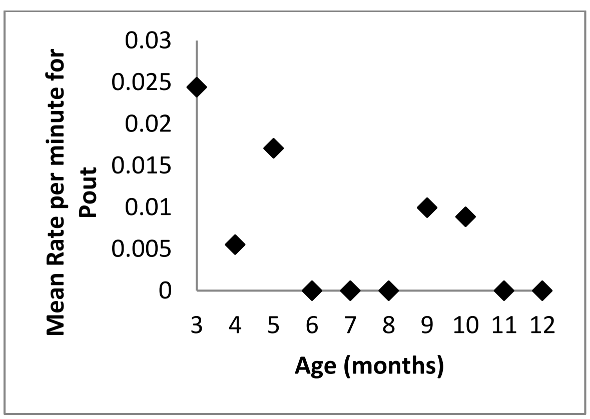


Figure 8(e): Growth trend for lip pout.

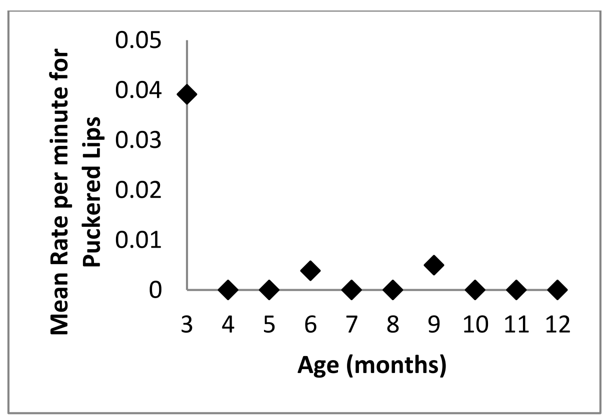


Figure 8(f): Growth trend for puckered lips.

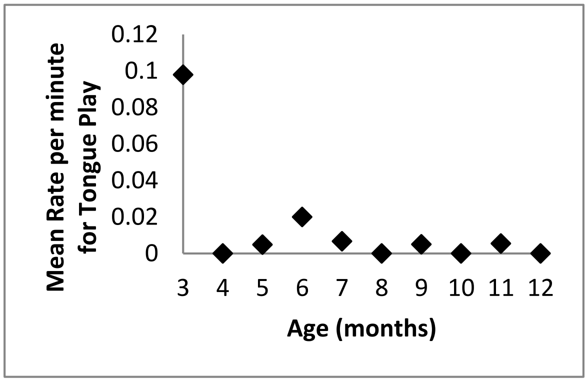
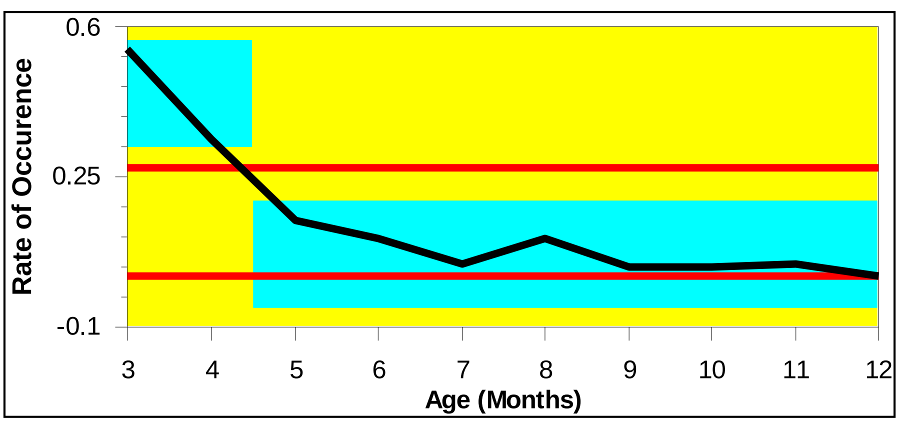


Figure 8(g): Growth trend for tongue play.

Figures 8 (a, b, c, d, e, f & g) depict the quadratic growth trends for each gesture. It was seen that the gestures 'mouthing' (Fig. 8(a); R^2=0.77) and 'tongue protrusion' (Fig. 8(b); R^2=0.94) demonstrated exponential growth trajectories, while 'lip play' (Fig. 8(c); R^2=0.65) and 'lip protrusion' (Fig. 8(d); R^2=0.63) demonstrated polynomial growth trajectories. Gestures 'pout' (Fig. 8(e)), 'puckered lips' (Fig. 8(f)), and 'tongue play' (Fig. 8(g)) exhibited unpredictable growth trajectories.



Note: In the figure, blue shaded region-region expected t contain data points; red lines-upper & lower control limits; black line-rate of occurrence.

Figure 9: Change point analysis for facial movements.

Figure 9 shows the results of the change point analysis which reveals a significant change in the rate of occurrence of facial movements in the 5th month of age (92% confidence interval). Further, it is also observed that the rates of occurrence of this gesture decreased beyond this age at which change was observed.

2. Gaze behaviours

The following gaze behaviours were observed in the study, namely, ‘gaze at action’, ‘gaze at object’, ‘gaze at person’, ‘gaze away’, ‘gaze shift’ and ‘gaze track’. The means, standard deviations and medians for the rates of occurrence of gaze behaviours are shown in Table 15. It can be comprehended that all gaze behaviours were observed from the 3rd month of age, except for the gesture ‘gaze shift’. Overall, there seemed to be an increase in occurrences of ‘gaze at action’, ‘gaze at object’, and ‘gaze track’ as the age of the infants increased. The opposite trend was seen for ‘gaze shift’ which was the only gesture that emerged from the 6th month. Gestures ‘gaze at person’ and ‘gaze away’ showed slight variations in the rate across the different months of study.

Friedman test revealed that there were significant differences in the rates of occurrence of only ‘gaze at object’ [$\chi^2(2, N=9) = 16.22; p=0.000$] at 0.001 alpha levels of significance. The results of the pair-wise comparisons reveal that there were significant differences ($p<0.05$) in the rates of occurrence of four gaze behaviours across the months, namely, ‘gaze at action’, ‘gaze at object’, ‘gaze away’ and ‘gaze track’. These differences were seen for the rates of occurrence between all the months in the case of ‘gaze at object’, whereas for ‘gaze at action’ and ‘gaze track’ these differences were noted between the 3rd, 4th and 5th months with all other months above the age of 8 months. For gesture 'gaze away' these differences were seen between the 4th, 5th, 6th months and all the ages above the 10th month.

Table 15

Means, SD's & Medians for rates of occurrence of gaze

Age of the infants in Months	Gaze at Action	Gaze at Object	Gaze at Person	Gaze Away	Gaze Shift	Gaze Track
3	1.22 (0.93); 1.19	0.95 (1.09); 0.32	2.84 (1.59); 3.49	2.75 (1.22); 3.33	0.00 (0.00); 0.00	0.12 (0.12); 0.15
4	0.61 (0.33); 0.51	2.72 (0.97); 2.57	3.17 (0.85); 3.20	3.44 (1.01); 3.14	0.00 (0.00); 0.00	0.27 (0.20); 0.25
5	0.96 (0.80); 0.87	4.71 (2.36); 4.00	2.63 (1.19); 2.37	3.07 (1.25); 3.28	0.00 (0.00); 0.00	0.21 (0.16); 0.20
6	1.23 (0.79); 0.99	4.44 (1.16); 4.27	3.06 (1.04); 2.56	3.29 (0.92); 3.39	0.03 (0.04); 0.00	0.33 (0.28); 0.16
7	1.68 (1.24); 1.12	4.60 (0.75); 4.24	3.33 (0.93); 3.24	2.51 (0.56); 2.32	0.00 (0.00); 0.00	0.29 (0.15); 0.23
8	2.71 (1.49); 2.70	5.26 (0.61); 4.89	2.69 (0.95); 2.50	2.95 (0.45); 2.78	0.00 (0.00); 0.00	0.48 (0.41); 0.35
9	3.04 (1.25); 2.60	5.22 (1.29); 4.80	2.63 (1.04); 2.18	1.99 (1.58); 1.11	0.03 (0.04); 0.00	0.56 (0.28); 0.55
10	4.03 (2.01); 4.78	5.96 (1.17); 5.91	3.09 (1.09); 2.54	1.53 (0.40); 1.63	0.03 (0.06); 0.00	0.86 (0.46); 0.84
11	4.35 (1.75); 4.13	6.80 (1.08); 6.73	3.95 (0.94); 4.13	2.85 (0.86); 2.70	0.01 (0.02); 0.00	1.13 (0.73); 0.74
12	4.87 (2.24); 4.70	6.66 (1.91); 6.65	2.53 (0.77); 2.54	1.09 (0.52); 1.00	0.00 (0.00); 0.00	0.20 (0.12); 0.12

The Spearman's correlation analysis revealed that with age, there was a highly significant positive correlation in the rates of occurrence of 'gaze at action' (r=0.73; p=0.000), 'gaze at object' (r=0.74; p=0.000), and 'gaze track' (r=0.42; p=0.000), and a highly significant negative correlation in the occurrence of 'gaze away' (r=-0.44; p=0.000) at 0.001 alpha level of significance. Table 16 shows the relationship in the rates of occurrence of different gaze behaviours with age. As can be noted, there were significant positive correlations in the rates of occurrence of 'gaze at object' with 'gaze at action'; 'gaze away' with 'gaze at person'; 'gaze track' with 'gaze at action'; gaze at object' with 'gaze at shift'. There were also significant negative correlations in the occurrences of 'gaze away' with 'gaze at action' and 'gaze at object'.

Table 16

Correlation coefficients among gaze behaviours with age

Rates of occurrence	Gaze at action	Gaze at object	Gaze at person	Gaze away	Gaze shift	Gaze track
Gaze at action		0.67***	-0.01	-0.41***	0.12	0.50***
Gaze at object			0.19	-0.25*	0.13	0.51***
Gaze at person				0.38**	0.06	0.19
Gaze away					-0.09	-0.01
Gaze shift						0.25*
Gaze track						

Note: *** p≤0.00; **p≤0.01; * p≤0.05

Figures 10 (a, b, c, d, e & f) depict the quadratic growth trends for each gesture. Gesture 'gaze at action' (Fig. 10(a); R^2= 0.87) showed an exponential trajectory, while 'gaze away' (Fig. 10(b); R^2= 0.57) showed polynomial trajectory, and 'gaze at object' (Fig. 10(c); R^2= 0.84) showed a linear trajectory. The trajectories were found to be unpredictable for 'gaze at person' (Fig. 10(d)), 'gaze shift' (Fig. 10(e)) and 'gaze track' (Fig. 10(f)).

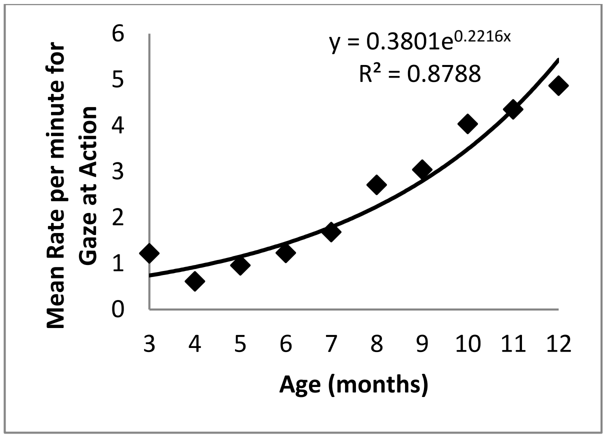


Figure 10(a): Growth trend for gaze at action.

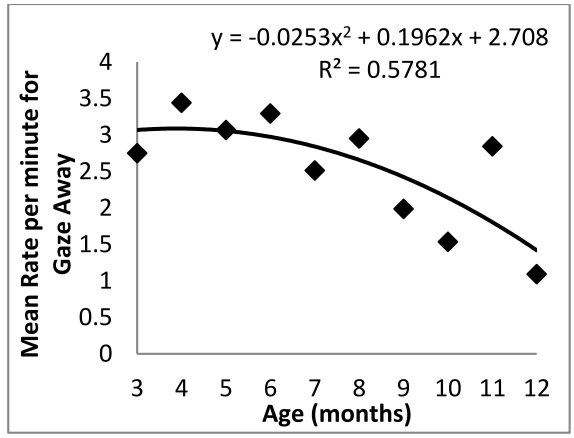


Figure 10(b): Growth trend for gaze away.

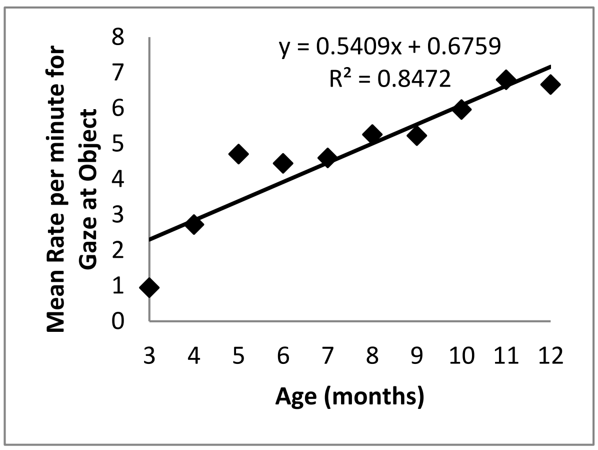


Figure 10(c): Growth trend for gaze at object.

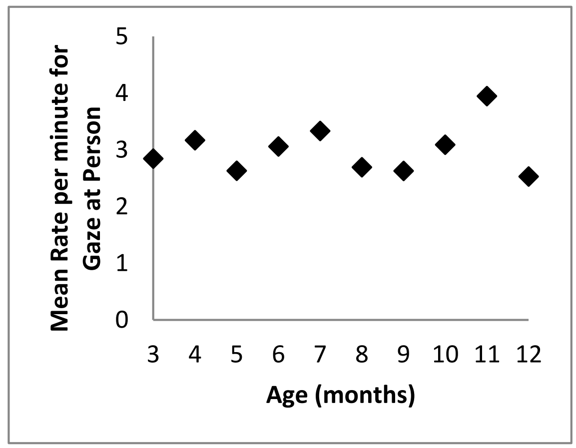


Figure 10(d): Growth trend for gaze at person.

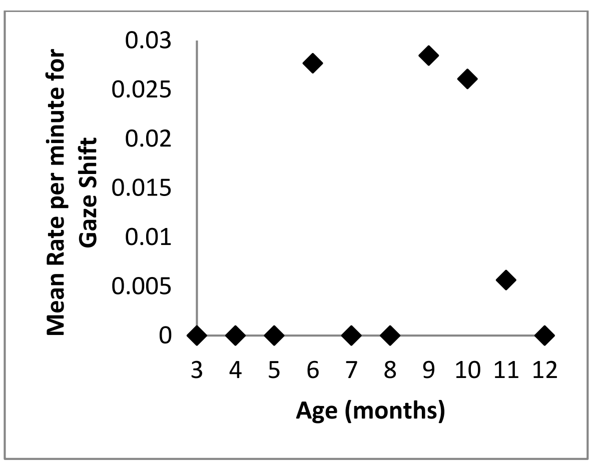


Figure 10(e): Growth trend for gaze shift.

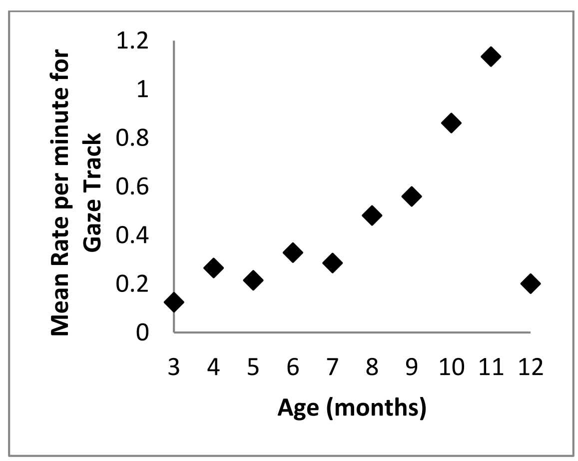
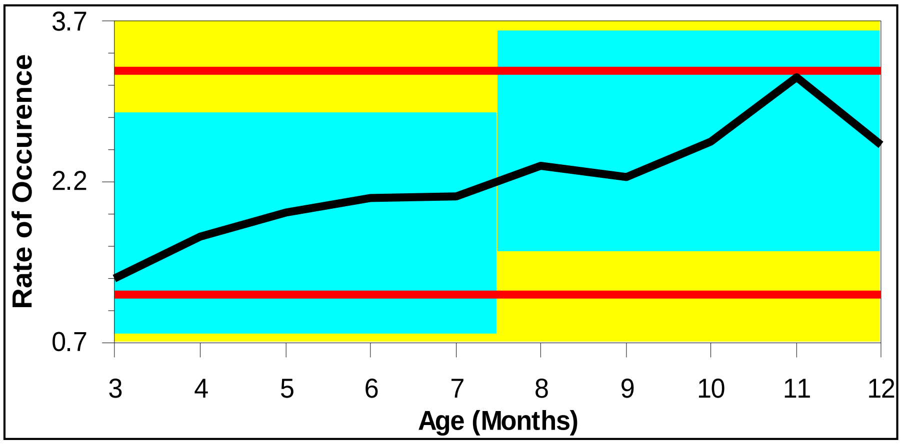


Figure 10(f): Growth trend for gaze track.

Figure 11 shows the results of the change point analysis which reveals a significant change in the rate of occurrence of gaze behaviours in the 8th month of age (96% confidence interval). Further, the analysis suggests that the rates of occurrence of this gesture increased beyond this age at which change was observed.



Note: In the figure, blue shaded region-region expected to contain data points; red lines-upper & lower control limits; black line-rate of occurrence.

Figure 11: Change point analysis for gaze behaviours.

3. Head movements

The head movements that were analyzed in the study were 'head extension', 'head lowering', 'head turn' and rhythmical movements of 'head nod' and 'head shake'. The means, standard deviations and medians for the rates of occurrence of head movements are shown in Table 17. It is seen that all head movements were observed from 3 and 4 months of age. 'Head turn' and rhythmic 'head nod' were the two gestures that showed an increase in the occurrence with age, while 'head extension' and 'head lowering' showed the opposite trend. 'Head shake' was the only rhythmic gesture which showed variation in the rates across all the months of study.

Table 17

Means, SD's & Medians for rates of occurrence of head movements

Age of the infants in Months	Head Extension	Head Lowering	Head Nod	Head Shake	Head Turn
3	0.67 (0.81); 0.40	0.25 (0.64); 0.00	0.00 (0.00) 0.00	0.03 (0.05); (0.00)	3.99 (2.07); 5.06
4	0.64 (0.86); 0.22	0.38 (0.68); 0.00	0.01 (0.02); 0.00	0.02 (0.02); 0.00	4.94 (1.34); 5.18
5	0.45 (0.49); 0.27	0.76 (0.79); 0.48	0.01 (0.03); 0.00	0.00 (0.01); 0.00	6.35 (2.37); 8.63
6	0.51 (0.81); 0.80	0.65 (0.72); 0.32	0.01 (0.02); 0.00	0.09 (0.11); 0.00	9.41 (3.30); 10.32
7	0.20 (0.17); 0.23	0.02 (0.03); 0.00	0.00 (0.00); 0.00	0.04 (0.04); 0.00	11.88 (2.52); 10.32
8	0.15 (0.24); 0.00	0.17 (0.49); 0.00	0.01 (0.03); 0.00	0.10 (0.08); 0.05	12.33 (2.15); 12.45
9	0.22 (0.45); 0.04	0.43 (1.05); 0.22	0.00 (0.00); 0.00	0.10 (0.11);0.36	11.42 (3.14); 9.56
10	0.26 (0.54); 0.04	0.41 (0.91); 0.36	0.01 (0.02); 0.00	0.10(0.17); 0.00	12.46 (2.19); 13.52
11	0.20 (0.21); 0.13	0.19 (0.52); 0.00	0.08 (0.12); 0.00	0.09 (0.08); 0.00	13.50 (1.08); 13.70
12	0.09 (0.14); 0.00	0.21 (0.59); 0.16	0.10 (0.21); 0.00	0.14 (0.22); 0.06	13.41 (3.00); 14.16

The data was treated with Friedman test, which revealed significant differences in the rates of occurrence of 'head lowering' [χ^2 (2, N=9)=19.06; p=0.025], and 'head turn' [χ^2 (2, N=9)=52.26; p=0.000], at 0.05 and 0.001 alpha levels of significance. Pair-wise comparisons revealed that there were significant differences ($p<0.05$) in the rates of occurrence of three gestures, namely, 'head extension', 'head lowering' and 'head turn'. In the case of 'head extension' there were differences in the rates between the 3rd, 4th, 6th, 8th and the months above the 10th month, while for 'head lowering' these differences were seen between the 5th and 6th month and the 11th and 12th months. For 'head turn', this was seen between the 3rd, 4th, 5th months and all the months above the 10th.

Table 18

Correlation coefficients among head movements with age

Rates of occurrence	Head extension	Head lowering	Head nod	Head shake	Head turn
Head extension		0.49***	-0.09	-0.04	-0.29*
Head lowering			-0.08	0.15	-0.24*
Head nod				0.47***	0.20
Head shake					0.32**
Head turn					

Note: *** p≤0.00; ** p≤0.01; * p≤0.05

The Spearman's correlation revealed that with age, there was a highly significant positive correlation in the rates of occurrence of 'head turn' (r=0.79; p=0.000) at 0.001 alpha level of significance, and a significant positive correlation in the occurrence of 'head nod' (r=0.31; p=0.005) and 'head shake' (r=0.34; p=0.002) at 0.01 alpha levels of significance. 'Head extension' (r=-0.33; p=0.003) showed a significant negative correlation at 0.01 alpha level of significance. Table 18 demonstrates the relationship in the rates of occurrence of various head movements with age. It can be seen that there were significant positive correlations in the occurrence of 'head extension' with 'head lowering'; 'head shake' with 'head nod'; and 'head shake' with 'head turn'. Also, there was a significant negative correlation in the rate of occurrence of 'head turn' with 'head lowering' and 'head extension'.

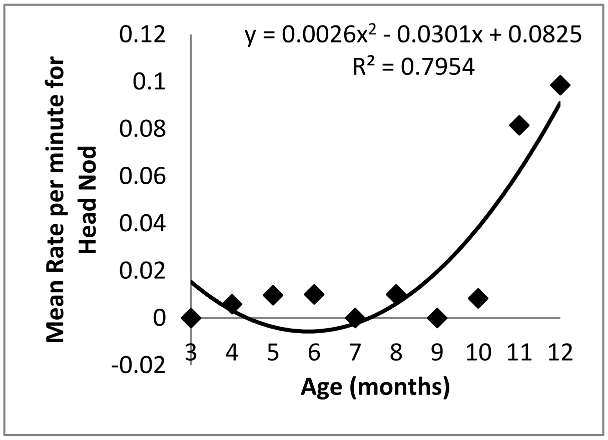


Figure 12(a): Growth trend for head nod.

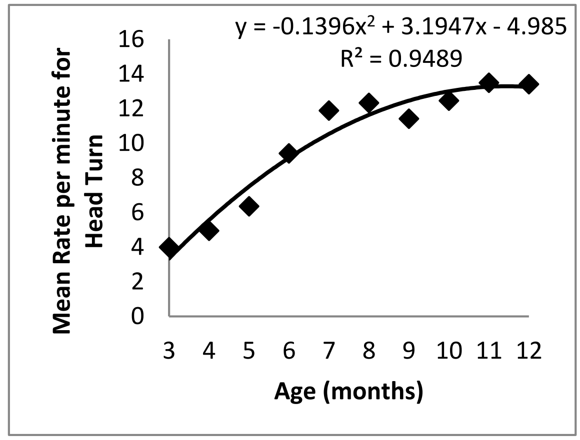


Figure 12(b): Growth trend for head turn.

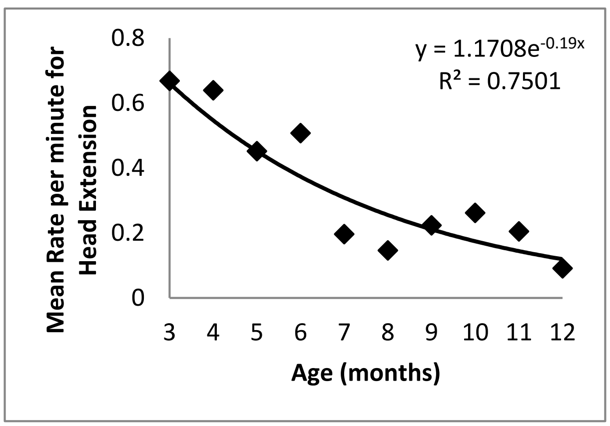


Figure 12(c): Growth trend for head extension.

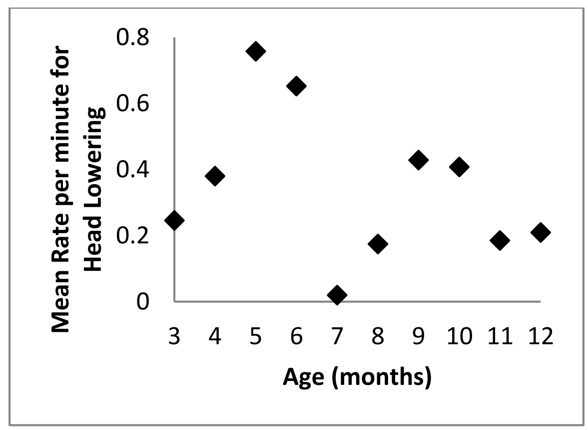


Figure 12(d): Growth trend for head lowering.

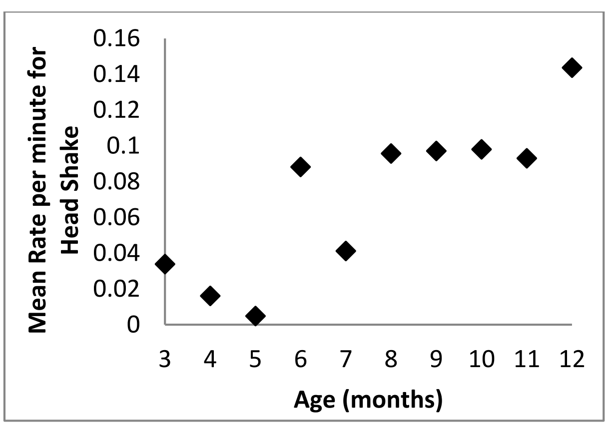
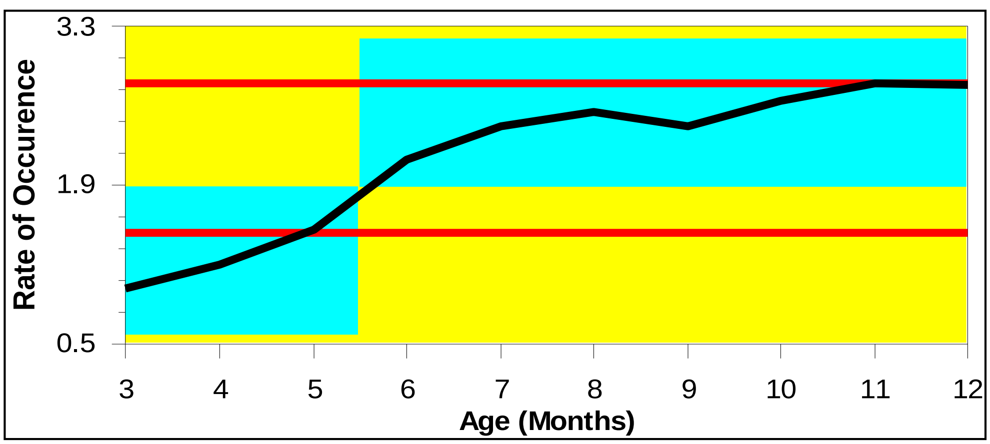


Figure 12(e): Growth trend for head shake.

Figures 12 (a, b, c, d, & e) show the quadratic growth trends for each gesture. Both 'head nod' (Fig. 12(a); R^2= 0.79) and 'head turn' (Fig. 12(b); R^2= 0.95) showed polynomial trajectories, while 'head extension' (Fig. 12(c); R^2= 0.75) exhibited an exponential growth trajectory. Gestures 'head lowering' (Fig. 12(d)) and 'head shake' (Fig. 12(e)) were found to have unpredictable trajectories.

Figure 13 shows the results of the change point analysis which reveals a significant change in the rate of occurrence of head movements in the 8th month of age (96% confidence interval). Further, it is seen that the rates of occurrence of this gesture increased beyond 8th month at which change was observed.



Note: In the figure, blue shaded region-region expected to contain data points; red lines-upper & lower control limits; black line-rate of occurrence.

Figure 13: Change point analysis for head movements.

4. Leg movements

Four types of movements of legs, namely, 'feet in contact', and rhythmical movements of 'foot rub', 'single leg kick', and 'both leg kicks' were seen in all the infants. The means, standard deviations and medians for the rates of occurrence of leg movements are shown in Table 19. It can be noted from the table that, all leg gestures were seen from the age of 3 months, with the highest rate of occurrence noted between 3 and 5 months of age. Beyond this age, the occurrences of these gestures seemed to reduce with a corresponding increase in age. Gesture 'foot rub' was observed only till the age of 8 months.

Friedman test administered on the data revealed that there were no significant differences in the rates of occurrence of leg movements across the three months of comparison. The results of the pair-wise comparisons revealed that there were significant differences in the rates of occurrence of all four gestures across months. It was seen that these differences were seen in the rates of these gestures between the 3rd, 4th, 5th and 6th months and months from the age of the 8th month.

The Spearman's analysis revealed that with age, there was a highly significant negative correlation in the rates of occurrence of 'both leg kicks'(r=-0.57; p=0.000), 'feet in contact'(r=-0.60; p=0.000), 'foot rub' (r=-0.48; p=0.000) and 'single leg kick'(r=-0.57; p=0.000), at 0.001 alpha levels of significance. Table 20 shows the relationship in the rates of occurrence of various leg movements with age. Significant positive correlations were noted in the rates of occurrence of all gestures.

Table 19

Means, SD's & Medians for rates of occurrence of leg movements

Age of the infants in Months	Both Leg Kicks	Feet in Contact	Foot Rub	Single Leg Kick
3	1.33 (1.09); 0.83	1.87 (1.66); 1.27	0.8 (0.86); 0.42	2.34 (0.74); 2.26
4	1.79 (1.34); 1.17	2.91 (1.94); 3.43	1.57 (1.75); 0.79	1.95 (1.57); 1.69
5	1.42 (1.27); 1.08	1.23 (0.86); 1.12	0.86 (0.73); 0.37	2.33 (2.50); 0.58
6	0.98 (1.33); 0.23	1.27 (1.42); 0.43	0.28 (0.37); 0.06	1.29 (0.74); 0.95
7	0.65 (0.63); 0.60	0.69 (1.20); 3.08	0.20 (0.40); 1.00	1.49 (1.80); 2.12
8	0.05 (0.10); 0.00	0.13 (0.23); 0.00	0.03 (0.08); 0.00	0.26 (0.36); 0.13
9	0.06 (0.06); 0.04	0.02 (0.03); 0.08	0.00 (0.00); 0.00	0.24 (0.28); 0.28
10	0.04 (0.04); 0.04	0.03 (0.08); 0.00	0.00 (0.00); 0.00	0.04 (0.04); 0.04
11	0.03 (0.03); 0.04	0.02 (0.05); 0.00	0.00 (0.00); 0.00	0.28 (0.33); 0.13
12	0.02 (0.03); 0.00	0.01 (0.02); 0.00	0.00 (0.00); 0.00	0.20 (0.09); 0.25

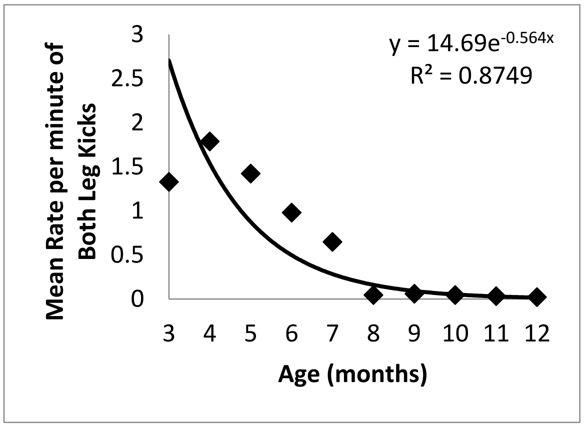
Table 20

Correlation coefficients among leg movements with age

Rates of occurrence	Both leg kicks	Feet in contact	Foot rub	Single leg kick
Both leg kicks		0.43***	0.29**	0.65**
Feet in contact			0.85***	0.34**
Foot rub				0.30**
Single leg kick				

Note: *** p≤0.00; ** p≤0.01

Figures 14 (a, b, c & d) show the quadratic growth trends for each gesture. Exponential growth trajectories were exhibited by 'both leg kicks' (Fig. 14(a); R^2= 0.87), 'feet in contact' (Fig. 14(b); R^2= 0.90) and 'foot rub' (Fig. 14(c); R^2= 0.73). The gesture 'single leg kick' (Fig. 14(d); R^2= 0.86) demonstrated a polynomial trajectory.



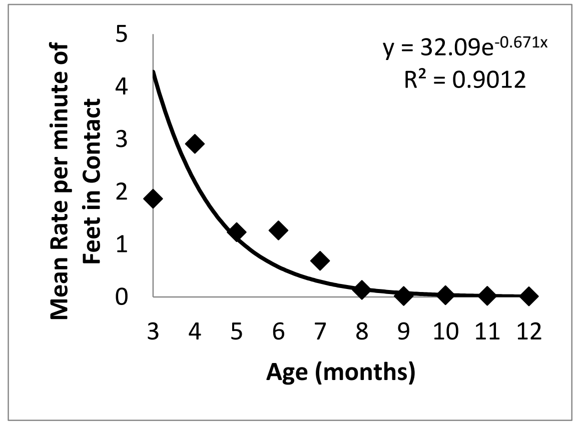
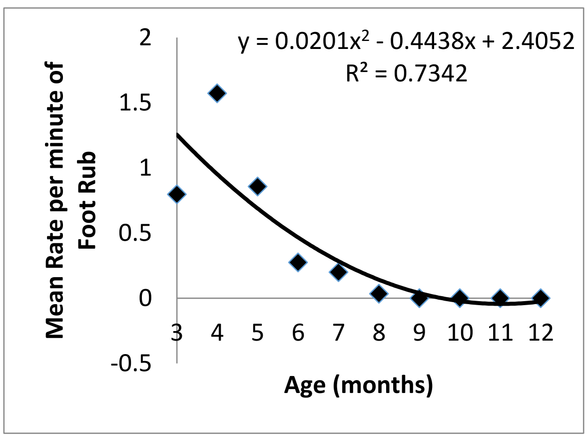


Figure 14(a): Growth trend for both leg kicks.

Figure 14(b): Growth trend for feet in contact.



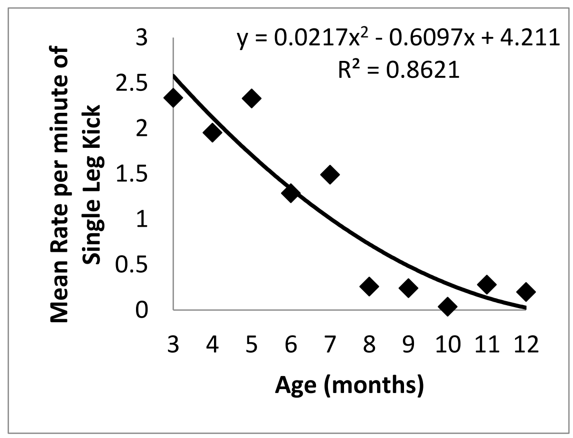
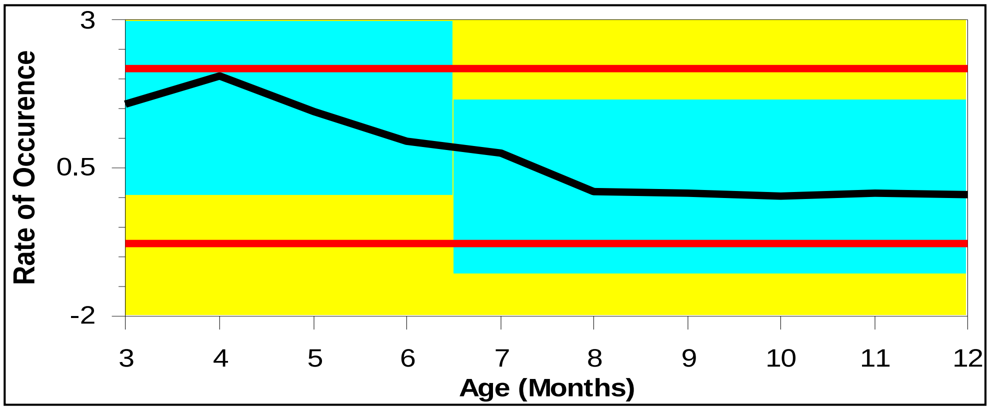


Figure 14(c): Growth trend for foot rub.

Figure 14(d): Growth trend for single leg kick.

Figure 15 shows the results of the change point analysis which reveals a significant change in the rate of occurrence of leg movements in the 7th month of age (96% confidence interval). Further, the analysis suggests that the rates of occurrence of this gesture decreased beyond this age at which change was observed.



Note: In the figure, blue shaded region-region expected to contain data points; red lines-upper & lower control limits; black line-rate of occurrence.

Figure 15: Change point analysis for leg movements.

5. Movements of torso

'Bounce' and 'rock' were the two rhythmical gestures that were observed as movements of torso. The means, standard deviations and medians for the rates of occurrence of torso movements are as shown in Table 21. The result in the table reveals that both the rhythmical gestures 'rock' and 'bounce' were seen from the age of 3 months. There was an increase in the occurrence of both behaviours between 5 and 8 months, following which there was a relative decrease in the occurrence.

Analysis using Friedman test suggested that significant differences were seen in the occurrence rates of both 'bounce' [χ^2 (2, N=9)=6.46; p=0.040], and 'rock' [χ^2 (2, N=9)=7.60; p=0.022], at 0.05 alpha level of significance. Pair-wise comparisons revealed that the gestures demonstrated similar trends; for both 'bounce' and 'rock' differences were seen in the rates between the 3rd month and all months from the 6th month as well as between the 4th month and all other months of observation, except the 11th month in the case of ‘rock’. These were significant at $p<0.05$ alpha level of significance.

Table 21

Means, SD’s & Medians for rates of occurrence of torso movements

Age of the infants in Month	Bounce	Rock
3	0.05 (0.11); 0.00	0.01 (0.02); 0.00
4	0.01 (0.02); 0.00	0.01 (0.02); 0.00
5	0.48 (0.66); 0.08	0.22 (0.37); 0.08
6	0.54 (0.96); 0.11	0.29 (0.39); 0.03
7	0.59 (0.55); 0.33	0.41 (0.42); 0.04
8	0.71 (1.15); 0.39	0.34 (0.32); 0.08
9	0.59 (1.07); 0.07	0.21 (0.25); 0.00
10	0.33 (0.37); 0.12	0.14 (0.14); 0.08
11	0.64 (1.04); 0.30	0.30 (0.24); 0.17
12	0.17 (0.16); 0.18	0.36 (0.18); 0.72

Table 22

Correlation coefficients among torso movements with age

Rates of occurrence	Bounce	Rock
Bounce		0.49***
Rock		

Note: *** $p\leq 0.00$

The Spearman’s correlation revealed that with age, there was a significant positive correlation in the rate of occurrence of ‘rock’ ($r=0.32$; $p=0.005$) with age. Table 22 shows the relationship in the rates of occurrence of different movements of torso with age. It was seen that there was a positive correlation in the occurrence of ‘rock’ with ‘bounce’.

Figures 16 (a & b) demonstrates the quadratic growth trends for torso movements. Gesture ‘bounce’ (Fig. 16(a); $R^2= 0.72$) showed a polynomial trajectory, and the trajectory for ‘rock’ (Fig. 16(b)) was found to be unpredictable. The change point analysis did not reveal an age at which significant change was observed in the occurrence of torso movements within the first year of life.

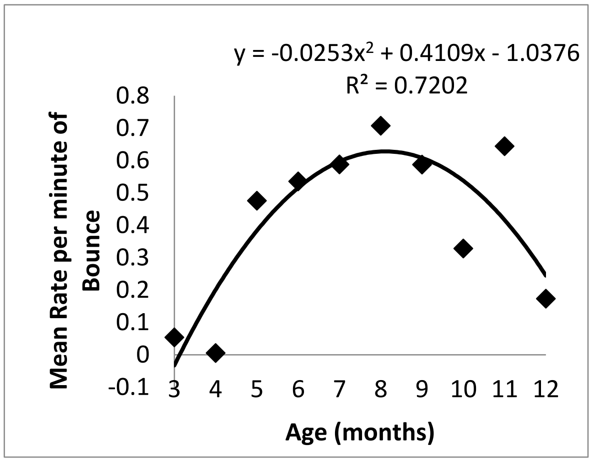


Figure 16(a): Growth trend for bounce.

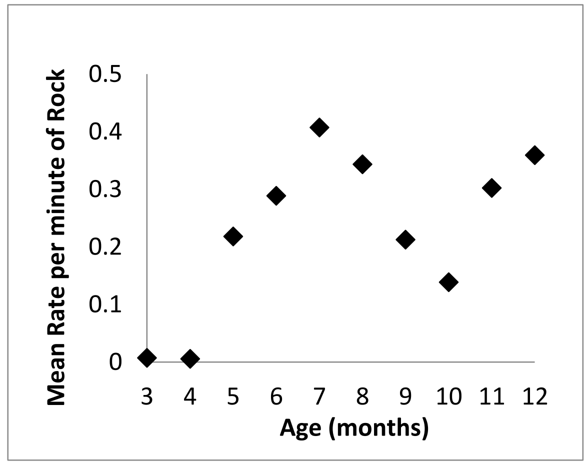


Figure 16(b): Growth trend for rock.

6. Whole body movements

The different whole body movements that were studied were 'crawl', 'lean', 'turn', 'roll over', 'stand with support', 'stand', 'walk with support' and 'walk'. The means, standard deviations and medians for the rates of occurrence of whole body movements are shown in Table 23. It can be seen that there were variations seen in the ages at which most gestures occurred. For example, 'turn' was seen from the 3rd month, 'crawl' was seen from the 6th month, while both 'stand' and 'walk' emerged between 10 and 11 months of age. There was a decrease seen in the occurrence of most behaviours, except in the cases of 'stand' and 'walk', as the age of the infants increased.

The data was subjected to Friedman test and the results revealed that only one gesture, namely, ‘turn’ [χ^2 (2, N=9)=6.86; p=0.032] demonstrated a significant difference in the rates of occurrence across the three months, at 0.05 alpha level of significance. The pair-wise comparisons suggested that in the case of ‘crawl’, significant differences ($p<0.05$) were seen in the rates between the 9th, 11th and 12th months and those below the 6th month. The same trend was shown by gesture ‘lean’, while for ‘turn’ these differences were seen between the 3rd and 4th months with the 6th and 7th months.

The Spearman’s analysis revealed that with age, there was a highly significant positive correlation in the rates of occurrence of ‘crawl’(r=0.40; p=0.000), ‘lean’(r=0.81; p=0.000), ‘stand’ (r=0.43; p=0.000) and ‘walk’(r=0.38; p=0.000), at 0.001 alpha levels of significance. Table 24 shows the relationship in the rates of occurrence of whole body movements with age. It can be seen that there were significant positive correlations in the rate of occurrence of ‘lean’ with ‘crawl’, ‘stand’, ‘stand with support’ and ‘walk’; ‘turn’ with ‘roll over’; ‘walk’ with ‘stand’.

Figures 17 (a, b, c, d, e, f, g, & h) demonstrate the quadratic growth trends for whole body movements. Gestures ‘roll over’ (Fig. 17(a)) and ‘walk with support’ (Fig. 17(b)) exhibited unpredictable trajectories, while ‘turn’ (Fig. 17(c); R^2= 0.62), ‘lean’ (Fig. 17(d); R^2= 0.80), ‘crawl’ (Fig. 17(e); R^2= 0.48), ‘stand with support’ (Fig. 17(f); R^2= 0.51), ‘stand’ (Fig. 17(g); R^2= 0.73), and ‘walk’ (Fig. 17(h); R^2= 0.62), showed polynomial trajectories.

Table 23

Means, SD's & Medians for rates of occurrence of whole body movements

Age of the infants in Months	Crawl	Lean	Roll Over	Stand with Support	Stand	Turn	Walk with Support	Walk
3	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.11 (0.25); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00
4	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.05 (0.15); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.35 (0.65); 0.13	0.00 (0.00); 0.00	0.00 (0.00); 0.00
5	0.00 (0.00); 0.00	0.10 (0.20); 0.00	0.00 (0.00); 0.00	0.09 (0.26); 0.00	0.00 (0.00); 0.00	0.73 (0.65); 0.41	0.00 (0.00); 0.00	0.00 (0.00); 0.00
6	0.15 (0.43); 0.00	0.61 (0.61); 0.61	0.13 (0.35); 0.99	0.08 (0.09); 0.08	0.00 (0.00); 0.00	0.59 (1.06); 3.11	0.00 (0.00); 0.00	0.00 (0.00); 0.00
7	0.13 (0.29); 0.00	0.42 (0.53); 1.33	0.11 (0.20); 0.09	0.15 (0.11); 0.33	0.00 (0.00); 0.00	0.92 (0.55); 1.14	0.00 (0.00); 0.00	0.00 (0.00); 0.00
8	0.3 (0.39); 0.00	2.39 (1.26); 0.09	0.00 (0.00); 0.00	0.23 (0.28); 0.00	0.00 (0.00); 0.00	0.50 (0.44); 0.46	0.01 (0.02); 0.00	0.00 (0.00); 0.00
9	0.38 (0.33); 0.20	2.72 (1.25); 2,48	0.00 (0.00); 0.00	0.04 (0.05); 0.04	0.00 (0.00); 0.00	0.44 (0.33); 0.36	0.01 (0.02); 0.00	0.00 (0.00); 0.00
10	0.40 (0.46); 0.27	2.17 (0.63); 2.45	0.00 (0.00); 0.00	0.18 (0.19); 0.09	0.08 (0.19); 0.00	0.54 (0.36); 0.81	0.00 (0.00); 0.00	0.06 (0.13); 0.00
11	0.59 (0.55); 0.45	2.96 (0.95); 2.62	0.00 (0.00); 0.00	0.16 (0.18); 0.54	0.73 (1.02); 0.04	0.46 (0.36); 0.45	0.02 (0.05); 0.00	0.69 (1.03); 0.00
12	0.12 (0.2); 0.05	2.80 (0.74); 2.55	0.00 (0.00); 0.00	0.01 (0.03); 0.00	0.52 (0.51); 0.40	0.25 (0.18); 1.77	0.00 (0.00); 0.00	0.37 (0.40); 0.16

Table 24

Correlation coefficients among whole body movements with age

Rates of occurrence	Crawl	Lean	Roll over	Stand	Stand with support	Turn	Walk	Walk with support
Crawl		0.53***	-0.11	0.02	0.20	-0.00	0.03	0.01
Lean			-0.13	0.29**	0.24*	-0.02	0.29*	0.21
Roll over				-0.06	-0.00	0.50***	-0.05	-0.04
Stand					-0.08	-0.15	0.97***	-0.06
Stand with support						0.14	-0.09	0.12
Turn							-0.15	-0.08
Walk								-0.06
Walk with support								

Note: *** p≤0.00; **p≤0.01; * p≤0.05

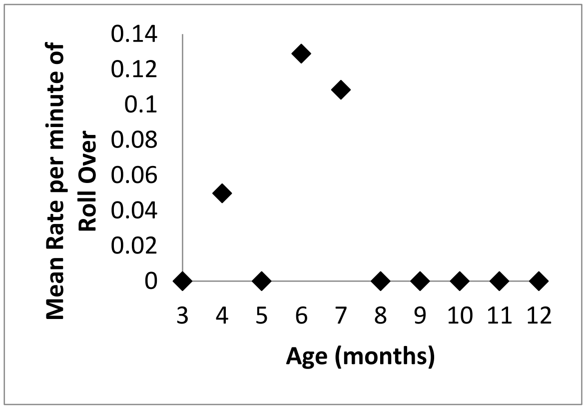


Figure 17(a): Growth trend for roll over.

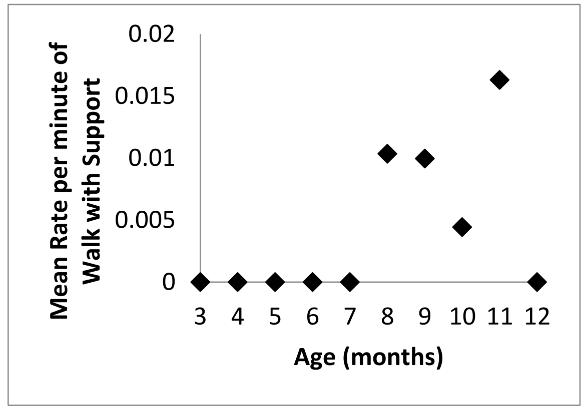


Figure 17(b): Growth trend for walk with support.

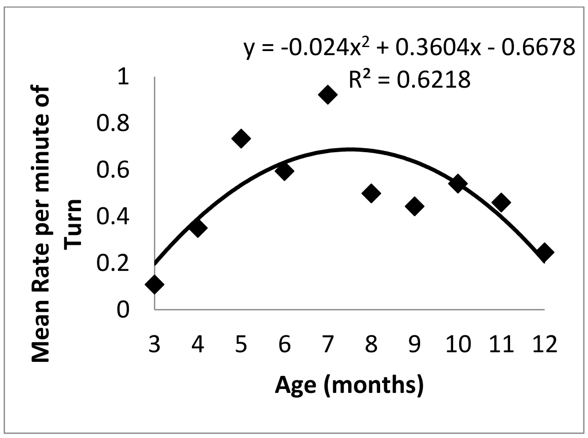


Figure 17(c): Growth trend for turn.

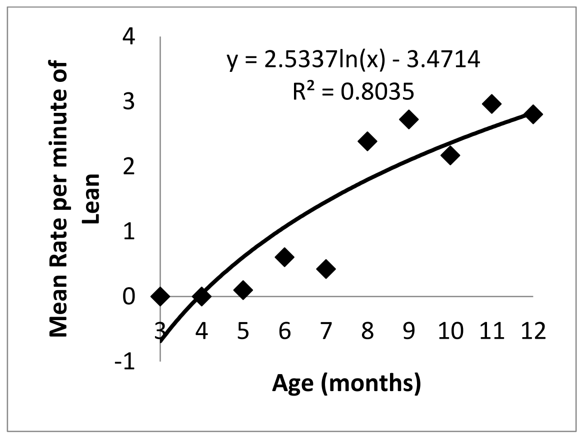


Figure 17(d): Growth trend for lean.

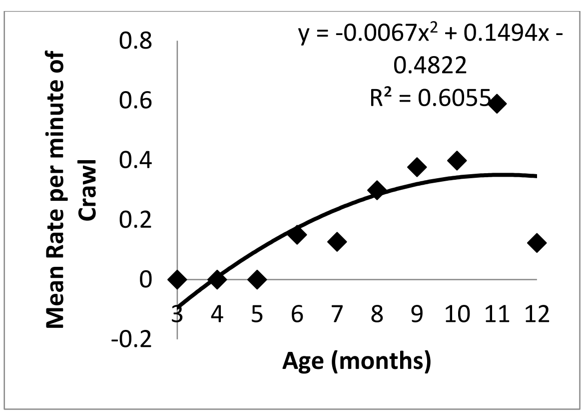


Figure 17(e): Growth trend for crawl.

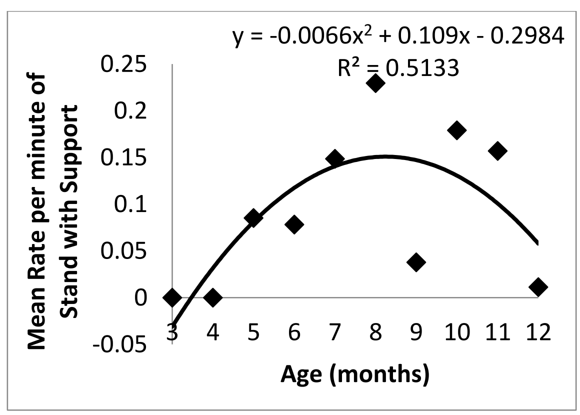


Figure 17(f): Growth trend for stand with support.

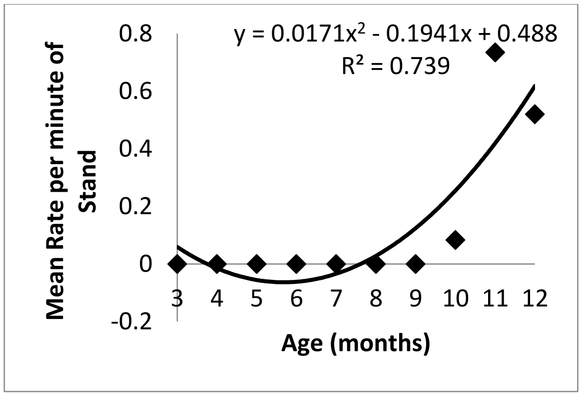


Figure 17(g): Growth trend for stand.

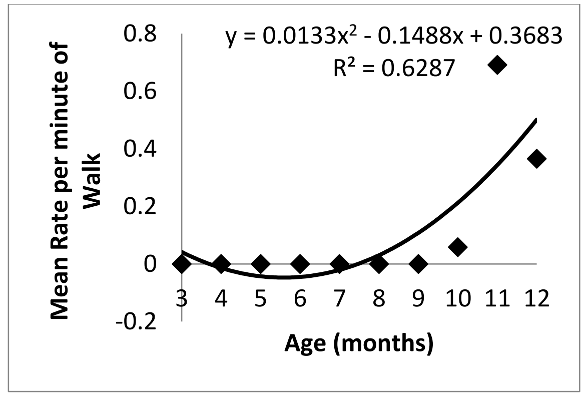
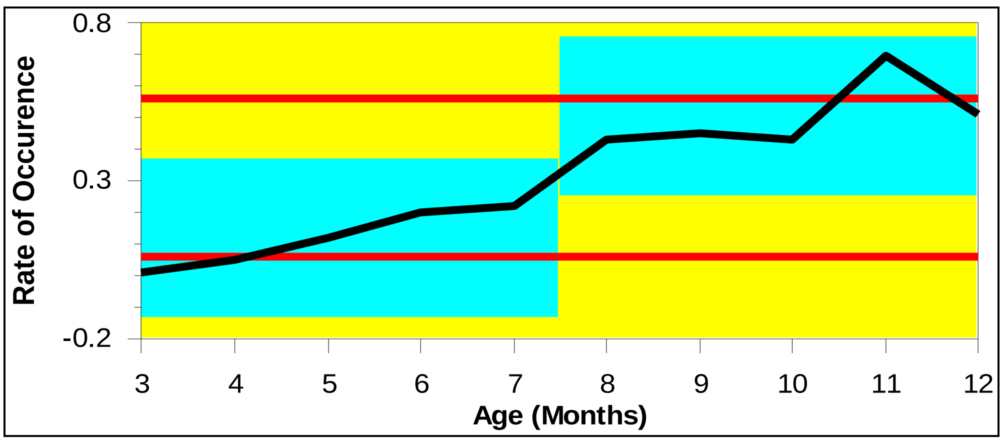


Figure 17(h): Growth trend for walk.



Note: In the figure, blue shaded region-region expected to contain data points; red lines-upper & lower control limits; black line-rate of occurrence.

Figure 18: Change point analysis for whole body movements.

Figure 18, shows the results of the change point analysis which reveals a significant change in the rate of occurrence of whole body movements in the 7th month of age (95% confidence interval). The analysis also suggests that the rates of occurrence of this gesture increased beyond this age at which change was observed.

7. Hand movements

The samples were observed for pre-symbolic (gestures that do not convey meaning) and symbolic (gestures that convey meaning in the presence or absence of referent) hand movements and these were further categorized as gestures produced bi-manually (using both hands) and those produced using either the left or the right hand for all the participants. The pre-symbolic bimanual movements were ‘clap’, ‘clasp’ and ‘up’ and the other pre-symbolic movements were ‘hand in mouth’, ‘toy in mouth’, ‘curled’, ‘spread’, ‘grasp’, ‘index finger extension’, ‘reach’ and ‘up’. The pre-symbolic rhythmic movements included ‘bang’, ‘cycling’, ‘shake’, ‘twist’, ‘flex’, and ‘swing’, while the symbolic movements included both deictic and representational gestures such as ‘point’, ‘show’, ‘request’, ‘give’, ‘take’ and ‘hand configurations’.

7.1. Pre-symbolic hand movements

7.1.1. Pre-symbolic bimanual movements.

The means, standard deviations, and medians for the rates of occurrence of pre-symbolic bi-manual movements are shown in Table 25. The table suggests that among the bimanual gestures expressed by the infants, ‘clasp’ was seen from the 3rd month of age, while clap was seen only from the 6th month, and infants seemed to produce these gestures less frequently as their age increased. Gesture ‘up’ was expressed the least by all the infants, throughout the study period.

Table 25

Means, SD's & Medians for rates of occurrence of pre-symbolic bi-manual movements

Age of the infants in Months	**Clap**	**Clasp**	**Up**
3	0.00 (0.00); 0.00	0.86 (0.97); 0.38	0.00 (0.00); 0.00
4	0.00 (0.00); 0.00	0.51 (0.34); 0.68	0.00 (0.00); 0.00
5	0.00 (0.00); 0.00	0.20 (0.26); 0.07	0.00 (0.00); 0.00
6	0.01 (0.03); 0.00	0.23 (0.22); 0.15	0.01 (0.01); 0.00
7	0.00 (0.00); 0.00	0.06 (0.07); 0.00	0.00 (0.00); 0.00
8	0.04 (0.07); 0.00	0.12 (0.15); 0.00	0.00 (0.00); 0.00
9	0.01 (0.03); 0.00	0.02 (0.04); 0.00	0.00 (0.00); 0.00
10	0.04 (0.06); 0.00	0.08 (0.08); 0.00	0.00 (0.00); 0.00
11	0.03 (0.05); 0.00	0.04 (0.04); 0.04	0.00 (0.00); 0.00
12	0.01 (0.04); 0.00	0.04 (0.06); 0.00	0.00 (0.00); 0.00

Friedman's test revealed that there were no differences in all three gestures in the rates of their occurrence for the three months of analysis. Pair-wise comparisons suggested that there were significant differences ($p<0.05$) in the rates of 'clasp' between the 3^{rd}, 4^{th}, 5^{th} and 6^{th} months and those from the age of 7 months.

There was a significant positive correlation in the occurrence of 'clap' ($r=0.25$; $p=0.02$) at 0.05 alpha level of significance, and a high negative correlation in the occurrence of 'clasp' ($r=-0.49$; $p=0.000$) at 0.001 alpha level of significance with age, according to Spearman's correlation analysis. Table 26 depicts the correlation in the rates of occurrence of bi-manual gestures with age, and it can be seen that there were no statistically significant correlations seen in the occurrence of these gestures.

Table 26

Correlation coefficients among bimanual movements with age

Rates of occurrence	**Clap**	**Clasp**	**Hands up**
Clap		-0.05	-0.04
Clasp			0.17
Hands up			

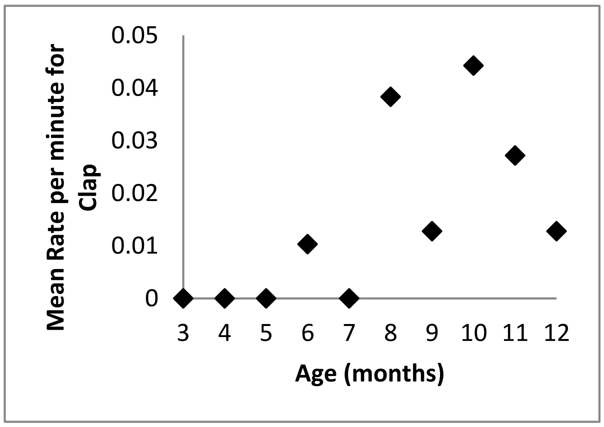


Figure 19(a): Growth trend for clap.

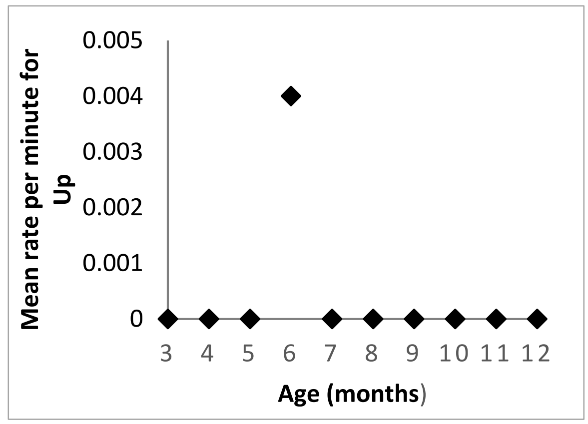


Figure 19(b): Growth trend for up.

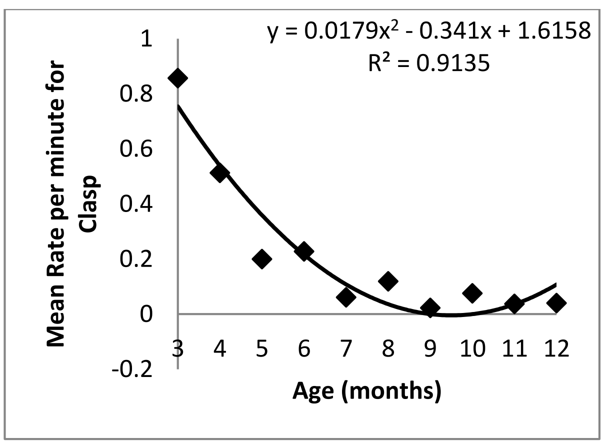


Figure 19(c): Growth trend for clasp.

Figures 19 (a, b & c) show the quadratic growth trends for each bi-manual gesture. Gestures ‘clap’ (Fig. 19(a)) and ‘up’ (Fig. 19(b)) showed unpredictable trajectories, and ‘clasp’ (Fig. 19(c); R^2= 0.91) showed a polynomial growth trajectory. The change point analysis did not reveal an age at which significant change was observed in the occurrence of bi-manual gestures within the first year of life.

7.1.2. Pre-symbolic movements of left hand.

The means, standard deviations, and medians for the rates of occurrence of pre-symbolic movements of the left hand are as shown in Table 27. As can be seen from the table, most hand gestures were seen from the age of 3 and 5 months. 'Grasp', 'reach' and 'spread' showed an increase in rates with increasing age, while the opposite trend was seen for other gestures. Gesture 'up' was not frequently produced by all the infants throughout the study period.

Data was treated with Friedman's test and the results revealed significant differences in the occurrence rates of 'curled' [χ^2 (2, N=9)=10.750; p=0.004], 'reach' [χ^2 (2, N=9)=3.55; p=0.011], and 'hand held toy in mouth' [χ^2 (2, N=9)=8.26; p=0.016] across the three months, at 0.01 and 0.05 alpha levels of significance. Results of the pair-wise comparisons revealed that gestures 'hand in mouth' and 'grasp' demonstrated similar trends; but there were differences seen in the rates between all the months. For gestures 'curled', and 'spread', the differences were seen between the rates for the 3rd month and the months above the 5th month, while in the case of 'index finger extension' these differences were seen between the 3rd, 4th and 5th months with the 11th and 12th months of age. For 'reach' differences were seen in the rates between the 3rd and 4th months and above the 8th month. These were significant at $p<0.05$.

Table 27

Means, SD's & Medians for rates of occurrence of left hand pre-symbolic movements

Age of the infants in Months	Hand in Mouth	Hand held toy in Mouth	Curled	Spread	Grasp	Index Finger Extension	Reach	Up
3	0.30 (0.38); 0.13	0.00 (0.00); 0.00	2.76 (1.08); 2.60	2.93 (1.08); 2.80	0.87 (0.76); 0.52	1.31 (1.21); 0.70	0.18 (0.26); 0.12	0.00 (0.00); 0.00
4	0.25 (0.22); 0.21	0.07 (0.07); 0.05	2.14 (1.62); 1.85	3.70 (1.85); 3.82	1.44 (1.07); 1.09	0.84 (1.04); 0.47	0.62 (0.54); 0.36	0.00 (0.00); 0.00
5	0.08 (0.13); 0.00	0.23 (0.42); 0.03	1.21 (0.70); 0.55	3.76 (1.25); 4.00	1.98 (0.95); 2.42	0.50 (0.79); 0.09	1.26 (0.95); 1.41	0.01 (0.03); 0.00
6	0.05 (0.09); 0.00	0.60 (0.42); 0.49	1.19 (0.83); 0.57	4.90 (0.70); 4.50	3.90 (0.92); 3.70	0.19 (0.26); 0.03	2.05 (0.46); 2.23	0.01 (0.01); 0.00
7	0.08 (0.18); 0.00	0.71 (0.67); 0.28	1.13 (0.68); 0.67	4.57 (1.15); 4.16	3.61 (1.45); 3.55	0.15 (0.23); 0.00	2.55 (0.91); 2.49	0.00 (0.00); 0.00
8	0.00 (0.00); 0.00	0.52 (0.60); 0.09	0.97 (0.61); 0.39	5.34 (2.25); 7.33	4.61 (2.04); 3.26	0.08 (0.09); 0.17	2.99 (1.47); 2.25	0.00 (0.00); 0.00
9	0.04 (0.07); 0.00	0.71 (0.61); 0.64	0.85 (0.63); 1.32	4.61 (0.71); 1.56	4.78 (1.64); 5.05	0.14 (0.26); 0.07	3.14 (0.87); 3.78	0.00 (0.00); 0.00
10	0.02 (0.03); 0.00	0.17 (0.26); 0.18	0.70 (0.23); 0.68	4.56 (2.13); 3.87	5.08 (2.17); 6.13	0.34 (0.18); 0.63	3.19 (1.47); 2.70	0.01 (0.02); 0.00
11	0.00 (0.00); 0.00	0.21 (0.31); 0.21	1.18 (0.91); 0.43	5.37 (1.33); 4.60	4.93 (1.45); 0.31	0.22 (0.20); 2.30	3.42 (1.13); 4.00	0.00 (0.00); 0.00
12	0.01 (0.02); 0.00	0.26 (0.59); 0.00	0.63 (0.51); 0.08	5.66 (2.50); 8.86	6.03 (2.82); 9.44	0.35 (0.66); 0.08	3.95 (2.79); 2.90	0.00 (0.00); 0.00

The Spearman's analysis revealed that with age, there was a highly significant negative correlation in the occurrence of gestures 'curled' (r=-0.50; p=0.000), 'hand in mouth' (r=-0.46; p=0.000), and 'index finger extension' (r=-0.46; p=0.001) at 0.001 alpha level of significance. The opposite trend was observed for gestures 'grasp' (r=0.71; p=0.000), 'reach' (r=0.70; p=0.000), and 'spread' (r=0.43; p=0.000), in that there was a highly significant positive correlation in the occurrence of these gestures at 0.001 alpha level of significance. Table 28 gives the association in the occurrence of left hand pre-symbolic hand gestures with age. It was observed that there were significant positive and negative correlations in the rate of occurrence of most hand gestures, especially in the occurrence of other gestures with 'grasp', and 'reach'.

Table 28

Correlation coefficients among left hand pre-symbolic movements with age

Rates of occurrence	Hand in mouth	Hand held toy in mouth	Curled	Spread	Grasp	Index finger extension	Reach	Up
Hand in mouth		-0.21	0.24*	-0.27*	-0.43***	0.08	-0.40***	0.01
Hand held toy in mouth			-0.25*	0.08	0.29**	0.22	0.19	0.11
Curled				-0.43***	-0.51***	0.61***	-0.49***	-0.05
Spread					0.77***	-0.27*	0.81***	-0.04
Grasp						-0.39**	0.92***	0.01
Index finger extension							-0.37**	0.01
Reach								0.03
Up								

Note: *** p≤0.00; **p≤0.01; * p≤0.05

Figures 20 (a, b, c, d, e, f, g & h) show the quadratic growth trends for each gesture. Polynomial growth trajectories were exhibited by 'index finger extension' (Fig. 20(a); R^2= 0.93), 'curled' (Fig. 20(b); R^2= 0.87), 'hand in mouth' (Fig. 20(c); R^2= 0.89) and 'hand held toy in mouth' (Fig. 20(d); R^2= 0.66). 'Reach' (Fig. 20(e); R^2= 0.93) and 'grasp' (Fig. 20(f); R^2= 0.91) were the two gestures that showed linear trends in growth. Quadratic growth trajectory was exhibited by gesture 'spread' (Fig. 20(g); R^2= 0.72), while gesture 'up' (Fig. 20(h)) showed an unpredictable trend.

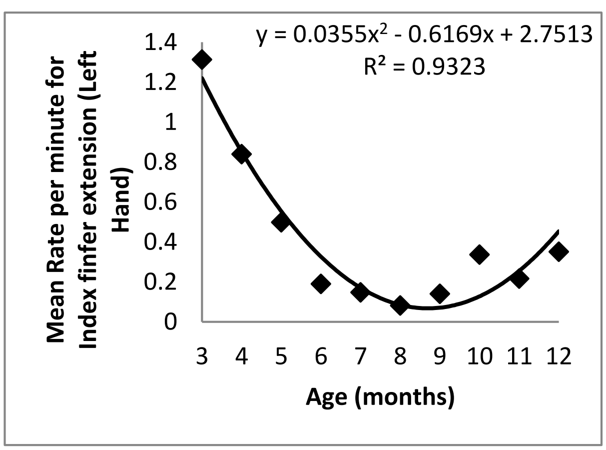


Figure 20(a): Growth trend for index finger extension (left hand).

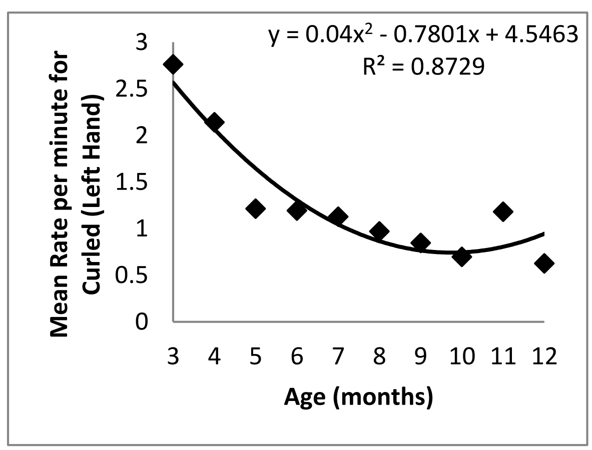


Figure 20(b): Growth trend for curled (left hand).

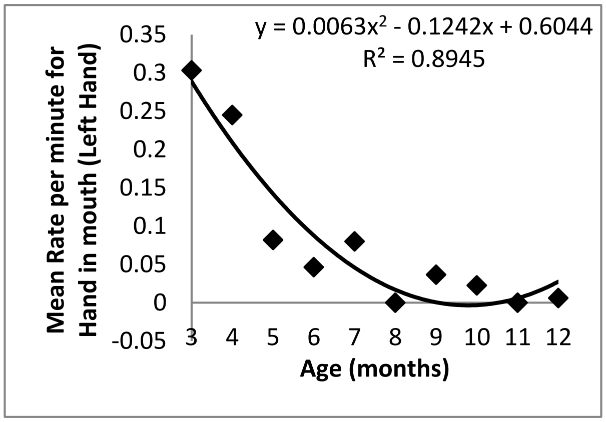


Figure 20(c): Growth trend for hand in mouth (left hand).

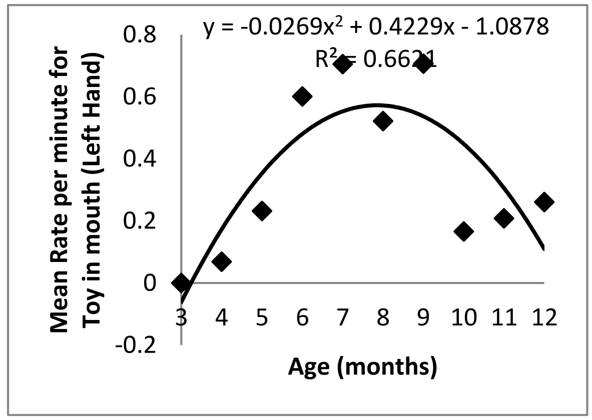


Figure 20(d): Growth trend for hand held toy in mouth (left hand).

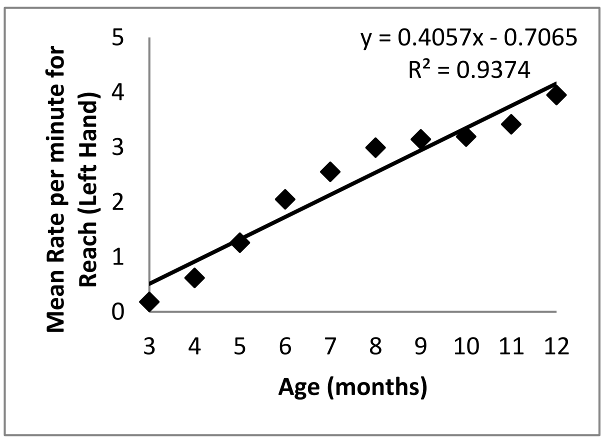


Figure 20(e): Growth trend for reach (left hand).

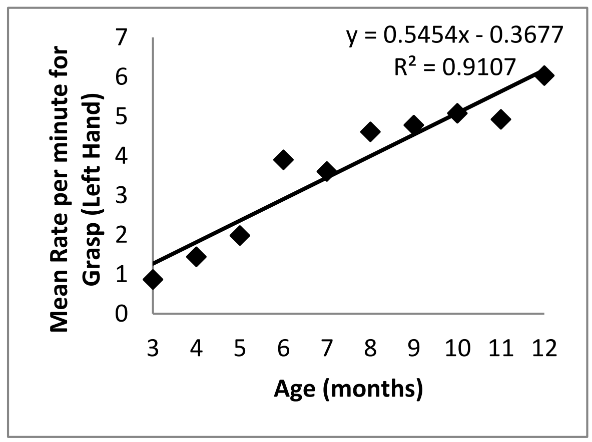


Figure 20(f): Growth trend for grasp (left hand).

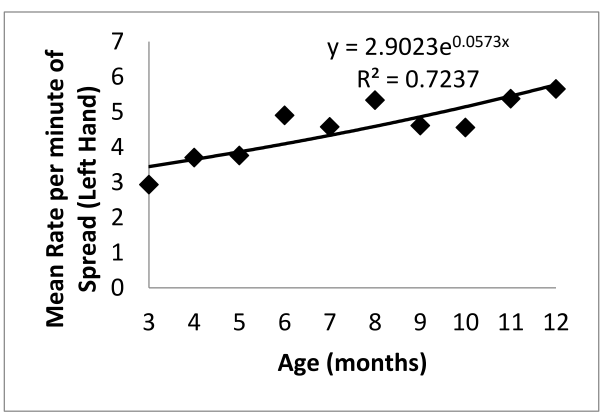


Figure 20(g): Growth trend for spread (left hand).

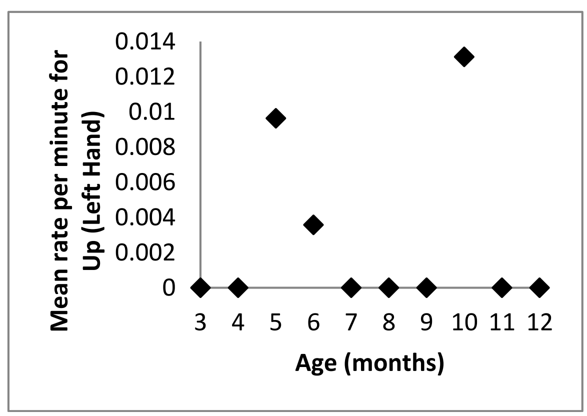
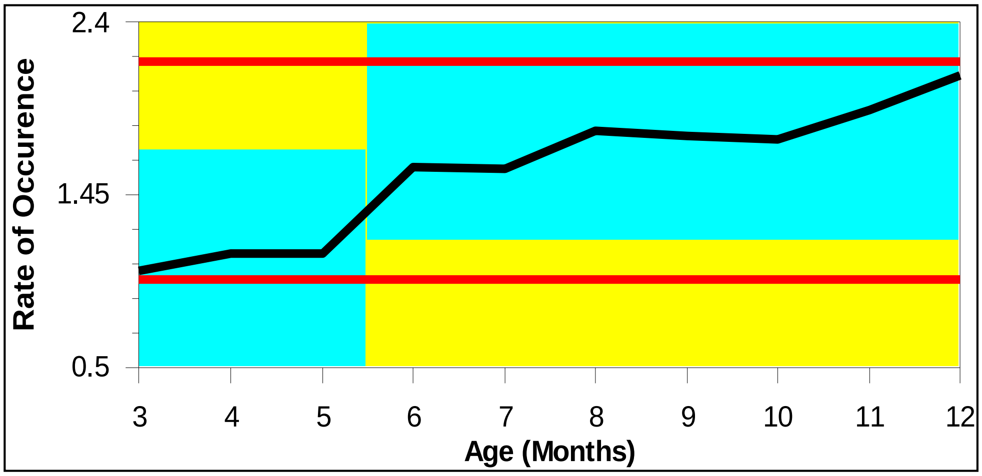


Figure 20(h): Growth trend for up (left hand).



Note: In the figure, blue shaded region-region expected t contain data points; red lines-upper & lower control limits; black line-rate of occurrence.

Figure 21: Change point analysis for pre-symbolic left hand gestures.

Figure 21 shows the result of the change point analysis which suggests that a significant change in the rate of occurrence of pre-symbolic left hand movements was seen in the 6th month of age (92% confidence interval). Further, it can be seen that the rates of occurrence of this gesture increased beyond this age.

7.1.3. Pre-symbolic movements of right hand.

The means, standard deviations and medians for the rates of occurrence of pre-symbolic movements of the right hand are shown in Table 29. As can be seen, most of the right hand gestures were seen between 3 and 5 months of age. ‘Spread’, ‘reach’, ‘grasp’ and ‘index finger extensions’ showed an increase in rates with increasing age, while the opposite trend was seen for other gestures. Gesture ‘up’ was not frequently produced by all the infants throughout the study period, however the occurrence of this gesture produced by the right hand was frequent when compared to that produced by the left hand.

Friedman test revealed significant differences in the rates of occurrence of gestures 'curled'[χ^2 (2, N=9)=9.55; p=0.008], 'grasp'[χ^2 (2, N=9)=6.88; p=0.032], 'reach'[χ^2 (2, N=9)=10.88; p=0.004], 'spread'[χ^2 (2, N=9)=6.00; p=0.050], and 'hand held toy in mouth'[χ^2 (2, N=9)=8.26; p=0.016], at 0.01 and 0.05 alpha levels of significance. Pair-wise comparisons suggested that the gestures 'hand in mouth', 'hand held toy in mouth' 'grasp', 'reach', and 'index finger extension' showed similar trends; there were differences seen in the rates of occurrence of these gestures between the 3rd and 4th months with all the months from 5th onwards. In the case of 'spread' gesture, the differences were seen between the rates for the 3rd and 4th months with the 11th and 12th months of age, and for 'curled' the differences were seen between the rates of the 3rd and 4th months with the months above the age of 9 months. These were significant at $p<0.05$ alpha level of significance.

The Spearman's correlation analysis revealed that with age, there was a highly significant correlation in the occurrence of 'grasp' (r=0.78; p=0.000), 'reach' (r=0.74; p=0.000) and 'spread' (r=0.59; p=0.000), at 0.001 alpha level of significance. On the other hand, gestures 'curled' (r=-0.59; p=0.000), and 'hand in mouth' (r=-0.33; p=0.003) demonstrated a significant negative correlation in the occurrence with age at 0.001 and 0.01 alpha levels of significance. Table 30 shows the association in the occurrence between various right hand pre-symbolic gestures with age. It can be seen that, there were significant positive and negative correlations in the rate of occurrence of most hand gestures, especially in the occurrence of most gestures with 'grasp', and 'reach'. There seems to be a common trend across these gestures irrespective of the hand used to produce them.

Table 29

Means, SD's & Medians for rates of occurrence of right hand pre-symbolic movements

Age of the infants in Months	Hand in Mouth	Hand held toy in Mouth	Curled	Spread	Grasp	Index Finger Extension	Reach	Up
3	0.26 (0.31); 0.05	0.00 (0.00); 0.00	3.45 (1.18); 3.20	2.71 (1.28); 2.87	0.85 (0.69); 0.70	1.14 (0.86); 1.15	0.36 (0.64); 1.08	0.00 (0.00); 0.00
4	0.24(0.23); 0.15	0.15 (0.26); 0.05	2.31 (1.59); 2.60	3.88 (1.56); 3.78	1.65 (0.98); 1.58	0.30 (0.23); 0.22	0.98 (0.91); 0.89	0.00 (0.00); 0.00
5	0.32 (0.72); 0.00	0.23 (0.36); 0.34	1.62 (1.14); 2.41	4.21 (1.05); 5.78	2.18 (0.87); 1.83	0.58 (0.70); 1.12	1.11 (0.61); 2.12	0.01 (0.03); 0.00
6	0.06 (0.14); 0.00	0.51 (0.35); 0.28	1.17 (0.96); 0.24	5.06 (1.34); 6.65	3.60 (1.26); 4.75	0.27 (0.27); 0.08	1.93 (0.80); 2.64	0.01 (0.02); 0.00
7	0.11 (0.19); 0.03	0.60 (0.64); 1.57	1.38 (1.20); 0.67	5.04 (1.04); 5.67	3.90 (1.41); 5.47	0.34 (0.45); 0.07	2.37 (0.54); 2.73	0.01 (0.01); 0.00
8	0.04 (0.05); 0.00	0.44 (0.43); 0.04	1.07 (0.66); 0.85	5.91 (1.32); 5.79	5.91 (2.17); 4.35	0.27 (0.27); 0.22	3.40 (1.40); 3.31	0.00 (0.00); 3.31
9	0.04 (0.07); 0.00	0.64 (0.59); 0.42	1.00 (0.78); 1.76	5.19 (0.30); 4.82	6.16 (1.90); 3.98	0.55 (0.78); 2.26	3.26 (1.32); 2.09	0.00 (0.00); 0.00
10	0.00 (0.00); 0.00	0.23 (0.17); 0.22	0.65 (0.39); 0.86	5.56 (2.14); 4.16	6.93 (2.06); 4.95	0.66 (0.49); 0.62	3.53 (0.72); 3.33	0.01 (0.02); 0.00
11	0.03 (0.05); 0.00	0.25 (0.31); 0.17	0.93 (0.53); 0.60	6.01 (1.29); 5.52	5.74 (0.75); 5.91	0.29 (0.21); 0.17	3.78 (0.97); 3.56	0.00 (0.00); 0.00
12	0.00 (0.00); 0.00	0.28 (0.57); 0.00	0.48 (0.35); 0.45	6.74 (2.79); 5.49	6.88 (2.76); 6.21	0.90 (1.54); 0.18	4.69 (2.99); 2.94	0.00 (0.00); 0.00

Table 30

Correlation coefficients among right hand pre-symbolic movements with age

Rates of occurrence	Hand in mouth	Hand held toy in mouth	Curled	Spread	Grasp	Index finger extension	Reach	Up
Hand in mouth		-0.16	0.21	-0.28*	-0.33**	-0.09	-0.30*	-0.01
Hand held toy in mouth			-0.18	0.08	0.30**	-0.18	0.19	0.13
Curled				-0.52***	-0.54***	0.24*	-0.50***	-0.09
Spread					0.77***	-0.14	0.81***	-0.14
Grasp						-0.12	0.90***	-0.05
Index finger extension							-0.17	-0.10
Reach								-0.04
Up								

Note: *** p≤0.00; **p≤0.01; * p≤0.05

Figures 22 (a, b, c, d, e, f, g & h) show the quadratic growth trends for each pre-symbolic hand gesture. Polynomial growth trajectories were exhibited by 'index finger extension' (Fig. 22(a); R^2= 0.50), 'hand in mouth' (Fig. 22(b); R^2= 0.77) and 'hand held toy in mouth' (Fig. 22(c); R^2= 0.71). 'Reach' (Fig. 22(d); R^2= 0.96), 'spread' (Fig. 22(e); R^2= 0.85), and 'grasp' (Fig. 22(f); R^2= 0.89) were the gestures that showed linear trends in growth. Quadratic growth trajectory was exhibited by gesture 'curled' (Fig. 22(g); R^2= 0.87), while gesture 'up' (Fig. 22(h)) showed an unpredictable trend.

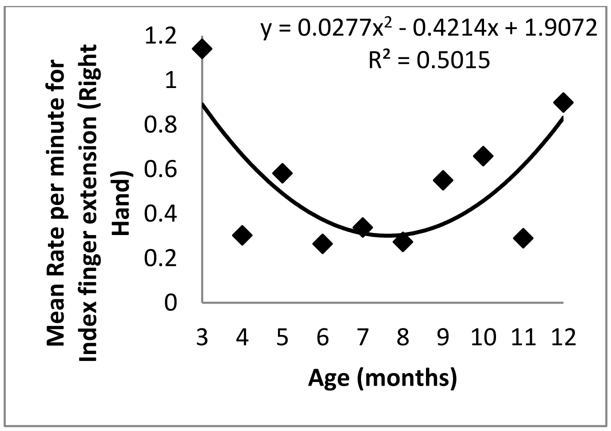


Figure 22(a): Growth trend for index finger extension (right hand).

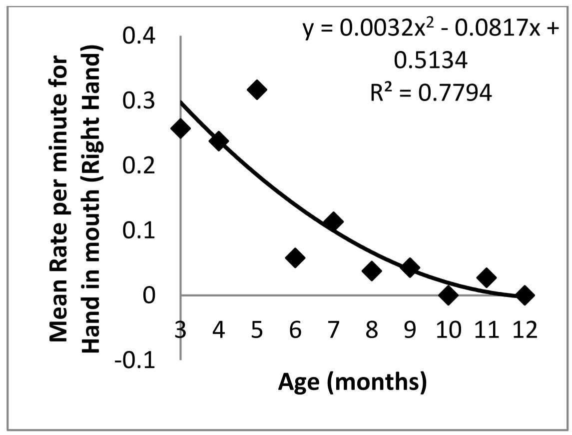


Figure 22(b): Growth trend for hand in mouth (right hand).

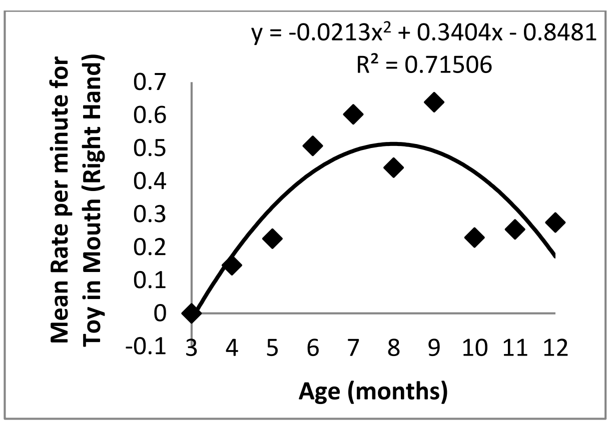


Figure 22(c): Growth trend for hand held toy in mouth (right hand).

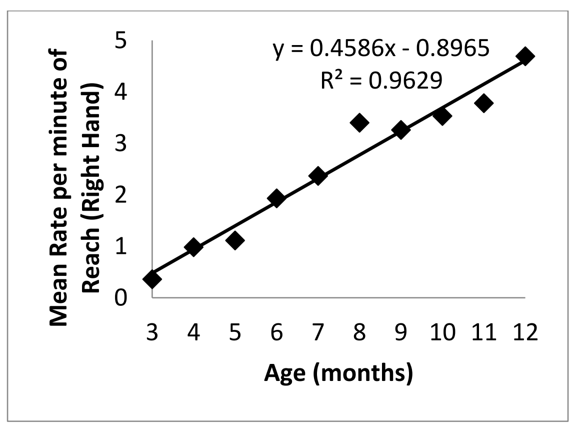


Figure 22(d): Growth trend for reach (right hand).

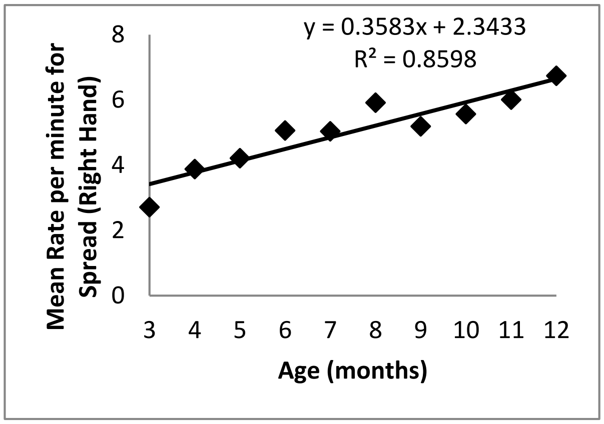


Figure 22(e): Growth trend for spread (right hand).

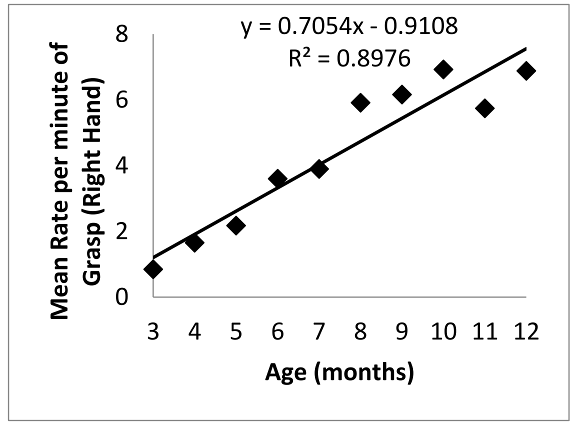


Figure 22(f): Growth trend for grasp (right hand).

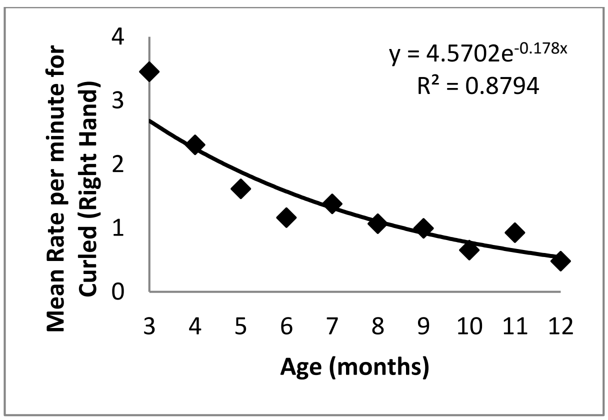


Figure 22(g): Growth trend for curled (right hand).

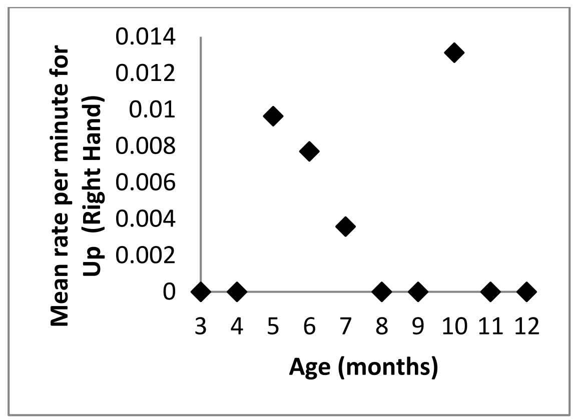
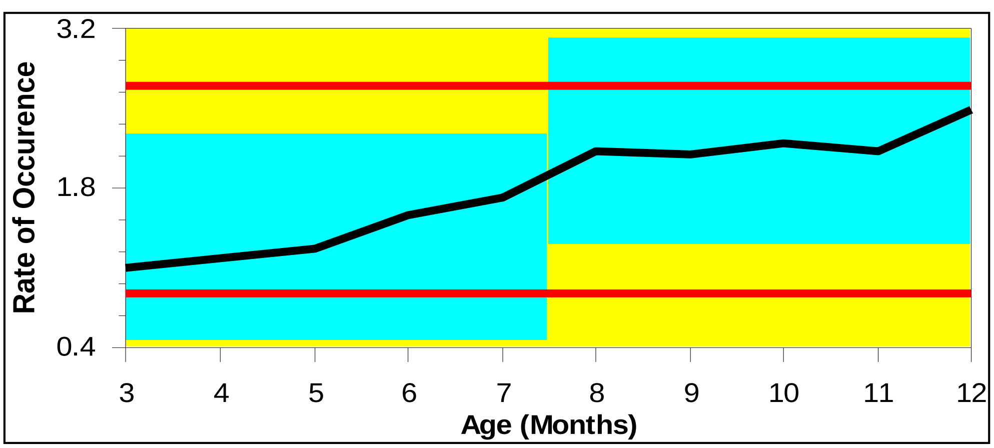


Figure 22(h): Growth trend for up (right hand).



Note: In the figure, blue shaded region-region expected to contain data points; red lines-upper & lower control limits; black line-rate of occurrence.

Figure 23: Change point analysis for pre-symbolic right hand gestures.

Figure 23 shows the results of the change point analysis which reveals a significant change in the rate of occurrence of pre-symbolic left hand movements in the 8th month of age (98% confidence interval). The analysis also suggests that the rates of occurrence of this gesture increases beyond this age at which change was observed.

On comparing the data between gestures produced using left and right hands, some similarities and differences are observed. Wilcoxon Signed-rank test was carried out to see if there were statistically significant differences based on hand preferences in the production of these gestures, and the analysis revealed that there were significant differences in the usage of hands for ‘curled’ in the 3rd month (Z=1.955; p=0.051), ‘grasp’ in the 9th (Z=2.023; p=0.043) and 10th (Z=2.023; p=0.043) months and ‘index finger extension’ in the 8th month (Z=2.197; p=0.028) at 0.05 levels of significance. Higher rates of occurrences were seen for gestures produced using the right hand for these months.

7.1.4. Pre-symbolic rhythmic movements of left hand.

The means, standard deviations, and median for the rates of occurrence of pre-symbolic rhythmic movements of the left hand were calculated and are as shown in Table 31. It is seen that most of the rhythmic hand gestures were seen from the ages of 3 and 4 months, except in the cases of ‘flex’ and ‘twist’, which were observed from the age of 5 months. Most of these gestures occurred more frequently between the ages of 6 and 8 months, with a slight decrease in occurrence observed in the following months.

The results of the Friedman test indicated significant differences in the rates of occurrence of ‘bang’ [χ^2 (2, N=9)=10.75; p=0.005], and ‘shake’ [χ^2 (2, N=9)=6.24; p=0.016] for the three months of analysis, at 0.01 alpha level of significance. Results of the pair-wise comparisons revealed that there were significant differences ($p<0.05$) in the rates of occurrence for three gestures. In the case of ‘bang’ the differences were seen between the ages of 4 months with all other months, while in the case of ‘shake’ differences were seen between the 3rd month and all other months. In the case of ‘swing’, the differences in the rates were noted between the 3rd month and the 7th, 9th, 10th and 12th month.

Table 31

Means, SD’s & Medians for rates of occurrence of left hand pre-symbolic rhythmic movements

Age of the infants in Months	**Bang**	**Cycling**	**Shake**	**Swing**	**Flex**	**Twist**
3	0.00 (0.00); 0.00	0.20 (0.16); 0.11	0.00 (0.00); 0.00	1.58 (0.81); 1.93	0.00 (0.00); 0.00	0.00 (0.00); 0.00
4	0.00 (0.00); 0.00	0.24 (0.34); 0.13	0.17 (0.48); 0.00	1.96 (1.35); 2.70	0.00 (0.00); 0.00	0.00 (0.00); 0.00
5	0.31 (0.54); 0.15	0.23 (0.18); 0.00	0.23 (0.20); 0.34	1.24 (0.43); 0.15	0.00 (0.00); 0.00	0.00 (0.00); 0.00
6	0.47 (0.43); 0.78	0.44 (0.67); 0.41	0.68 (0.37); 0.60	0.80 (0.31); 1.23	0.07 (0.21); 0.57	0.04 (0.10); 0.28
7	0.37 (0.18); 0.11	0.22 (0.26); 0.75	0.25 (0.20); 0.19	0.43 (0.27); 0.15	0.09 (0.16); 0.39	0.00 (0.00); 0.00
8	1.31 (1.39); 0.80	0.34 (0.41); 0.97	0.42 (0.31); 0.38	0.71 (0.62); 0.38	0.00 (0.00); 0.00	0.02 (0.05); 0.00
9	0.68 (0.63); 0.29	0.16 (0.13); 0.33	0.47 (0.46); 0.19	0.29 (0.15); 0.09	0.01 (0.00); 0.00	0.00 (0.00); 0.00
10	0.79 (0.59); 0.77	0.20 (0.33); 0.77	1.10 (1.14); 0.42	0.56 (0.67); 1.72	0.09 (0.19); 0.00	0.06 (0.10); 0.22
11	0.78 (0.43); 0.65	0.45 (0.56); 0.08	0.71 (0.36); 0.49	0.73 (0.57); 0.73	0.01 (0.02); 0.00	0.01 (0.02); 0.00
12	0.88 (0.78); 0.49	0.27 (0.29); 0.74	0.80 (0.51); 0.90	0.59 (0.42); 0.16	0.01 (0.02); 0.00	0.00 (0.00); 0.00

The Spearman's correlation analysis suggested that with age, there were highly significant positive correlations in the occurrence of 'bang' (r=0.44; p=0.000) and 'shake' (r=0.49; p=0.000), while there was a negative correlation in the rates of occurrence of 'swing' (r=-0.49; p=0.000) at alpha levels of significance. Table 32 gives the association in the occurrence of rhythmic hand gestures with each other across age. It can be seen that, among all the behaviours, there were significant positive correlation in the occurrence of 'twist' with 'flex' and 'shake' alone.

Table 32

Correlation coefficients among left hand pre-symbolic rhythmic hand movements with age

Rates of occurrence	**Bang**	**Cycling**	**Flex**	**Shake**	**Swing**	**Twist**
Bang		0.09	0.10	0.00	-0.16	0.16
Cycling			0.10	0.17	0.12	0.18
Flex				-0.05	-0.10	0.58***
Shake					-0.11	0.48***
Swing						0.11
Twist						

Note: *** p≤0.00

Figures 24 (a, b, c, d, e & f) demonstrate the quadratic growth trends for these hand gestures. 'Bang' (Fig. 24(a); R^2= 0.69) and 'swing' (Fig. 24(b); R^2= 0.80) were seen to exhibit polynomial growth trajectories, while 'shake' (Fig. 24(c); R^2= 0.58) exhibited exponential trend. The trajectories were found to be unpredictable for 'cycling' (Fig. 24(d)), 'flex' (Fig. 24(e)) and 'twist' (Fig. 24(f)). The change point analysis did not reveal an age at which significant change was observed in the occurrence of pre-symbolic rhythmic hand movements within the first year of life.

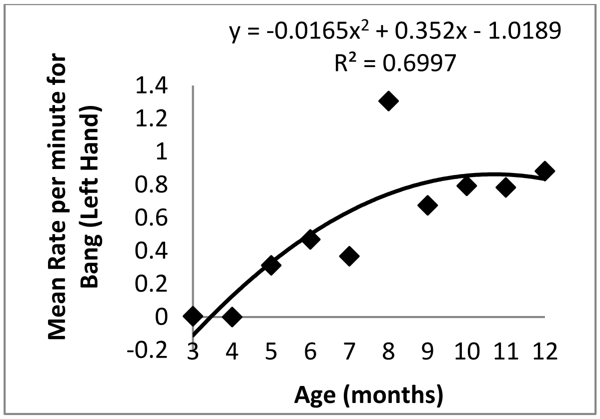


Figure 24(a): Growth trend for bang (left hand).

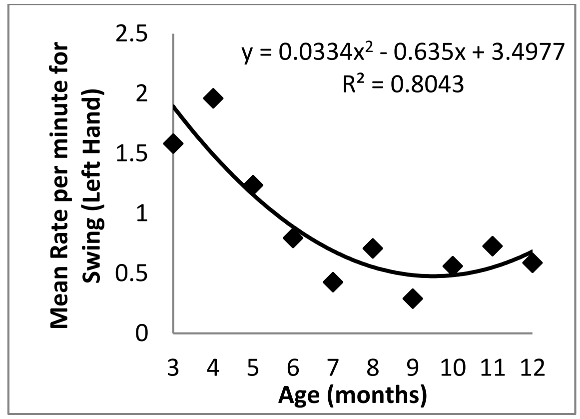


Figure 24(b): Growth trend for swing (left hand).

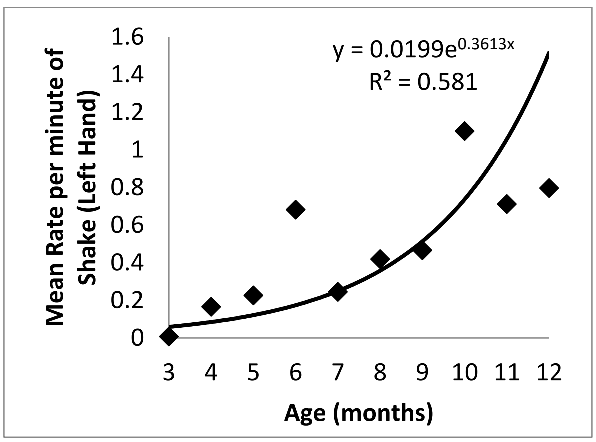


Figure 24(c): Growth trend for shake (left hand).

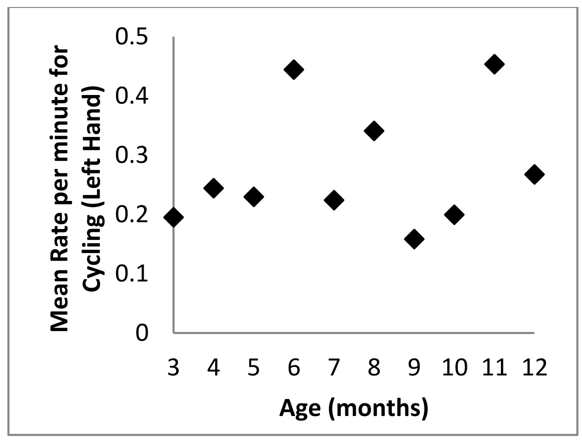


Figure 24(d): Growth trend for cycling (left hand).

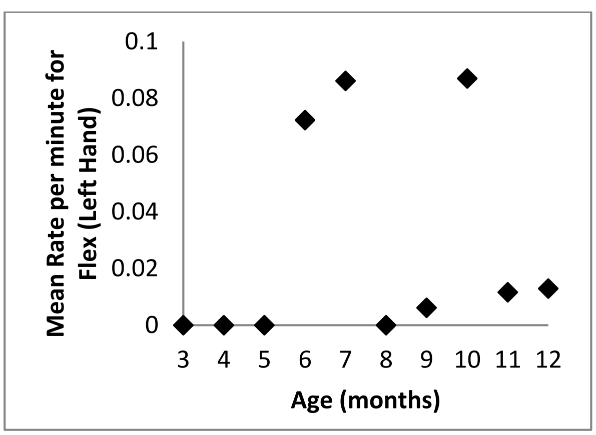


Figure 24(e): Growth trend for flex (left hand).

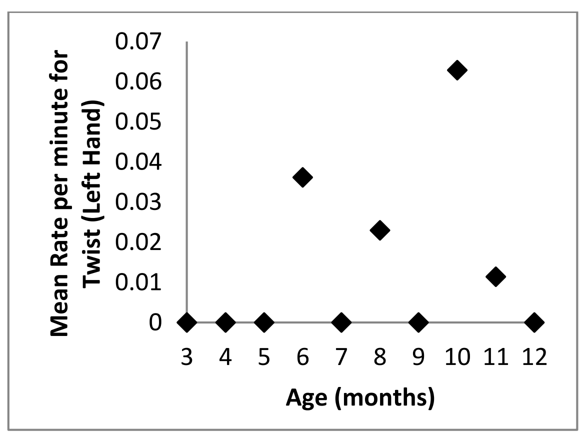


Figure 24(f): Growth trend for twist (left hand).

7.1.5. Pre-symbolic rhythmic movements of right hand.

The means, standard deviations, and medians for the rates of occurrence of pre-symbolic rhythmic movements of the right hand were calculated and these are represented in Table 33. All rhythmic hand gestures were seen from the ages of 3 and 4 months, except in the cases of 'flex' and 'twist', which were observed from the age of 6 months. Most of these gestures were seen to occur at high rates between the ages of 6 and 9 months, with a slight decrease in occurrence observed for the following months. When compared to the rate of occurrence of left hand gestures, the infants seemed to frequently produce right hand gestures across the months.

Analysis using Friedman test suggested that there were significant differences in the occurrence rates of only 'bang' [χ^2 (2, N=9)=13.46; p=0.001], at 0.01 alpha level of significance. Further pair-wise comparisons revealed that in the case of 'bang', the significant differences ($p<0.05$) in rates were seen between the 9th month and those below the 6th month, and in the case of 'shake' variations were seen between the 10th month and all the other months below the 9th month. For 'swing' behavior, these differences were noted for the rates of the 3rd and 4th months and all the months from the 8th.

The Spearman's correlation analysis revealed that with age, there were highly significant positive correlations in the occurrence of 'bang' (r=0.52; p=0.000) and 'shake' (r=0.56; p=0.000), while there was a negative correlation in the rates of occurrence of 'swing' (r=-0.47; p=0.000) at alpha levels of significance. These were similar to the trends seen for the gestures produced using left hand. Table 34 shows the correlation coefficients for the rates of occurrence of rhythmic hand gestures with each other across age. As can be seen, there were significant positive correlations in the occurrence of 'twist' with 'flex' and 'shake', and 'bang' with 'cycling' and 'shake'. The occurrence of right hand rhythmic gestures seemed to be more coordinated during development, when compared to gestures produced using the left hand.

Table 33

Means, SD's & Medians for rates of occurrence of right hand pre-symbolic rhythmic gestures

Age of the infants in Months	**Bang**	**Cycling**	**Shake**	**Swing**	**Flex**	**Twist**
3	0.00 (0.00); 0.00	0.21 (0.19); 0.22	0.04 (0.07); 0.00	1.94 (0.94); 2.04	0.00 (0.00); 0.00	0.00 (0.00); 0.00
4	0.01 (0.02); 0.00	0.27 (0.23); 0.21	0.14 (0.27); 0.00	2.03 (1.33); 1.69	0.00 (0.00); 0.00	0.00 (0.00); 0.00
5	0.45 (0.48); 0.33	0.23 (0.26); 0.30	0.32 (0.28); 0.56	1.66 (0.63); 1.65	0.00 (0.00); 0.00	0.00 (0.00); 0.00
6	0.49 (0.49); 1.19	0.43 (0.50); 2.90	0.46 (0.35); 0.90	0.75 (0.45); 0.99	0.07 (0.12); 0.28	0.01 (0.03); 0.08
7	0.85 (0.63); 1.04	0.33 (0.11); 0.47	0.47 (0.34); 0.63	0.63 (0.43); 0.43	0.23 (0.36); 0.43	0.03 (0.05); 0.00
8	2.28 (2.04); 0.63	0.61 (0.52); 0.67	0.88 (0.86); 0.38	1.07 (0.66); 0.43	0.04 (0.06); 0.43	0.03 (0.05); 0.11
9	2.00 (1.95); 1.49	0.27 (0.15); 0.54	0.88 (0.57); 0.83	0.27 (0.14); 0.79	0.01 (0.03); 0.04	0.01 (0.02); 0.00
10	2.19 (1.05); 0.73	0.33 (0.33); 0.57	2.31 (1.71); 0.71	0.75 (0.60); 0.48	0.08 (0.15); 0.00	0.04 (0.06); 0.00
11	1.32 (0.73); 2.69	0.50 (0.39); 0.60	1.04 (0.34); 2.19	0.88 (0.64); 1.45	0.01 (0.02); 0.00	0.02 (0.03); 0.00
12	1.53 (0.95); 1.08	0.35 (0.33); 0.47	1.09 (0.64); 1.17	0.81 (0.72); 0.91	0.01 (0.02); 0.00	0.00 (0.00); 0.00

Table 34

Correlation coefficients among right hand pre-symbolic rhythmic movements with age

Rates of occurrence	**Bang**	**Cycling**	**Flex**	**Shake**	**Swing**	**Twist**
Bang		0.30**	0.06	0.66***	-0.20	0.15
Cycling			0.09	0.21	-0.02	0.01
Flex				0.21	-0.11	0.27**
Shake					-0.15	0.32**
Swing						0.04
Twist						

Note: *** p≤0.00; **p≤0.01

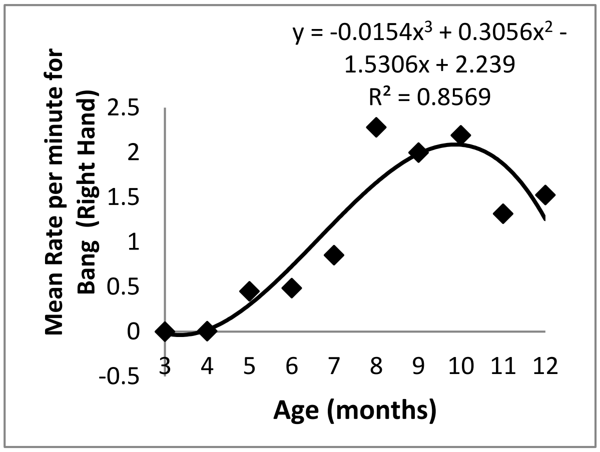


Figure 25(a): Growth trend for bang (right hand).

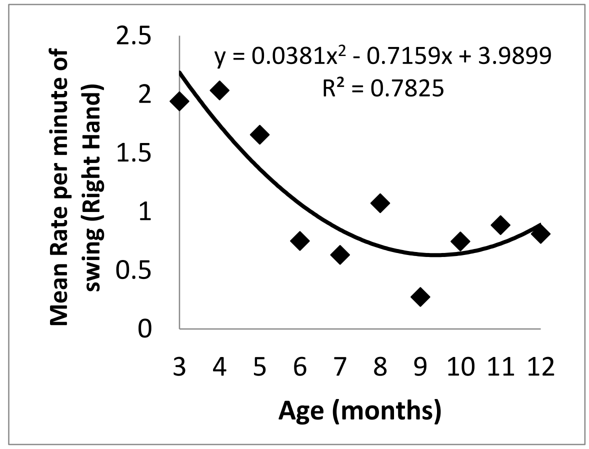


Figure 25(b): Growth trend for swing (right hand).

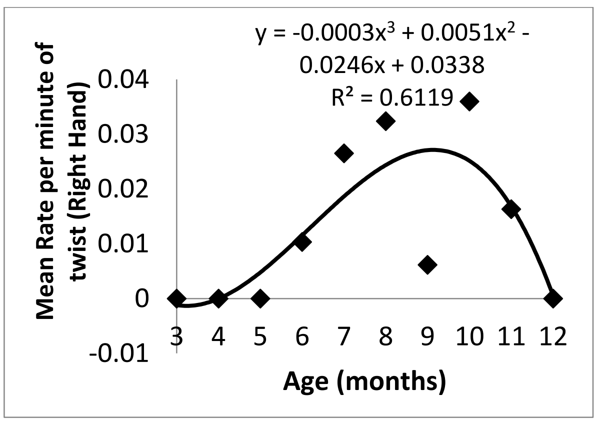


Figure 25(c): Growth trend for twist (right hand).

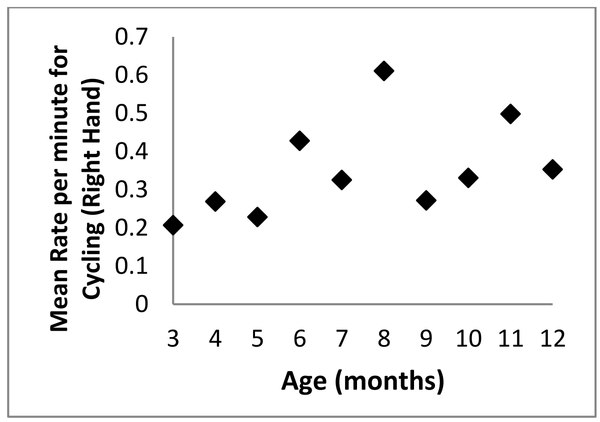


Figure 25(d): Growth trend for cycling (right hand).

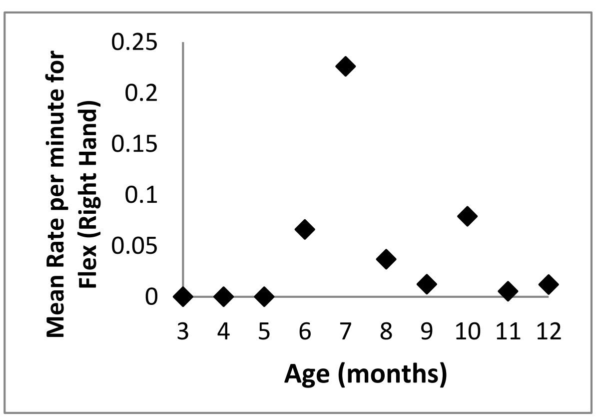


Figure 25(e): Growth trend for flex (right hand).

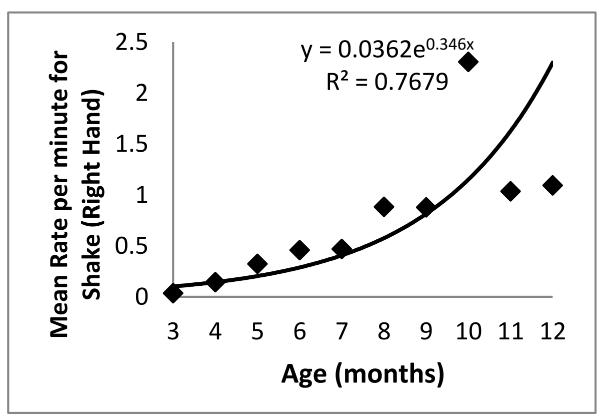
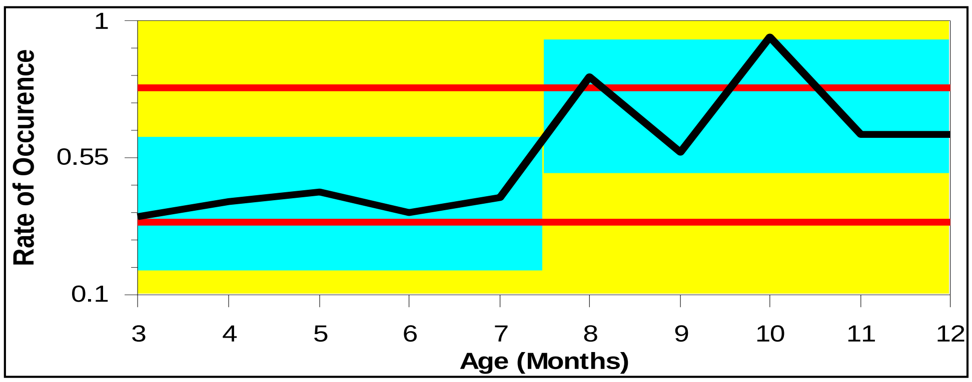


Figure 25(f): Growth trend for shake (right hand).

Figures 25 (a, b, c, d, e & f) reveal the quadratic growth trends for these hand gestures. 'Bang' (Fig. 25(a); R^2= 0.85), 'swing' (Fig. 25(b); R^2= 0.78), and 'twist' (Fig. 25(c); R^2= 0.61) were seen to exhibit polynomial growth trajectories, while the trajectories were found to be unpredictable for 'cycling' (Fig. 25(d)), and 'flex' (Fig. 25(e)). Gesture 'shake' (Fig. 25(f); R^2= 0.76) exhibited exponential trend.



Note: In the figure, blue shaded region-region expected to contain data points; red lines-upper & lower control limits; black line-rate of occurrence.

Figure 26: Change point analysis for pre-symbolic right hand rhythmic gestures.

The result of the change point analysis in Figure 26 reveals a significant change in the rate of occurrence of right hand rhythmic movements in the 8th and 11th month of age (95% confidence interval). Further, the analysis suggests that the rates of occurrence of these gestures decreased beyond the age of 11 months.

On comparing the data between gestures produced using left and right hands, some similarities and differences in the occurrence of rhythmic gestures were observed. Wilcoxon signed-rank test was used to see if these observations were supported by statistical analysis. The results revealed that there were significant differences in the usage of hands for 'bang' in the 9th (Z=2.201; p=0.028), 10th (Z=2.023; p=0.043), 11th (Z=2.240; p=0.025), and 12th (Z=1.963; p=0.050) months, at 0.05 levels of significance. These differences were also seen for 'shake' in the 7th (Z=2.201; p=0.028), 9th (Z=2.201; p=0.028), 10th (Z=2.023; p=0.043), and 11th (Z=2.100; p=0.036) months, whereas for 'swing' these were seen in the 5th (Z=2.666; p=0.008) and 11th (Z=2.201; p=0.028) months at 0.05 and 0.01 levels of significance respectively. The rates of occurrences were higher for those gestures produced using the right hand for all these months.

7.2. Symbolic hand movements

7.2.1. Symbolic movements of left hand.

The means, standard deviations and medians for the rates of occurrence of symbolic movements of the left hand are shown in Table 35. Most of these gestures, such as, 'give', 'take', and 'hand configurations' were seen from the age of 7 months, while 'point', 'show' and 'request' were only seen from the 11th month. The occurrence of all gestures was less frequent when compared to pre-symbolic hand movements.

Treating the data with Friedman test revealed that there were no significant differences in the occurrence rates of these gestures across the three months. Additionally, pair-wise comparisons across all the months did not reveal significant differences in the rates of occurrence of these gestures produced using the left hand.

Table 35

Means, SD's & Medians for rates of occurrence of left hand symbolic movements

Age of the infants in Months	**Point**	**Show**	**Request**	**Give**	**Take**	**Hand Configuration**
3	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00
4	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00
5	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00
6	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00
7	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00(0.00); 0.00	0.01 (0.02); 0.00	0.00 (0.00); 0.00	0.01 (0.03); 0.00
8	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.01 (0.02); 0.00
9	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.01 (0.01); 0.03	0.01 (0.01); 0.00	0.00 (0.00); 0.00
10	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.02 (0.02); 0.04	0.00 (0.00); 0.00
11	0.01 (0.03); 0.04	0.03 (0.06); 0.00	0.00 (0.00); 0.00	0.08 (0.14); 0.00	0.04 (0.07); 0.04	0.09 (0.25); 0.00
12	0.03 (0.05); 0.00	0.01 (0.02); 0.00	0.01 (0.01); 0.00	0.04 (0.10); 0.00	0.00 (0.00); 0.00	0.47 (0.88); 2.24

Correlation analysis using Spearman's test revealed that there was a significant positive correlation in the occurrence of 'give' (r=0.30; p=0.000), 'hand configurations' (r=0.29; p=0.010), 'point' (r=0.35; p=0.002), and 'show' (r=0.26; p=0.018) with age, at 0.001 and 0.01 alpha levels of significance. Table 36 provides the association between the rates of occurrence of various left hand symbolic movements. As can be seen, there were significant positive correlations in the occurrence of 'point' with 'show', 'request' and 'hand configurations'; 'show' with 'request', 'take', and 'hand configurations'; 'give' with 'take'.

Table 36

Correlation coefficients among left hand symbolic hand movements with age

Rates of occurrence	Point	Show	Request	Give	Take	Hand Configuration
Point		0.48***	0.27**	0.01	0.05	0.22*
Show			0.25*	0.19	0.30**	0.26*
Request				0.02	-0.02	0.00
Give					0.38**	0.07
Take						0.19
Hand configuration						

Note: *** p≤0.00; **p≤0.01; * p≤0.05

The quadratic growth trends in Figures 27 (a, b, c, d, e & f) for symbolic gestures produced using the left hand shows that all gestures exhibited an unpredictable trend within the first year of life. Additionally, the change point analysis also did not reveal an age at which significant change was observed in the occurrence of these gestures within the first year of life.

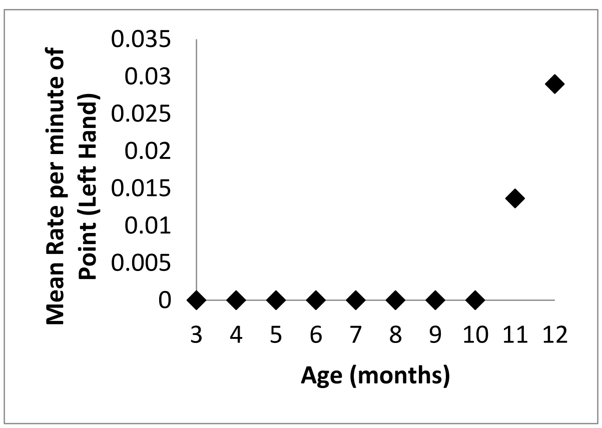


Figure 27(a): Growth trend for point (left hand).

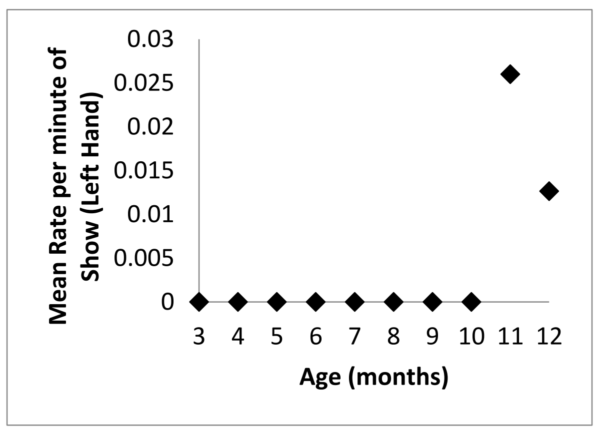


Figure 27(b): Growth trend for show (left hand).

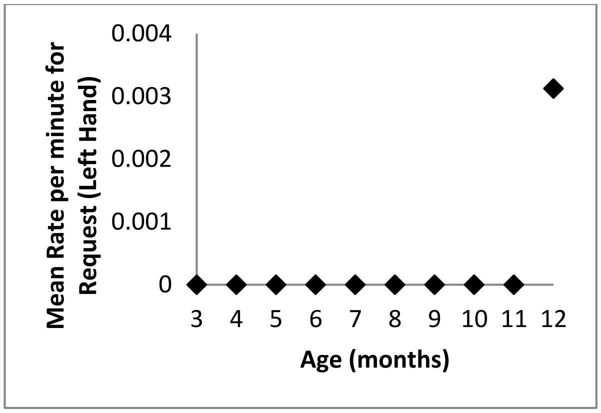


Figure 27(c): Growth trend for request (left hand).

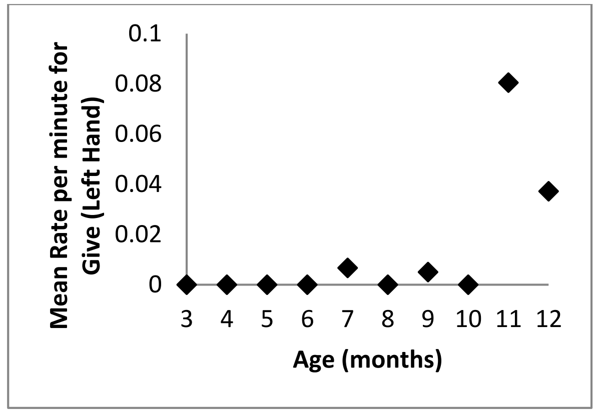


Figure 27(d): Growth trend for give (left hand).

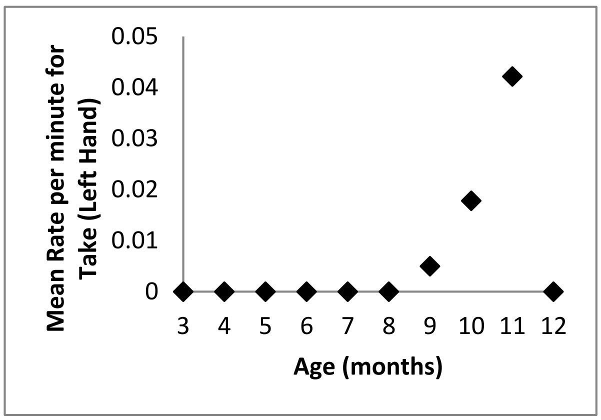


Figure 27(e): Growth trend for take (left hand).

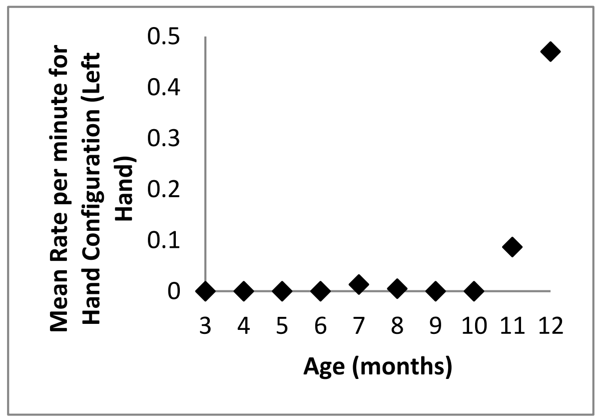


Figure 27(f): Growth trend for hand configuration (left hand).

7.2.2. Symbolic movements of right hand

The means, standard deviations and medians for the rates of occurrence of symbolic movements of the right hand were calculated and these are shown in Table 37**.** As can be noted, most of these gestures were seen from between the ages of 6 and 8 months, except for gesture 'request' which was only seen in the 12th month. The occurrence of these right hand gestures was more frequent when compared to left hand symbolic gestures.

Table 37

Means, SD's & Medians for rates of occurrence of right hand symbolic movements

Age of the infants in Months	Point	Show	Request	Give	Take	Hand Configuration
3	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00
4	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00
5	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.01 (0.03); 0.00
6	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00
7	0.01 (0.02); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.07 (0.16); 0.00
8	0.01 (0.03); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.02 (0.05); 0.00	0.02 (0.06); 0.00	0.09 (0.18); 0.18
9	0.01 (0.01); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.04 (0.06); 0.03	0.01 (0.01); 0.00	0.04 (0.06); 0.00
10	0.02 (0.03); 0.04	0.01 (0.01); 0.00	0.00 (0.00); 0.00	0.02 (0.04); 0.00	0.04 (0.06); 0.13	0.03 (0.07); 0.00
11	0.17 (0.27); 0.21	0.02 (0.05); 0.00	0.00 (0.00); 0.00	0.09 (0.13); 0.00	0.07 (0.10); 0.04	0.19 (0.42); 0.21
12	0.10 (0.20); 0.00	0.04 (0.07); 0.05	0.01 (0.02); 0.00	0.07 (0.12); 0.00	0.01 (0.01); 0.00	0.26 (0.33); 0.86

Friedman test revealed that there were no significant differences in the occurrence rates of these gestures across the three months. Further, the pair-wise comparison across all the months also suggested that there were no significant differences in the rates of occurrence of these gestures produced using the right hand.

The Spearman's correlation revealed that there was a significant positive correlation in the occurrence of 'give' (r=0.41; p=0.000), 'hand configurations' (r=0.37; p=0.001), 'point' (r=0.35; p=0.002), 'take' (r=0.28; p=0.012) and 'show' (r=0.34; p=0.002) with age, at 0.001 and 0.01 alpha levels of significance. Table 38 provides the correlation between the rates of occurrence of various right hand symbolic gestures. As can be seen, the occurrence of most gestures demonstrated significant positive correlations with each other.

Table 38

Correlation coefficients among right hand symbolic movements with age

Rates of occurrence	**Point**	**Show**	**Request**	**Give**	**Take**	**Hand Configuration**
Point		0.78***	0.53***	0.50***	0.69***	0.49***
Show			0.78***	0.30**	0.32**	0.24*
Request				0.22*	0.03	0.19
Give					0.56***	0.30**
Take						0.36**
Hand configuration						

Note: *** p≤0.00; **p≤0.01; * p≤0.05

Figures 28 (a, b, c, d, e & f) shows the quadratic growth trends for symbolic gestures produced using the right hand. As can be noted, gestures ‘point’ (Fig. 28(a); R^2= 0.66), ‘show’ (Fig. 28(b); R^2= 0.83), ‘give’ (Fig. 28(c); R^2= 0.82), and ‘hand configurations’ (Fig. 28(d); R^2= 0.79) exhibited polynomial trends. ‘Request’ (Fig. 28(e)) and ‘take’ (Fig. 28(f)) were found to have unpredictable growth trajectories. Further, the change point analysis did not reveal an age at which significant change was observed in the occurrence of symbolic hand gestures of the right hand, within the first year of life.

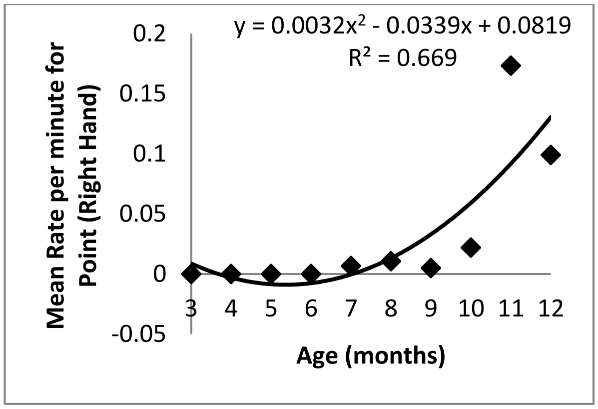


Figure 28(a): Growth trend for point (right hand).

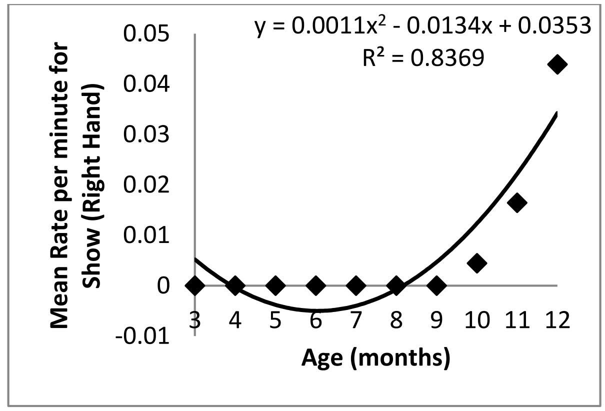


Figure 28(b): Growth trend for show (right hand).

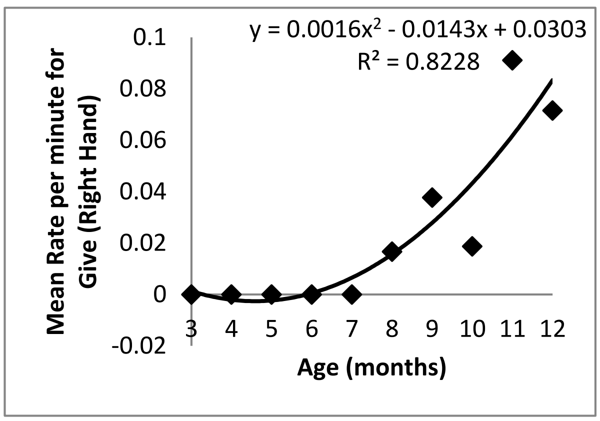


Figure 28(c): Growth trend for give (right hand).

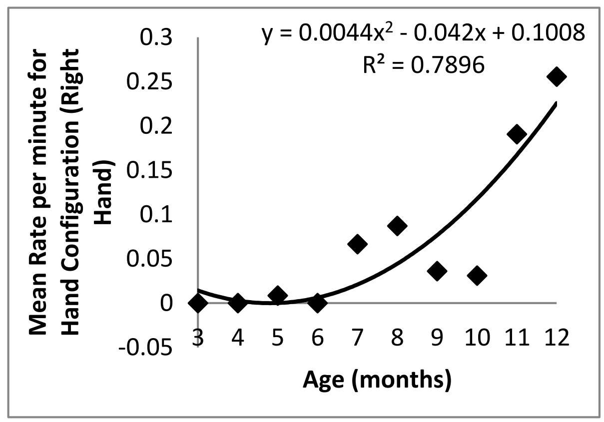


Figure 28(d): Growth trend for hand configuration (right hand).

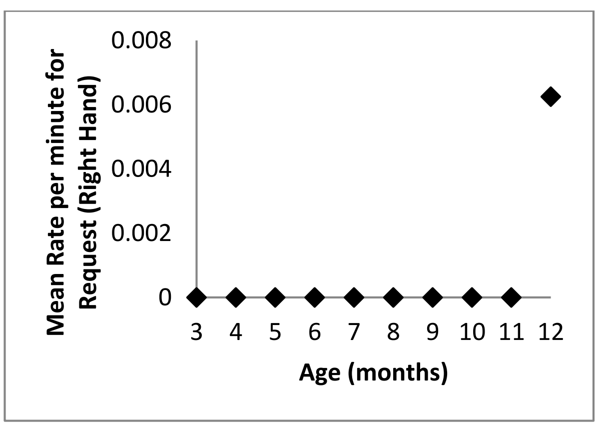


Figure 28(e): Growth trend for request (right hand).

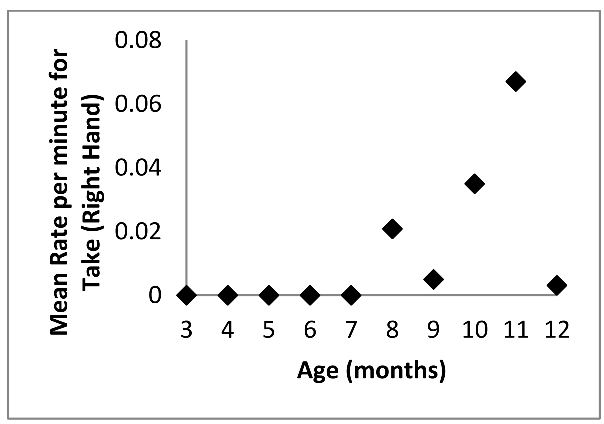


Figure 28(f): Growth trend for take (right hand).

There were differences seen in the rates of occurrence and in the developmental patterns of most symbolic gestures produced using right and left hands. However, Wilcoxon signed-rank test revealed that there were no statistically significant differences in the use of either hands in the production of these symbolic gestures.

8. Speech behaviours

All the samples were coded for four types of speech behaviours, namely, pre-speech, vocalic, syllabic, and verbal utterances. Additionally, the vocal productions (except pre-speech utterances) were also observed for the *prosodic variations* produced within the utterance.

8.1. Pre-speech utterances

Under this category, the behaviours that were analyzed were ‘click’, ‘cry’, ‘grunt’, ‘laugh’, ‘pleasure sounds’, ‘shout’, ‘squeal’, ‘whimpering’ and ‘vocal play’. The means, standard deviations, and medians for the rates of occurrence of all the pre-speech utterances are as shown in Tables 39(a) and 39(b). It is seen that most pre-speech utterances were observed from the age of 3 months and continued to occure throughout the study period. However, it was noted that some behaviours such as ‘pleasure sound’ were infrequently seen.

The results of the Friedman test revealed that there were no significant differences in the occurrence rates of these gestures across the three months. Further, the pair-wise comparison across all the months suggested that there were significant differences ($p<0.05$) in the rates of occurrence of four pre-speech behaviours; for 'click', these differences were seen between the 3rd and the 12th month of age; for 'cry' differences were seen between the 5th and 6th months with all other months; while in the case 'vocal play' the differences were noted between the 4th month and all other months. For the behaviour 'whimpering' the variations were seen in the rates between the 6th month and all other months, except the 11th month.

Analysis using Spearman's correlation revealed that there was a significant positive correlation in the occurrence of 'vocal play' (r=0.26; p=0.020) with age, at 0.05 alpha level of significance. The occurrences of gestures 'pleasure sound' (r=0.23; p=0.040), 'click' (r=0.37; p=0.001), 'cry' (r=0.28; p=0.012), and 'grunt' (r=0.50; p=0.000) showed the opposite trend, in that, their occurrence negatively correlated with age, at 0.05, 0.01, and 0.001 alpha levels of significance. Further, the analysis revealed that there was only one significant instance of positive correlation in the occurrence of these behaviours, namely, 'vocal play' with 'shout' (r=.23; p=0.021).

Table 39(a)

Means, SD's & Medians for rates of occurrence of pre-speech utterances

Age of the infants in Month	**Click**	**Cry**	**Grunt**	**Laugh**
3	0.08 (0.07); 0.05	0.08 (0.07); 0.07	0.07 (0.05); 0.07	0.03 (0.05); 0.00
4	0.03 (0.04); 0.00	0.11 (0.17); 0.00	0.09 (0.10); 0.05	0.03 (0.04); 0.05
5	0.03 (0.05); 0.00	0.21 (0.24); 0.39	0.14 (0.18); 0.04	0.21 (0.29); 0.25
6	0.02 (0.04); 0.00	0.24 (0.32); 0.04	0.26 (0.51); 0.15	0.18 (0.42); 1.20
7	0.00 (0.00); 0.00	0.16 (0.11); 0.16	0.09 (0.08); 0.00	0.13 (0.17); 0.08
8	0.03 (0.07); 0.00	0.03 (0.07); 0.00	0.05 (0.06); 0.00	0.05 (0.10); 0.00
9	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.01 (0.02); 0.00	0.06 (0.16); 0.38
10	0.01 (0.02); 0.00	0.16 (0.22); 0.00	0.03 (0.07); 0.00	0.16 (0.28); 0.04
11	0.00 (0.00); 0.00	0.05 (0.07); 0.00	0.03 (0.05); 0.00	0.33 (0.41); 0.18
12	0.03 (0.07); 0.00	0.06 (0.17); 0.00	0.02 (0.04); 0.00	0.13 (0.18); 0.00

Table 39(b)

Means, SD's & Medians for rates of occurrence of pre-speech utterances

Age of the infants in Months	Pleasure Sound	Shout	Squeal	Whimpering	Vocal Play
3	0.02 (0.04); 0.00	0.02 (0.04); 0.00	0.03 (0.06); 0.00	0.06 (0.18); 0.00	0.36 (0.75); 0.04
4	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.01 (0.03); 0.00	0.01 (0.02); 0.00	0.09 (0.15): 0.00
5	0.00 (0.00); 0.00	0.14 (0.30); 0.00	0.02 (0.04); 0.00	0.08 (0.17); 0.00	0.14 (0.19); 0.60
6	0.00 (0.00); 0.00	0.14 (0.27); 0.12	0.08 (0.20); 0.00	0.21 (0.24); 0.74	0.24(0.29); 0.12
7	0.00 (0.00); 0.00	0.01 (0.03); 0.00	0.07 (0.11); 0.00	0.09 (0.15); 0.00	0.31 (0.44); 0.12
8	0.00 (0.00); 0.00	0.01 (0.04); 0.00	0.02 (0.02); 0.00	0.06 (0.12); 0.00	0.20 (0.23); 0.04
9	0.00 (0.00); 0.00	0.01 (0.02); 0.00	0.01 (0.02); 0.00	0.01 (0.02); 0.00	0.14 (0.16); 0.08
10	0.00 (0.00); 0.00	0.04 (0.09); 0.00	0.00 (0.00); 0.00	0.08 (0.17); 0.00	0.23 (0.10); 0.22
11	0.00 (0.00); 0.00	0.09 (0.18); 0.00	0.02 (0.04); 0.00	0.14 (0.23); 0.04	0.73 (0.84); 0.39
12	0.00 (0.00); 0.00	0.01 (0.02); 0.00	0.02 (0.04); 0.00	0.05 (0.07); 0.00	0.41 (0.40); 0.22

Figures 29 (a, b, c, d, e, f, g, h, & i) show the quadratic growth trends for pre-speech utterances. The growth trajectories were unpredictable for most behaviours, except in the case of 'click' (Fig. 29(i); R^2= 0.68) and 'vocal play' (Fig. 29(j); R^2= 0.40) which demonstrated polynomial trends. Further, the change point analysis did not reveal an age at which significant change was observed in the occurrence of pre-speech utterances, within the first year of life.

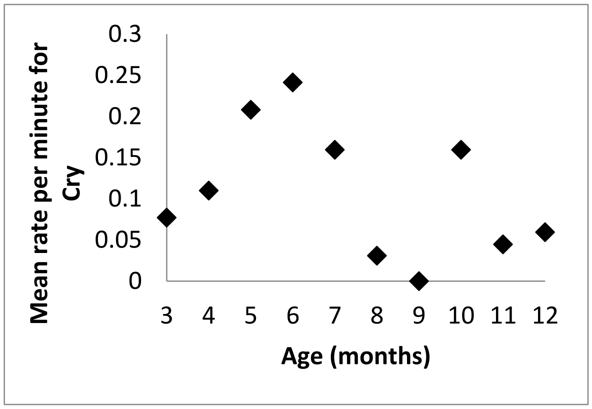


Figure 29(a): Growth trend for cry.

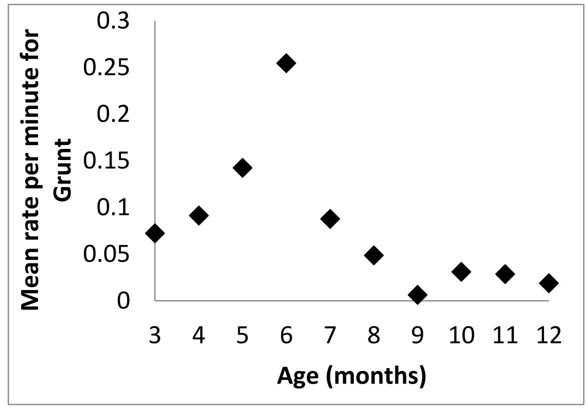


Figure 29(b): Growth trend for grunt.

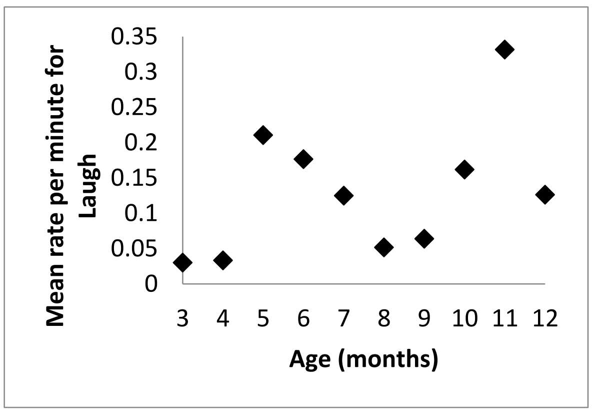


Figure 29(c): Growth trend for laugh.

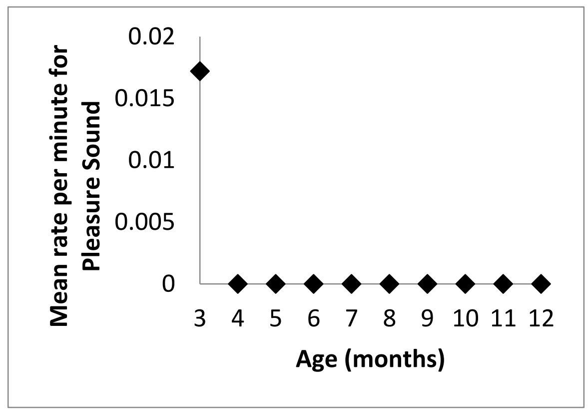


Figure 29(d): Growth trend for pleasure sounds.

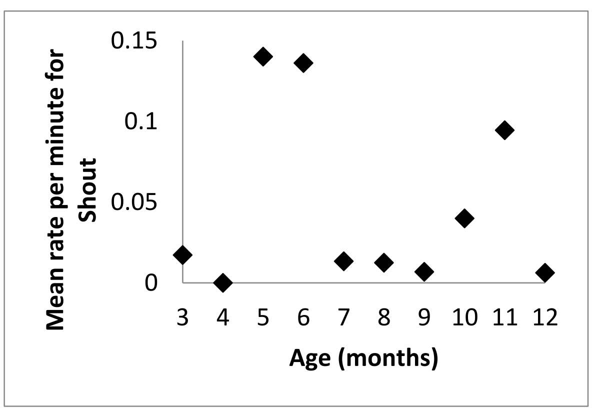


Figure 29(e): Growth trend for shout.

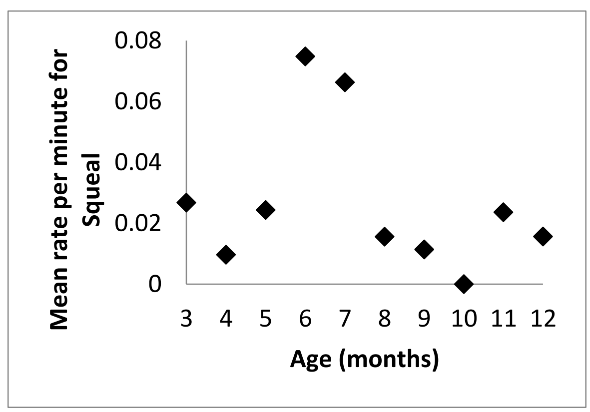


Figure 29(f): Growth trend for squeal.

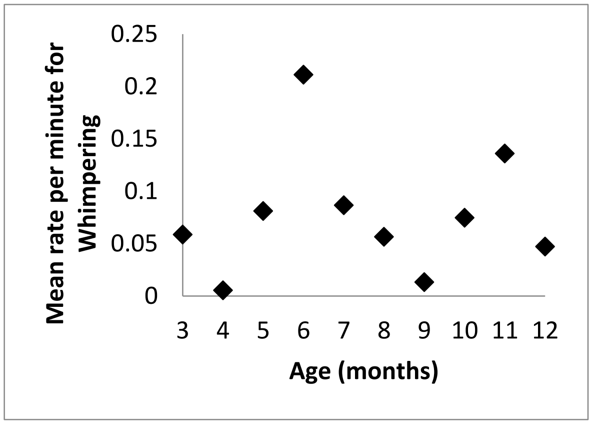


Figure 29(g): Growth trend for whimpering.

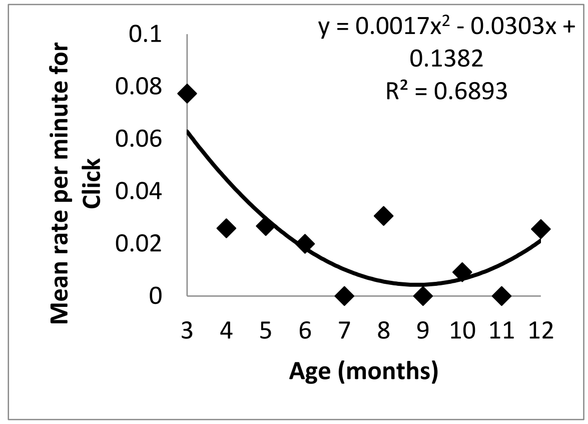


Figure 29(h): Growth trend for click.

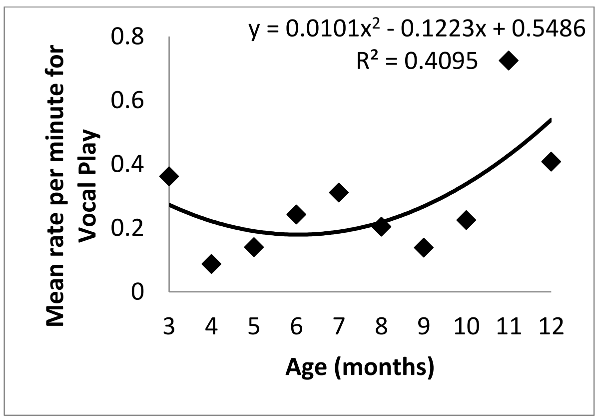


Figure 29(i): Growth trend for vocal play.

8.2. Vocalic utterances

Four patterns of vocalic utterances were analyzed from all the samples, namely, ‘hum’, ‘hum with prosodic alterations’, ‘vowelization’ and ‘vowelization with prosodic alterations’. The means, standard deviations and medians for the rates of occurrence of vocalic utterances are shown in Table 40. From the table it can be seen that all vocalic behaviours were seen from the age of 3 months itself. When compared to ‘hum’, the occurrence of ‘vowelization’ seemed to be more frequent as the age of the children increased. There were variations in the occurrence of ‘vowelization with prosodic alterations’ across the months.

Friedman test suggested that there were no significant differences in the occurrence rates of these gestures across the three months. Pair-wise comparisons across all the months suggested that there were significant differences noted in the rates of occurrence of 'vowelization'; differences were seen between the 4th month and the 8th month of age.

Table 40

Means, SD's & Medians for rates of occurrence of vocalic utterances

Age of the infants in Months	**Hum**	**Hum with prosodic alterations**	**Vowelization**	**Vowelization with prosodic alterations**
3	0.50 (0.14); 0.52	0.07 (0.07); 0.07	1.08 (0.56); 0.96	0.83 (0.86); 0.64
4	0.48 (0.48); 0.27	0.33 (0.58); 0.31	0.65 (0.40); 0.64	0.61 (0.44); 1.04
5	0.64 (0.48); 0.58	0.58 (0.60); 0.38	0.55 (0.51); 0.51	0.79 (0.99); 1.07
6	0.56 (0.64); 0.23	0.94 (0.97); 0.64	0.53 (0.61); 0.65	0.92 (0.81); 0.82
7	0.55 (0.34); 0.27	0.78 (1.00); 0.23	0.62 (0.47); 0.28	0.57 (0.33); 0.48
8	0.21 (0.16); 0.18	0.41 (0.35); 0.56	0.39 (0.63); 0.24	0.65 (0.62); 0.58
9	0.27 (0.22); 0.68	0.20 (0.16); 0.24	0.46 (0.54); 0.34	0.65 (0.52); 0.41
10	0.15 (0.09); 0.16	0.17 (0.14); 0.16	0.49 (0.29); 0.52	0.59 (0.31); 0.33
11	0.23 (0.13); 0.30	0.30 (0.34); 0.08	0.68 (0.42); 0.66	0.91 (0.36); 0.08
12	0.21 (0.23); 0.15	0.23 (0.16); 0.20	0.49 (0.44); 0.40	0.61 (0.37); 0.65

With age, there was a significant positive correlation in the occurrence of 'hum with prosodic alterations' (r=0.30; p=0.007), based on the correlation analysis (Spearman's test). None of the other vocalic behaviours demonstrated any such trend. Table 41 depicts the correlation patterns among the different vocalic utterances. There were significant negative correlations in the occurrence of 'vowelization' with both 'hum' and 'hum with prosodic alterations', while 'vowelization with prosodic alterations' positively correlated with 'vowelization' and negatively with 'hum with prosodic alterations'.

Table 41

Correlation coefficients among vocalic utterances with age

Rates of occurrence	Hum	Hum with prosodic alterations	Vowelization	Vowelization with prosodic alterations
Hum		0.17	-0.26**	0.22
Hum with prosodic alterations			-0.15*	-0.17***
Vowelization				0.86***
Vowelization with prosodic alterations				

Note: *** p≤0.00; **p≤0.01; * p≤0.05

Figures 30 (a, b, c & d) demonstrate the quadratic growth trends for vocalic utterances. Gestures 'hum with prosodic alterations' (Fig. 30(a); R^2= 0.41) and 'vowelization' (Fig. 30(b); R^2= 0.67) exhibited polynomial growth trajectories. Exponential growth trend was seen in the development of 'hum' (Fig. 30(c); R^2= 0.66), while the trend was unpredictable for 'vowelization with prosodic alterations' (Fig. 30(d)). Also, the change point analysis did not reveal an age at which significant change was observed in the occurrence of vocalic utterances, within the first year of life.

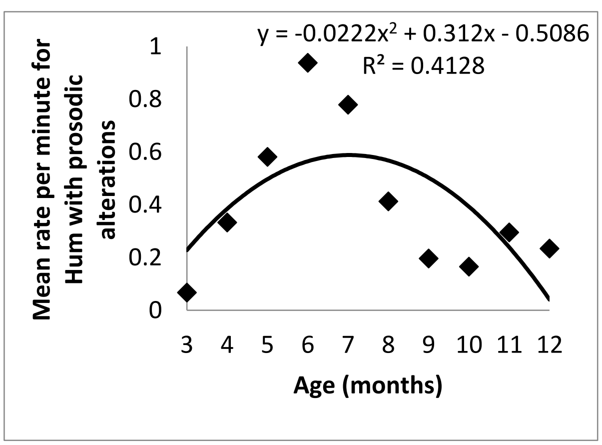


Figure 30(a): Growth trend for hum with prosodic alterations.

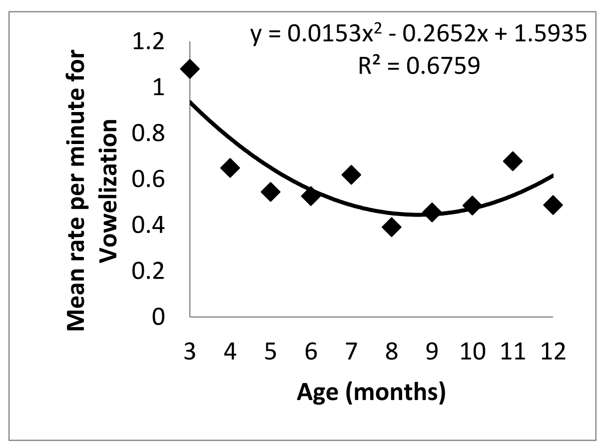


Figure 30(b): Growth trend for vowelization.

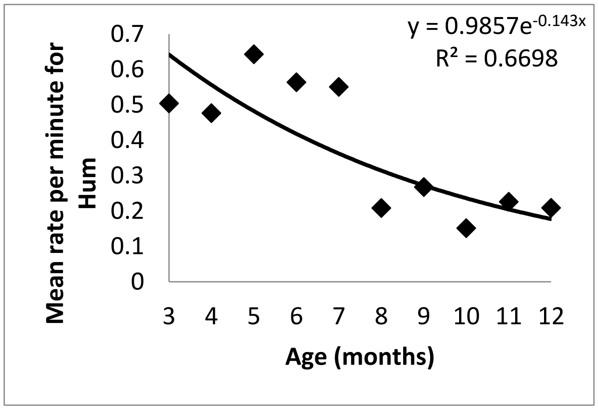


Figure 30(c): Growth trend for hum.

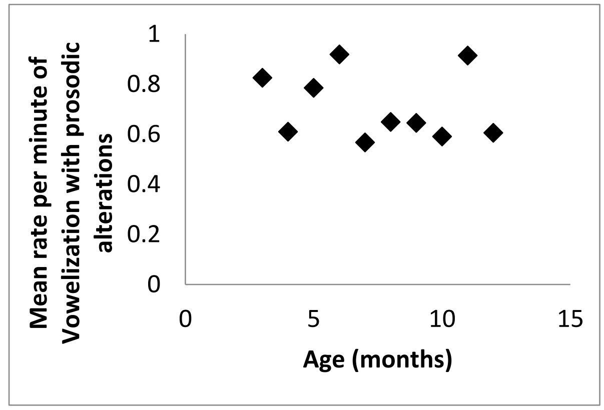


Figure 30(d): Growth trend for vowelization with prosodic alterations.

8.3. Syllabic utterances

The syllabic utterances that were observed in the study were the various syllabic shapes, which were combinations of consonants and vowels with and without prosodic variations. The means, standard deviations and medians for the rates of occurrence of syllabic utterances are shown in Tables 42(a) & 42(b). These tables reveal that simple syllabic structures (e.g. 'CV strings') were seen from the age of 3 months and occurred throughout the study period. The complex utterances (e.g. 'CVCV strings') were mostly seen from the age of 5 months and were infrequently seen even towards the end of the first year. The rates of occurrences of most of simple syllabic utterances seemed to increase with age.

The data treated to Friedman's test revealed that the rates of occurrence of speech behaviour 'CV string' [χ^2 (2, N=9)=6.00; p=0.050] showed near-significant differences across the three months, at 0.05 alpha level of significance. The pair-wise comparisons revealed that there were significant differences (p<0.05) seen in occurrence rates of 'CV string' between the 3rd month with the 4th and 12th months. Other behaviours such as 'articulatory gesture with weak vocal elements' showed variation in the rates between the 4th and 5th months with the 8th and 10th month of age, while 'VCV string' demonstrated differences between the 3rd month with the 9th and 10th months.

With age, there was a positive and significant correlation in the occurrence of 'articulatory gesture with weak vocal element' (r=0.55; p=0.000), 'CV string' (r=0.29; p=0.001) and 'CV string with prosodic alterations' (r=0.33; p=0.004) at 0.001 and 0.01 alpha levels of significance, as revealed by the Spearman's correlation analysis. Moreover, there were only two instances of positive significant correlation in the occurrence among syllabic utterances across age, at 0.05 level of significance. These were seen for 'CV string' with 'CV string with prosodic alterations' (r=.23; p=0.043) and for 'VC string' with 'VC string with prosodic alterations' (r=.22; p=0.046).

Figures 31 (a, b, c, d, e, f, g, h, i, j & k) show the quadratic growth trends for each vocalic behaviour. The 'CV string with prosodic alterations' (Fig. 31(a); R^2= 0.69), 'VC string' (Fig. 31(b); R^2= 0.81) and 'VCV string' (Fig. 31(c); R^2= 0.41) showed polynomial trajectories, while 'CV string' (Fig. 31(d); R^2= 0.80) was seen to have an exponential trajectory. The growth trajectories for the other behaviours were found to be unpredictable. Further, the change point analysis did not reveal an age at which significant change was observed in the occurrence of syllabic utterances.

Table 42(a)

Means, SD's & Medians for rates of occurrence of syllabic utterances

Age of the infants in Month	Articulatory gesture with weak vocal element	CV string	CV string with prosodic alterations	CVC string	CVC string with prosodic alterations
3	0.00 (0.00); 0.00	0.06 (0.09); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.01 (0.02); 0.00
4	0.02 (0.07); 0.00	0.20 (0.23); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00
5	0.02 (0.07); 0.00	0.06 (0.14); 0.00	0.01 (0.02); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00
6	0.00 (0.00); 0.00	0.12 (0.19); 0.04	0.01 (0.02); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00
7	0.00 (0.00); 0.00	0.15 (0.28); 0.04	0.00 (0.00); 0.00	0.01 (0.02); 0.00	0.00 (0.00); 0.00
8	0.17 (0.42); 0.00	0.15 (0.24); 0.09	0.03 (0.04); 0.00	0.01 (0.01); 0.00	0.00 (0.00); 0.00
9	0.04 (0.06); 0.03	0.13 (0.11); 0.14	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00
10	0.13 (0.11); 0.13	0.31 (0.40); 0.26	0.01 (0.02); 0.00	0.00 (0.00); 0.00	0.04 (0.06); 0.00
11	0.15 (0.25); 0.69	0.19 (0.24); 0.17	0.02 (0.02); 0.00	0.00 (0.00); 0.00	0.01 (0.02); 0.00
12	0.06 (0.07); 0.05	0.45 (0.42); 0.75	0.12 (0.15); 0.05	0.00 (0.00); 0.00	0.00 (0.00); 0.00

Table 42(b)

Means, SD's & Medians for rates of occurrence of syllabic utterances

Age of the infants in Month	CVCV string	VC string	VC string with prosodic alterations	VCCV string	VCV string	VCV string with prosodic alterations
3	0.00 (0.00); 0.00	0.03 (0.05); 0.00	0.01 (0.02); 0.00	0.00 (0.00); 0.00	0.06 (0.08); 0.00	0.00 (0.00); 0.00
4	0.00 (0.00); 0.00	0.02 (0.05); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.07 (0.11); 0.00	0.01 (0.02); 0.00
5	0.00 (0.00); 0.00	0.02 (0.04); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.05 (0.14); 0.00	0.01 (0.01); 0.00
6	0.00 (0.00); 0.00	0.04 (0.05); 0.00	0.01 (0.02); 0.00	0.01 (0.02); 0.00	0.07 (0.15); 0.00	0.02 (0.03); 0.00
7	0.00 (0.00); 0.00	0.02 (0.03); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.13 (0.13); 0.08	0.01 (0.02); 0.00
8	0.00 (0.00); 0.00	0.05 (0.09); 0.00	0.01 (0.01); 0.00	0.00 (0.00); 0.00	0.07 (0.16); 0.00	0.00 (0.00); 0.00
9	0.00 (0.00); 0.00	0.03 (0.05); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.15 (0.30); 0.11	0.00 (0.00); 0.00
10	0.01 (0.02); 0.00	0.01 (0.02); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.13 (0.26); 0.00	0.01 (0.02); 0.00
11	0.00 (0.00); 0.00	0.01 (0.02); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.07 (0.09); 0.04	0.01 (0.01); 0.00
12	0.00 (0.00); 0.00	0.01 (0.02); 0.05	0.01 (0.03); 0.08	0.00 (0.00); 0.00	0.11 (0.15); 0.08	0.02 (0.02); 0.00

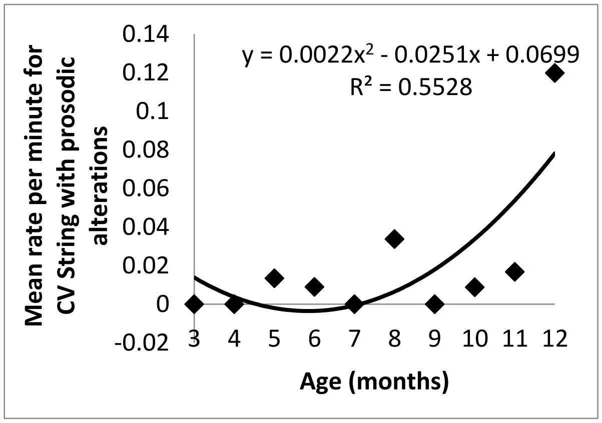


Figure 31(a): Growth trend for CV string with prosodic alterations.

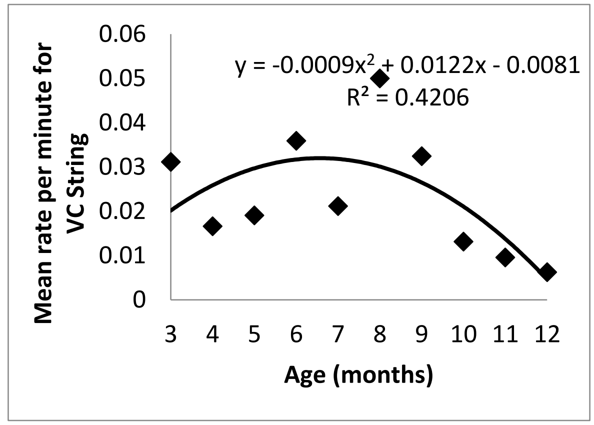


Figure 31(b): Growth trend for VC string.

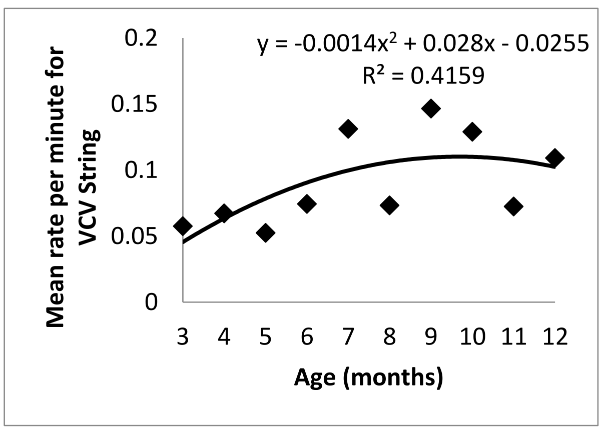


Figure 31(c): Growth trend for VCV string.

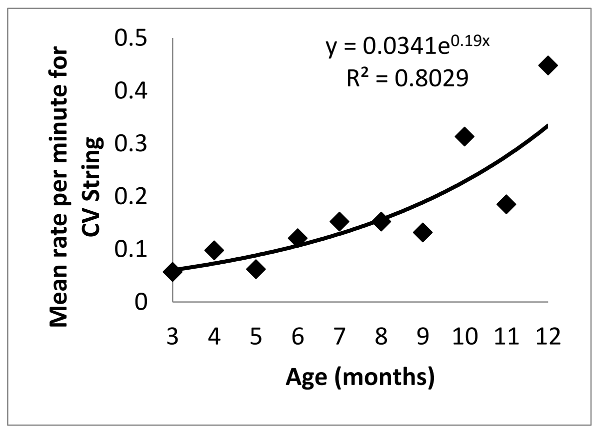


Figure 31(d): Growth trend for CV string.

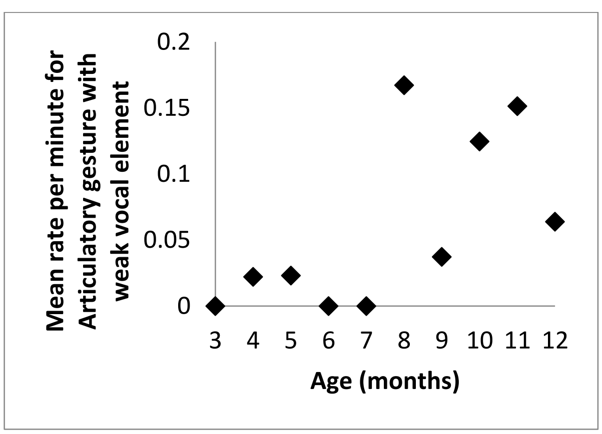


Figure 31(e): Growth trend for articulatory gesture with weak vocal element.

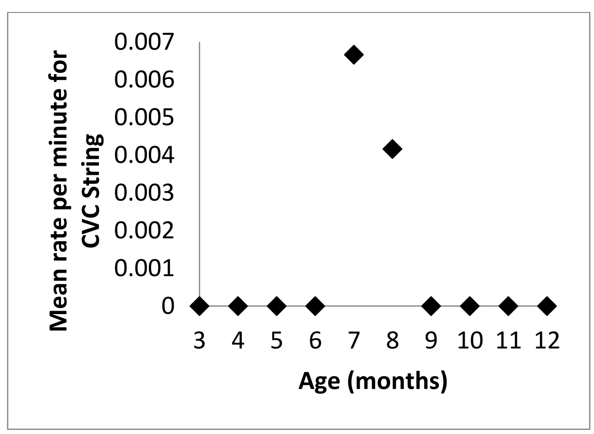


Figure 31(f): Growth trend for CVC string.

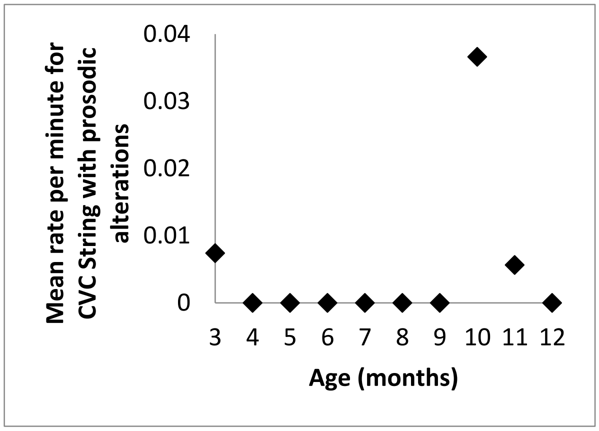


Figure 31(g): Growth trend for CVC string with prosodic alterations.

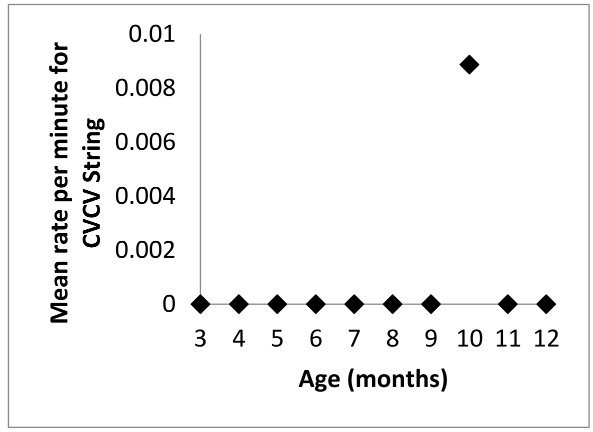


Figure 31(h): Growth trend for CVCV string.

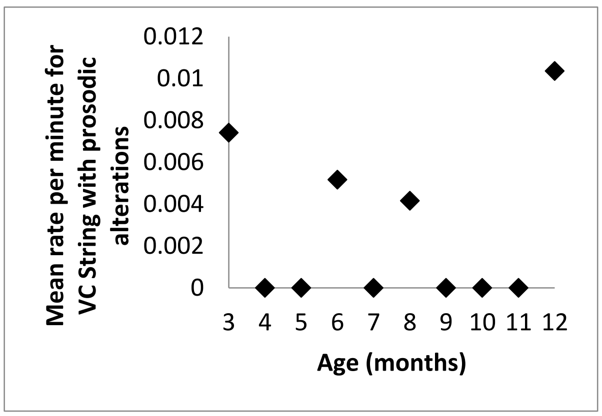


Figure 31(i): Growth trend for VC string with prosodic alterations.

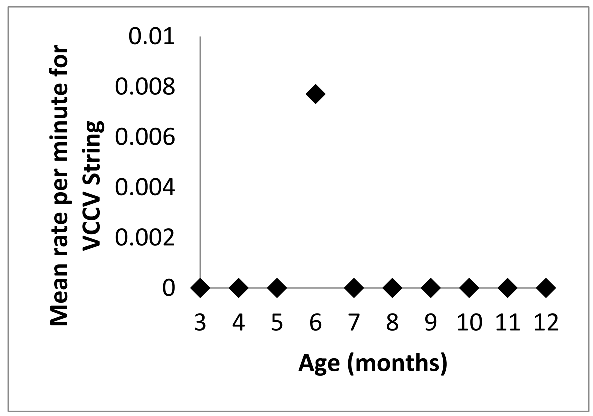


Figure 31(j): Growth trend for VCCV string.

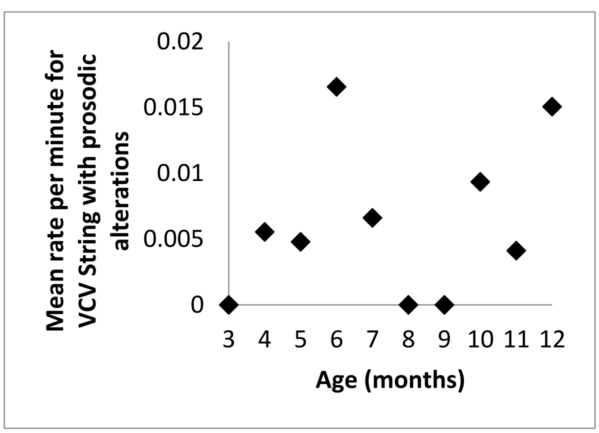


Figure 31(k): Growth trend for VCV string with prosodic alterations.

8.4. Verbal utterances

The verbal utterances that were observed in the study were ‘verbalization’, ‘verbalization with prosodic alterations’, ‘jargon’ and ‘words’. The means, standard deviations and medians for the rates of occurrence of verbal utterances are as shown in Table 43. The data in Table 43 shows that both ‘verbalizations’ and ‘jargon’ were seen from the age of 7 months and ‘verbalization with prosodic alterations’ and ‘words’ were seen from the 10th month of age. However, the rates of occurrence of ‘jargon’ were seen to decrease as the age of the children increased and the opposite trend was seen for the other behaviours.

Table 43

Means, SD’s & Medians for rates of occurrence of verbal utterances

Age of the infants in Month	Verbalization	Verbalization with prosodic alterations	Jargon	Word
3	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00
4	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00
5	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00
6	0.00 (0.00) 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00
7	0.09 (0.21); 0.00	0.00 (0.00); 0.00	0.01 (0.02); 0.00	0.00 (0.00); 0.00
8	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00	0.00 (0.00); 0.00
9	0.06 (0.06); 0.05	0.00 (0.00); 0.00	0.01 (0.02); 0.00	0.00 (0.00); 0.00
10	0.29 (0.22); 0.24	0.03 (0.04); 0.00	0.32 (0.71); 0.27	0.02 (0.02); 0.00
11	0.21 (0.16); 0.18	0.05 (0.06); 0.04	0.04 (0.08); 0.00	0.00 (0.00); 0.00
12	0.44 (0.20); 0.50	0.08 (0.09); 0.05	0.03 (0.03); 0.00	0.04 (0.05); 0.05

The Friedman test revealed that there were no significant differences in the occurrence rates of these behaviours across the three months, since these behaviours were not produced till the age of 7 months. Additionally, pair-wise comparisons across all the months did not reveal significant differences in the rates of occurrence of verbal utterances.

The Spearman's correlation analysis suggested that, with age, there was a significant positive correlation in the occurrence of 'jargon' (r=0.45; p=0.000), 'verbalization' (r=0.72; p=0.000), 'verbalization with prosodic alterations' (r=0.58; p=0.000), and 'word' (r=0.35; p=0.002), at 0.001 and 0.01 levels of significance. Table 44 suggests that all verbal behaviours had significant positive correlations in their occurrences during the first year of life, at 0.001 and 0.01 levels of significance.

Table 44

Correlation coefficients among verbal utterances with age

Rates of occurrence	**Jargon**	**Verbalization**	**Verbalization with prosodic alterations**	**Word**
Jargon		0.42***	0.38**	0.23***
Verbalization			0.49***	0.44***
Verbalization with prosodic alterations				0.34**
Word				

Note: *** p≤0.00; **p≤0.01

Figures 32 (a, b, c, & d) give the quadratic growth trends for each type of verbal utterance. It can be seen that 'verbalizations' (Fig. 32(a); R^2= 0.85) and 'verbalizations with prosodic alterations' (Fig. 32(b); R^2= 0.93) showed polynomial trajectories, while 'jargon' (Fig. 32(c)) and 'word' (Fig. 32(d)) showed unpredictable trajectories. Also, the change point analysis did not reveal an age at which significant change was observed in the occurrence of verbal utterances, within the first year of life.

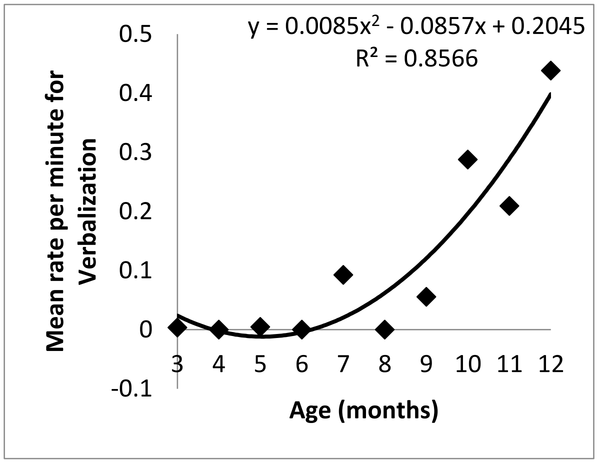


Figure 32(a): Growth trend for verbalization.

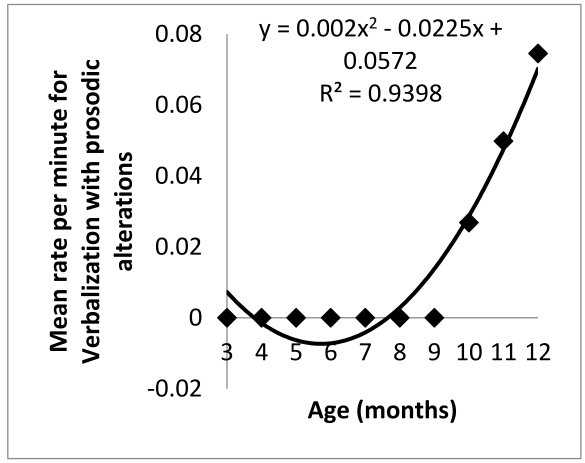


Figure 32(b): Growth trend for verbalization with prosodic alterations.

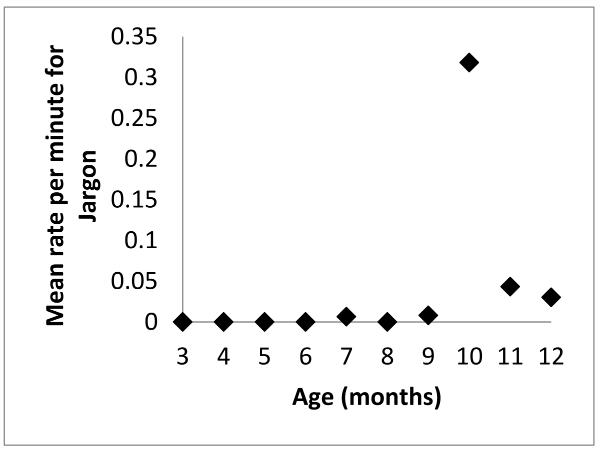


Figure 32(c): Growth trend for jargon.

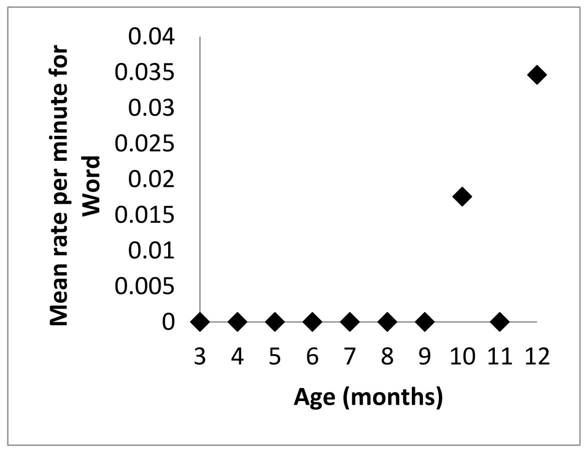


Figure 32(d): Growth trend for word.

9. Gestures and speech in development

The frequency of occurrence (in percentage) of gestures and speech was used to plot the trends in the development of both behaviours within the first year of life. For the purpose of this analysis, the data points of all gestures (gestures of face, gaze, head, torso, leg, whole body and hands) were grouped as one and compared to all speech behaviours (pre-speech, vocalic, syllabic, and verbal utterances), which were also grouped. Figure 33 shows the trends in the occurrence of both behaviours. As can be seen, gestures occur with higher frequency when compared to speech, from the 3rd month till the 12th month of age. Also, both modalities are exhibiting near-similar trends across all the months, with both behaviours developing in a parallel manner within the first year of life.

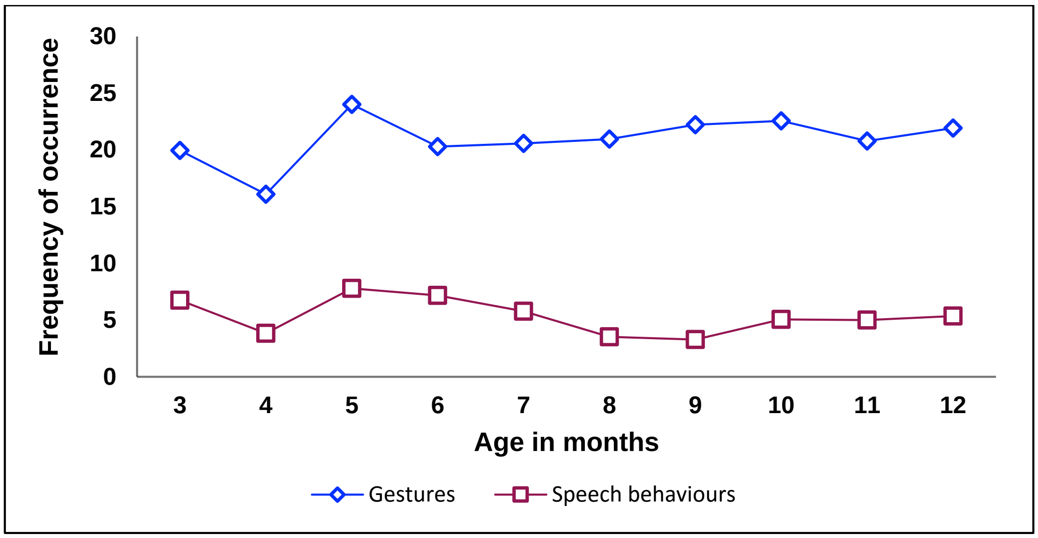


Figure 33: Frequency of occurrence (in percentage) of gestures and speech between 3 and 12 months of age.

From the observed results, it is clear that during development within the first year of life, gestures and speech shared both common and different characteristics of growth. Overall, it was seen that gestures were produced with higher frequency than speech behaviours across all the months of study. The growth trends seen were as follows:

- There were significant differences observed in the rates of occurrence of most behaviours within both modalities across the months of study, suggestive of differences in the acquisition of these behaviours. In addition, it was seen that behaviours either demonstrated positive or negative correlations with age, suggesting that behaviours either increase or decrease in their occurrence with age.

- Most behaviours within each system demonstrated coordinated patterns of growth as evidenced by either positive or negative correlations seen in their occurrences, which is suggestive of nesting patterns in development.

- Most behaviours exhibited non-linear patterns of growth, with only few behaviours within the gestural modality exhibiting linear patterns. This possibly suggests that development pattern is not consistent and is variable. However, despite the variability, behaviours in the gestural modality (except movements of torso and symbolic hand movements) showed significant changes in the patterns of occurrence of behaviours at certain ages. This trend was not seen for behaviours in the speech modality. Further, there was no clear trend observed for behaviours that occurred infrequently or when the occurrence was highly variable for every month of observation. This was especially true for mature and novel behaviours in both modalities (symbolic hand movements and verbal utterances).

II. Patterns of co-occurrence of speech and gestures

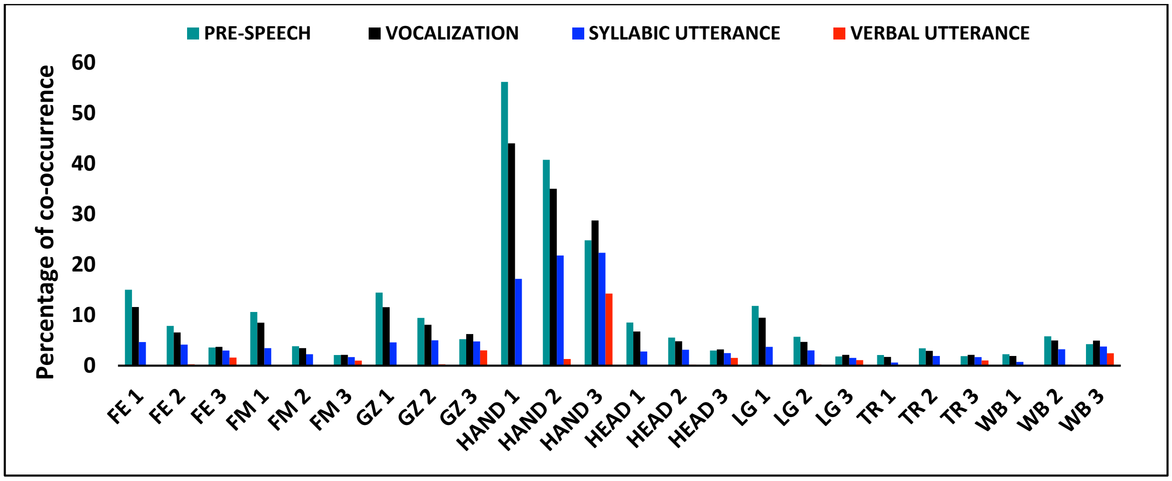
Speech and gestural behaviours were identified as coordinated behaviors when either of these behaviours exhibited some degree of temporal overlap. There were mainly two patterns of overlap observed in the study: (a) the onsets of behaviours were nearly simultaneous, (b) the onset of one behaviour (either speech or gesture) occurred during an ongoing bout of another behaviour (either speech or gesture). The latter was noted to be the most frequently occurring pattern in the study, and there were very few instances of simultaneous co-occurrence of behaviours observed throughout the study period.

An *event-based approach* was used to annotate the data in this study, which focuses on the sequencing of temporally overlapping events in multiple modalities than when compared to a time-based analysis in which the annotation of the coordinated event is fixed for a specific time interval. Previous studies have employed either one of the approaches in the analysis of coordinated behaviours (Weinberg &Tronick, 1994; Yale, Messinger, Eilers, Oller & Cobo-Lewis, 1999). Since the patterns of temporal overlap across the different modalities observed in the study were not uniform, an event-based approach seemed to be appropriate to describe the patterns seen.

Under each of the main categories that were studied, it was also noted that not every speech and gestural behaviour co-occurred with each other. The patterns of combinations were very inconsistent across infants. It was noted that all the infants included in the study did not demonstrate all the patterns documented in the results. Since the numbers of these co-occurrences were low and occurred inconsistently, the coordinated bouts were grouped under each of the types of speech and gestures for further statistical analysis. Further, Wilcoxon signed-rank test revealed that there were no significant differences based on laterality in the production of coordinated behaviours, for gestures produced using the left and right hands with speech behaviours. Therefore, the data of gestures produced using the right and left hands was collapsed for further analysis.

Further, the data was grouped into time periods loosely based on the dynamic developmental progression for the *coupled oral-manual system* proposed by Iverson and Thelen (1999). This pattern was followed because there were wide variations seen in the number of co-occurrences of the different speech and gestural behaviours across each month of analysis. Therefore, the data was collapsed and analyzed for three time frames, namely, >3 months to $\leq$ 5 months, 29 days (initial pre-linguistic phase), >6 months to $\leq$ 7 months, 29 days (middle pre-linguistic phase) and >8 months to $\leq$ 12 months (final pre-linguistic phase) months. The grouped results of co-occurrence of speech and gestures are presented below.

Figure 34 gives the percentage frequency of co-occurrence of speech with gestures and it can be seen that all type of speech behaviours co-occurred with highest frequency with hand movements, and this was consistently seen across all the developmental time frames that were studied.



Note: FE-Facial expressions; FM-Facial movements; GZ-Gaze behaviours; HAND-Hand movements; HEAD-Head movements; LG-Leg movements; TR-Torso movements; WB-Whole body movements; 1-Initial phase; 2-Middle phase; 3-Final phase.

Figure 34: Percentage frequency of co-occurrence of speech and gestures across the developmental time frames.

1. Co-occurrence of pre-speech utterances and gesture types

The means, standard deviations and medians for the rates of co-occurrence of pre-language utterances and gestures are as shown in Table 45. From the table, it can be observed that the highest rate of co-occurrence was seen for the co-production of 'facial movements' in the initial phase and the least rate of co-occurrence was seen in the co-production of 'head movements' in the final phase of development. It is also seen that there is not much variation seen in the mean rates of co-occurrence of most pre-speech utterances and gestural behaviours, across time frames. For e.g. speech behaviours co-occurred with gaze behaviours at similar frequency across the three time frames. Some variations were observed in the rates of co-occurrence within each developmental time period, especially in the case of facial movements (initial phase) and head movements (final phase), and these are as shown in Figure 35.

However, they were not statistically significant on the analysis. From the figure, it is also clear that coordination between the two modalities did not differ in the final phase of development, when compared to the other two time periods.

Table 45

Means, SDs & Medians for rates of co-occurrence of pre-speech utterances and gestures

Types of Gesture	Initial developmental phase	Middle developmental phase	Final developmental phase
Facial Expressions	0.47 (0.16); 0.42	0.51 (0.19); 0.50	0.45 (0.19); 0.34
Facial Movements	0.61 (0.18); 0.91	0.47 (0.08); 0.37	0.48 (0.22); 0.65
Gaze Behaviours	0.47 (0.17); 0.51	0.47 (0.14); 0.60	0.45 (0.10); 0.42
Hand Movements	0.51 (0.16); 0.27	0.43 (0.15); 0.43	0.43 (0.12); 0.28
Head Movements	0.48 (0.14); 0.30	0.48 (0.22); 0.58	0.39 (0.19); 0.45
Leg Movements	0.50 (0.16); 0.38	0.47 (0.14); 0.52	0.49 (0.18); 0.38
Movements of Torso	0.47 (0.23); 0.34	0.41 (0.11); 0.22	0.47 (0.15); 0.31
Whole body Movements	0.53 (0.18); 0.34	0.42 (0.15); 0.46	0.46 (0.12); 0.39

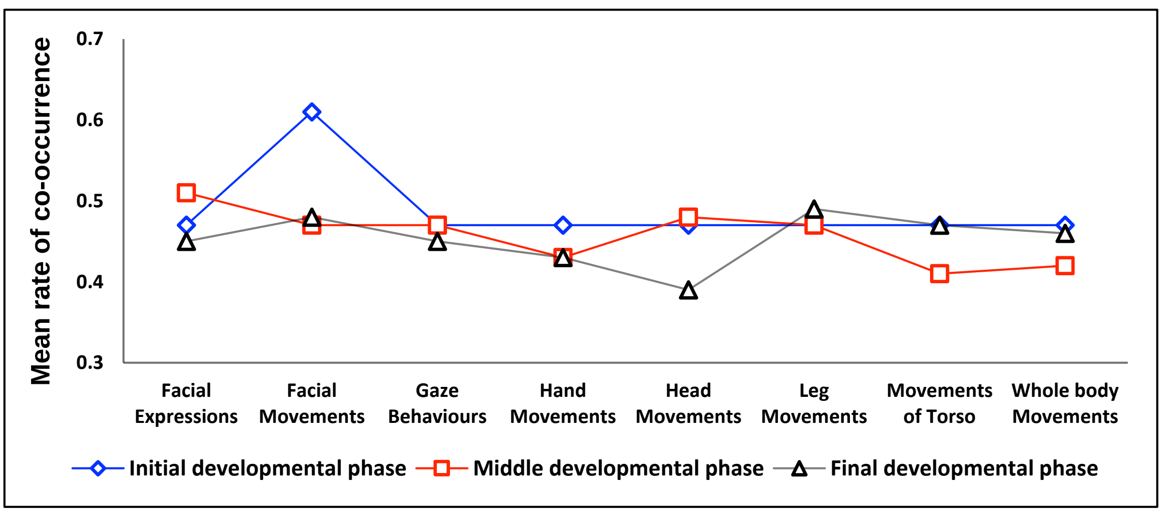


Figure 35: Rates of co-occurrence of pre-speech utterances and gestures across the time periods.

Across the three time periods, however, Friedman test revealed that there were statistically significant differences in the rates of co-occurrence of pre-speech utterances with ‘facial movements’ [χ^2 (2, N=9)=2.658; p=0.038] and ‘hand gestures’ [χ^2 (2, N=9)= 2.433; p=0.002] at 0.05 and 0.01 levels of significance, respectively. Further, pair-wise comparisons revealed that the source of this effect was the difference seen in the rates of co-occurrence of pre-speech utterances with ‘mouthing’ (facial movement), and hand movements such as ‘curled’, ‘index finger extension’, and ‘hand held toy in mouth’, between the initial and final pre-linguistic phases of development. These were significant at $p<0.05$.

It was interesting to note that there were variations observed in the co-occurrence of individual behaviours of pre-speech utterances and gestures, in that not all gestural behaviours co-occurred with speech. The distribution of rates of co-occurrences of each of the pre-speech and gestural behaviours, for all the developmental time periods is as shown in Figures 36 (a, b, c, d, e, f, g, h, i, & j).

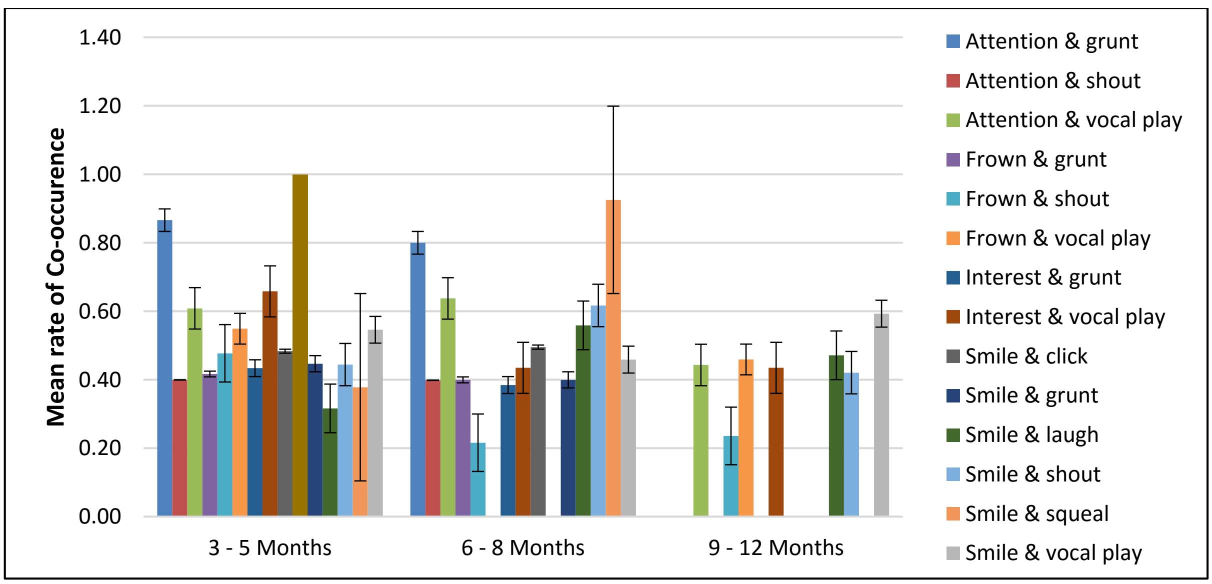


Figure 36(a): Co-occurrence of pre-speech utterances and facial expressions.

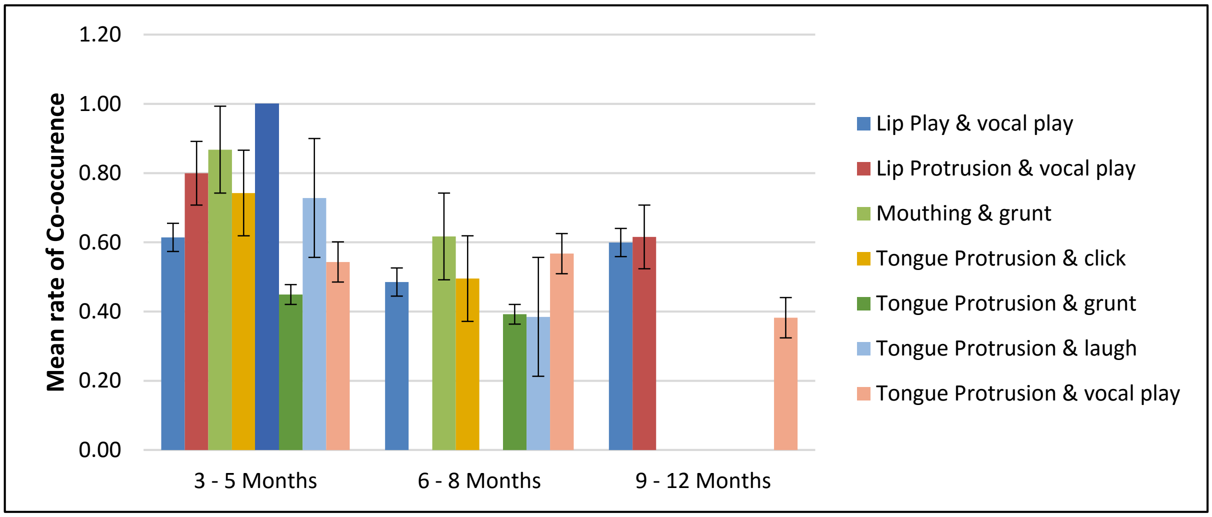


Figure 36(b): Co-occurrence of pre-speech utterances and facial movements.

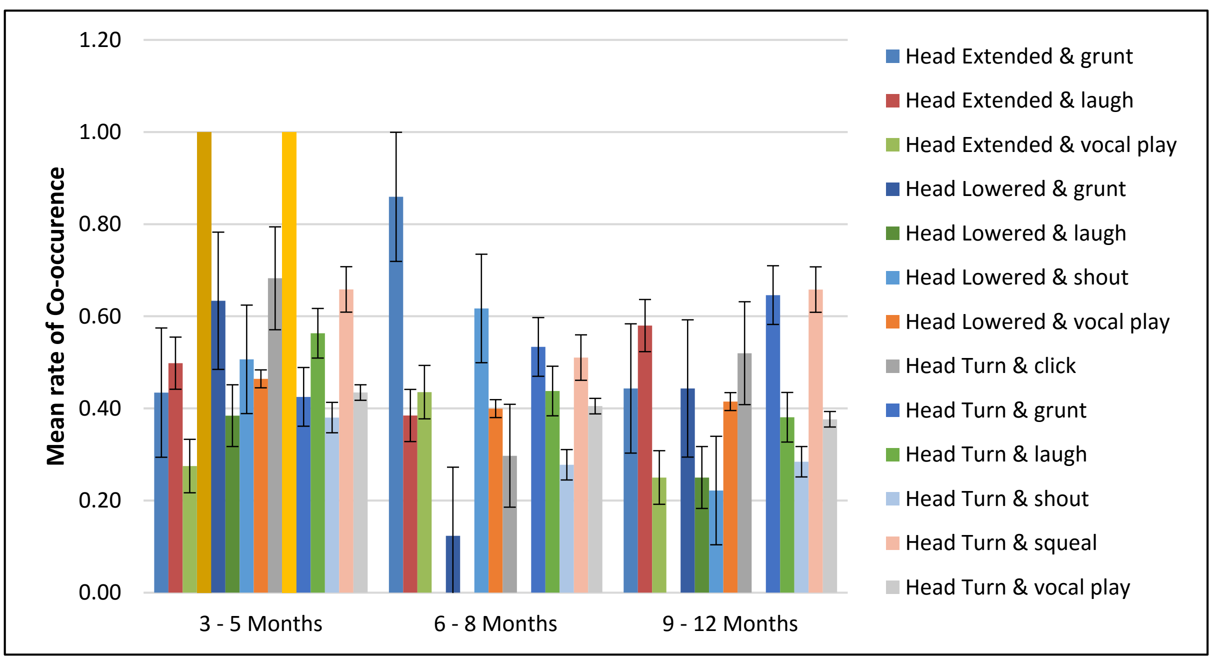


Figure 36(c): Co-occurrence of pre-speech utterances and head movements.

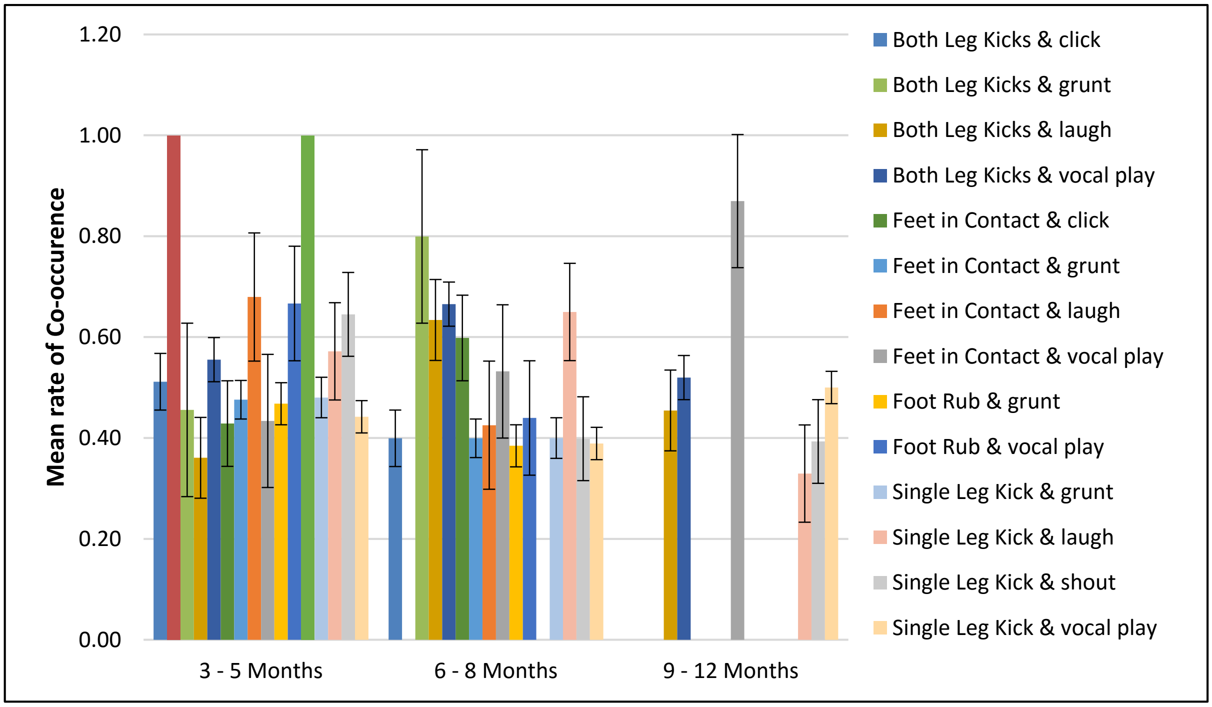


Figure 36(d): Co-occurrence of pre-speech utterances and leg movements.

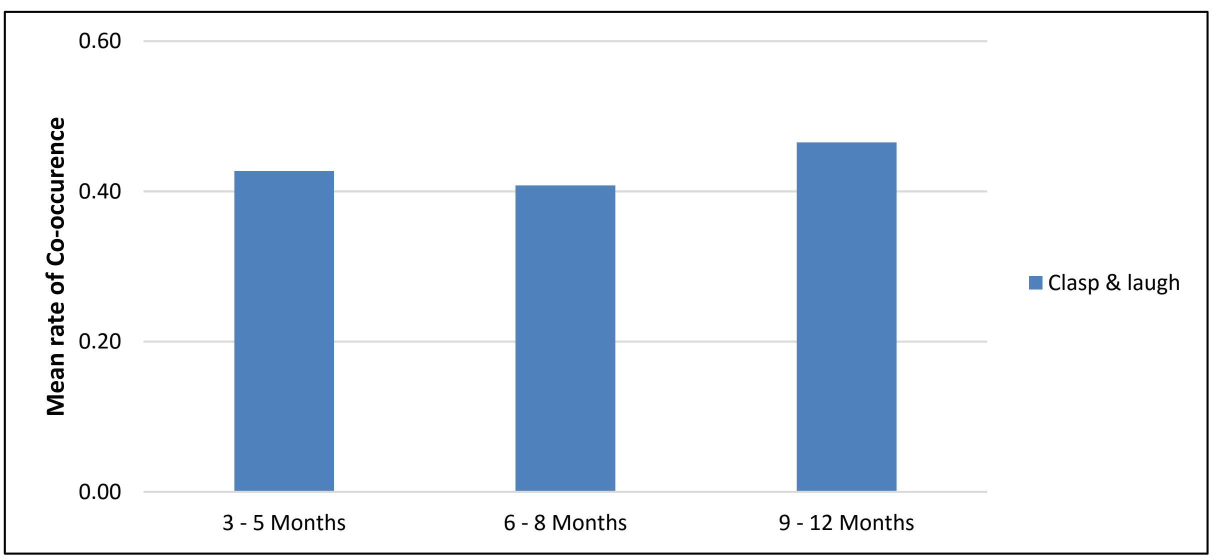


Figure 36(e): Co-occurrence of pre-speech utterances and bimanual gestures.

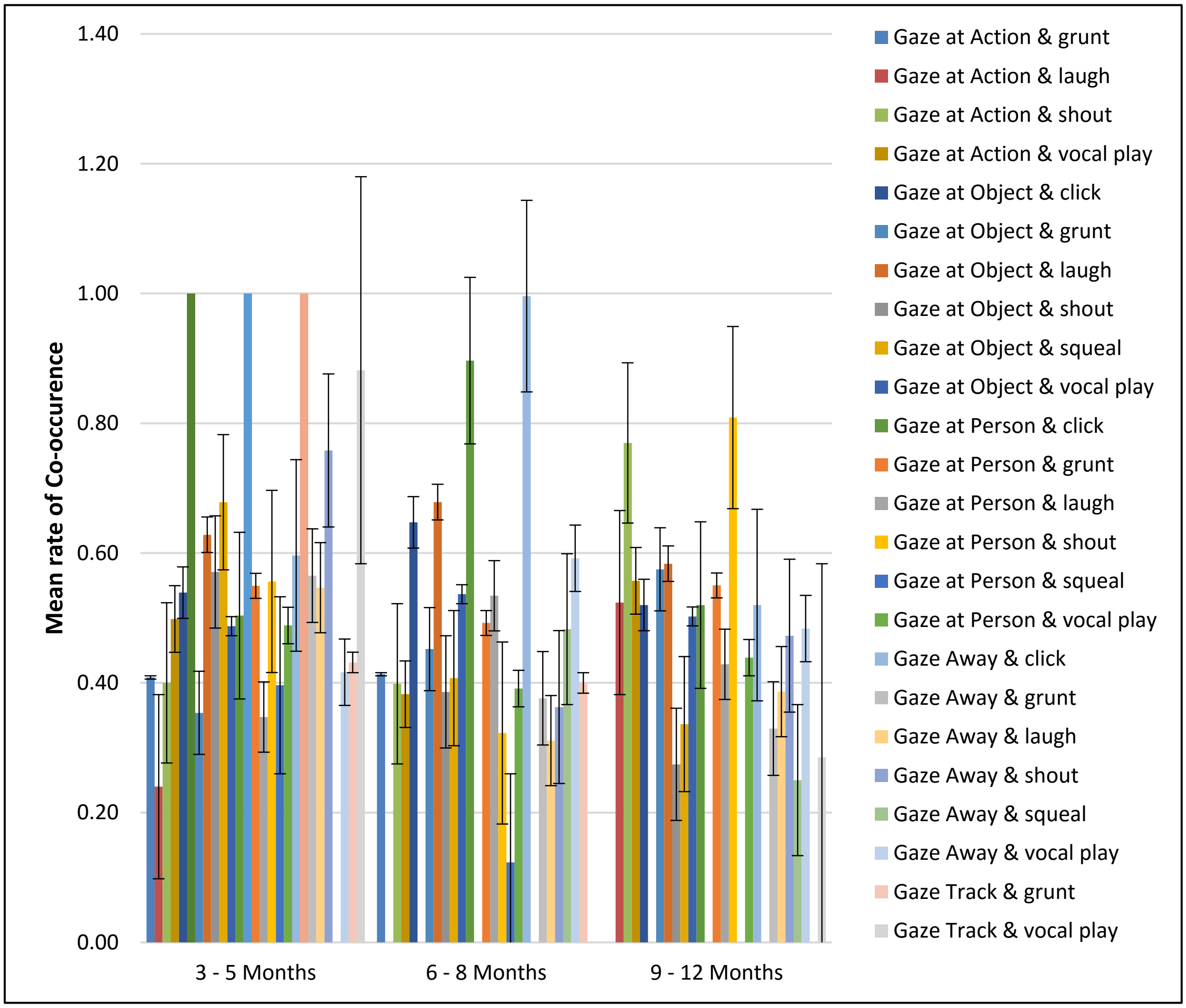


Figure 36(f): Co-occurrence of pre-speech utterances and gaze behaviours.

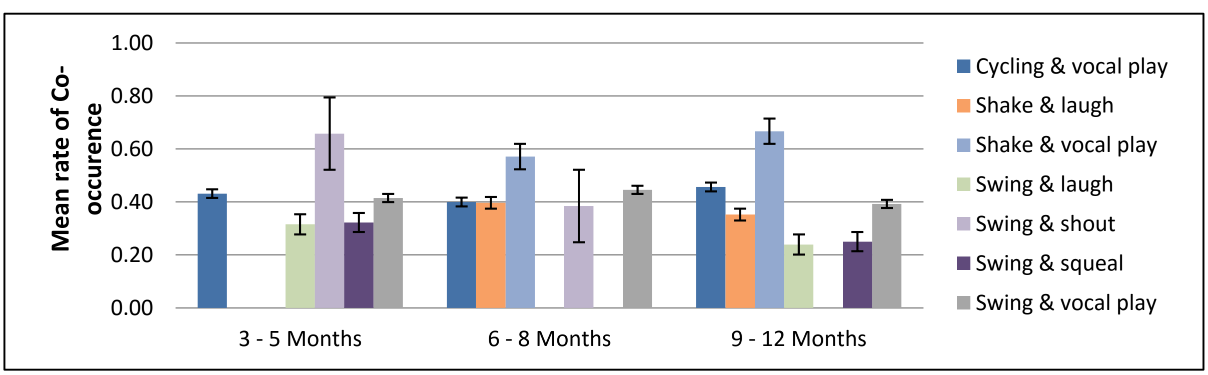


Figure 36(g): Co-occurrence of pre-speech utterances and pre-symbolic hand rhythmic gestures.

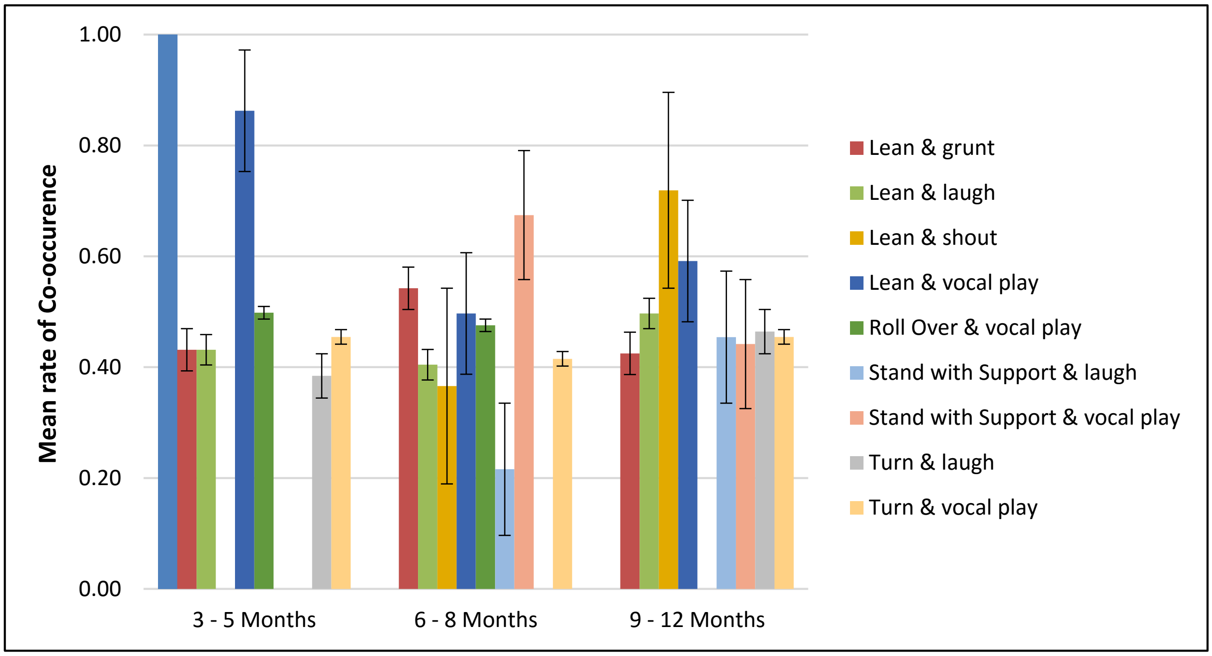


Figure 36(h): Co-occurrence of pre-speech utterances and whole body movements.

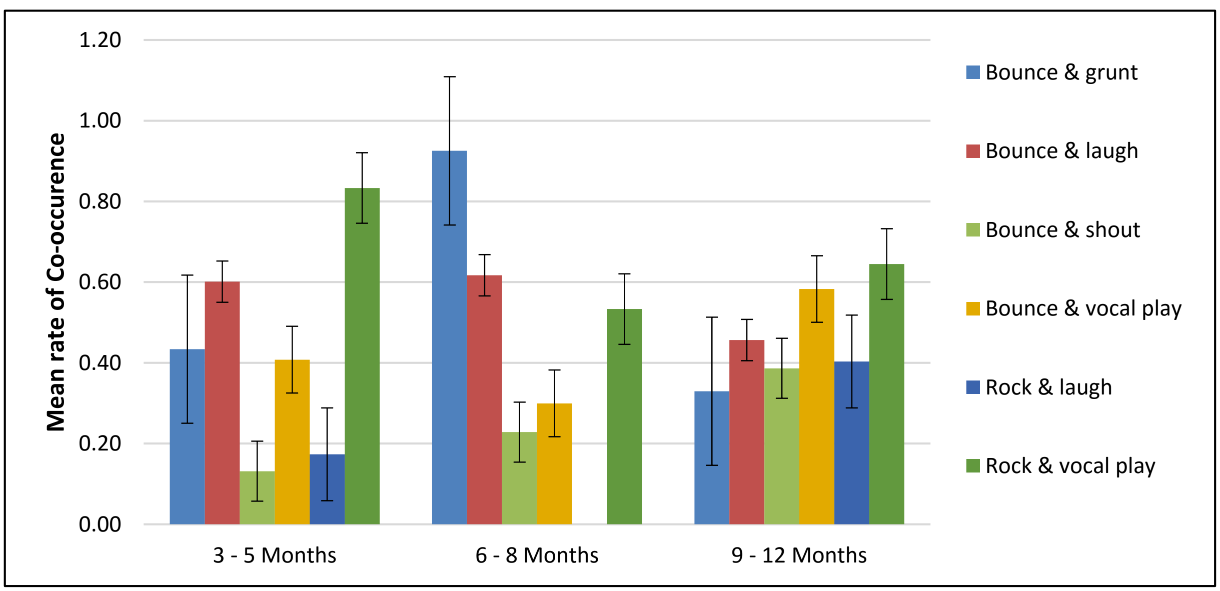


Figure 36(i): Co-occurrence of vegetative productions and movements of torso.

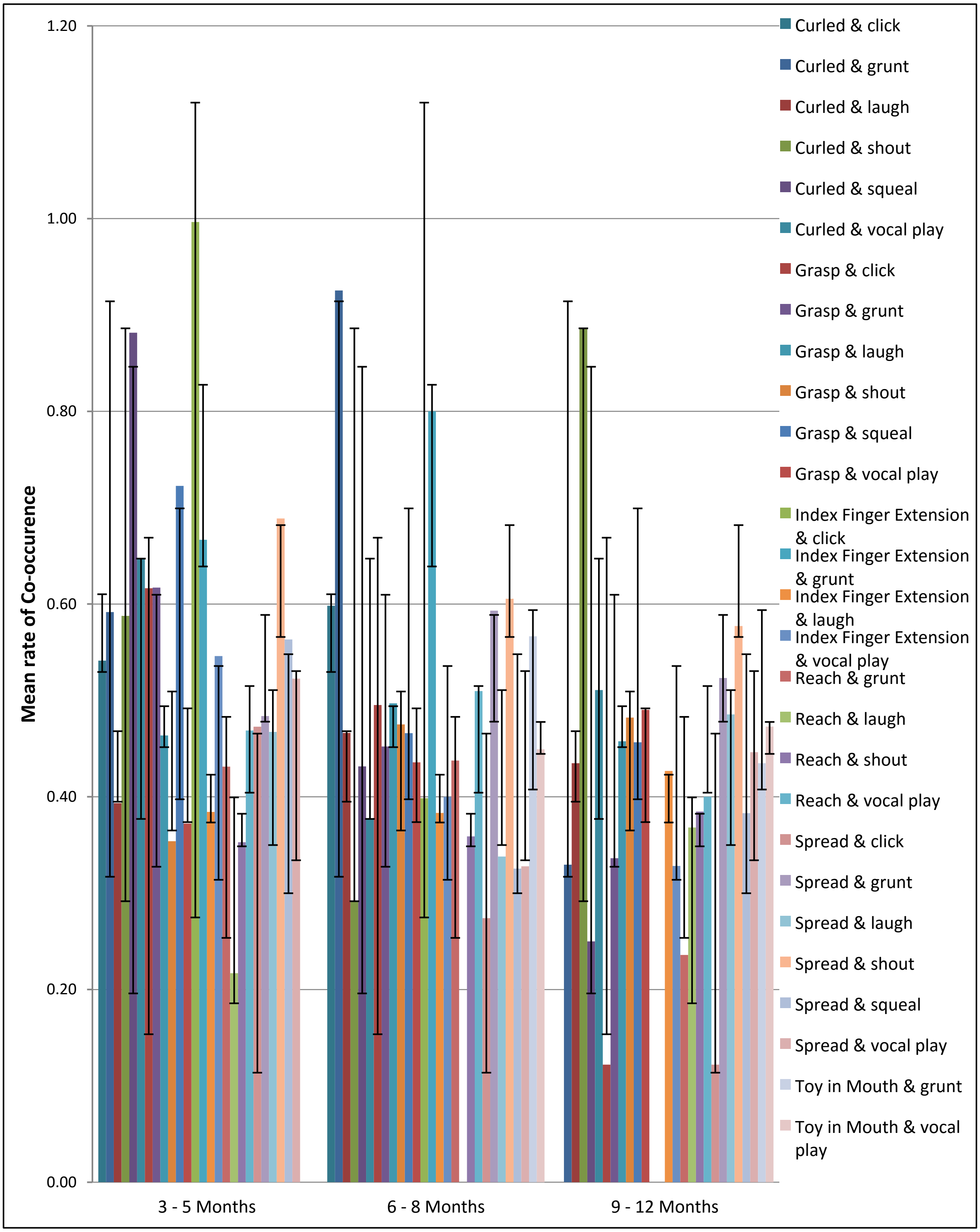


Figure 36(j): Co-occurrence of pre-speech utterances and pre-symbolic hand gestures.

To summarize, pre-speech utterances were seen to co-occur with all types of gestural behaviours, at variable frequency, during all the three phases of development. These patterns of co-occurrence seem to reflect the frequency with which speech and gestural behaviours were produced in the study. For example, frequently occurring pre-speech utterances such as 'vocal play' seemed to co-occur with most gestural behaviours. However, this trend did not apply to all behaviours. It must also be noted that there were also instances where the two modalities did not co-occur. For example, none of the pre-language utterances co-occurred with 'twist', and this was consistently seen for all developmental time frames.

2. Co-occurrence of vocalic utterances and gesture types

The means, standard deviations and medians for the rates of co-occurrence of individual vocalic utterances and gestures are shown in Table 46. As can be seen, in the initial pre-linguistic phase, the rate of vocalic utterances co-occurring with whole body movements was higher when compared to other behaviours; while in the middle phase, there was a lower rate of co-occurrence of vocalic utterances with head movements. Apart from these instances, the other gestures co-occurred with speech at similar rates. For example, hand movements co-occurred with vocalic utterances at the same rates across the developmental phases. In the same vein, there were not many differences observed in the rates of co-occurrence across behaviours within each time period, as can be seen from Figure 37. The figure also reflects that coordination between the two modalities did not vary in the final phase of development, when compared to the other two time periods.

Further, both these patterns were reflected in the statistical analysis that was carried out, which revealed no significant differences in the rates of co-occurrence both within and across time periods.

Table 46

Means, SDs & Medians for rates of co-occurrence of vocalic utterances and gestures

Types of Gesture	Initial developmental phase	Middle developmental phase	Final developmental phase
Facial Expressions	0.46 (0.14); 0.23	0.48 (0.16); 0.40	0.47 (0.16); 46
Facial Movements	0.42 (0.14); 0.30	0.47 (0.15); 0.51	0.39 (0.14); 0.46
Gaze Behaviours	0.47 (0.11); 0.51	0.42 (0.08); 0.37	0.43 (0.09); 0.46
Hand Movements	0.43 (0.08); 0.46	0.43 (0.08); 0.33	0.43 (0.09); 0.35
Head Movements	0.48 (0.17); 0.27	0.38 (0.16); 0.30	0.44 (0.23); 0.38
Leg Movements	0.46 (0.10); 0.43	0.48 (0.15); 0.63	0.42 (0.14); 0.37
Movements of Torso	0.49 (0.18); 0.34	0.46 (0.16); 0.35	0.51 (0.21); 0.48
Whole body Movements	0.53 (0.21); 0.46	0.44 (0.17); 0.39	0.47 (0.16); 0.48

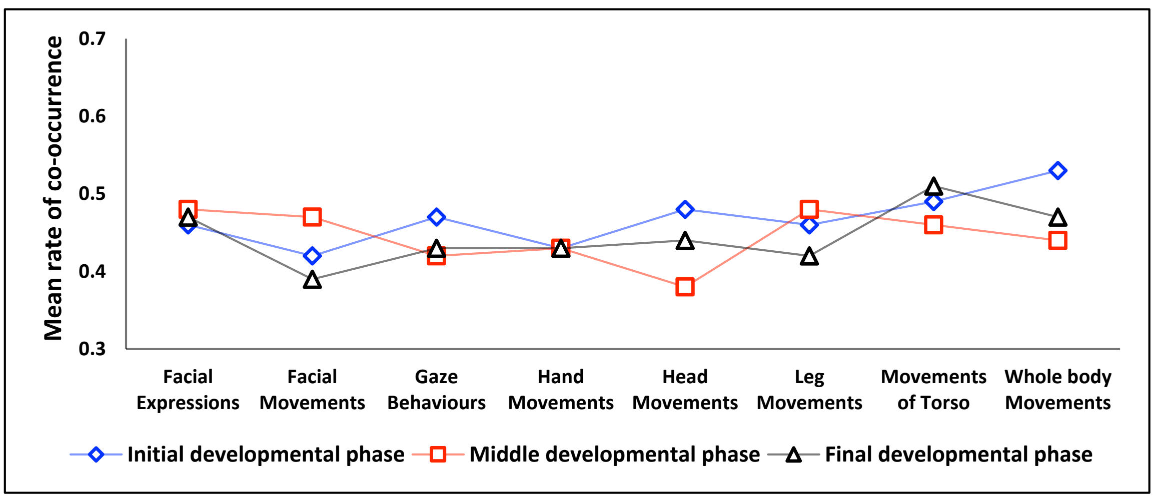


Figure 37: Rates of co-occurrence of vocalic utterances and gestures across the time periods.

There were variations observed in the co-occurrence of individual behaviours of vocalic utterances and gestures, since not all the gestures co-occurred with speech. The distribution of mean rates of co-occurrences for each of the vocalic and gestural behaviours for all the developmental time frames is as shown in Figures 38 (a, b, c, d, e, f, g, h, i, j, & k).

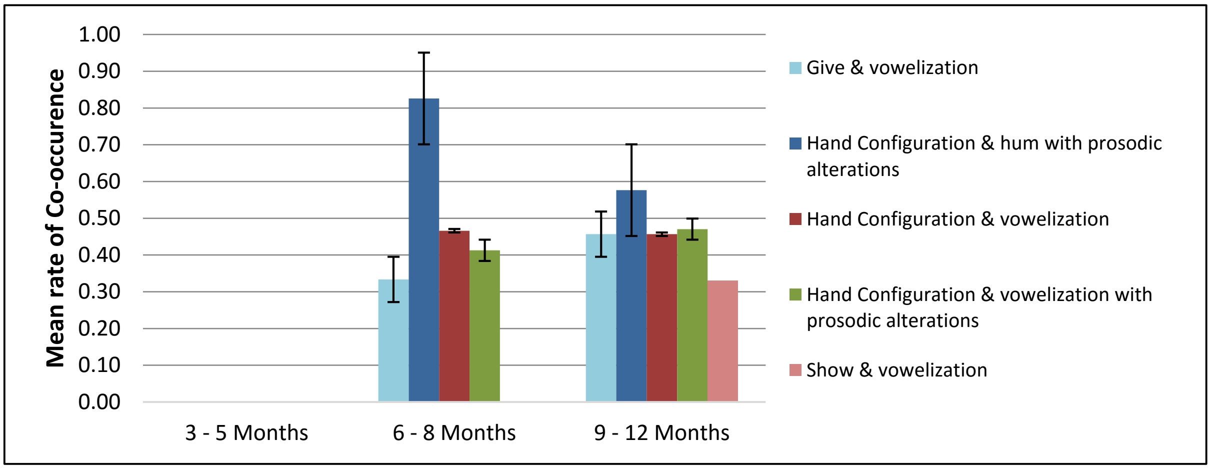


Figure 38(a): Co-occurrence of vocalic utterances and symbolic hand gestures.

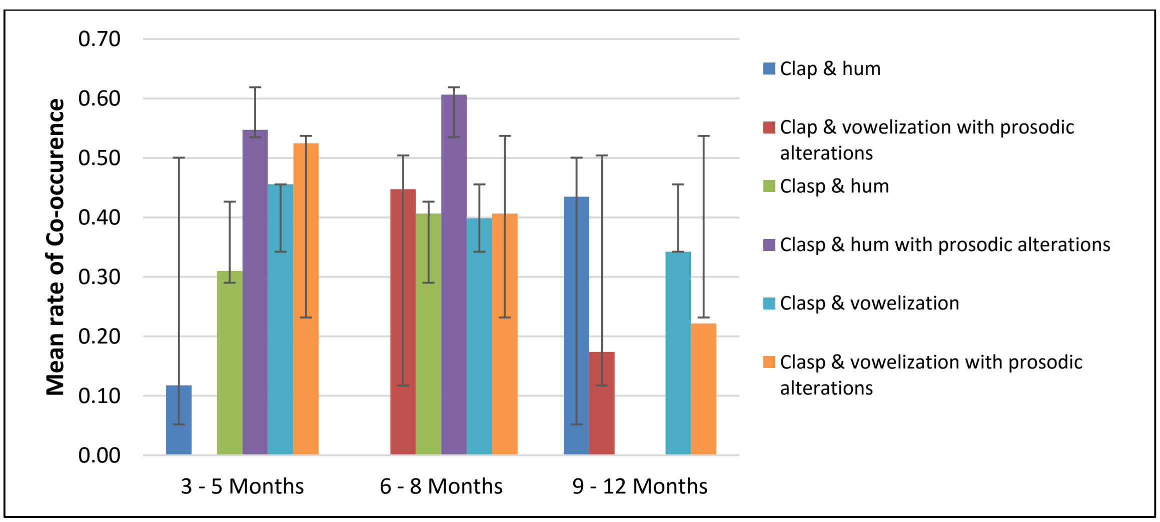


Figure 38(b): Co-occurrence of vocalic utterances and bimanual gestures.

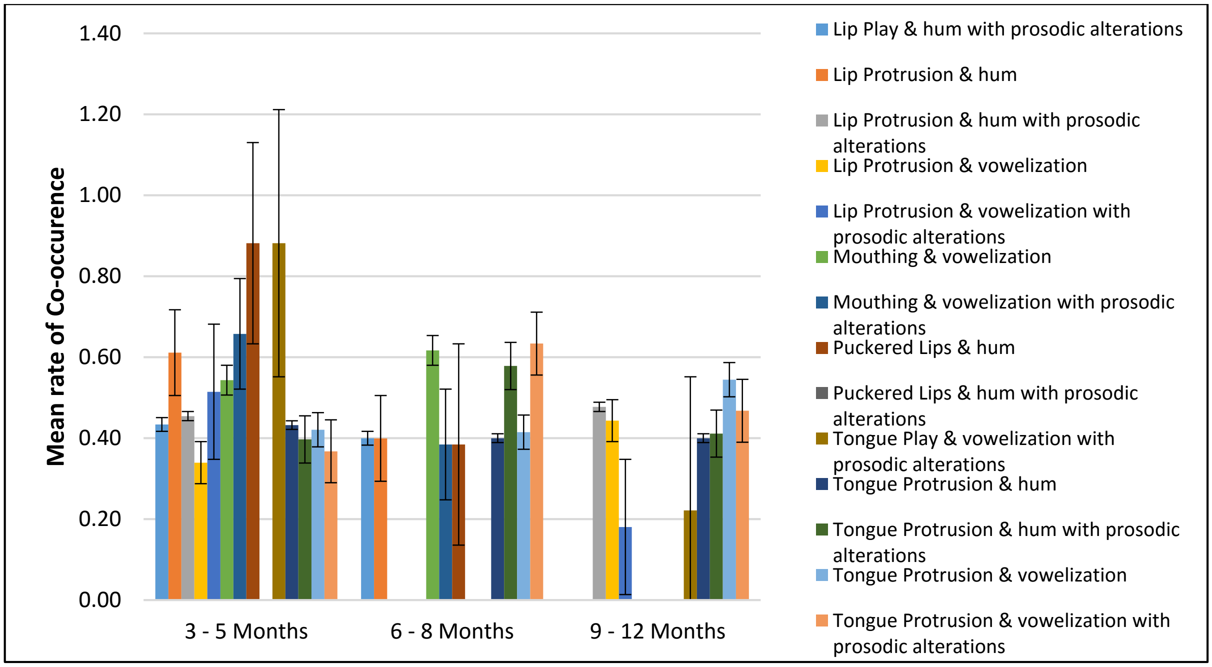


Figure 38(c): Co-occurrence of vocalic utterances and facial movements.

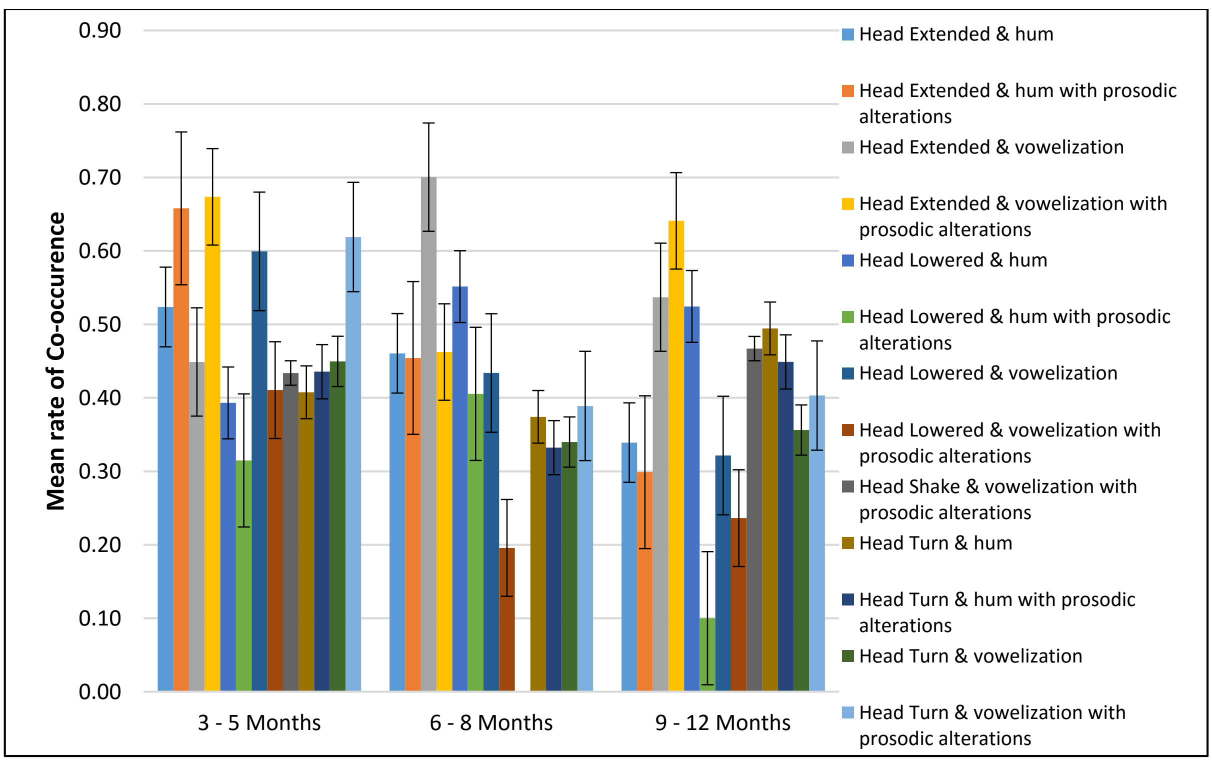


Figure 38(d): Co-occurrence of vocalic utterances and head movements.

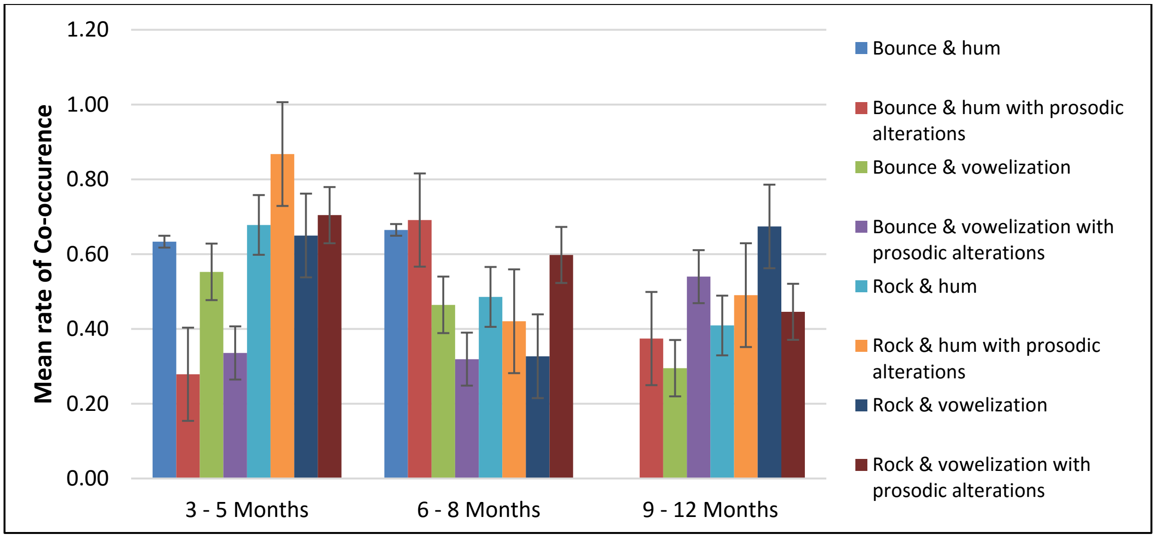


Figure 38(e): Co-occurrence of vocalic utterances and movements of torso.

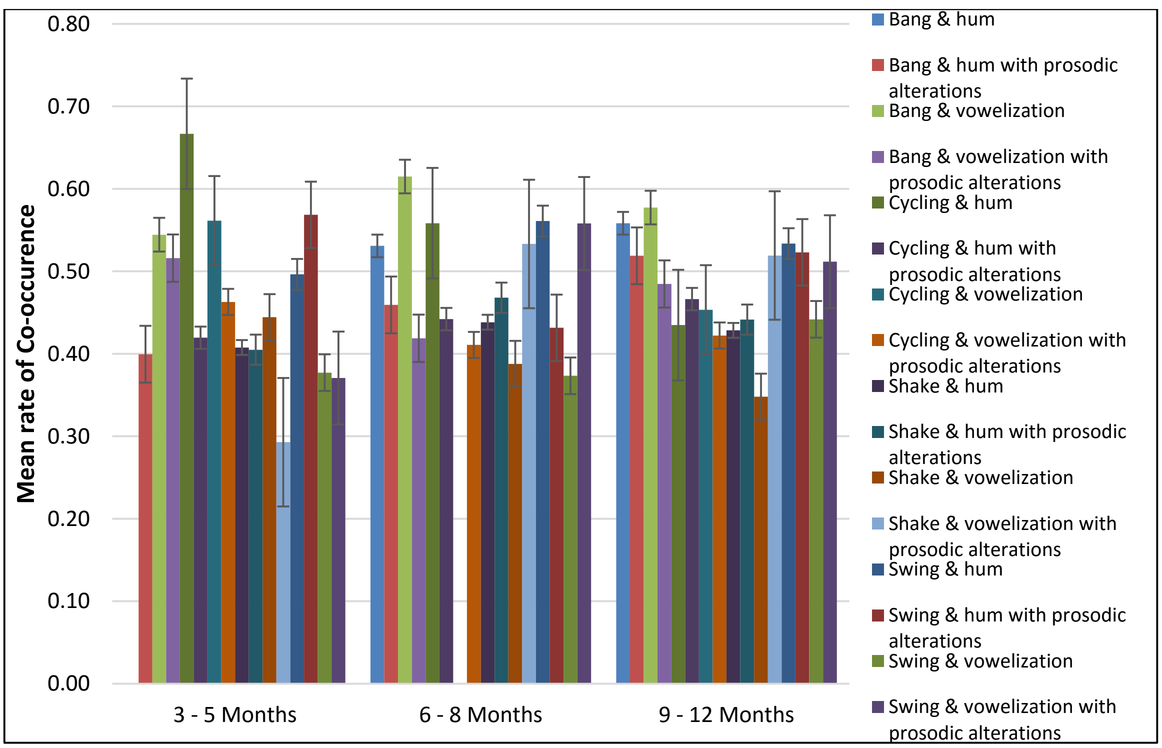


Figure 38(f): Co-occurrence of vocalic utterances and pre-symbolic hand rhythmic gestures.

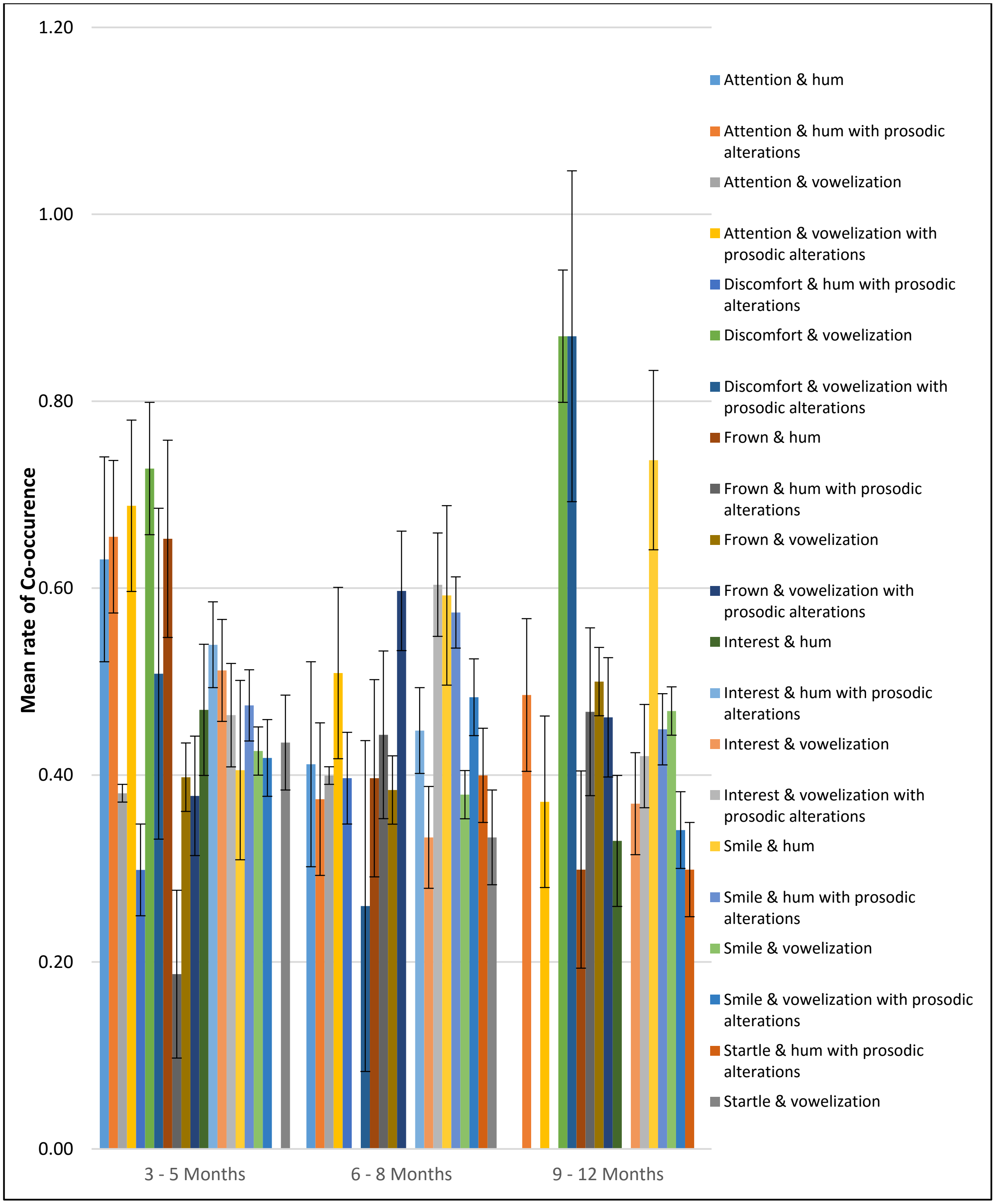


Figure 38(g): Co-occurrence of vocalic utterances and facial expressions.

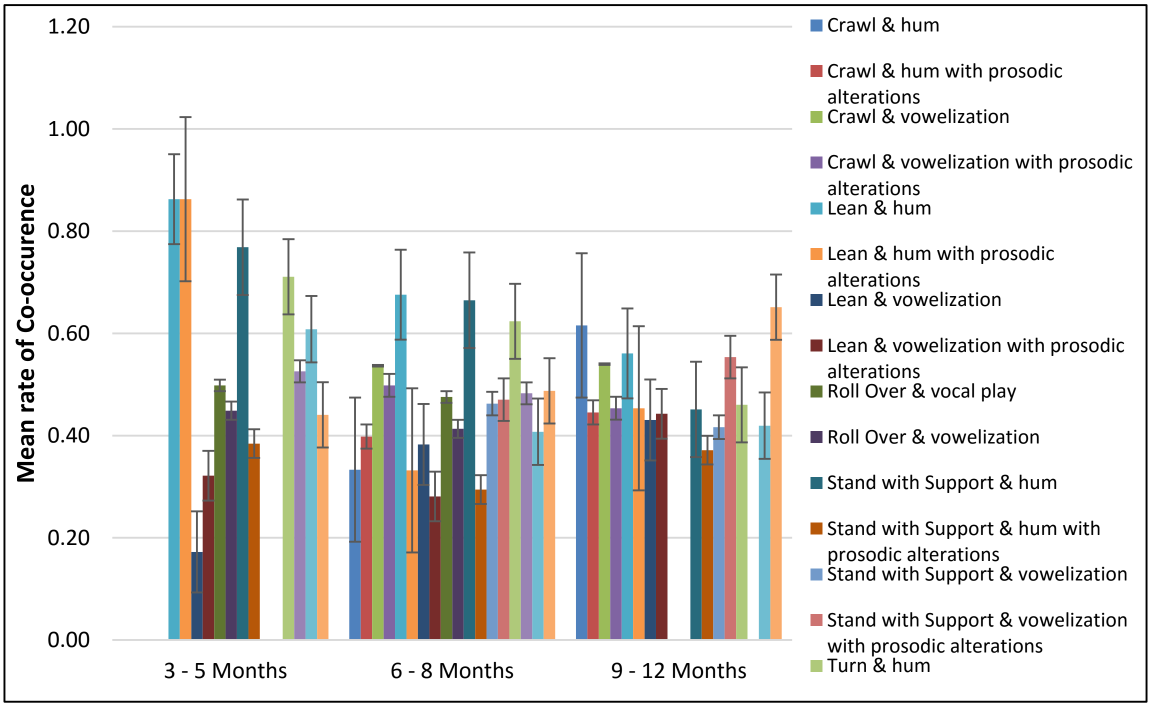


Figure 38(h): Co-occurrence of vocalic utterances and whole body movements.

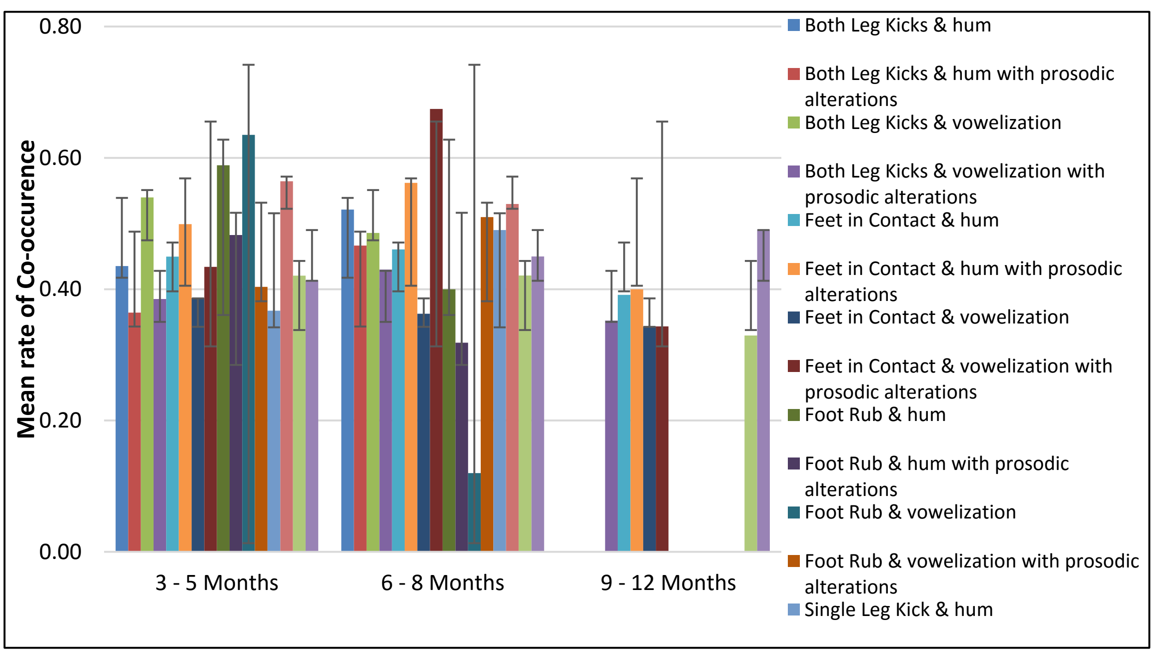


Figure 38(i): Co-occurrence of vocalic utterances and leg movements.

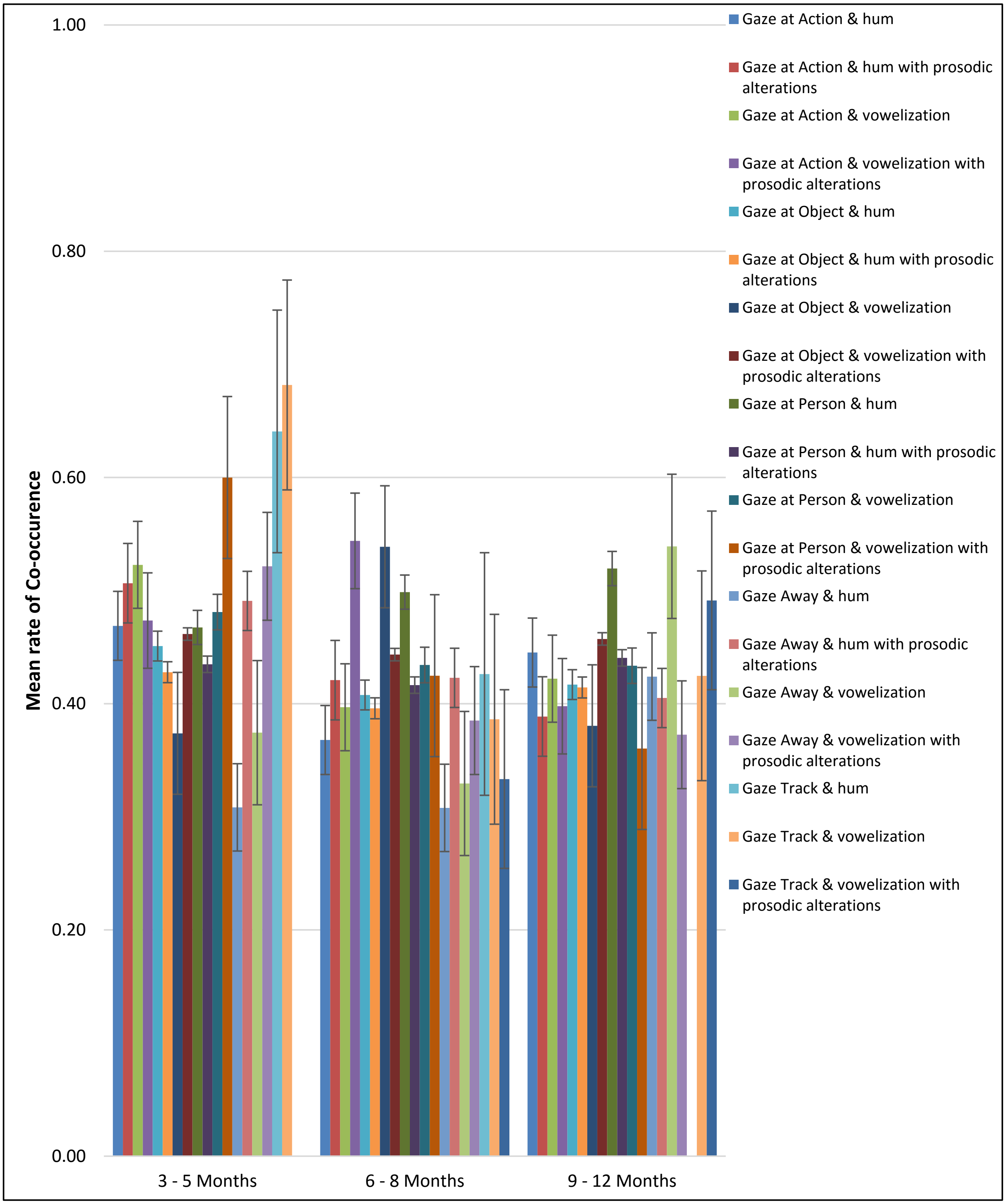


Figure 38(j): Co-occurrence of vocalic utterances and gaze behaviours.

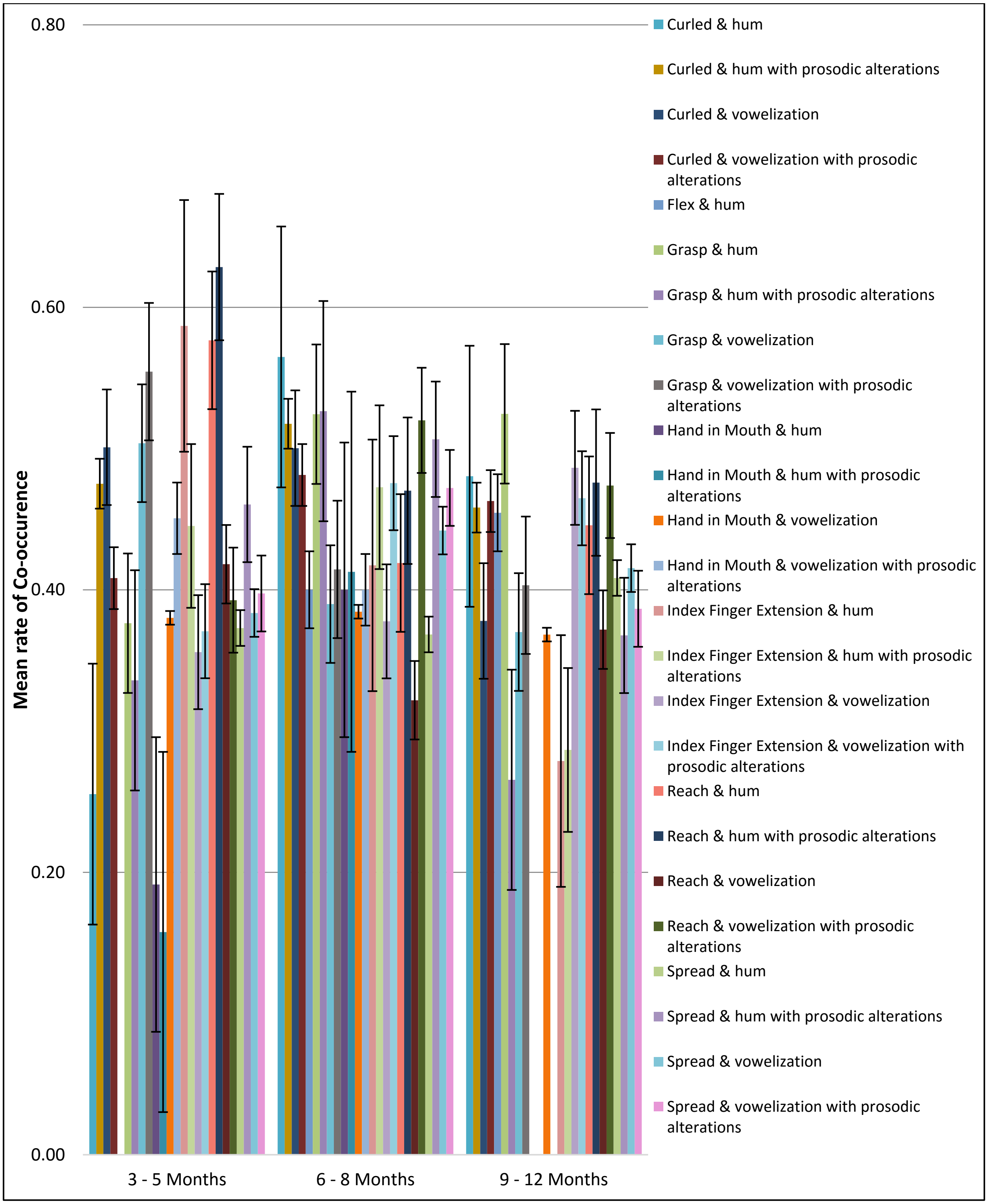


Figure 38(k): Co-occurrence of vocalic utterances and pre-symbolic hand gestures.

From the figures, it can be seen that vocalic utterances co-occurred with all types of gestural behaviours, at variable frequencies, during all the three phases of development. Moreover, the patterns of co-occurrence seem consistent with the occurrence frequency of both speech and gestural behaviours as documented in the study. For example, frequently occurring vocalic utterances such as 'vowelizations with prosodic alterations' seemed to co-occur with most gestural behaviours. It was also observed that there were instances of lack of co-occurrence between the two modalities. For example, vocalic utterances did not co-occur with 'head nod', and this was consistently seen for all developmental time frames.

3. Co-occurrence of syllabic utterances and gesture types

The means, standard deviations and medians for the rates of co-occurrence of syllabic utterances and gestures are as shown in Table 47. From the table one can understand that there are variations in the co-occurrence of syllabic and gestural behaviours, with an increase in age. It can be noted that syllabic utterances co-occurred most frequently with head movements in the initial developmental phase and at low rates with facial movements in the final phase.

The variations in rates of certain coordinated bouts, across the time frames, were reflected in the results of the statistical analysis. There were no statistically significant differences seen in the co-occurrences of these behaviours and speech within each developmental phase. Data treated to Friedman test revealed that statistically significant differences were seen in the rates of co-occurrences across the three time frames for 'facial expressions' (χ^2 (2, N=9)=8.737; p=0.013), 'leg movements' (χ^2 (2, N=9)=12.072; p=0.002) ‘hand gestures’ (χ^2 (2 ,N=9)=5.733; p=0.057), and ‘head movements’ (χ^2 (2, N=9)=12.585; p=0.001) at 0.01 and 0.05 levels of significance, respectively. Further, pair-wise comparisons indicated that the source of this effect ($p<0.05$) was the differences seen in the rates of co-occurrence of syllabic utterances with ‘frown’ (facial expression), ‘clasp’ (hand movement), ‘head shake’ (head movement), ‘head lowering’ (head movement), ‘both leg kicks’ (leg movement) and ‘feet in contact’ (leg movement) between the first and the third pre-linguistic phases.

Table 47

Means, SDs & Medians for rate of co-occurrence of syllabic utterances and gestures

Types of Gesture	**Initial developmental phase**	**Middle developmental phase**	**Final developmental phase**
Facial Expressions	0.49 (0.15); 0.51	0.39 (0.05); 0.26	0.37 (0.11); 0.26
Facial Movements	0.44 (0.21); 0.43	0.50 (0.24); 0.39	0.32 (0.15); 0.24
Gaze Behaviours	0.51(0.16); 0.67	0.46 (0.12); 0.32	0.44 (0.15); 0.27
Hand Movements	0.51 (0.12); 0.44	0.49 (0.16); 0.45	0.47 (0.13); 0.54
Head Movements	0.59 (0.25); 0.33	0.47 (0.13); 0.34	0.37 (0.17); 0.41
Leg Movements	0.50 (0.14); 0.47	0.40 (0.03); 0.28	0.57 (0.20); 0.62
Movements of Torso	0.42 (0.02); 0.25	0.41 (0.09); 0.33	0.40 (0.09); 0.54
Whole body Movements	0.49 (0.11); 0.38	0.49 (0.26); 0.50	0.42 (0.16); 0.40

Figure 39 shows the rates of co-occurrence of these speech behaviours with gestures across the developmental time periods. There were variations seen in the rates across behaviours in the final developmental phase, especially for facial, leg and head movements. However, none of these were statistically significant. Further, it can also be seen that the coordination patterns between the two modalities did differ slightly in the final phase of development, when compared to the other two time periods.

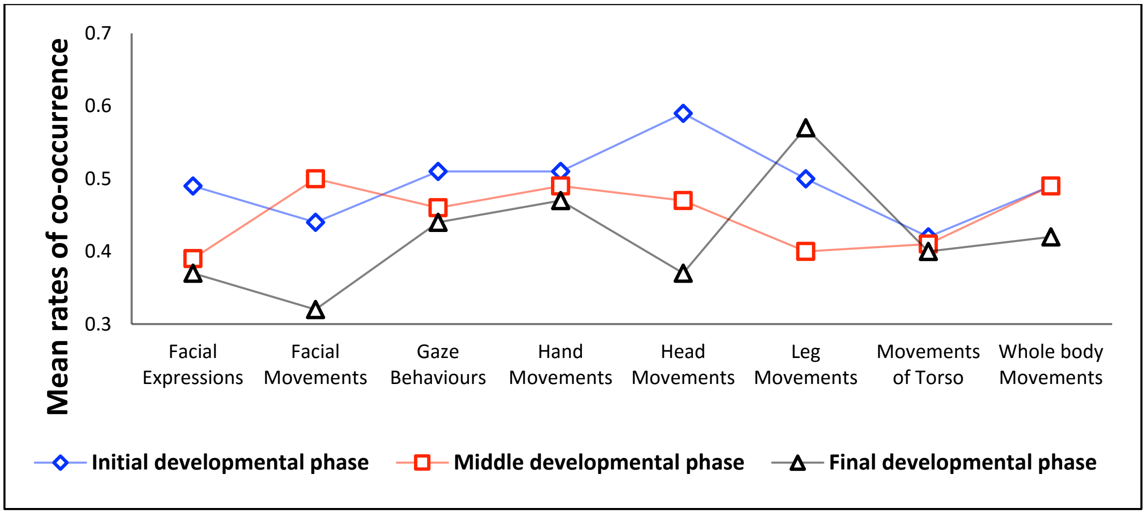


Figure 39: Rates of co-occurrence of syllabic utterances and gestures across the time periods.

Variations were also observed in the co-occurrence of individual behaviours of syllabic utterances and gestures, in that not all gestures co-occurred with speech. The distribution of mean rates of co-occurrences for each of the syllabic and gestural behaviours in each of the developmental time frames is as shown in Figures 40 (a, b, c, d, e, f, g, h, i, & j).

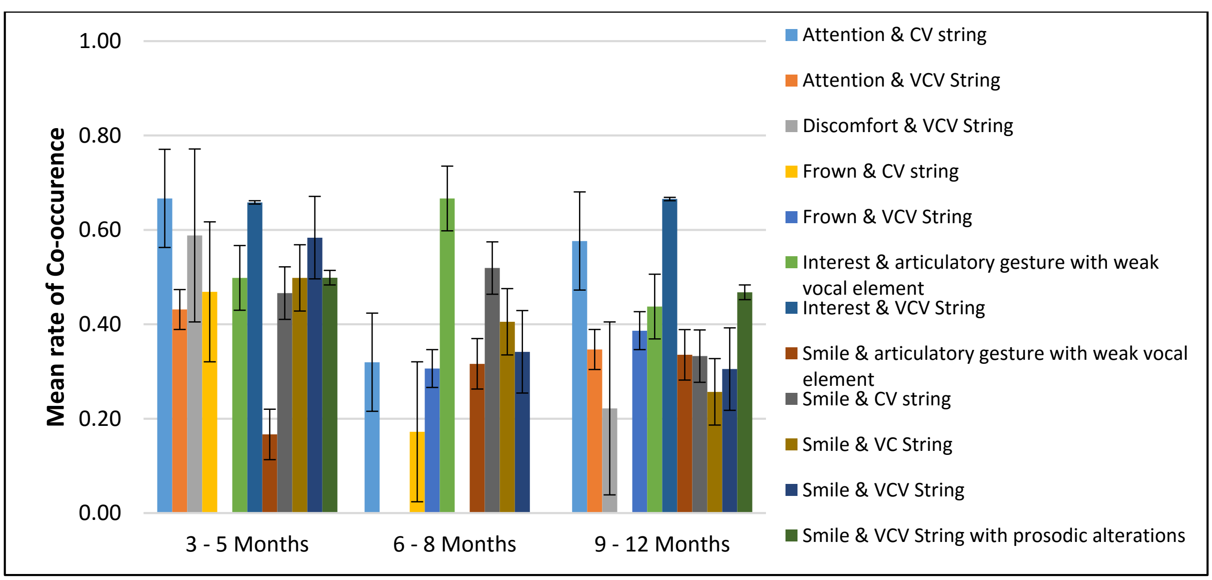


Figure 40(a): Co-occurrence of syllabic utterances and facial expressions.

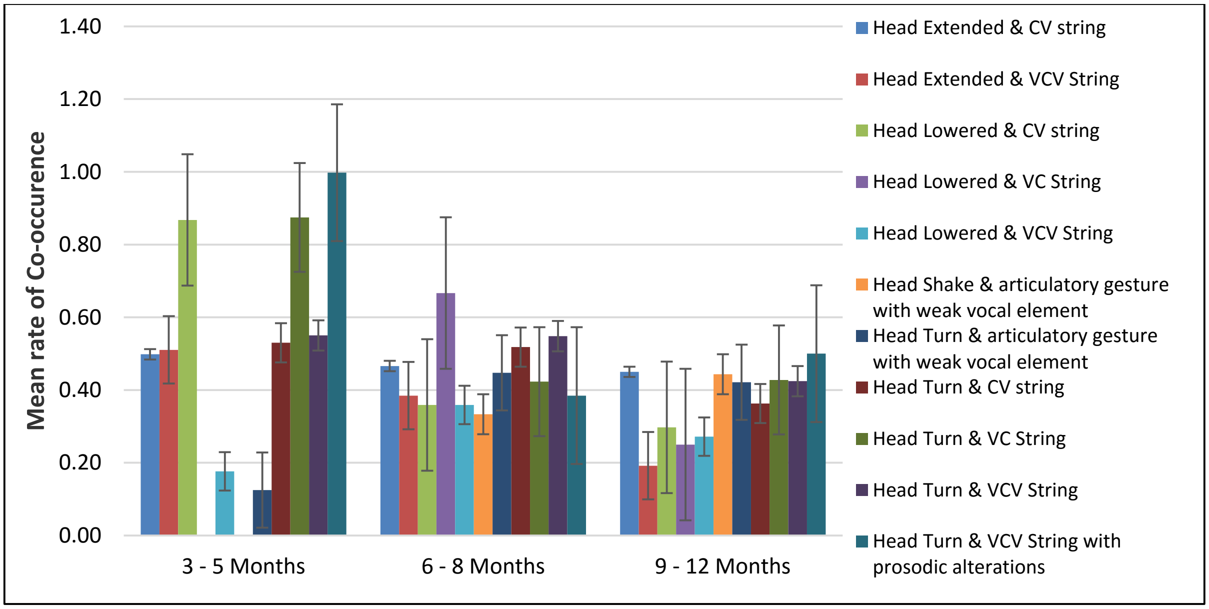


Figure 40(b): Co-occurrence of syllabic utterances and head movements.

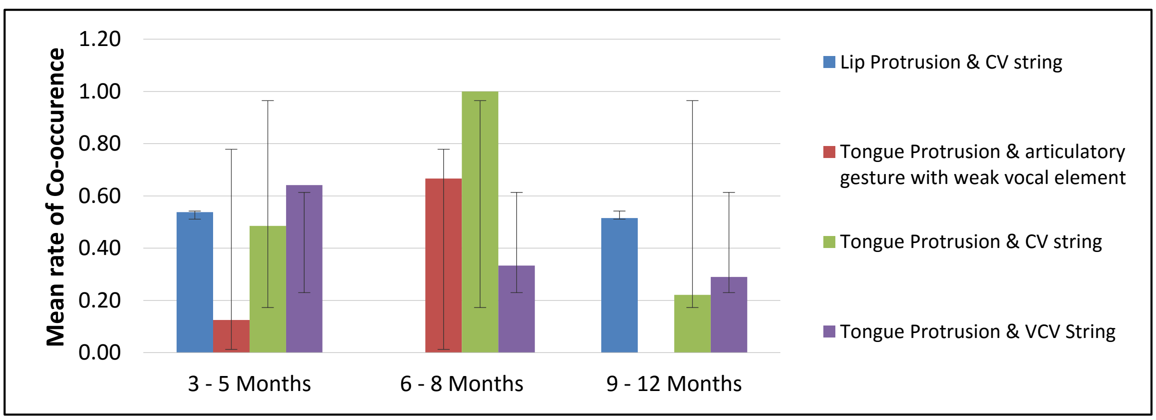


Figure 40(c): Co-occurrence of syllabic utterances and facial movements.

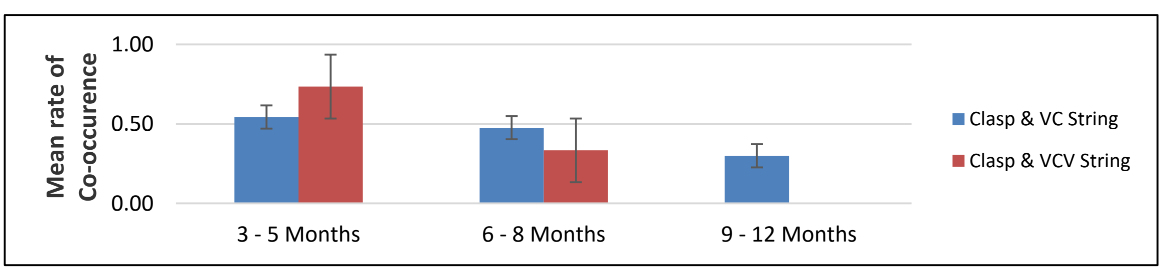


Figure 40(d): Co-occurrence of syllabic utterances and bimanual gestures.

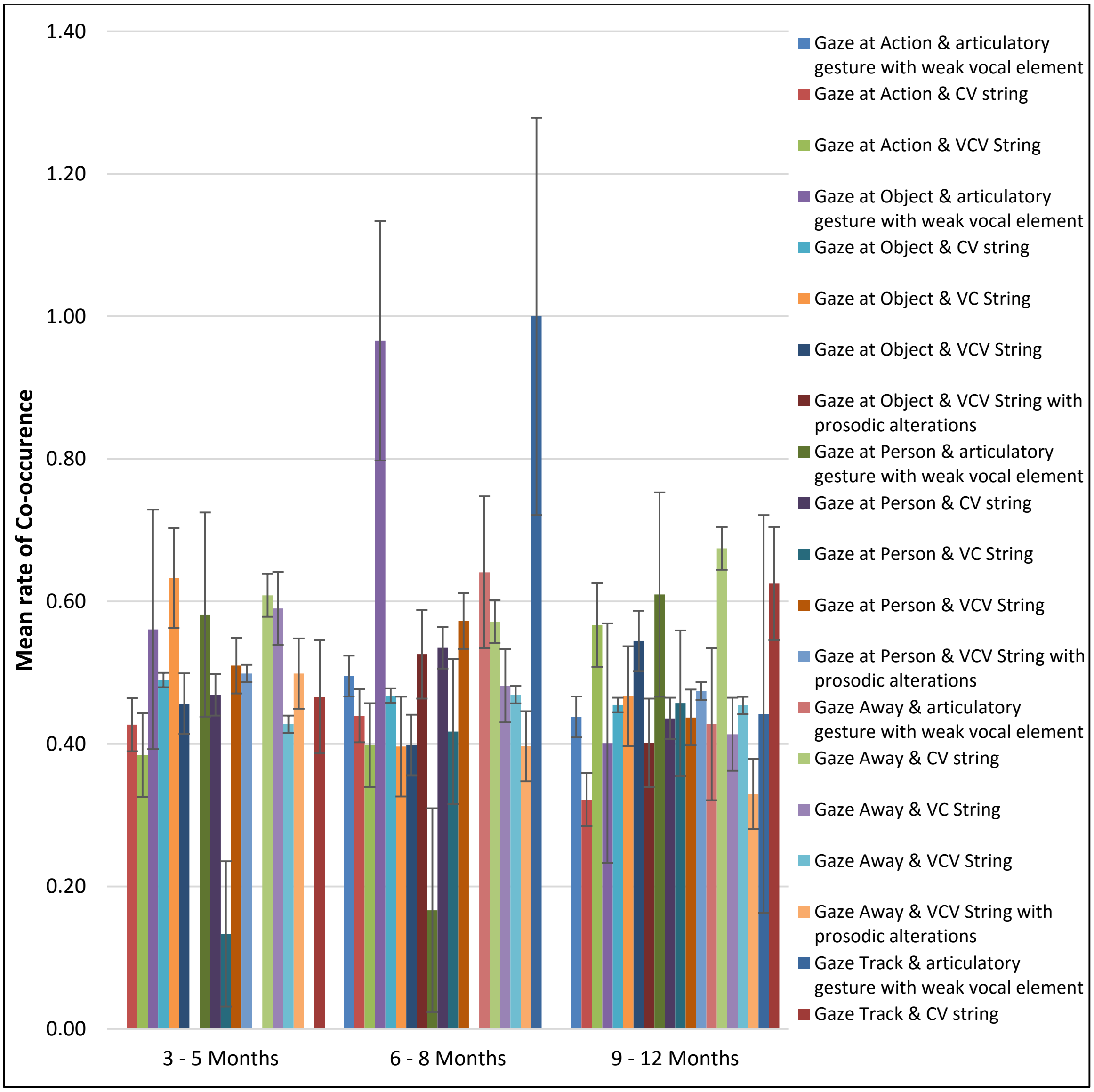


Figure 40(e): Co-occurrence of syllabic utterances and gaze behaviours.

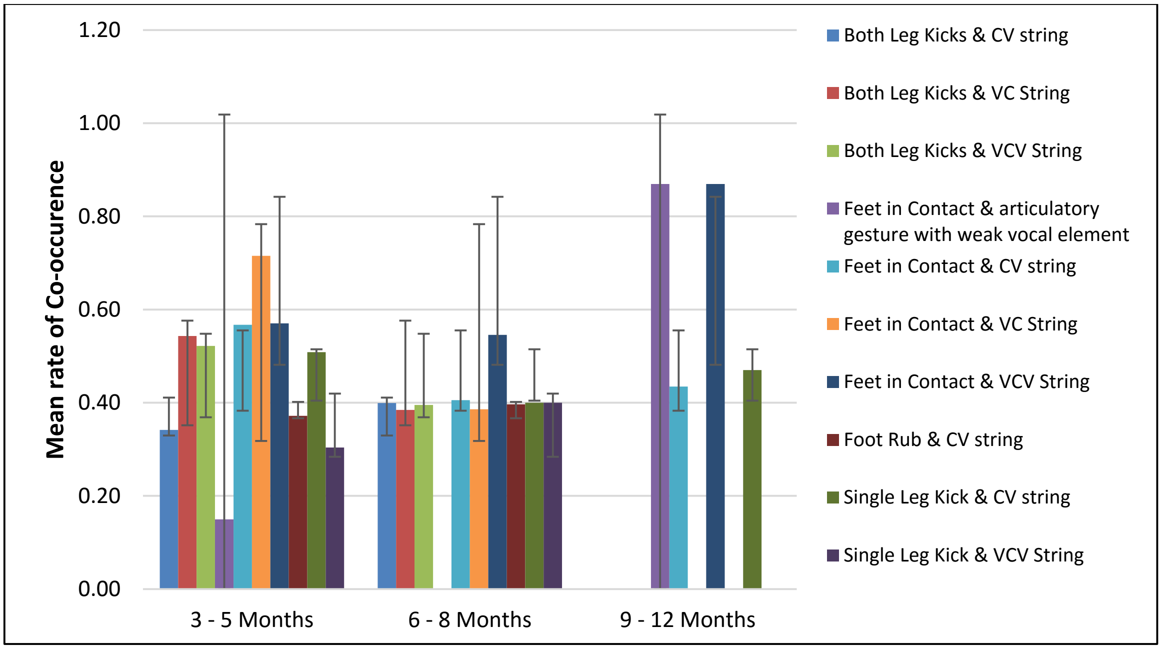


Figure 40(f): Co-occurrence of syllabic utterances and leg movements.

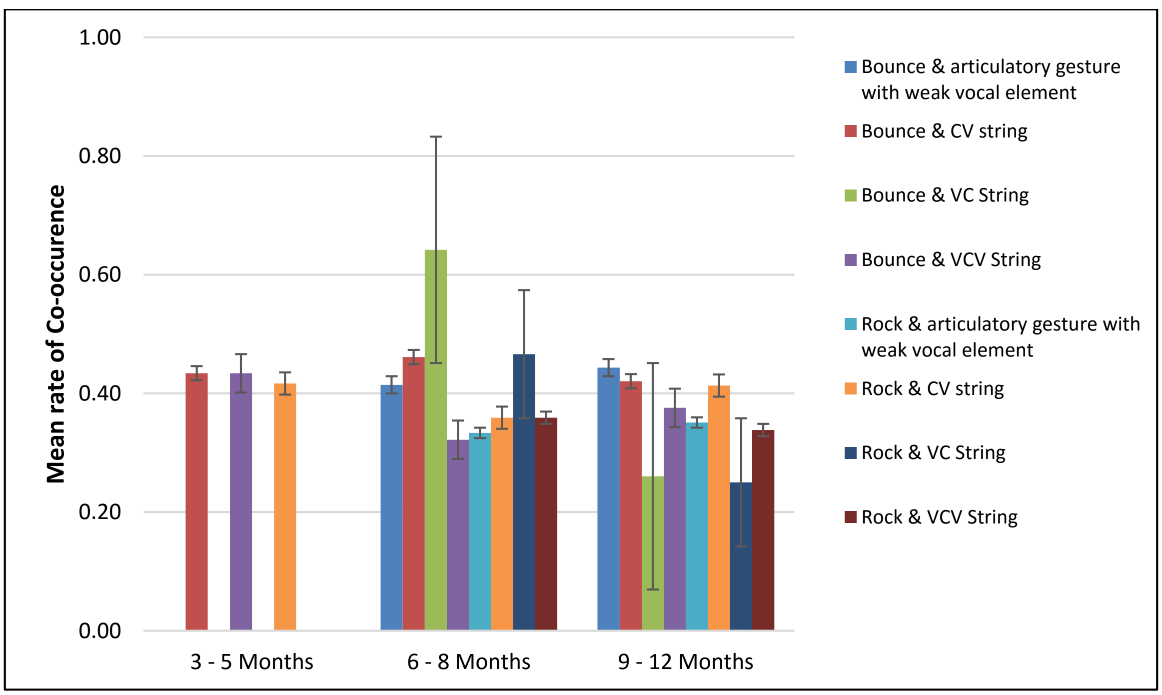


Figure 40(g): Co-occurrence of syllabic utterances and movements of torso.

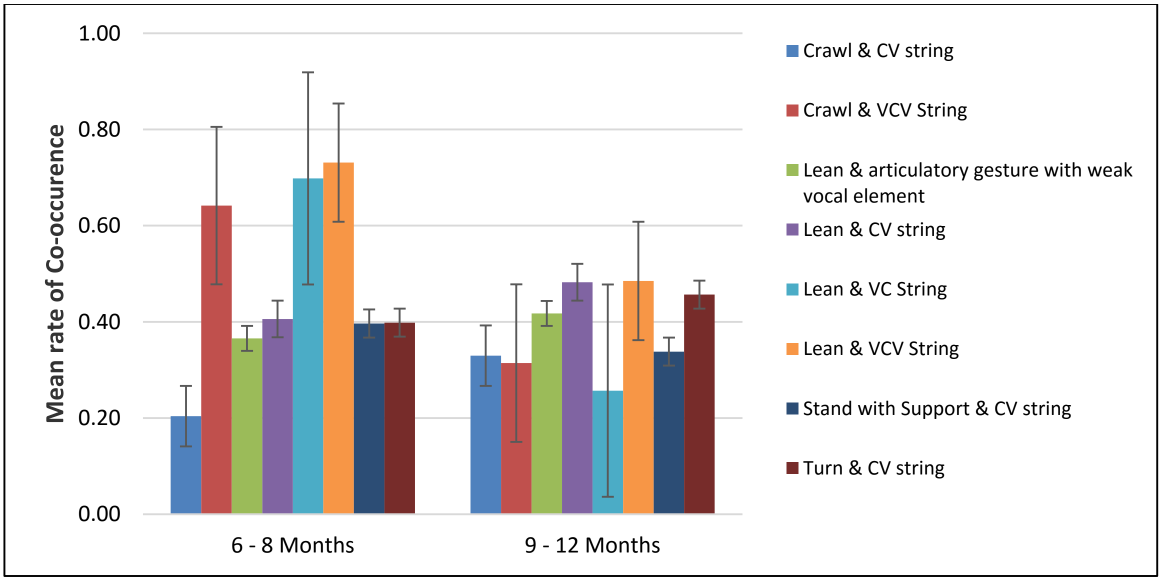


Figure 40(h): Co-occurrence of syllabic utterances and whole body movements.

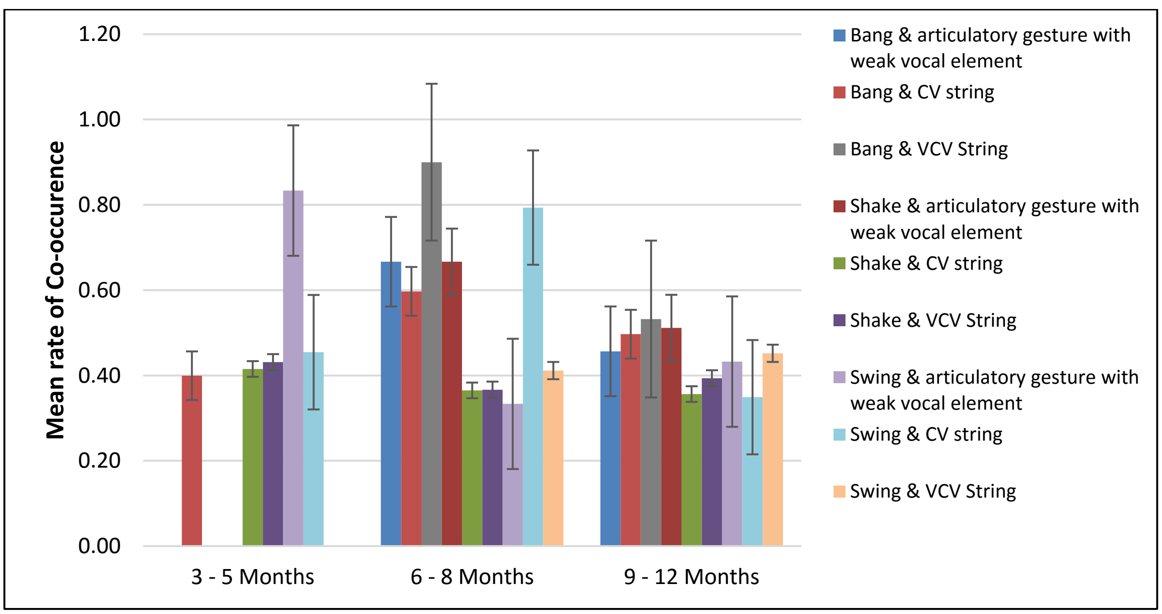


Figure 40(i): Co-occurrence of syllabic utterances and pre-symbolic hand rhythmic gestures.

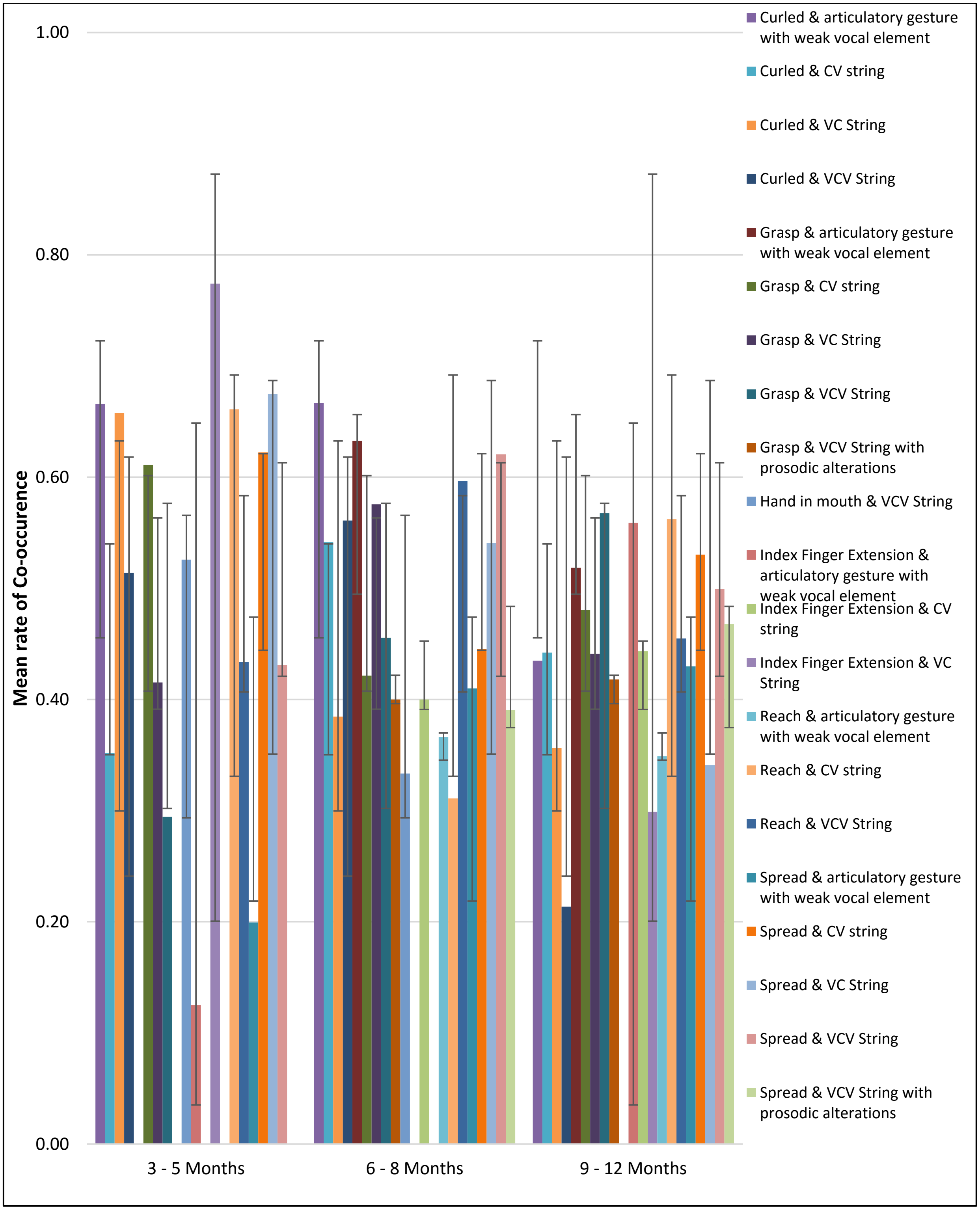


Figure 40(j): Co-occurrence of syllabic utterances and pre-symbolic hand gestures.

From the figures, it can be seen that during all the phases of development, syllabic utterances co-occurred with all types of gestural behaviours, at both high and low frequency. The patterns of co-occurrence seem consistent with the frequency of occurrence of both speech and gestural behaviours as documented in the study. For example, frequently occurring syllabic utterances such as ‘CV string’ co-occurred with most gestural behaviours. However, it must be kept in mind that this was not a common trend that applied to all behaviours. For example, it was also observed that there were instances where two of the behaviours did not co-occur. For example, syllabic utterances did not co-occur with ‘walk’, and this was the trend for all developmental time frames.

4. Co-occurrence of verbal utterances and gesture types

The means, standard deviations and medians for the rates of co-occurrence of verbal utterances and gestures are as shown in Table 48. It should be noted that there were no instances of co-occurrence of these behaviours in the initial pre-linguistic phase of development. This table shows that there was a slightly varied pattern observed in the rates of co-occurrence of verbal utterances and gestural behaviours, across the two developmental time frames. During the middle pre-linguistic phase, the rates of co-occurrence of verbal utterances with facial expressions were lower when compared to other gestural behaviours. Verbal utterances co-occurred most frequently with head and leg movements in the final phase. However, there were no statistically significant differences seen in the co-occurrences of these behaviours between the two developmental time periods.

Table 48

Means, SDs & Medians for rate of co-occurrence of verbal utterances and gestures

Types of Gesture	Initial developmental phase	Middle developmental phase	Final developmental phase
Facial Expressions		0.23 (0.00); 0.33	0.36 (0.28); 0.43
Gaze Behaviours		0.38 (0.03); 0.42	0.41 (0.10); 0.56
Hand Movements		0.35 (0.07); 0.33	0.39 (0.10); 0.40
Head Movements		0.31 (0.11); 0.36	0.42 (0.27); 0.55
Leg Movements		0.39 (0.00); 0.41	0.42 (0.07); 0.57
Movements of Torso		0.00 (0.00); 0.00	0.36 (0.14); 0.24

Further, Figure 41 shows the rates of co-occurrence of verbal utterances with gestures across the time periods, and it suggests that the co-occurrence occurs most frequently in the final developmental phase. This was unlike the patterns seen for the co-ordination bouts exhibited by the other speech behaviours. It can also be seen that there are slight variations in the co-occurrence rates of both behaviours within the middle phase of development, although these were not statistically significant.

It was interesting to note that there were variations observed in the co-occurrence of verbal utterances and gesture types, since all gestures did not co-occur with speech. The distribution of mean rates of co-occurrences for each of the verbal and gestural behaviours for all the developmental time frames is as shown in Figures 42 (a, b, c, d, e, f, & g).

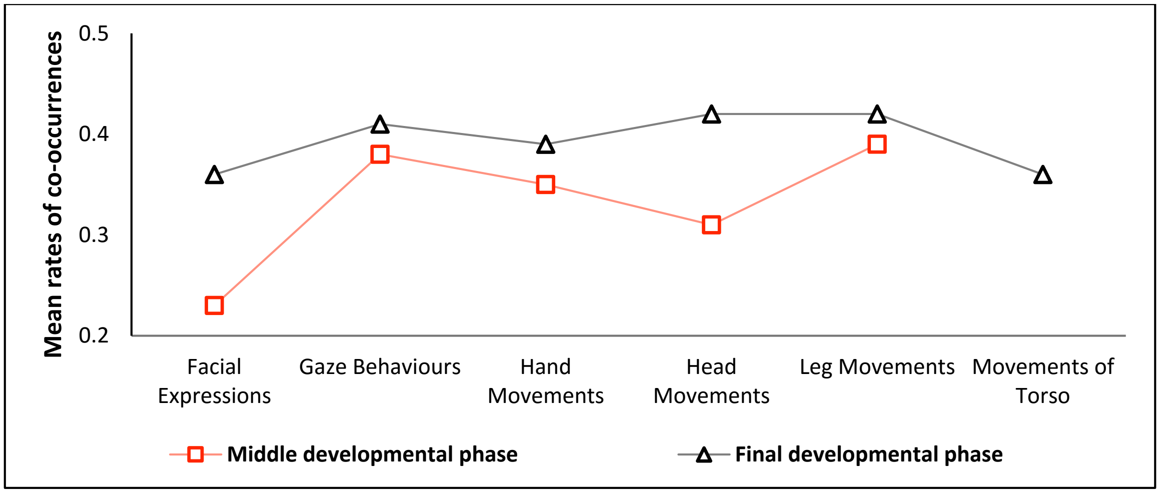


Figure 41: Rates of co-occurrence of verbal utterances and gestures across the time periods.

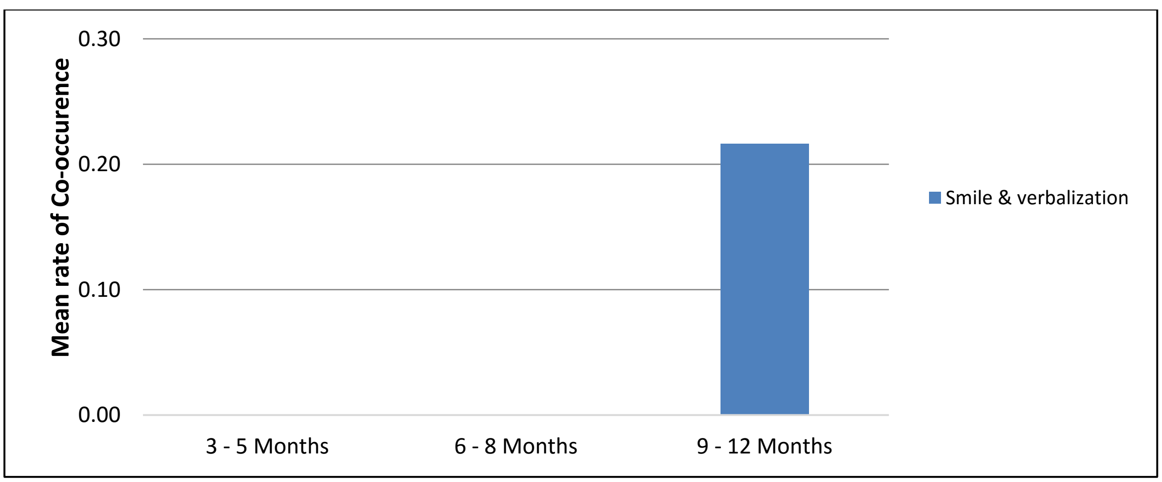


Figure 42(a): Co-occurrence of verbal utterances and facial expressions.

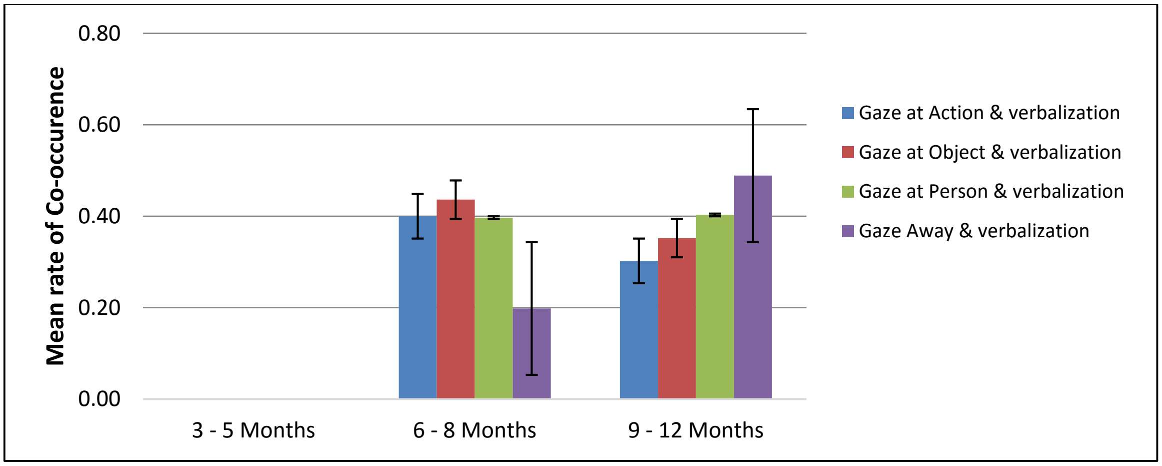


Figure 42(b): Co-occurrence of verbal utterances and gaze behaviours.

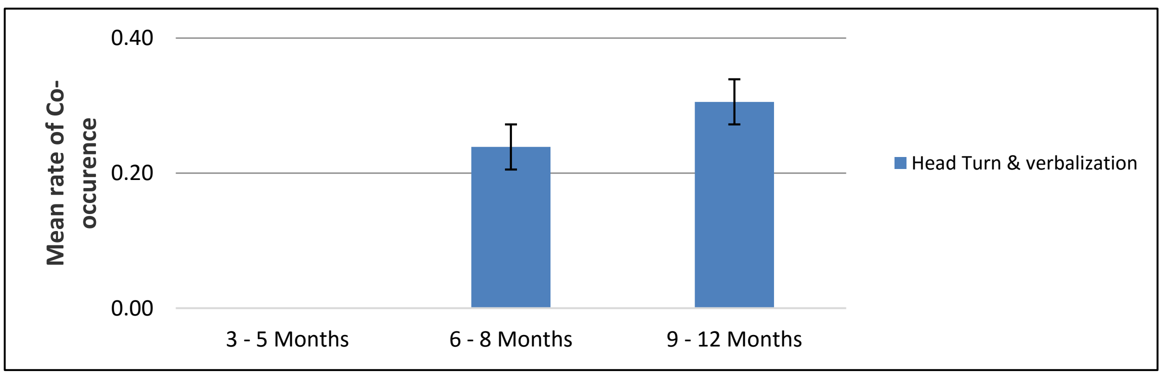


Figure 42(c): Co-occurrence of verbal utterances and head movements.

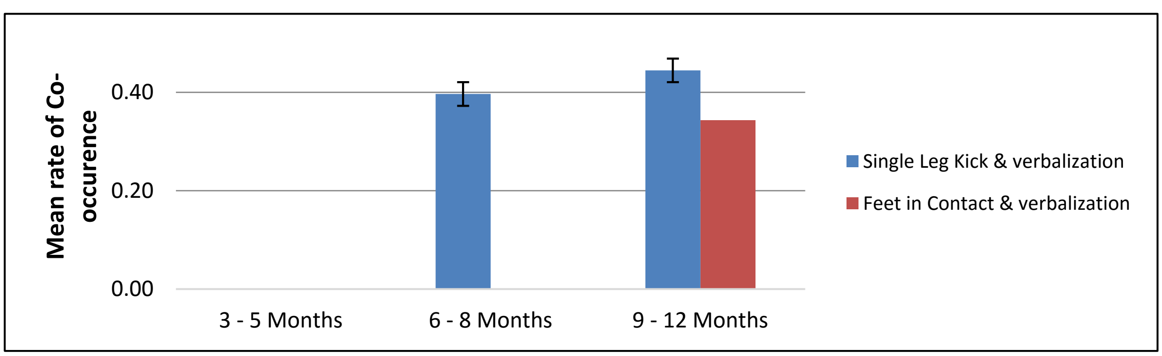


Figure 42(d): Co-occurrence of verbal utterances and leg movements.

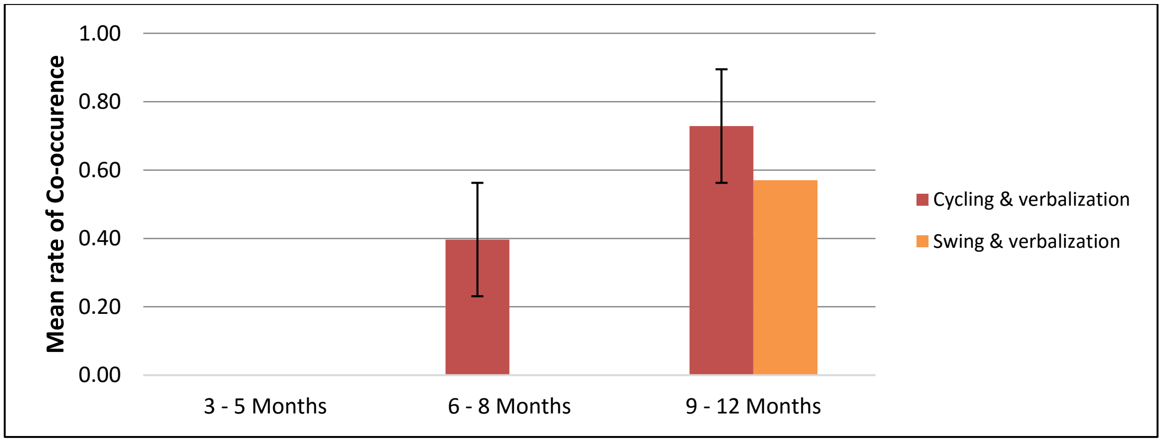


Figure 42(e): Co-occurrence of verbal utterances and pre-symbolic rhythmic hand gestures.

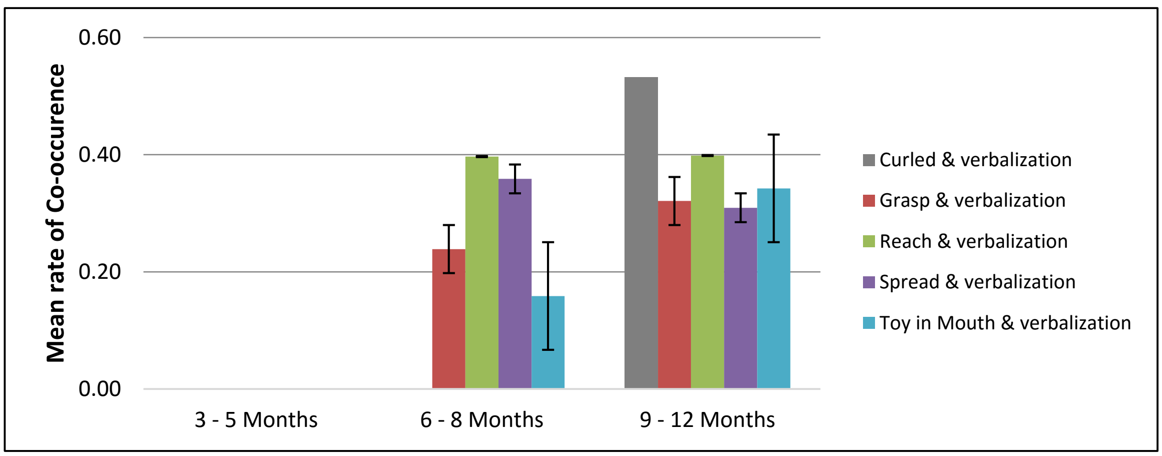


Figure 42(f): Co-occurrence of verbal utterances and pre-symbolic hand gestures.

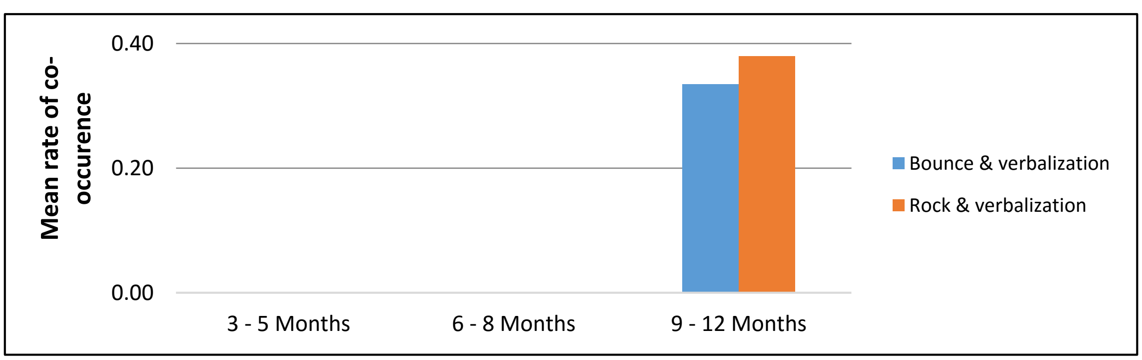


Figure 42(g): Co-occurrence of verbal utterances and movements of torso.

To summarize, it is seen that verbal utterances occurred less frequently with all types of gestural behaviours, during the middle and final phases of development. It was also observed that there were many instances of lack of co-occurrence between the two types of behaviours. For example, among the verbal utterances, 'jargon', 'word', and 'verbalization with prosodic alterations' did not co-occur with any of the gestural behaviours, and this was consistently seen for both developmental time frames. Moreover, it must be noted that although 'verbalization' co-occurred with gestural behaviours, it did not co-occur with frequently occurring behaviours, such as 'gaze track', which were documented with high frequency beyond the age of 6 and 7 months.

Spearman's correlation analysis was carried out to understand if there were significant associations between the coordinated behaviours. The results suggested that, with age, there was a significant positive correlation in the co-occurrence of few pre-speech utterances, namely, 'pleasure sound' with 'smile' (r=0.34; p=0.002); 'vocal play' with 'gaze at object' (r=0.30; p=0.008) and 'head turn' (r=0.30; p=0.007) at 0.01 alpha level of significance. In the case of syllabic utterances the analysis suggested that there were significant positive correlations in the co-occurrence of 'CV string' with 'bang' (r=0.23; p=0.016) and 'grasp' (r=0.36; p=0.001) and negative correlations with 'attention' (r=0.27; p=0.016); 'articulatory gesture with weak vocal element' positively correlated with 'reach' (r=0.47; p=0.000), 'grasp' (r=0.54; p=0.000), 'give' (r=0.44; p=0.000), 'show' (r=0.30; p=0.001) and 'stand' (r=0.30; p=0.007) and negatively with 'attention' (r=-0.32; p=0.004) and 'swing' (r=-0.30; p=0.007); 'CVC string' positively correlated with 'gaze at action' (r=0.29; p=0.009), 'give' (r=0.31; p=0.005) and 'shake' (r=0.36; p=0.001); 'VCV string' co-occurred positively with 'gaze at person' (r=0.26; p=0.021), at 0.05, 0.01 and 0.00 alpha levels of significance.. Among verbal utterances, it was seen that the co-occurrence of ‘verbalizations’ positively correlated with ‘gaze at action’ (r=0.47; p=0.000), and ‘gaze at object’ (r=0.42; p=0.000), while it negatively correlated with ‘attention’ (r=-0.29; p=0.009), at 0.00 alpha levels of significance.

From the above results, it can be understood that speech and gestures co-occurred with each other from the age of 3 months, and with age, there were differences observed in the patterns of co-occurrence for behaviours in both modalities. It was also seen that hand movements co-occurred with speech at highest frequencies across the developmental timeframes that were studied. The other trends seen were as follows:

- There were significant developmental influences seen in the co-occurrence of pre-speech and syllabic utterances with gestures, in that these behaviours co-occurred at lower rates in the final developmental phase suggestive of a decrease in the co-occurrence of both modalities

- There was wide variation seen in the co-occurrence of various behaviours within both modalities and this seemed to reflect that co-occurrence depends on the frequency of occurrence of these behaviours. However, this trend was not uniform across all behaviors suggesting that entrainment does not always depend on occurrence frequency.

- Novel behaviours in both modalities did not co-occur, probably suggesting that only well-practiced behaviours in either modality can influence the occurrence of other behaviours.

DISCUSSION

DISCUSSION

Gestures of face (facial movements and facial expressions), gaze, hands, torso, legs, whole body, and speech behaviours which comprised of vegetative, vocalic, syllabic and verbal utterances were studied in 9 infants (6 boys and 3 girls), in a longitudinal study design. It was hypothesized that: [1] there will be similar patterns of development in gesture and speech systems within the first year of life, and [2] there will be coordination between gestures and speech from the third month of age and further, there will be differential patterns of coordination observed between the various behaviours analyzed across both the modalities within the first year of age. The results as revealed through growth trends and patterns of occurrence, demonstrated the patterns in the occurrence of gestures and speech behaviours, as well as the co-development of gestures and speech. The results were presented under the following sections in the previous chapter and the discussion will follow the same order.

I. Development of gestures and speech

II. Patterns of co-occurrence of speech and gestures

I. Development of gestures and speech

1. Facial gestures

While considering the emergence of facial expressions and facial movements in infants, some interesting trends were seen.

1.1. Growth trends

Among the facial expressions analyzed, the occurrence of ‘attention’, ‘displeasure’, ‘discomfort’, ‘frown’ and ‘interest’ were found to have a statistically significant developmental influence on the production of these behaviours, with these gestures occurring at lower rates as the age of the infants increased. Amongst the facial movements, the occurrence of ‘mouthing’, ‘lip protrusion’ and ‘tongue protrusion’ were found to have statistically significant developmental influence, with the trend being the same as that of facial expressions, i.e. with age there was a reduction in the occurrence of these behaviours. These findings suggest that there were significant changes in the occurrence of these behaviours with an increase in age. Additionally, the correlation analysis revealed that ‘attention’, ‘frown’, ‘interest’, ‘discomfort’, and ‘smile’ exhibited a significant negative correlation in the rates of occurrence with age. Among facial movements, both ‘mouthing’ and ‘tongue protrusion’ exhibited similar trends towards the end of the first year of life. These results point towards the trend of reduced frequency of occurrence towards the end of the first year of life for facial gestures.

The occurrence patterns of facial gestures also revealed good correlation among the various types. For example, with age, the rates of occurrence of ‘frown’ positively complemented the occurrence of ‘attention’, and the occurrence of ‘tongue protrusion’ positively complemented the occurrence of ‘mouthing’. Thus, apart from the influence of biological maturation on development, it seems like one gesture influences the occurrence of others within the same system, i.e. face, for the purpose of development (Smith & Thelen, 2003), and this is similar to what has been observed in the development of linguistic (de Bot et al., 2007; Vihman et al, 2009) and even prosodic systems (Schmidt & Post, 2015).

Behaviors such as ‘attention’, ‘frown’, ‘interest’, ‘discomfort’, ‘smile’, ‘mouthing’, ‘tongue protrusion’, ‘lip play’ and ‘lip protrusion’ demonstrated non-linear growth trajectories, possibly suggesting that development of facial expressions does not happen in a step-wise manner, but in stage-like shifts (Thelen & Smith, 1994), within the first year of life. This variability might also account for variation observed in the frequency of production and even in the ages of acquisition of these gestures in typically developing children (Vereijken & Adolph, 1999). This perhaps suggests that variation in the occurrence of behaviours does not indicate non-normal development. Interestingly, ‘displeasure’, ‘startle’ ‘pout’, ‘puckered lips’ and ‘tongue play’ exhibited unpredictable trends, possibly since these gestures occurred less frequently in the study. It was also seen that the occurrences of most facial movements were scattered across various months. This points out that, the growth trends of all gestures are not predictable within the first year of life.

Further, there was a significant change in the occurrence rates of both facial expressions (in the 6^{th} month) and facial movements (in the 5^{th} month) within the first year of life. This implies that even though there are variations seen in the production of these gestures, one can expect a significant change in the occurrence of gestures within the facial system. This is in consonance with studies that have studied the development of other systems, such as limbs (hands and legs) and vocal systems (Abney et al., 2014; Adolph & Robinson, 2015).

1.2. Patterns of occurrence

All facial expressions, except ‘displeasure’, were seen at the age of 3 months, with most of these gestures occurring at low frequencies even in the 12th month. The gesture ‘interest’ was primarily seen when the infant was gazing at the mother’s face or when a new object was introduced, especially during the months when the infants were either in a supine position or were being held by the mother. The same was the case for ‘attention’ and ‘frown’. Both these gestures, i.e. ‘attention’ and ‘frown’ often occurred when the infants were vocalizing. This does seem to imply that these expressions do have a link to active information processing (Doherty-Sneddon & Phelps, 2005) as well as the possibility that these gestures are indicative of the effort needed for speech production. A reason for the same could be that at an early age, the production of vocal behaviors might require the allocation of many resources which may not be easily available to the infant considering the poor neuromuscular and postural control. The subsequent decline in their occurrence could again imply that as the skills of the infants mature, they no longer require these facial expressions to convey their interest in novel stimuli, objects or even in other contexts such as that of vocal production.

Further, ‘attention’ and ‘frown’ are reported to be seen in those situations in which the infant feels challenged or in those that require problem solving (Bronson, 1972; Lewis & Michelson, 1983). It has been suggested that these expressions are seen frequently in younger infants, and is seen to decrease between the ages of 2 and 8 months followed by their re-appearance between 10-12 months (Lewis, Sullivan & Alessandri, 1990; Malatesta & Haviland, 1982). Similar to what was observed in the current study, these earlier studies have speculated that these gestures are a form of focused and effortful attention associated with active information processing, and changes in their occurrence depends on the type and quality of stimulation that the infant encounters during interactions.

There were variations in the occurrence of ‘startle’ throughout the study period. A possible explanation for this variation could be that this gesture occurred only in a specific context, that is, when a sudden and novel stimulus was introduced. For example, in the study, most often the presence of a loud auditory stimulus, either a musical toy or objects falling in the background elicited this response from infants. Startle has often been compared to the surprise expression seen in infants, and it has been documented as an expression that is rarely seen in young infants (Bennett, Bendersky & Lewis 2002; Camras, 1992). Even in this study, ‘startle’ was not observed in all the infants, as evidenced by their reduced frequency of occurrence when compared to that of the other facial expressions. It has been suggested that infants begin to show mild expressions of surprise to novel events by 6 months of age and that some infants may exhibit the same behavior prior to 6 months (Bennett, Bendersky & Lewis 2002; Charlesworth & Kreutzer, 1973). Providing support to the latter observation, infants in this study were found to exhibit this expression as early as 3 months of age. It has also been suggested that startle or surprise might occur only in emotionally reactive children, and is dependent on factors such as the suddenness of the stimulus and its intensity. These factors could have also played a role in this study, but these were not examined closely.

‘Smile’ was often elicited when the infant was interacting with his/her mother, especially when the mother was speaking to the child or being playful. At later months, the infants seemed to be conscious of the presence of the examiner and did not tend to smile very often. When it did occur, smiles were observed when the infant watched the actions of the mother or during object manipulation. It was also observed that among the nine infants, there was one female child who rarely smiled even at the age of 3 months, implying that there are variations in the emotional reactivity of infants. Sullivan and Lewis (2003) reported that smiles are seen in infants between 6 and 8 weeks to both auditory and visual stimulation. By 16 weeks of age, dramatic changes are said to occur in this expression in response to social stimulation. Beyond this age, it has been observed that infants become more discriminating regarding their smiles. The elicitation might depend largely on familiarity and the behavioural styles of the interactive partner. A similar pattern was seen in the current study.

'Displeasure' and 'discomfort' are said to reflect expressions of pain that are indicative of both physical and non-physical pain (Oster, Hegley & Nagel, 1992). These gestures are also considered as negative emotional responses that convey emotional and regulatory responses to various forms of aversive stimulation (Grunau, Oberlander, Holsti & Whitfield, 1998; Oberlander, 2001). These expressions have been documented from the newborn period with little change occurring in the following months (Craig, 1992; Johnston, Stevens, Craig & Granau, 1993; Lilley, Craig & Grunau, 1997). In this study, both 'displeasure' and 'discomfort' were produced less frequently. However, this finding has to be interpreted with caution since the investigator did not continue recording whenever there was excessive crying or fussing, and this obviously lead to fewer annotations of these gestures. There were differences in the situations that elicited both these gestures, in that, 'discomfort' was always seen when the child was crying, whereas 'displeasure' was seen when the infant was no longer interested in a stimuli or was in an uncomfortable position and this was not often accompanied by crying.

Among the facial movements, all gestures were seen from the age of 3 months in the study, with only ‘lip protrusion’, ‘mouthing’ and ‘tongue protrusion’ occurring at very low frequencies in the 12th month. Infants produced the gestures ‘lip play’ and ‘tongue play’ at their own will and they seemed to enjoy producing these behaviours. These were often seen when the infants were engaged in play or looking at the actions of the mother or even while looking at the mother. They were also seen to occur during the production of ‘raspberry’/ or bilabials trills during vocal play, and were frequent during the period when infants were confined to a supine posture. With improved neuromuscular and vocal maturation there seemed to be a reduction in these behaviours. For example, vocal behaviours such as trills are reported to be seen only between 4 and 6 months (Stark, 1978) and beyond this age, infants have mature vocal repertoires, and hence a possible reduction in these facial gestures.

‘Lip protrusion’ and ‘tongue protrusion’ were observed to occur randomly, both when the infants were resting as well as when engaged in play, and the infants did not seem to produce these with any purpose. Jacobson (1979) proposed that tongue protrusion may be a neonatal reflex which is adapted for feeding and therefore any stimulus approaching the infant’s mouth might trigger this. Even in this study, such a ‘trigger’ condition was observed. Tongue protrusion was often seen when the infants were smiling or when they had a hand-held toy approaching the mouth and both protrusion of the ‘tongue’ and ‘lips’ were seen when the infants assumed an ‘open-mouth’ posture. In another study on infant imitation, it was reported that tongue protrusions could also reflect early attempts at oral exploration of interesting objects within the reach of the children (Jones, 1996). This would, then, explain the presence of these behaviours at a very young age and their relative disappearance with improved manual exploratory skills. Thelen (1981) has suggested that tongue protrusions may be considered as rhythmical movements of the tongue as it involves the pushing-out and pulling-in motion of the tongue. However, in her study (longitudinal study comprising of 20 infants) there was only one instance of production of this gesture, which was observed only in one infant. In the current study, ‘tongue protrusions’ were the most frequently produced gestures among all facial movements.

‘Lip pouting’ and ‘lip puckering’ were behaviours that were least observed in this study as they were produced by only few infants. It was noted that these gestures occurred when the infants seemed upset about a stimulus or situation, and not accompanied by crying. These movements often involved the infant fixing his/her gaze at the mother, which in turn elicited a response from the mother. In a similar vein, Sullivan and Lewis (2003) have suggested that pouts are observed in situations that frustrate or elicit fear in the children, and are typically directed at a social partner. These behaviors are said to occur across all age ranges and it has been suggested that they might reflect an internal self-regulatory process or a competing tendency (Oster, 2004).

In this study, ‘mouthing’ was described as any movement of the tongue or lip that resembled ‘speech-like’ utterances without vocal accompaniment. It was a frequently noted behavior in these infants at younger ages with a decline in the occurrence as the study progressed. This decline possibly indicates a transition towards the production of mature vocal productions in the infants such as ‘articulatory gestures with weak vocal elements’, which resembled mouthing but were accompanied by vocal productions. Also, it is well established that from the 4th month of life, infants begin to produce speech-like utterances and are more vocally active (Stark, 1978), which could in turn lead to a reduction in the occurrence of 'mouthing'.

A close look at the raw data did reveal that girl infants exhibited higher rates of occurrences for 'displeasure', 'smile' and 'startle' over several months. The same was the case for facial movements. For example, boys were observed to produce lesser instances of movements such as 'pout', 'puckered lips' and 'tongue play'. A previous study on emotional and behavioural expressions in 6 month old infants, reported that boys expressed significantly more instances of anger and joy, while girls demonstrated more instances of interest (Weinberg, 1992), which is contrary to the observations in this study. Weinberg, (1992) explained this difference as indicative of boys being possibly more affectively reactive and socially directed than girls who were more object-oriented. This suggestion does not seem plausible for the infants observed in this study.

There are also accounts which propose that gender-related differences in parental behaviors which are often evidenced as differences in the interactional styles of the parents, may contribute to differences in the production of behaviours. Mothers are reported to engage in face-to-face interaction with their daughters than their sons and are also observed to hold and touch their male infants longer than their female infants during attempts to soothe the infants (Goldberg & Lewis, 1969; Golombok & Fivush, 1994; Lewis, 1972; Parke & Sawin, 1980). Even in this study, differences in the interactional styles towards infants of different genders was noted, but one cannot arrive at conclusions since there was lack of uniformity in the number of male and female infants included in the study. However, mothers of the two boy infants seemed to exhibit the interactional styles similar to that mentioned in these previous studies (Goldberg & Lewis, 1969; Golombok & Fivush, 1994; Lewis, 1972; Parke & Sawin, 1980).

There is a lack of previous evidence in terms of gender differences in the production of facial movements. Since these movements seem to randomly occur and appear closely related to exploratory skills of the infants, it might suggest that these gestures are seen in all infants irrespective of the gender. However, the observation in this study suggests that this might not be the case, but, this has to be further explored in studies with even number of participants to represent both genders.

2. Gaze behaviours

Gaze is considered an important cue into understanding of infant behavior (Baron-Cohen, 1995; Langton, Watt, & Bruce, 2000), and in the current study there were some definite trends seen in the development of the gaze system.

2.1. Growth trends

Among the gaze behaviours, a significant developmental influence on the occurrence of 'gaze at action', 'gaze away', 'gaze at object', and 'gaze track' was seen. The trend suggests that with an increase in age, the occurrence of these gestures changed; with 'gaze away' demonstrating reduction in rates, and 'gaze at action' and 'gaze at object' increasing in rates. 'Gaze track' also exhibited an increase in occurrence, although there was a marked reduction in the occurrence of this gesture in the 12^{th} month of age. Additional support for these findings was derived from the correlation analysis as this suggested high positive correlation in the production of 'gaze at action', 'gaze at object', and 'gaze track' with age, and the opposite trend for 'gaze away'.

There were also varied patterns of coordination observed among these gestures, as suggested previously by Smith & Thelen (2003). For example, the occurrence of 'gaze at object' and 'gaze at action' positively complemented each other with age, while that of 'gaze away' and 'gaze at object' negatively complemented their occurrences. Both these trends can be assumed to aid the maturation of skills such as environmental manipulation and exploration. For instance, with age, infants possess better information processing capacities, and therefore, would not need to possibly exhibit 'gaze away' behaviour, as a mechanism of re-orientation (Johnson, Posner & Rothbart, 1991; Ruff & Rothbart, 1996), which will in turn help them maintain attention and motivation to interact with environmental stimuli for a prolonged period of time. Subsequently, this interaction, results in the production of object-related gaze behaviours.

Additionally, gestures such as 'gaze at action' and 'gaze away' demonstrated non-linear trajectories, while 'gaze at object' showed a linear trend, both suggesting that development within the first year of life does not necessarily happen in a step-wise manner, but in stage-like shifts (Thelen & Smith, 1994), similar to what has been previously observed in the development of linguistic (de Bot et al., 2007; Vihman et al, 2009) and even prosodic systems (Schmidt & Post, 2015). Such variability might also account for differences seen in occurrence rates and ages of acquisition of these gestures in typically developing children, often not indicative of non-normal development (Vereijken & Adolph, 1999). Further, 'gaze at person’, ‘gaze track’, and ‘gaze shift’ demonstrated unpredictable trends. Infrequent occurrence of behaviours could explain the unpredictable pattern in the case of ‘gaze shift’, but not in the case of ‘gaze at person’ and ‘gaze track’, probably suggesting the influence of other factors in play. It is possible that the toys that were provided to the children at this age (e.g. kitchen set/tool house and farm animals) did not elicit tracking behaviour in the children, since this reflects the ability of the infant to follow the path of an object, and in this case, none of these toys exhibit motion. This suggests that the production of gaze behaviours is dependent on the characteristics of the stimuli that children encounter. While in the case of ‘gaze at person’, it was noted that there were only slight variations seen in the occurrence rates, but this was seen for every month of observation. To some extent, therefore, the results of the change point analysis are consistent with previous reports for the development of limbs and vocal systems (Abney et al., 2014; Adolph & Robinson, 2015), in that there was a significant change in the occurrence of gaze behaviours in the 8th month of age, suggesting that within the first year of life one can expect a change in this system.

2.2. Patterns of occurrence

All gaze behaviours, except ‘gaze shift’ were seen from the age of 3 months in the study. Few of these gestures were found to occur more frequently even in the 12th month of age, while others had low occurrence rates at this age. ‘Gaze at person’ was a gesture seen in all infants. By 6 weeks of age, infants are able to visually fix on their mother’s eyes and are able to hold this fixation, which continues to lay the foundation for further social interactions with the caregiver, especially if the caregiver also reciprocates (Owens, 2012). This could possibly explain the high occurrence of ‘gaze at person’ behaviour seen in this study at the age of 3 months itself and this gesture continued to occur across all the months of study.

Johnson (2001) also observed that in the first few months of life, infants’ attention is slow and that they may have difficulty shifting their gaze between different stimuli (Johnson, 2001). There is a shift in this pattern as the infant grows older as the orienting system becomes functional (Johnson, Posner & Rothbart, 1991; Ruff & Rothbart, 1996). This in turn helps infants in shifting attention between stimuli, and thus helps them improve gaze control. This may also explain the high frequency of occurrence of ‘gaze away’ gesture at younger ages and the relative decrease in the occurrences of this behaviour as the infants grew older. This suggests that the infant is looking away from a stimulus with gaze not focused on any other stimuli; and it is possible that since their cognitive and attentional abilities are poorer at younger ages, they may have to ‘look away’ to re-orient themselves to the stimuli or just disengage their gaze.

Between the ages of 3 to 6 months, infants are reported to be attracted by novel form of objects and events (Newson & Newson, 1975). This was also evidenced in this study. Gestures such as ‘gaze at object’ and ‘gaze at action’ were found to increase with age. This further coincides with the maturation and progression of motor milestones of neck and limbs which allows the infant to explore its environment independently. Acquisition of this mobility aids the infant in locating objects, events or actions of caregiver that evokes the infants’ attention. Similar justification holds good to explain the pattern seen for gesture ‘gaze track’.

‘Gaze shifts’ were seen only in some months and were produced by very few infants. Studies have suggested that gaze shifting is primarily reactive and governed by the novelty of the stimulus (Blaga & Colombo, 2006; Dannemiller, 2005), which would explain the trend seen for this gesture in the study. Infants were observed to shift their gaze when a novel stimulus was introduced by the caregiver or while they gazed at the caregiver while simultaneously manipulating an object in their hands.

A closer look at the samples during the coding of the behaviours revealed that there were context-dependent influences in the production of these gestures. For example, it was observed that most of these behaviours were frequently seen in those infants whose mothers showed good initiative to play with their children. Infants who were not engaged by their mothers often fixed their gaze on objects of their interest or frequently exhibited ‘gaze away’ behaviour. Moreover, as infants grew older, their interest and attention was frequently held by objects and their own actions on objects, although they did not ignore the presence of the caregiver. Both self- motivational factors and maturation of related motor skills such as head and neck control, ability to sit, locomotion and development of hand movements seems to have an influence on the emergence of the gaze behaviours. For example, the ability to track the movement of an object or person depends on the infant’s ability to turn his/her head along the path of the movement. Such a skill is enhanced when the child is able to sit and observe the trajectory of the object independently, when compared to a supine position. This could possibly explain the trend for ‘gaze track’ seen in the study. Similarly, as the infants grew older they were able to independently explore and manipulate their environment, which in turn resulted in the emergence and frequent occurrence of different patterns of gaze such as ‘gaze track’. On the other hand, when the same infants were younger, they mostly looked at their caregiver or the object that the caregiver brought to their field of vision. However, it must be noted that there was a decline in the occurrence of ‘gaze-track’ in the 12th month, possibly due to the immobile nature of toys (e.g. kitchen set/tool house and farm animals) that were provided to the infants.

Few differences in the occurrence patterns were observed across the genders for the gaze system, namely, the rates of occurrences of ‘gaze at object’, ‘gaze at person’ and ‘gaze away’ were higher in girl infants. Weinberg (1992) reported that among 6 month old infants, female infants were seen to divert more attention to objects and therefore, exhibited significantly more instances of gazing at objects. There also seemed to be differences in the instances of ‘gaze shift’ produced by the infants, in that, girls produced less number of gaze shifts than boys, suggesting that girls paid more attention to certain stimulus and were resistant to shift their gaze rapidly between stimuli.

Another possible explanation for these differences could be the variations in the interaction styles of the mothers with their children. Owens (2012) has also reported that mothers of young infants modify their gaze behaviours along with their speech when interacting with their children, which in turn helps in maintaining an infant’s interest and focus on a stimulus. The mothers of the girl infants seemed to engage their children in conversations and repeated play with objects. This could have led to higher occurrences of expressions of these gaze behaviours in girl infants.

Fehr and Exline (1987) suggested that different cultures create their own rules concerning gaze and visual attention especially for adults. For example, Arabs are reported to gaze for longer periods and directly at their partners than Americans (Hall, 1963; Watson & Gravess, 1966). There are also studies which imply that there are differences in gaze patterns and visual behaviours between different ethnic groups (Exline, Jones & Maciorowski, 1977; LaFrance & Mayo, 1976). It has been observed that across cultures, caregivers vary with respect to the types of linguistic input, and maternal responsiveness that is determined by an interplay between the maturational levels of the infant and culture-specific interactional patterns (Kartner, Keller, & Yovsi, 2010). It has also been suggested that apart from culture, factors such as race, education and socioeconomic class can also influence the behaviours of the mother towards their child (Owens, 2012).

Some of these factors could have also influenced the interactional styles of the mother-child dyads in this study. The mothers were from different socio-economic (both lower and upper middle-class), religious and educational backgrounds. Mothers who were educated and belonged to the upper middle class were observed to interact with their infants and engage them in play with objects very frequently and consistently. Apart from these factors, there were also differences in the manner in which the mothers interacted with their male or female infant. Such differences in the interactional styles of mothers based on the gender of their infant have also been reported across cultures (Goldberg & Lewis, 1969; Golombok & Fivush, 1994; Kosiak, 2013; Lewis, 1972; Owens, 2012; Parke & Swain, 1980). However, the extent and the role of influence of these factors on the emergence of gaze behaviours were not addressed in this study.

3. Head movements

Owens (2012) observed that head movements of infants are of high signal values to the caregiver, due to the relatively higher degree of maturation levels in these structures when compared to the rest of an infant's body. Some significant trends were observed in the emergence of various movements of the head in the study.

3.1. Growth trends

A significant developmental influence on the occurrence of head movements was found for 'head extension', 'head turn' and 'head lowering', which suggests that the occurrence of these gestures changes within the first year of life. Head movements of 'extension' and 'lowering' were found to decrease with age, while the opposite trend was noted for 'head turn'. The correlation analysis revealed that, with age, there were significant correlations in the production of 'head turn', 'head nod', and 'head shake', while the opposite trend was noticed for 'head extension'. There were also varied patterns of coordinations observed among these gestures. For example, the occurrence of 'head shake' and 'head nod' positively complemented each other with age, while that of 'head turn' and 'head lowering' negatively complemented their occurrences. This finding probably suggests that the associations between these behaviours reflects the maturation of the system, especially in the case of 'head shake' and 'head nod' as both these gestures provide a means for the infants to communicate their desires. This is somewhat consistent with what has been proposed earlier for the development of any skill in children (Smith & Thelen, 2003).

Additionally, the gestures of 'head extension', 'head nod', and 'head turn' showed non-linear growth trajectories, suggesting that development within the first year of life does not necessarily happen in a step-wise manner, but in stage-like shifts (Thelen & Smith, 1994). Such trends might also account for differences in rates of occurrence and ages of acquisition of these gestures in typically developing children, and is no different from what has been observed in the development of other systems, such as the linguistic (de Bot et al., 2007; Vihman et al, 2009) and prosodic systems (Schmidt & Post, 2015). Thus, variability in occurrence seems reflective of typical development (Vereijken & Adolph, 1999). 'Head lowering' and 'head shake' were seen to demonstrate unpredictable trends, possibly due to the extremely variable rates of occurrence across the months that were studied. Further, the results of the change point analysis revealed a significant age (8th month) at which a change occurred in the head movements. This implies that despite the variable occurrence of behaviours, there is a predictable age at which change occurs within this system. This has also been reported for other developing systems (Abney et al., 2014; Adolph & Robinson, 2015).

3.2. Patterns of occurrence

All head gestures were seen from the age of 3 and 4 months, and the frequency of occurrence of only two gestures, 'head extension' and 'head lowering' were found to be less in the 12th month. 'Head turn' was the most frequently occurring behaviour when compared to other gestures, across all the months. This is consistent with the observed notion that even as a newborn, an infant is capable of making rudimental head turns to view a human face (Owens, 2012), and with the achievement of head control this ability is further strengthened. An infant is motivated to turn its head in an attempt to observe visual stimuli or to locate auditory stimuli or even to follow the trajectory of a person or object (Miranda, Hack & Fantz, 1977). The same was observed in the current study and this ability seemed to develop hand in hand with gaze behaviours. This observation gathers support from Snell's (1997) report which suggests that in newborns, the head and eyes tend to move together, while older infants are able to move their eyes and head independent of each other.

Head 'extension' and 'lowering' were two other gestures that were seen from the age of 3 months. Illingworth (1983) observed that when infants achieve head control, they are in a position to flex or lower as well as extend their necks, which in turn results in the corresponding movements of the head. This would explain the presence of head 'extension' and 'lowering' at the age of 3 months since most of the infants in the study had attained head control by this age, with the exception of one male infant who achieved it by the age of 4 months. Younger infants were observed to produce 'head extensions' especially when they were in the supine and prone positions, while 'head lowering' was mostly seen when the infants were in prone position as well as while they were sitting. Further, 'extension' was mostly seen while the infant attempted to view a stimulus which was of interest to them but was not in their line of vision, whereas 'lowering' was seen when the infants were at rest or had stopped an activity and were looking 'away'; this most often followed an 'extension' behaviour. Further, a decrease in the occurrence of these gestures with age could probably be attributed to maturational effects in their neuromuscular skills.

Rhythmic movements of 'head nod' and 'head shake' occurred more frequently as the infants grew older. In a study by Thelen (1979) on twenty infants, rhythmical movements of the head were recorded to occur less frequently compared to the same movements involving the rest of the body, and since the number of bouts was few, these were not subjected to any further analysis. Head shakes were reported to be produced by more number of infants than head nods by Thelen (1979). The same trend was seen in the present study, in that, the rates of occurrences for 'head shakes' were much higher than that of 'head nods'. Also, as the infants grew older, there were reasons to imply that these gestures are context-dependent and part of their communication process. For example, 'head nod' occurred in relevant contexts to indicate acceptance, between the ages of 11 and 12 months, while 'head shake' was observed to be meaningfully produced to indicate refusal between the ages of 8 and 12 months. However, in the study by Kettner and Carpendale (2013) based on diary observations on 8 infants from Canadian English speaking backgrounds, shaking of head for 'no' was noted to emerge between 13 and 15 months and nodding for 'yes' was seen between 16 and 18 months. These differences may be attributed to variations in the method followed in the studies or the maternal interactional styles of the caregivers or even the individual characteristics of the infants. Therefore, the current finding does not warrant a conclusion that rhythmic head gestures may be seen at an earlier age in infants from Kannada speaking linguistic background.

There were no gender differences noted in the production of head gestures in the study, based on observation of the occurrence rates of all gestures between boys and girls. This is in confirmation with the findings in the study on male and female infants under the age of 1 year by Thelen (1979), and this possibly indicates that these movements are universally seen across all infants, irrespective of their gender.

4. Leg movements

The four types of leg movements that were documented in the study demonstrated some interesting trends.

4.1. Growth trends

It was also observed that the occurrence of ‘feet in contact’, ‘foot rub’, ‘single leg kick’ and ‘both leg kicks’ were found to have a significant developmental influence, suggesting that the occurrence of these gestures changes with age. All gestures were found to decrease towards the end of the first year of life. Subsequently, the correlation analysis revealed that, with age, there was a significant negative correlation in the occurrence of all four gestures. The occurrence of all gestures complemented each other, suggesting they demonstrate coordinated patterns of growth in the first year of life (Smith & Thelen, 2003). In the case of leg movements, such coordination possibly suggest that these gestures can be considered as transition skills that help the infant achieve mature skills, such as, walking.

Moreover, the four gestures demonstrated nonlinear growth trajectories, confirming that development within the first year of life does not necessarily happen in a step-wise manner, but in stage-like shifts (Thelen & Smith, 1994). Such trends might also account for differences in rates of occurrence and ages of acquisition of these gestures in typically developing children, suggesting that the development is not necessarily deviant if children exhibit variability (Vereijken & Adolph, 1999). Similar trends have also been documented for other systems such as the linguistic (de Bot et al., 2007; Vihman et al, 2009) and prosodic systems (Schmidt &

Post, 2015) in both young and older children. Further, the results of the change point analysis revealed that there was a significant age (7th month) at which there was change in the occurrence of leg movements. This implies that despite the variable occurrence there is a predictable age at which change can occur within the system, and this is consistent with previous reports (Abney et al., 2014; Adolph & Robinson, 2015).

4.2. Patterns of occurrence

All leg movements were seen from the age of 3 months in the study and the occurrences of all these gestures were seen to reduce as the age of the infants increased. The highest rates of these behaviours were seen in the younger months, especially when the children were mostly confined to a supine position. With the achievement of sitting behaviour, gestures such as ‘foot rub’ and ‘feet in contact’ were less frequently produced, however children did produce kicking movements. With the acquisition of standing and walking, kicking movements were also seen to decrease.

Regarding the context that elicited these behaviours, ‘feet in contact’ seemed to occur randomly when the infants were idle or even when they were engaged in an activity. This could be because, when in a supine position younger infants assumed a semi-flexed posture of the legs, which brought the heels of the feet in closer proximity and led to the occurrence of this gesture. As age increased, the infants no longer assumed this posture and a subsequent decline were observed in this behaviour.

‘Foot rub’, and ‘kicking’ movements are regarded as rhythmical movements of the legs (Thelen, 1979), and these were most often seen when the children were observing the mother talking to them, while in discomfort or even when they were excited during play. In this study, these were seen from the young age of 3 months, which is similar to the findings of another longitudinal study on infants (Thelen, 1979). In this earlier study, it was documented that bouts of rhythmic leg movements were seen from birth, although the mean bouts from the age of 14 weeks were higher compared to the younger months, and there was an increase in the occurrence between 24 and 32 weeks.

However, in the present study a slightly different trend was observed. The rates of occurrences were higher between 4 and 6 months for all rhythmic movements, except in the case of ‘single leg kick’, which had higher rates of occurrence between the ages of 3 and 7 months. This difference in the findings of both studies could be due to possible variations in child-rearing practices across different cultures. In the present study, few of the mothers were observed to hold the feet of their infants when they began producing movements of legs. This was especially seen during play or even when the infant was beginning to get fussy or showing signs of discomfort. It was also noted that even when the children were sitting and playing on their own, the mothers would often have their hands around the legs in a possible attempt to provide better support to the child. These could have influenced the occurrences of these behaviours and led to observation of differences in the ages of occurrence across the studies.

Boy infants were seen to produce ‘foot rub’ more frequently than girls, however this observation is not very conclusive since the production of the gesture depends on the posture that the legs assume. Thelen (1979), in her study, also reported that there were no differences seen across the genders for rhythmic movements of the legs. This might imply that male and female infants do not differ in their production of leg movements.

5. Movements of torso

Movements of torso are considered rhythmical movements (Thelen, 1979, 1981), and the trend observed in the current study is discussed.

5.1. Growth trends

Both 'bounce' and 'rock' demonstrated significant developmental trends, in that, the occurrence of these gestures changed with age. The trends indicated an increase in the occurrence of both gestures as the infants grew older. The correlation analysis revealed that there was a positive correlation in the production of gesture 'rock', with age, however there was no trend seen for 'bounce'. Interestingly, the occurrence of both these gestures complemented each other, suggesting that they show coordinated patterns of growth in the first year of life, which is suggested as an expectation in any developing system (Smith & Thelen, 2003). Moreover, 'bounce' demonstrated a non-linear trend, while the trend was unpredictable for 'rock', mostly due to the extreme variations seen in the production of this gesture across months. But, these might to some extent, support the notion that variability results in stage-like shifts in skills during development (Thelen & Smith, 1994), almost consistent with what has been previously observed in the development of linguistic (de Bot et al., 2007; Vihman et al, 2009) and prosodic systems (Schmidt & Post, 2015). This does call for an understanding of variability in development as the norm for most systems (Vereijken & Adolph, 1999). The change point analysis did not reveal a predictable age at which change occurred within this system, unlike what was seen for other systems in this study as well as what has been previously reported (Abney et al., 2014; Adolph & Robinson, 2015). However, it is possible that a change in this system might occur at a later stage.

5.2. Patterns of occurrence

It was interesting to note that rhythmic movements of torso, that is, 'bounce' and 'rock' were seen throughout the study period, although the occurrence of 'bounce' seemed to reduce as the age of the infants increased. This finding is in consonance with that of Thelen (1979), in whose study, the development of rhythmical movements of the torso were observed while infants were in various positions such as, prone, supported on hands and knees, supported on hands and feet, sitting, kneeling and standing positions, with specific emergence seen between 25 and 40 weeks. Kravitz and Boehm (1971) observed body-rocking behavior to emerge at a median age of 6.1 months. In this study, only the occurrence of these rhythmic movements were annotated and not the postures assumed by the infants while the movements were being produced. But they were mostly observed when the children were in supine, prone, supported on hands and knees, supported on hands and feet, sitting, kneeling and standing positions.

It was also observed that infants produced these movements randomly and their occurrence did not seem context dependent. As the children developed mature motor skills, such as the ability to sit, stand and walk, the frequency of 'bounce' behavior reduced considerably, possibly suggesting a link to neuromuscular maturation. However, the same was not observed for ‘rock’ behavior, indicating that the mechanisms that control these movements and the purpose for which these movements are produced may be different.

The raw data revealed that girl infants had higher rates of production of both ‘bounce’ and ‘rock’ in certain months. However, these observations need to be confirmed in further studies, as this is different from the findings in the study by Thelen (1979) on rhythmical movements of infants under the age of 1 year, where it was reported that there was no difference seen in the production of these gestures based on gender.

6. Whole body movements

The achievement of motor autonomy is an important task that any infant faces in the first year of life, and the process is described as a series of distinct stages, and the mastery of each stage is suggestive of the progression to the next stage (Esposito & Venuti, 2009). The main milestones of motor development have been identified as lying, rolling, sitting, crawling, standing and walking. Esposito and Venuti (2009) have also suggested that typically developing children may skip few of these stages with no negative consequences on their development. On a similar note, even in this study it was observed that there was considerable variation seen in the ages of acquisition of most of these motor milestones, across infants who were studied. It must be noted that this study did not document the developmental ages and patterns for ‘lying’ and ‘sitting’.

6.1. Growth trends

Among these gestures, ‘crawl’, ‘lean’, and ‘turn’ were found to have a statistically significant developmental influence, indicating that there were changes in the occurrence rates of these behaviours with age. The trend was in favor of an increase in occurrence for ‘crawl’ and ‘lean’, while for ‘turn’ the occurrence rates were slightly reduced towards the end of first year. Further, the correlation analysis revealed that there were significant correlations in the occurrence of ‘crawl’, ‘lean’, ‘stand’ and ‘walk’, with age. Moreover, the results also suggested that few of these behaviours did exhibit coordinated patterns of growth. For example, the occurrence of ‘lean’ correlated with ‘crawl’, ‘stand’ and ‘walk’. This possibly suggests that ‘lean’ is a behaviour that helps in the occurrence of the other higher-order behaviours during development; this is probably because ‘lean’ is often considered a righting posture that helps infants balance themselves while engaged in other movements (Teitelbaum et al., 1998), and subsequently, for an infant it might be a means to achieve an end (e.g. reaching for an object). This finding of the presence of coordination of structures within a system derives support from the suggestions based on studies on the development of reaching skills in infants (Smith & Thelen, 2003).

Most of the whole body movements showed non-linear trends in growth for the first year of life, which goes on to suggest that development of these gestures does not happen in a step-wise manner, but possibly in stage-like shifts (Thelen & Smith, 1994). This is consistent with previous reports that suggest similar findings in the development of linguistic (de Bot et al., 2007; Vihman et al, 2009) and prosodic systems (Schmidt & Post, 2015). This possibly points to the variability seen in the development of behaviours even in typically developing children (Vereijken & Adolph, 1999), and this might contribute to the differences seen in occurrence rates and ages of acquisition of these gestures in typically developing children. ‘Roll over’ and ‘walking with support’ demonstrated unpredictable trends, possibly because of high variability seen in their occurrences across the various months. The results of the change point analysis did reveal that there is an age at which significant changes can be identified in the system, in this case in the 7th month, supporting the findings of previous studies for vocal and limb systems (Abney et al., 2014; Adolph & Robinson, 2015).

6.2. Patterns of occurrence

All these gestures emerged at various points in time during the first year, and all were found to occur in the 12th months. The only exception to this trend was noted in the case of ‘roll over’ as this gesture was not seen beyond the age of 7 months. ‘Rolling over’ was one of the early occurring whole body movements that was recorded in the study. This movement is considered critical for improving the infant’s coordination abilities. It was seen to occur between 4th and 5th months for most infants, and was seen till the age of 7 months. Esposito and Venuti (2009) have reported that rolling can be seen from the first few months of life itself in most children, however they have also suggested that this behaviour may not emerge until the age of seven or eight months in many children. Initially, the infants under study demonstrated the front-to-back rolling pattern and later as they mastered this skill, the back-to-front pattern was also seen. This is similar to what has been reported in previous studies (Illingworth, 1979; Nelson et al., 2004).

‘Turn’ was another behaviour that was seen from an early age, and most of the times, these were associated with attempts to roll-over in the beginning. Further, increased instances of this behaviour were seen between the ages of 5 and 7 months, which coincided with the acquisition of sitting behaviour. Sitting was observed to permit the infants to engage in independent play and they were found to produce ‘turns’ to observe the trajectory of objects or care givers, or while manipulating or getting closer to an object of their interest. This behaviour was seen to decrease with the achievement of ‘crawling’ and ‘walking’ as these mature behaviours improved the mobility of the infants to achieve the above goals of exploration.

‘Lean’ was observed to emerge by the 5^{th} month in the study, and the frequency with which it was produced increased with the age of the infants. This movement helped infants in reaching and grasping an object of interest especially while sitting. It has been suggested that ‘lean’ seems to arise from an early sensitivity to the distance that separates the object from the infant (Yonas & Hartman, 1993). Thus, infants frequently produced this behaviour as their exploratory skills improved and it may be considered as a skill that aids the child in manipulating objects of interest in their environment.

Freedland and Bertenthal (1994) have reported that various patterns of crawling emerge between 32 and 42 weeks of age in typically developing children. In the current study, ‘crawl’ was seen from the age of 6 months in few of the infants, and was seen in all the children by the age of 8 months. However, this finding does not necessarily imply that this is the pattern for all infants since ‘crawl’ seemed to be a motivation and context driven behaviour. In the present study, it was noted to be produced when the infants were interested in an object which the mother had strategically placed at a distance from the infant, in order to encourage the child to ‘crawl’. As a result, it is possible that the actual age of emergence of this movement may not have been captured in the scheduled monthly recordings undertaken in this study. Moreover, it was also observed that there was a decrease in the occurrence of ‘crawling’ with the emergence of ‘walking’.

‘Crawling’ is also considered as a milestone that can bring about dramatic changes in terms of the types and sources of social input that infants receive (Campos et al., 2000). It has been suggested that crawling infants encounter various objects and contexts in their surroundings and caregivers tend to respond to this behaviour by increasing their vocal communication in an attempt to regulate the exploring infant (Zumbahlen, 1997). The end result of this interaction is assumed to be the beginning of referential communication in infants since this exploratory communication comes from a communicator who is located at a distance from the child and it is in the context of a distal referent (Iverson, 2010). Similar patterns of interaction modifications were observed in most mothers, although these inflections were not considered for further analysis as they were not within the purview of the aims of this study.

‘Standing with support’ was seen between 5 and 6 months of age in the present study and independent ‘standing’ emerged around 10 and 12 months of age. It must also be noted that while all children in the study achieved ‘standing with support’, ‘standing’ was achieved by only 8 of the infants. Therefore, there were individual variations seen in the achievement of these skills among the infants. This is consistent with previous reports, which suggest that motor development is invariably marked with intra-subject variabiiltiy (Adolph, Cole & Vereijken, 2015). Esposito and Venuti (2009) have also reported that the ability to stand usually emerges from the tenth month of life and have suggested that this ability provides the infants with an opportunity to have a larger visual field, and better understand the concepts of distance and probability in their environment. In the current study, it was also observed that in the early months, the mothers encouraged their infants and helped them ‘stand with support’ but as the infants grew older, this behaviour was seen to be more self-motivated as the infants themselves were increasingly interested in exploring their surroundings and becoming more independent.

Walking is reported to be achieved between twelve and fifteen months of age and it has also been suggested that this age is normally distributed with a standard deviation of nearly 3 months (Esposito & Venuti, 2009). In the present study, ‘walking with support’ which was again a caregiver-driven behaviour, was seen to emerge between 8 and 11 months of age, while independent ‘walking’ was achieved by only few infants in the study and was seen from 11 and 12 months. This implies wide individual variations in the occurrence rates of this gesture, and this seems to be in consonance with the observations of Esposito and Venuti (2009) who have suggested that this skill will be acquired only once a child’s muscles have developed sufficiently to support his/her body weight.

Karasik, Tamis-LeMonda and Adolph (2013) have reported that when compared to crawling, walking provides an infant with enhanced opportunities to access objects that are distally located as it is less taxing. Moreover, the infant’s hands are free to carry objects unlike in the case of crawling, where they are involved in supporting the infant’s weight. Also, the upright position of the head while walking makes it easier for infants to locate objects and people in their surroundings. This transition is also considered as a turning point in the communicative abilities of an infant. Walking enables the infant to carry an object of interest and transport it to an adult who will in turn pay more attention to the social bids of the infant. Thus, it encourages the infant to play an active role in establishing interactions and subsequently paves way for richer opportunities for language learning (Clearfield, Osborne & Mullen, 2008; Tomasello & Farrar, 1986). These patterns were clearly seen in the current study, although these were not specifically documented for further analysis.

Further, while considering the overall patterns of development of these gestures, one must keep in mind the influence of child-rearing practices. Adolph and Robinson (2015) suggest that differences in childrearing practices can have profound impacts on motor development. For example, caregivers in Africa, the Caribbean and India are observed to perform customary massages and exercises as part of their daily routines (Adolph, Karasik & Tamis-LeMonda, 2010; Bril & Sabatier, 1986). On the other end of the scale, parents from a western society are observed not to engage in such practices. Adolph and Robinson (2015) speculate that such practices in turn can affect the motor development of infants reared in these communities. Indeed, it has been reported that infants who receive routine exercises and training are found to achieve sitting and walking at earlier ages than infants who do not receive such stimulation (Hopkins & Westra, 1988; Super, 1976). Therefore, it would be interesting to further explore the influences of such practices on the achievement of whole body skills in Kannada-speaking infants, considering that the levels of such stimulation may vary across families and even across caregivers within a family.

An observation of the raw data revealed that there were not many differences observed in the rates of occurrences between boys and girls for all behaviours, except that of ‘crawl’. It was seen that boy infants had higher rates than girls between 10th and the 12th months. This could be attributed to the observation that girl infants transitioned to walking behaviour at an earlier age than boys during the study period. Also, one of the boys did not demonstrate independent ‘walking’ during the study period.

There is very little consensus among researchers regarding the findings that consider the effects of gender on motor development in infants. Capute, Shapiro, Palmer, Ross and Wachtel (1985) conducted a longitudinal study on 12 gross motor milestones attained by infants in the first two years of their lives, and reported that there were only minor differences based on gender in the age of attainment of these skills. They suggested that boys may be more advanced in gross motor development when compared to girls. Gender differences have also been identified with respect to inter limb coordination in infants below the age of 6 months who were subjected to kinematic analysis (Piek, Gasson, Barrett & Case, 2002). It was found that the arm movements were more coordinated in female infants, while the leg movements were better coordinated in males, and the authors attributed these differences to variations in the gestational age, birth weight and head circumferences. This calls for further exploration of gender effects in the Indian context.

7. Hand movements

While considering the emergence of all the pre-symbolic gestures and symbolic hand gestures, one can observe some trends. In general, it was noted that the pre-symbolic gestures were observed in the infants from the 3rd month of age, while the symbolic gestures were observed in the later months of development, i.e. after 7 months, and there were very infrequent when compared to pre-symbolic gestures.

7.1. Growth trends

Among the pre-symbolic hand gestures, the occurrence of 'clasp', 'hand in mouth' (right and left), 'hand held toy in mouth' (right), 'curled' (right and left), 'spread' (right and left), 'grasp' (right and left), 'reach' (right and left), and 'index finger extension' (right and left) were found to have a statistically significant developmental influence. Among the rhythmic gestures, this was seen for gestures 'bang' (right and left), 'shake' (right and left) and 'swing' (right and left), and among the symbolic gestures, no significant differences were observed across the months. This suggests that there were changes in the occurrence rates of only pre-symbolic gestures with age, and in the case of symbolic gestures such differences might possibly be seen beyond the age of 1 year, when these behaviours are more frequently produced by infants during communication. Subsequently, the correlation analysis revealed that there was a significant high correlation in the occurrence of 'clap', 'grasp', 'reach', 'spread', 'bang', 'shake' and all symbolic hand gestures with age, while there was a significant negative correlation in the occurrence of 'clasp', 'curl', 'hand in mouth', 'index finger extension', and 'swing'.

The results also suggested that few of the pre-symbolic and symbolic hand gestures demonstrated coordinated patterns of occurrence during development, suggesting that the behaviours within the manual system demonstrated nested growth (Smith & Thelen, 2003). For example, 'reach' and 'grasp' positively correlated with each other, possibly aiding in object exploration abilities in children. Similarly, the occurrence of 'shake' and 'bang' were found to positively correlate with each other, while negatively correlating with 'swing'. This might suggest that among rhythmic gestures 'swing' might not play a role in influencing the development of mature hand gestures. Such a role for rhythmic hand gestures aiding in the development of symbolic gestures has been previously indicated by Thelen (1981). Among the symbolic gestures, especially of the right hand, most gestures were found to have high positive correlations with each other, probably hinting at the larger role that the manual system has to play in communication.

Additionally, it was also seen that the growth of these hand gestures were characterized by both linear and non-linear developmental trajectories, which goes on to suggest that development of hand gestures can happen in both step-wise and stage-like manners (Thelen & Smith, 1994). The fact that developing systems exhibit non-linear trends is similar to what has been reported for other systems in infants, such as that of language (de Bot et al., 2007; Vihman et al, 2009) or prosody (Schmidt & Post, 2015). These trends may lead to individual differences seen in the production and ages of acquisition of these gestures even in typically developing infants and children (Vereijken & Adolph, 1999). However, it has to be kept in mind that there were few gestures, such as, symbolic gestures of the left hand and rhythmic gestures like 'flex', which demonstrated unpredictable growth trends possibly due to infrequent instances of occurrence.

Further, the change point analysis revealed that there was a significant age at which change was observed in the occurrence of pre-symbolic gestures and right hand rhythmic gestures. This finding parallels previous findings on vocal and limb systems (Abney et al., 2014; Adolph & Robinson, 2015). It was interesting to note that rhythmic gestures had two significant ages at which change was observed, possibly suggesting that the developing system evolves and dissolves constantly (Smith & Thelen, 2003), across multiple time frames during development.

7.2. Patterns of occurrence

Pre-symbolic gestures such as ‘clasp’, ‘hand in mouth’, ‘hand held toy in mouth’, ‘curled’, ‘swing’, ‘spread’, ‘grasp’, ‘reach’ and ‘shake’ were seen from 3rd and 4th months of age. This finding is consistent with the findings of the study by Fogel and Hannan (1985), which documented the occurrence of select hand gestures in infants between the ages of 9 and 15 weeks. ‘Curl’, ‘spread’, ‘grasp’ and ‘point’ were observed in 28 infants from the age of 9 weeks, although there were variations in the number of infants who produced these gestures. It should be noted, however, that in the present study ‘point’ is considered as a symbolic gesture.

It was seen that all of these gestures, except for ‘cycling’ and ‘index finger extensions’, were observed while the children were playing with toys or familiar objects within their reach. Lew and Butterworth (1997) have suggested that, during the early months, the ability of an infant to interact with their environment is limited. This is because infants are often confined to a supine position, even while being held by caregivers due to their poor posture and neuromuscular control. This would explain the early occurrence of behaviours that are easily produced with minimal muscular effort and their subsequent decline over the coming months, when infants are more capable of interacting independently with their surroundings. Thus, gestures such as ‘clasp’, ‘hand in mouth’, ‘curled’ and ‘swing’ are probably providing infants with opportunities to explore their surroundings within the constraints of their physical system, and these might serve as trial and error behaviours that pave the way for more stable hand gestures.

‘Cycling’ and ‘index finger extensions’ were mostly observed when the child was idling, with the arms/hand in resting position, and also while either looking at an object or the mother. Since these behaviours seemed to occur randomly and were not accompanied by purposeful actions, this could have contributed to the variations in the occurrence of these behaviours across the months. Also, it was interesting to note that there was a decline in the rates of occurrences of both these gestures with the emergence of pointing behaviours. This might suggest that the relative evolution and dissolution of these gestures leads to the emergence of a mature and meaningful gesture, namely, ‘point’ (Thelen & Smith, 1994).

von Hofsten and Ronnqvist (1988) have reported that reach and other manipulations in relation to objects are seen from around 4-5 months of age and that children are found to demonstrate advanced skills in these behaviours, such as planning the timing, adjusting the opening or closing of the hand over the object etc., with advancing age. This was true even for the data in this study. Gestures such as ‘hand held toy in mouth’, ‘spread’, ‘grasp’, ‘reach’ and ‘shake’ were seen throughout the study period. This might suggest that the occurrence of these behaviours coincides with a shift in the interaction opportunities due to the maturation of the visual, tactile and neuromuscular systems (von Hofsten, 2007). From the 6th month, almost all the infants were able to sit independently and were able to manipulate and explore their environment effectively. It may be assumed that with age, these skills will stabilize, as the child will have better control over these behaviours and will exhibit these gestures with purposeful activities based on their internal motives.

Some of the remaining pre-symbolic gestures were also noted from the age of 6 months. Among these were ‘up’, ‘clap’, ‘twist’ and ‘flex’. ‘Up’ and ‘clap’ were often observed in situations where the infants were involved in interactions or play with caregivers. For example, ‘clap’ was seen when an infant was very excited about the trajectory of a toy or the action done by the toy. It was also noted that most of the times the infants imitated this gesture by observing their mother. Rhythmic gestures, namely, ‘flex’ and ‘twist’ of wrists were seen when the infant was idle and mostly observing their own hands. These gestures were noted to have fewer instances of occurrence throughout the study. A possible explanation for the same could be that, since these were not associated with meaningful actions, the behaviours did not occur at regular intervals; however, their presence might indicate that these may play a role in motor development since these movements provide proprioceptive and kinesthetic feedback to infants. It is also interesting to note that only few infants in the study demonstrated these four gestures. Thus, although these gestures evolved, there was relative inconsistency seen across the months and subsequent decline in the behaviours towards the end of the first year.

‘Bang’ was a rhythmic pre-symbolic gesture that was seen from the age of 6 months, with a peak in the behaviour observed in the 8th month. ‘Shake’ and ‘swing’ were produced from the 3rd month with a peak in the occurrence in the 10th month for ‘shake and in the 4th month for ‘swing’. These findings are slightly different from that reported in earlier accounts. Thelen (1979) suggests that all rhythmic stereotypies involving hands are seen with higher frequencies at around 6 months of life. These differences could hint at possible cultural variations in the development of rhythmic behaviours, however, this needs to be further explored in order to derive definitive conclusions.

Rhythmic stereotypes have been considered as transition or by product behaviours of the normal maturation process (Lourie, 1949; Thelen, 1981). These are assumed to be available to infants when higher-order complex behaviours are not accessible; this is despite the fact that they are simple and repetitive behaviours, devoid of goals and are largely not under sensory regulation. For example, cycling has been suggested as a behaviour that may precede grasping (Thelen, 1981). This view would therefore propose that all rhythmic gestures are part of normal maturation and might pave the way for meaningful manual actions, which might explain the high rate of occurrence of most of these rhythmic gestures beyond the age of 6 months.

Symbolic gestures, including deictic and representational gestures are reported to usually emerge between 9 and 13 months of age (Bates et al., 1979; Folven & Bonvillian, 1991). In this study too, similar observations were made, although some of the deictic gestures were seen from an earlier age. This was especially true in the case of gestures produced using the right hand. ‘Point’ was seen between 7 and 11 months, and ‘hand configurations’ were seen from the 7th month. ‘Take’ gesture emerged between 8 and 9 months, while ’give’ was noted between 6 and 8 months of age. ‘Show’ was seen between the 10th and 11th months and request was observed only in the 12th month. It is remarkable to note that the infants in the present study acquired the various types of symbolic gestures earlier than what has been reported in previous literature, both in American- (Bates et al., 1979) and Kannada-speaking (Veena, 2010; Veena & Rajshekar, 2015) children. The trend was the same even for the order in which these gesture types were acquired. It is possible that variations in the interaction styles of caregivers could have contributed to this finding, and it would be interesting to take a closer look at the contribution of these differences towards the acquisition of these gestures in a larger sample of infants.

Most of the gestures occurred during play with objects while the infants interacted with the caregiver. These gestures emerged at an age where the infants had independent control over their motor system, and, it was also interesting to note that these behaviours were context-dependent. The occurrences of these gestures seemed to vary based on the levels of input and the opportunities the caregiver provided during these interactions. This in turn was reflected on the motivation on the infant's part to initiate interactions. In this regard, the caregivers of the girl infants were seen to provide more opportunities to their children, in order to encourage them to produce these behaviours, when compared to the mothers of boys. The mothers of girls preferred to play with their infants than letting the child explore a toy on her own. Thus, boys and girls seemed to differ in terms of the ages of emergence and rate of occurrence of these gestures.

It was also observed that, the frequently occurring pre-symbolic gestures such as 'hand in mouth', 'hand held toy in mouth', 'curl', 'spread', 'grasp', 'index finger extension', 'reach', 'bang', 'cycling', 'shake' and 'swing', were generally repetitive behaviours which occurred very frequently, whereas symbolic gestures occurred only in specific contexts. Moreover, with the emergence of the symbolic gestures, only fewer pre-symbolic gestures were seen in the later months. For example, 'curl' was seen from 3 months of age, but there was a decrease noted in this behaviour with the emergence of 'spread'. Similarly, there was a decrease in 'cycling' with the emergence of 'reach' and 'grasp'. Previously, Thelen (1981) had also suggested that cycling might precede grasping. ‘Reach’, ‘grasp’ and ‘spread’ were most often seen as repetitive behaviours that occurred in a sequence, and these may have paved way for symbolic gestures of ‘take’, ‘give’ and ‘request’. Another striking example for this transition would be the emergence of ‘pointing’ gesture with a decrease in ‘index finger extension’. Similar observation was also made by Locke, Young, Service and Chandler (1990) who speculated that pointing might stem out of the child’s use of index finger to explore objects while he is either alone or when he is with others. It has also been suggested that when any behaviour becomes stable, that behaviour is preferred to the other un-stable behaviours and thus one would see a decline in the less well-established behaviours (Zanone & Kelso, 1991). This would explain the decrease in the occurrence of a good number of pre-symbolic gestures in the infants of this study following the emergence of symbolic ones. However, one needs to be cautious and further examine the data to affirmatively draw this conclusion.

The raw data seemed to show instances of differences in rates of occurrences of hand movements produced by boys and girls. Especially, this was seen for the category of symbolic gestures, where girl infants were observed to produce more number of instances of ‘point’, ‘give’, ‘take’ and ‘hand configurations’. A possible explanation for the same could be the variations in the interaction styles of the mother with their infants. The mothers of the girls in the study were found to be more tuned to the communicative attempts of their children and often encouraged them to produce more gestures. But considering that there was a lack of uniformity in the number of boys and girls in the study, the heterogeneity could have resulted in the fewer instances of significant variations seen between the genders.

However, these findings do parallel the study by Fenson, Dale, Reznick, Bates, Thal and Pethick (1994), who found significant differences, although of small magnitude, between boys and girls in the production of few gestures which were assessed on the MacArthur Communicative Development Inventories. The findings of this study are not in consonance with those done on French and Swedish children, where they observed that both boys and girls showed similar patterns of acquisition of gestures (Kern & Hilarie, 2003). They also observed that girls showed some amount of superiority in certain types of gestures that were activity specific e.g. gestures produced while playing with a doll, but the authors concluded this did not contribute to any significant differences between the two gender groups.

7.3. Handedness preferences in the production of gestures

The data did not reveal any clear pattern suggesting a right-hand bias in the production of gestures in the study. Significant differences were only seen for few of the pre-symbolic gestures, namely, 'curl', 'grasp', 'index finger extension', 'swing', 'bang' and 'shake', at certain months of age. Among these, for the rhythmic gestures as well as for 'grasp' and 'index finger extension', there was a right hand preference seen, especially towards the end of the first year (month 7 onwards). However, one must keep in mind that these instances are too few to support a conclusive laterality bias of higher magnitude. However, these findings are supported by previous studies, to some extent. For example, Ramsay (1985) reported that infants' show unimanual hand preference concerning toy contact activity, which includes hand banging that emerges following the onset of babbling. He suggested that the connection between hand banging and canonical babbling reflects the developmental change in hemispheric specialization of the brain, which is again related to speech and handedness.

Increase in repetitive right-handed activity at the same time during which infants begin to babble was also observed in a study by Locke, Bekken, McMinn-Larson & Wein (1995). Similarly, Hannan and Fogel (1987) studied one infant in interaction with the mother and they reported that 80% of the single occurrences of pointing and 87% of the total duration of pointing occurred on the right hand.

Conversely, Iverson, Hall, Nickel and Wozniak (2007) have reported that there was no shift in the arm preference for rhythmic stereotypes till the age of 9 months. The findings in this study show otherwise, although one has to keep in mind that the instances of right hand bias in the earlier months were found to be limited. However, there are no accounts that have studied pre-symbolic gestures systematically in the context of handedness during infancy. Therefore, the findings in this study, especially in relation to pre-symbolic gestures might provide new evidence to support the presence of laterality for rhythmic arm movements and gestures produced using fingers.

Previous studies on pointing gesture have supported the presence of a right-hand bias in infants and toddlers (Bates, O'Connell, Vaid, Sledge, & Oakes, 1986; Blake, O'Rourke, & Borzellino, 1994; Cochet & Vauclair, 2010; Young, Locke, & Service, 1985). However, there is no evidence in this study to support the same in the case of pointing as well as other symbolic gestures. Overall, one can conclude that the infants in the current study showed a right-hand bias, of smaller magnitude, only for rhythmic gestures with an increase in age. Since the findings were not the same for the other gestures included in the study, the question of hemispheric specialization for gesture still remains unanswered.

8. Speech behaviours

The emergence of speech behaviours in infants revealed some interesting trends. Most of these behaviours were seen at the age of 3 months in the study, with reduced frequency of occurrence towards the end of the first year. However, the trend was different for verbal utterances, which emerged after the age of 7 months.

8.1. Growth trends

Among the behaviours studied, the occurrence of pre-speech utterances such as ‘click’ (reduction in rate with age), ‘cry’ (reduction in rate with age), ‘vocal play’ (increased rates with age), and ‘whimpering’ (reduction in rate with age); vocalic utterances such as ‘vowelization’ (reduction in rate with age); syllabic utterances such as ‘CV string’ (increased rates with age), ‘articulatory gesture with weak vocal element’ (increased rates with age), and ‘VCV string’ (increased rates with age) were found to have a statistically significant developmental influence. This suggests that there were changes in the occurrence of these behaviours within the first year of life. Interestingly, verbal utterances did not demonstrate changes within the first year of life, a trend similar to that exhibited by symbolic hand gestures, possibly due to the novelty of these behaviours. The results of the correlation analysis revealed significant positive correlations in the occurrence of ‘vocal play’, ‘hum with prosodic alterations’, ‘articulatory gesture with weak vocal element’, ‘CV string’, and ‘CV string with prosodic alterations’, with age. The opposite trend was observed for the occurrence of reflexive behaviours such as ‘grunt’, suggesting that with age, children exhibited more controlled and communicative vocal behaviours.

Coordinated patterns of occurrence were exhibited by many of the pre speech behaviours during the first year of life, a finding that supports the notion that skills within a developing systems exhibits coordinations in order to aid in development (Smith & Thelen, 2003). For example, all the verbal utterances showed positive correlations in their occurrence with each other, which possibly demonstrates that all these behaviours influence each other and aid in the development of mature vocal communication in children. On the other hand, the occurrence of ‘hum’ negatively correlated with ‘vowelization’, possibly suggesting that reduction in primitive nasal resonances paves way for the production of mature oral resonances.

Additionally, it was seen that most pre speech behaviours demonstrated non-linear trends in growth, for the first year of life. This possibly suggests that, similar to other systems in children such as the language (de Bot et al., 2007; Vihman et al, 2009) or prosodic (Schmidt & Post, 2015) systems, development of vocal behaviours does not happen in a step-wise manner, but in stage-like shifts (Thelen & Smith, 1994). Such a trend can lead to inter- and intra-subject variability, both in the frequency of production and ages of acquisition of these behaviours, which can be considered as the norm in the development of any skill (Vereijken & Adolph, 1999). It was also observed that few of these behaviours exhibited upredictable trends, for example, this was seen for ‘jargon’ among verbal utterances. Either the infrequent occurrence of these behaviours or the variations seen in the rates across months could have led to these patterns. Further, unlike the gestural behaviours that were studied, speech behaviours did not exhibit an age at which significant change was observed in the vocal system. This could suggest that, in the case of vocal system, one can possibly only expect the variability in occurrence to stabilize beyond the first year of age. Such a difference could stem from the observation that infants are better versed in using their gestural system within the first year of life as these are frequently produced from birth, and therefore the gestural system shows signs of stability before the vocal system. This view derives support from previous accounts which suggest that development of speech follows the gestural system (Kuhl & Meltzoff, 1984; Luria, 1960).

8.2. Patterns of occurrence

Most of the pre-speech behaviours were seen at the age of 3 months in the study, with reduced frequency of occurrence towards the end of the first year. The ages of development of pre-speech utterances in Kannada-speaking infants in the present study seems to reflect universal trends when compared to infants from other linguistic backgrounds (Oller, 1980; Stark, 1980; Koopmans-van Beinum & Van der Stelt, 1986). The most frequently produced utterances were, ‘cry’, ‘whimpering’, ‘laugh’, ‘vocal play’, ‘squeal’ and ‘shout’. These were seen from the age of 3 months and though the rates of occurrence seemed to decrease with age, these behaviours were observed throughout the study period. Stark (1980) reported that reflexive vocalizations such as cry, discomfort sounds, and vegetative sounds are seen between birth and 1.6 months of age, while sounds such as cooing and laughter are typically seen around 1.6 and 3 months of age. Playful behaviours that comprise of squealing, yelling, production of noises and raspberries (bilabial trills) are also reported to be seen between the ages of 4 and 7 months.

‘Crying’ and whimpering’ were found to be produced when the infants were stressed or fussy, while ‘laugh’ was seen when they were happy and most often seen with ‘smile’.

‘Vocal play’, ‘squeal’ and ‘shout’ were seen when the infants were most playful. ‘Grunts’ and ‘clicks’ were seen during play and seemed to be voluntarily produced by the children.

Pre-speech behaviors of pre-linguistic infants are often considered as reflexive and primitive behaviours and are assumed to be seen only in the early stages of vocal development. However, an increasing body of evidence on these behaviours suggests that these earlier forms of vocal behaviour do not disappear as the child grows older, even when new skills emerge (Stark, Bernstein & Demorest, 1993; Hsu, Fogel & Cooper, 2000). Stark, Bernstein and Demorest (1993) have also described that pre-language utterances related to vegetative activities such as those of burping and sneezing persist into adulthood, whereas some other sounds such as wheezing noises, clicks and buzzing sounds are found to be produced only in the first few months of life. A similar trend was also seen in the present study, in that, some of these behaviours such as ‘pleasure sounds’, ‘click’ and ‘grunt’ were most frequently seen in the early months than during the later months. However, some of the other behaviours were seen from the age of 3 months till the end of the study period. This would then imply that early vocal behaviours do not emerge and disappear as infants grow older.

Among the vocalic behaviours, both ‘vowelizations’ and ‘hums’ were seen from the age of 3 months in the study and these were found to have decreased rates of occurrences as the children grew older, although these were present throughout the study period. This decrease in the rates seems to coincide with the frequent occurrence of syllabic utterances in the later ages. This finding derives support from a previous study on vowels in Malayalam infants (Reeny & Sreedevi, 2013). In their study on infants from the age of 4 to 12 months of age, it was documented that singleton vowels were frequently observed in the lower age range (4-6 months) in these infants. However, the presence of these behaviours throughout the study period provides support to the notion that vocal development is a continuous and non-linear process (Hsu, Fogel & Cooper, 2000).

Koopmans-van Beinum and van der Stelt (1986) studied Dutch infants and found that from birth to 2.6 months, infant vocalizations were characterized by uninterrupted utterances (without any articulatory movements or consonants) and interrupted phonations. On similar lines, Oller (1980) has also described the *phonation stage* in American English infants. This stage is reported to be seen between 0 and 2 months and infants are said to produce sounds called quasi-resonant nuclei, which are considered to be precursors to the occurrence of fully resonant vowels in the subsequent stages.

These descriptions resemble the characteristics of the vocalic behaviours recorded in the current study and the ages of acquisition of these behaviours are also similar. Bloom (1988) also suggested that infant vocalizations could be categorized as vocalic and syllabic sounds based on their characteristics. The vocalic behaviours considered in this study match the classification of vocalic sounds which differ only in terms of their resonance patterns, in that 'vowelizations' have an oral resonance and 'hums' have a nasal resonance. Stark, Bernstein and Demorest (1993) have also observed similar behaviours in infants, which they classified as 'reactive sounds' and were reported to be produced both during neutral and pleasurable contexts between 2 and 5 months of age. These sounds were also reported to be observed in the contexts of prolonged gaze-fixing at objects, actions or even people. In the present study these were also seen in the context of turn-taking, as a response to the stimulations from an adult.

Infants are found to imitate, discriminate and produce a large variety of melodic patterns during the pre-linguistic period (Kessen, Levine & Wendrich, 1979; Papousek, 1981; Trehub, Bull & Thrope, 1984). Tonkova-Yampolskaya (1973) suggested that early vocal development may be manifested in melodic contours produced during the first 6 months of life. A similar pattern was seen in the present study with the occurrence of prosodic alterations. Infants were found to produce simple prosodic contours between the ages of 3 and 4 months, for both vocalic patterns noted in the study. Further, it was seen that these infants were able to incorporate more variations in the patterns as they grew older. It has even been reported that, from early on, infants may produce melodic patterns that reflect various communicative functions, and may also vary the contours based on the contexts in which their vocalizations occurred (Delack & Fowlow, 1978; D'Odorico, 1984). However, this aspect was not investigated in the current study.

In the present study, syllabic utterances were categorized based on their syllabic shapes, and therefore, it has not explored the phonetic repertoire of these children. Immature syllabic forms of consonant and vowel combinations were seen as early as 3 months of age, and the frequency of occurrence was seen to increase towards the end of the first year. Oller (1980) has classified syllabic vocal behaviours as *marginal babbles* which are seen between 2 and 4 months of age in infants and are thought to be precursors to canonical babbles. Such early emerging syllabic shapes have also been described as utterances that require a single articulatory movement for their production, whereas mature babbled utterances are expected to be produced with two or more articulatory movements and may be seen only beyond the age of 7 months (Koopmans-van Beinum & van der Stelt, 1986; van der Stelt & Koopmans-van Beinum, 1986).

Marginal shapes of ‘CV’ and ‘VC’ strings were seen from the age of 3 months. These sounds were not adult-like syllables and were not well formed, however these were documented as syllabic forms by all the coders. Nathani and Oller (2001) have also suggested that these pre-canonical stages in infants are easily identified by even naïve listeners and thus they should be considered as important milestones that may have the predictive power comparable to that of canonical babbling. Such vocal behaviours were seen throughout the study period, with a marked increase in the rates of occurrence from 6 months of age, which is considered the age at which well-formed syllables are produced (Oller, 1980). It was also noted that there was a consistent increase in the production of ‘CV’ strings as the age of the infants increased.

‘VCV’ strings were also seen across all the months that were studied. ‘CVC’, ‘CVCV’ and ‘VCCV’ were some of the other syllabic shapes that were infrequently seen in the study, between the ages of 6 and 12 months. It was also observed that these shapes were not produced by all the infants that were studied. Bauman-Waengler (2000) reported that syllables ending in a vowel are the most frequently occurring syllable shapes seen in the later babbling period. This pattern is also observed in this study, although there were some shapes that ended in a consonant. A previous study on English speaking infants has also suggested that ‘CV’, ‘VCV’ and ‘CVCV’ syllable structures are the most common ones produced at the end of the babbling period (Kent & Bauer, 1985). They also found that closed syllables with a consonant ending were limited in the repertoire of infants at that particular stage of development.

Rupela and Manjula (2006) in a study on the phonotactic development of Kannada speaking children have also found that V, C, CV, VC and CVC syllable shapes were the most frequently seen in children. CV syllables were found to be the most commonly occurring syllable shape between 0 and 18 months of age, which is consistent with the findings of the current study. VC and CVC syllables were reported to be seen at the age of 12 months in the earlier study, however, these were seen from a younger age in the present study. In another study on Kannada-speaking infants between the ages of 6 and 12 months, it was reported that CV, VC, CVC and VCV were the most frequently occurring shapes, while CVCV and VCVCV were some of the multisyllabic shapes that were less frequently seen (Anjana & Sreedevi, 2008). These findings were in consonance with some of the observations in the current study, although there were variations seen in the ages of occurrence of the different shapes. In the earlier study, CV productions were observed to be maximally seen in the 6 - 7month age group, while in the current study this syllable shape was seen to have the highest rate of occurrence between 10 and 12 months. It was also found that VC and CVC shapes were rare across all the age groups in the previous study, while VCV syllables were seen to increase with the age of the children. The trends for CVC shapes were found to be similar even in this study, however, both VC and VCV shapes were observed across all the months of the study, although with reduced frequency. The previous study based their findings on the argument that open ended syllables are more frequent in Kannada than close ended syllables (Hiremath, 1980), and to some extent this seems to also hold good for the current study.

'Articulatory gestures with weak vocal element' were seen from the age of 4 months in the study. These behaviours seem similar to 'jaw wags' reported in some of the earlier studies, which are described as repeated articulatory movements without voicing and are reported to be seen at the start of the babbling phase (Meier, McGarvin, Zakia & Willerman, 1997). However, in the present study these were seen even after the onset of the babbling stage, although there was a decrease in its occurrence with age. Further, it has also been suggested that jaw wags may only be seen at a stage where the infants have poor coordination of the phonatory and articulatory movements (Meier, et al., 1997), and if that holds good, then the data from the present study seems to suggest that the coordination between the two systems still continues to develop well into the first year of life.

With regards to the prosodic features of the syllabic utterances, infants started producing pitch variations frequently between 4 and 5 months of age, although some infants infrequently produced prosodic variations even in the 3rd month. It was also observed that these variations had higher rates of occurrence with 'CV'. Bloom (1993) found that even at the age of 3 months, the syllabic sounds exhibited by infants demonstrated more variable pitch patterns when compared to their vocalic sounds. Such a comparison was not considered in the study. However, from the raw data, it was noted that the rates of occurrences of prosodic variations for vocalic utterances seemed to be much higher and occurring at an earlier age when compared to that of the syllabic utterances. This could possibly occur due to differences in the duration of these utterances; in that syllabic utterances were shorter than vocalic ones, and so, it was much easier to appreciate prosodic variations in these utterances. It was also noted that these infants did not produce melodic patterns during the production of multisyllabic utterances (e.g. VCCV strings).

With regard to the context in which these syllabic sounds were produced, it was observed that these were frequently produced when the infants were engaged in an activity than when they were in an idle state. Stark, Bernstein and Demorest (1993) have described syllabic behaviours as sensorimotor ones, which are often directed towards the environment while the child is engaged in mouthing, shaking objects or even crawling. Even in the present study, infants are found to exhibit these behaviours when engaged in an activity that was of high interest to them and as a result they may not have directed these vocal behaviours to an adult. However, most caregivers were found to respond to these vocal behaviours of the infants.

Verbal utterances were seen after the age of 7 and 10 months in the study, although the frequency of occurrence slightly varied towards the end of the first year. 'Jargons' and 'verbalizations' seemed to mark the beginning of a transition towards more adult-like utterances and were seen from the age of 7 months in few infants and from the age of 9 months in most of them. Stark (1980) described these utterances as non-duplicated babbling, where the child produces various combinations of consonants and vowels in multisyllabic utterances. She also named these behaviors as 'jargon babbling' to account for a variety of stress and intonation patterns that reflect adult-like speech. These utterances are reported to be usually achieved between 10 and 14 months (Oller, 1980; Stark, 1980).

In the current study, 'verbalizations with prosodic alterations' were also seen from the age of 10 months. It was interesting to note that infants incorporated these prosodic variations more frequently while interacting with the adult than when playing with a toy, and these inflections seemed to resemble improved communicative intent, when compared to syllabic and vocalic utterances with prosodic alterations. Children are reported to develop intentional communication between the ages of 9 and 12 months (Bates et al., 1979), and this also coincides with the age of emergence of non-verbal acts of intentionality, such as symbolic hand gestures. So, these prosodic variations might provide additional support to the assumption that infants develop intentional communication by the end of the first year of life.

In the study, true ‘words’ were not observed in all the infants even by the age of 12 months. However, there were few instances of context-based use of words that were produced by mostly the female infants and one male infant and these were seen from 10 months of age. A peak in the occurrence of this behaviour was noted in the 12th month. This finding is in consonance with the previous studies done on English and Dutch speaking infants, which have reported that the first words are seen around 12 months of age or later (Oller, 1980; Stark, 1980; Koopmans-van Beinum & van der Stelt, 1986).

Stark (1980) has suggested that the early words produced by children are used as symbols and that they refer to specific and recurring sets of objects or events. In the current study, among the infants who started producing words, it was observed that they used them to refer to routine acts, such as requests, as well as to nouns, such as addressing the caregiver. It was also noted that the infants who began using words had caregivers who were generally talking and interacting at higher frequency than the caregivers of the infants who did not exhibit words. This observation may lend support to the view that caregiver input can bring about changes in language acquisition. But one cannot arrive at a definite conclusion since this study did not aim to quantify the amount of language stimulation these infants received.

Overall, for all the various speech behaviours produced by these infants, it was interesting to note that as the age of the infants increased, the number and the length of utterances increased considerably. An utterance is described as a vocalization or groups of vocalizations that are separated by audible ingressive breaths or by pauses (Lynch, Oller & Steffens, 1989; Oller, Eilers, Bull & Carney, 1985; Stark, 1980). Considering this criterion, in the present study, it was observed that at younger ages, infants were able to produce utterances with a single string of vocalization. The frequency of these utterances was also less at these ages for the whole length of the recording. However, as the children grew older, it was seen that they produced utterances more frequently and these comprised of multiple strings. This could be attributed to an overall improvement in their neuromuscular development and coordination with respect to being able to sustain longer vocalizations in one breath cycle.

In another study on infant vocal development in the first six months of life, it was found that syllabic sounds were significantly longer and frequently produced than when compared to vocalic sounds (Hsu, Fogel & Cooper, 2000). It was documented that vocalizations with complex melodic contours were longer in duration, though these were less frequent when compared to simple melodic contours. They also suggested that there was a non-linear developmental trajectory with respect to the mean durations of syllabic and vocalic categories, which is unlike previous findings that propose that the mean duration increases over time (Delack, 1978; Laufer & Horii, 1976; Stark, 1989). This suggests the need for future studies to explore this phenomenon in a systematic manner even in Kannada-speaking infants.

In this study, there were few observed differences across gender for certain speech behaviours, although of smaller magnitude. From the raw data, it was observed that girls had higher rates of occurrence of verbal utterances for few months when compared to the boys. Previous accounts have consistently reported gender differences in the development of verbal abilities in children, with girls acquiring these abilities earlier than the boys (Fenson et al., 1994). Few other studies have documented these differences in acquisition, but for children and not in infants below the age of 1 year (McCormack & Knighton, 1996). It is also important to note that many studies on the early speech development of infants have not commented on differences based on gender. In the light of this observation, the findings of the current study points towards the need for documenting the presence or absence of a gender bias in future studies with larger numbers of participants.

9. Gestures and speech in development

It was seen that the percentage frequency of occurrence of gestures remained high throughout the study period, when compared to that of speech. This is somewhat consistent to earlier proposals of the cognitive (Piaget, 1954) and social interactionist approaches (Luria, 1959, 1960) of language acquisition, in that, the sensorimotor experiences (such as imitation, shaking a rattle etc.) and the nonverbal system helps the infant interact with their physical and social environments right from birth, giving rise to the verbal system, which along with the nonverbal system will then participate in the mediation of newer linguistic experiences.

This assumption derives support from studies that have especially looked into the development of symbolic hand gesture and speech systems. It has been reported that typically developing children achieve language milestones in gesture before attaining the same milestone in speech (Bates et al., 1979). For example, children are shown to point to an object before they are able to produce the verbal label for the object (Iverson & Goldin-Meadow, 2005). It has also been demonstrated that hand gestures can even predict further language development in children, in that the earlier a child uses a gesture, the earlier the same child will produce spoken language (Acredolo & Goodwyn, 1988). In a similar vein, the number of gestures and range of meanings conveyed in gestures are said to predict the range of verbal vocabulary till the age of 5 years of age (Rowe & Goldin-Meadow, 2009). These trends are paralleled in the development of children with even atypical profiles (Ozcaliskan, Levine & Goldin-Meadow, 2013; Thal & Tobias, 1992).

Based on the results of this study, it seems plausible that the nonverbal system, including the hand system, is dominant till the end of the first year. Further, it is possible that beyond this age, the trend might change with the verbal system taking over a bigger role in communication. This supposition again stems from the studies on the relationship between symbolic hand gestures and speech. As children grow older (beyond 26 months of age), they rely more on verbal symbols than gestures, and this has been seen in infants from Italian and English speaking backgrounds (Caprici et al., 2005; Namy & Waxman, 1998). Therefore, it would be interesting to see at what age this shift occur in Kannada-speaking children, and this can be taken up in future studies.

In summary, the observed trend in the development of gestures and speech suggests that both modalities demonstrate some similarities and differences within the first year of life. Thus, these results do not entirely provide support to the prediction made that these modalities would demonstrate similar growth patterns since they are components of the same system. Similarities were seen at three levels: (i) in the occurrence rates of some of these behaviours, such as, reduction in facial gestures or movements of legs and pre-speech utterances or even an increase in the rates of symbolic hand gestures and verbal utterances; (ii) in the non-linear and unpredictable growth trajectories demonstrated by behaviours in both modalities; and (iii) in the coordinated patterns of growth among behaviours within each modality. The salient finding seen in the development of these systems was a lack of evidence to predict the age at which changes in the occurrence rates of speech behaviours could be observed in the first year of life. On the other hand, most gestural behaviours exhibited this trait. This is indicative of the fact that components within the same communication system need not show the same trends in growth. A possible reason for the same could be that gestures are behaviours which are seen from early age in infants and hence they attain levels of maturity much earlier than vocal ones.

II. Patterns of co-occurrence of speech and gestures

1. Growth trends

Results on the coordinated occurrence of vocal and the gestural systems, indicates that infants coordinate their bodily actions with that of speech from a very early age. According to Iverson and Thelen (1999), these serve as the beginnings of the synchrony between gestures and speech, as seen in adult speakers. There are ample illustrations of various types of gestures co-occurring with different types of speech behaviours within each of the developmental phases that were studied. This possibly suggests that the various systems within an infant coordinate with each other to help in the emergence of a highly synchronized communication system like that of adults. However, one must also bear in mind that there were individual variations observed in the co-production of these modalities in the study. Not all children were seen to exhibit the various combination of behaviours that were documented in the study.

In the present study, it was observed that coordination between speech and the various other motor systems were in place from the 3rd month of life till the infants turned 1 year of age. Moreover, it must be noted that not all of the speech and gesture behaviours that were observed in the study co-occurred with each other. There were variations seen across the different months as well as among the infants that were studied. The probability of co-occurrence largely seemed to depend on the frequency of occurrence of most of the behaviours.

Among the vocal behaviours, it was observed that pre-speech utterances, syllabic and vocalic utterances frequently co-occurred with gestures than when compared to verbal utterances. In the case of gestural behaviours, it was noted that gestures of hands, gaze, facial expression, legs and head co-occurred frequently with vocal behaviours. However, it was also seen that not all the behaviours, both vocal and gestural, that were documented in the study demonstrated coupling across the developmental phases. Pre-speech utterances co-occurring with gestures were mostly seen during the initial and middle phases of development, while vocalic utterances co-occurring with gestures was frequently seen across all the three phases. Syllabic utterances co-occurring with gestures were frequent during the middle and final phases of development. Whereas, co-occurrences of verbal utterances with gestures were less frequent even in the middle and final phases. It was also interesting to note that among these verbal utterances, only verbalizations co-occurred with gestural behaviours, and tended to co-occur at higher rates with leg, head and gaze behaviours than with hands. The only explanation for this could be the presence of not-so-well practiced novel behaviours in both modalities, which could have resulted in a lack of coupling (Zanone & Kelso, 1991).

Considering the overall distribution of coordination bouts across the various developmental timeframes, it was seen that, when compared to other categories of gestural behaviours, hand movements co-occurred most frequently (highest percentage) with all categories of vocal behaviours. This could possibly suggest that from early on the vocal-hand link is strong and with age this link might pave way for the emergence of a mature gesture-speech system, as suggested by Iverson and Thelen (1999). This also warrants the need for studies using a time-based approach, which can yield useful information on the temporal and semantic nature of this co-ordination in infancy. Moreover, the findings in the study are not entirely consistent with the dynamic developmental progression as proposed by Iverson and Thelen (1999); in that, hand movements and gestures co-occurred at higher frequency in the initial pre-linguistic phase (>3 months to $\leq$ 5 months) and there was a reduction in the coordination bouts in the final pre-linguistic phase (>8 months to $\leq$ 12 months). According to Iverson and Thelen (1999), links between speech and hand movements should increase with age as they move towards adult-like coupling patterns, beyond the age of 14 months. Similar patterns were exhibited by the other gestural behaviours that co-occurred with various categories of speech behaviours in the study. It is possible that these differences are due to variations in the types of behaviours studied. For example, Iverson and Thelen (1999) have based their findings on hand movements co-occurring with only certain types of syllabic behaviours, such as CV. However, in the current study the coordination patterns of all speech behaviours that were grouped under the four categories were studied.

Across the three developmental timeframes that were studied, it was noted that there were few instances of significant differences seen in the patterns of coordination. These differences were only seen for the rates of co-occurrence of pre-speech utterances with facial movements and hand gestures, as well as for the co-occurrence of syllabic utterances with facial expression, leg movements, hand gestures and head movements. This suggests that the coupling between these behaviours is found to have a statistically significant developmental influence on the co-occurrence of these behaviours. These differences can be possibly attributed to the higher rates of co-occurrence of these behaviours during the initial pre-linguistic phase of development than when compared to the final phase of development. Since these instances were not many, it could suggest that there may not be variations of larger magnitude seen in the frequency of co-occurrences of behaviours across modalities with an increase in age. However, it should also be kept in mind that not all the infants in the study showed common patterns of co-occurrences, and this could have contributed to these findings.

There were correlations seen in the co-occurrence of few behaviours across the two modalities in the cases of pre-speech, syllabic and verbal utterances with gestures. Most of these demonstrated positive correlations with age. For example, syllabic utterances correlated with hand gestures. Verbalizations were found to correlate with gaze behaviours. These examples possibly provide additional support to the presence of a coordinated system, and suggest that the links between speech, hands and gaze systems are stronger when compared to the other systems towards the end of the first year of life. However, there were also instances of the speech behaviours negatively correlating with gestures. This was seen especially in the case of facial expression 'attention'. This possibly reflects the trend seen in the patterns of occurrence of this facial expression. As mentioned in the previous section, the observed behavior of 'attention' seems to suggest a link to active information processing (Doherty-Sneddon & Phelps, 2005) as well as to the possibility that this gesture might indicate the effort needed for speech production. Therefore, a decline in the co-occurrence could very well reflect the maturation of speech production skills and subsequently the weakening of the link between the two modalities.

Taking a closer look at each of the developmental time frames, some trends were evident. Gestures of the face, gaze, hand and movements of head, torso, leg, and whole body were seen to co-occur with pre-speech, vocalic and syllabic utterances in the initial pre-linguistic phase (>3 months to $\leq$ 5 months, 29 days). Pre-speech utterances were seen to co-occur at higher rates with facial movements; vocalic utterances were seen to co-occur at higher rates with whole body movements; and syllabic utterances co-occurred at higher rates with head movements. However, it was also seen that there were only marginal differences seen in the rates of co-occurrence of all speech types with the various gesture types in this phase.

Within this time period, there were variations seen in the patterns of co-occurrence of these behaviours, in that all the individual behaviours studied under each of the types of gestures and speech did not co-occur with each other. For example, among the facial expressions, 'displeasure' did not occur with any other behaviour during this time period. A possible reason for this pattern could be that the rate of occurrence 'displeasure' was less when compared to the other behaviours. This would also support the assumptions of the quantitative model as suggested by Iverson & Thelen (1999), which predicts that entrainment relies on the relative activation thresholds of either speech or hand gestures. Therefore, a more frequently occurring behaviour would have a low elicitation threshold and a high level of activation, which might enhance the chances of occurrence of entrainment. There were some evidences to support this claim in the co-occurrence of speech with manual (hand movements) and non-manual (other body movements) gestures. For example, 'vocal play' was a frequently produced pre-speech behaviour among the infants, during this time period. It was found to co-occur with other highly frequent behaviours such as 'attention' as well as less frequently occurring behaviours such as 'lean'. This suggests that 'vocal play' may be a behaviour of high activation level, and the production of this behaviour is possibly entraining other motor behaviours such as ‘attention’ and ‘lean’.

It was also interesting to note that there were instances in which even frequently occurring behaviours in one system did not entrain behaviours in the other system that were produced less frequently by infants during this time period. For example, ‘vocal play’ did not co-occur with ‘reach’ a hand gesture which occurred at low rates between 3 and 5 months of age. Such examples were seen even in the case of vocalic and syllabic utterances co-occurring with other motor behaviours. This may then suggest that a high level of activation of one behavior may not necessarily entrain another behaviour that exhibits low activation thresholds during this time frame. This would then refute the claims of the model (Iverson & Thelen, 1999).

However, these illustrations do support the presence of coordinated occurrence of bodily gestures and speech behaviours in young infants. This is in consonance with other studies that have looked into the co-ordination of behaviours in very young infants. For example, 2-month old infants were reported to demonstrate hand-waving, index-finger pointing, and fingertip-clasping movements near their faces during expressive vocalization and pre-speech facial movements such as tongue protrusion and lip contraction (Trevarthen, 1977). Fogel and Hannan (1985) also conducted a study on 9 to 15 weeks old infants and reported that manual actions such as index finger extensions, followed vocalization or mouthing movements. Curling action of fingers was also seen to co-occur with vocalizations, while spread of fingers was not found to occur with vocalizations. However, in the present study, both ‘curled’ and ‘spread’ were seen to co-occur with vocalizations.

In another study on infants between 9 and 15 weeks of age, index-finger extensions were observed to co-occur specifically with "speech like" vocalizations, but not with vocalic utterances (Masataka, 1995). However, there are other accounts that have documented that index finger extensions rarely occur with vocalizations (Blake, O'Rourke & Borzellino, 1994; Hannan, 1987). In the present study, however, index finger extensions were found to co-occur with pre-speech, vocalic and syllabic utterances, suggesting the possibility that patterns may vary among children. Another study examined the temporal relationship between facial actions (smile and frown) and vocalizations in infants at the ages of 3 and 6 months (Yale et al., 1999). They concluded that there was evidence that infants were systematically sequencing vocalizations and expressions within the first 6 months of life, further lending support to the findings in the present study.

In summary, it does seem that the co-occurrence of most types of gestures and pre-speech, vocalic and syllabic speech behaviours is relatively frequent during the initial pre-linguistic phase of development (>3 months to $\leq$ 5 months, 29 days). Moreover, this also seems to be in consonance with the proposed model by Iverson & Thelen (1999) which suggests that during the stage of initial linkages (0-5 months), there is a loose coupling between the hand and speech systems. The results of the current study possibly suggest that the model may be extended to understand the coupling between both manual and non-manual systems.

Even during the middle pre-linguistic phase (>6 months to $\leq$ 7 months, 29 days), it was observed that there were evidences of co-ordinations between pre speech behaviours and the various motor systems. Gestures of the face, gaze, hand and movements of head, torso, leg, and whole body were seen to co-occur with pre-speech, vocalic, syllabic and verbal utterances.

Pre-speech utterances were seen to co-occur at higher rates with hand gestures, while vocalic utterances were seen to co-occur at higher rates with facial expressions, syllabic utterances co-occurred at higher rates with facial movements and verbal utterances were seen to co-occur at higher rates with hand gestures. However, it was also seen that there were only marginal differences seen in the rates of co-occurrence of all speech types with the various gesture types that were studied.

Within this time period, there were variations seen in the co-occurrence of these behaviours. All behaviours studied under each of the types of gestures and speech did not co-occur with each other. For example, among the facial movements, 'lip protrusion' did not occur with any other behaviour. A possible reason for this could be that the rate of occurrence of 'lip protrusion' was less when compared to the other behaviours. This would possibly support the assumptions of the quantitative model (Iverson & Thelen, 1999), which predicts that entrainment relies on the relative activation thresholds of either speech or hand gestures. Therefore, a more frequently occurring behaviour would have a low elicitation threshold and a high level of activation, which might enhance the possibility of occurrence of entrainment. There were some evidences to support the claim in the co-occurrence of speech with both manual and non-manual gestures. For example, 'vowelization' was a frequently produced vocalic speech behaviour among the infants, during this time period. This was seen to co-occur with other highly frequent behaviours such as 'gaze at object' as well as less frequently occurring behaviours such as 'flex'. This suggests that 'vowelization' may be a behaviour of high activation level, and the production of this speech behaviour is possibly entraining other motor behaviours such as 'gaze at object' as well as 'flex'.

It was also interesting to note that there were instances in which frequently occurring behaviours in one system did not entrain behaviours in the other system that were produced less frequently by infants during this time period. For example, ‘gaze at object’ did not co-occur with ‘CV strings’ a syllabic speech behaviour which occurred at low rates between 6 and 8 months of age. Such examples were seen even in the case of pre-speech and verbal utterances co-occurring with other motor behaviours. Therefore, this may suggest that a high level of activation of one behavior may not necessarily entrain another behaviour that exhibits low activation thresholds during this time frame. This would then refute the claims of the model (Iverson & Thelen, 1999).

Nevertheless, the results do support the presence of a coupling between various bodily gestures and speech behaviours in infants between 6 and 8 months of age. This is in consonance with other studies that have looked into co-ordination of behaviours in infants between 6 and 9 months of age, although most of these studies have focused on the co-ordination of syllabic speech behaviours with rhythmic hand gestures. For example, Ejiri (1998) reported that infants exhibited rhythmic activities with higher frequency at the period around the onset of canonical babbling. This finding was also consistent with another cross-sectional study on infants' manual activity at the canonical babbling stage (Locke, Bekken, McMinn-Larson & Wein, 1995). In their study, Iverson and Fagan (2004) reported that relative to vocalizations without co-occurring rhythmic movement, a higher proportion of vocalizations with rhythmic movements consisted of CV repetitions. They also reported that these infants showed an age-related increase in the coordination of vocal behaviours with arm movements than when compared to movements of leg and torso. Further, Ejiri and Masataka (2001) found that infants exhibited rhythmic activities with high frequency at the period around the onset of canonical babbling. It was also noted that vocalizations frequently co-occurred with rhythmic action in infants during the pre-canonical stage, particularly before the month when infants began to babble, which then disappeared after the month when infants began to produce babbling. On the contrary, the infants in the present study did not produce syllabic utterances with greater frequency during this time period, rather they were produced with higher rates beyond the age of 9 months. Also, they were found to co-occur with relatively similar frequencies with even non-manual gestures. This might point to possible variations in the methodologies and annotation criteria used across these studies. It must also be kept in mind that since the sample size was small in the present study, the lesser instances of co-occurrences documented could have contributed to this observation.

In summary, it does seem that the co-occurrence of most types of gestures with pre-speech, vocalic, syllabic and verbal utterances is relatively frequent during the middle pre-linguistic phase of development (>6 months to ≤ 8 months, 29 days). To some extent, this also seems to be in consonance with the proposed quantitative model by Iverson & Thelen (1999), which suggests that during the stage of emerging control (6-8 months) there is continued coupling of hand and speech systems as a result of mutual influences. The findings in the current study possibly suggest that this model may be extended to understand the coupling between both manual and non-manual systems.

During the final pre-linguistic phase of development (>8 months to ≤ 12 months) in the current study, there were some evidences of co-ordinations between the two systems. However, it must be noted that there were more instances of lack of co-occurrences between speech and gestural behaviours during this phase. Gestures of the face, gaze, hand and movements of head, torso, leg, and whole body were seen to co-occur with pre-speech utterances, vocalic and syllabic utterances, while gestures of facial expression, gaze, hands, movements of head and torso co-occurred with verbal utterances.

Hence, there were differences seen in the rates of co-occurrence across different systems during this time period, which could be possibly explained by the rates of occurrence of these behaviours. For example, among the pre-speech utterances, 'laugh' and 'vocal play' were the only behaviours that were produced frequently by infants during this period and they co-occurred only with certain behaviours across the different types of gestures (e.g. co-occurrence was seen with single leg kicks and not with both leg kicks, among leg movements). Also, although few of the infants began producing words, these were not co-produced with any of the motor behaviours. The same was seen for symbolic hand gestures, which mostly emerged during this phase, but co-occurred only with early speech behaviours, namely vocalic utterances. This could be in accordance with the assumptions of the quantitative model for speech and hand gestures (Iverson & Thelen, 1999), in that, vocalic behaviours are frequently practiced and stable behaviours with relatively high levels of activation. Further, these in turn could have entrained the newly emerged manual behaviours that have relatively low levels of activation within this age range.

It was also noted that pre-speech utterances were seen to co-occur at higher rates with leg movements; vocalic utterances were seen to co-occur at higher rates with movements of torso; syllabic utterances co-occurred at higher rates with leg movements and verbal utterances were seen to co-occur at higher rates with hand gestures. However, it was also seen that there were only marginal differences seen in the rates of co-occurrence of all speech types with the various gesture types that were studied.

Within this time period, there were variations seen in the co-occurrence of these behaviours, in that all the individual behaviours studied under each of the types of gestures and speech did not co-occur with each other. For example, among the leg movements, 'both leg kicks' did not occur with any speech behaviour during this developmental phase. A possible reason for this pattern could be that the rate of occurrence 'both leg kicks' between 9 and 12 months was less when compared to other behaviours. There were also instances that lend support to the predictions of the quantitative model by Iverson & Thelen (1999), which assumes that entrainment relies on the relative activation thresholds of either a speech behaviour or hand gesture. Therefore, the assumption here is that a more frequently occurring behaviour would have a low elicitation threshold and a high level of activation, which might enhance the chances for entrainment to occur. For example, 'verbalization' was a frequently produced speech behaviour among the infants, during this time period. This was seen to co-occur to with other highly frequent behaviours such as 'grasp' as well as less frequently occurring behaviours such as 'curled'. This suggests that 'verbalization' may be a behaviour of high activation level, and the production of this speech behaviour is possibly entraining other motor behaviours such as 'grasp' as well as 'curled'.

On the other hand, there were instances in which frequently occurring behaviours in one system did not entrain behaviours in the other system that were produced less frequently by infants during this time period. For example, frequently occurring 'CV strings' did not co-occur with infrequently produced 'both leg kicks'. Such examples were seen even in the case of pre-speech, vocalic and syllabic utterances co-occurring with other motor behaviours. Therefore, this may suggest that a high level of activation of one behavior may not necessarily entrain another behaviour that exhibits low activation thresholds during this time frame. This would then refute the claims of the model (Iverson & Thelen, 1999).

However, some of these illustrations do support the presence of coupling and even the lack of coupling with few of the bodily gestures and speech behaviours in infants between 9 and 12 months of age. A study by Murillo and Belinchon (2012) on Spanish children from 9 to 15 months of age also reported similar findings favouring the presence of coupling. They coded vocalizations, gestures (any motor action) and gaze behaviours in these infants and concluded that the rate of use of multimodal patterns increased significantly with age for the observed periods. The findings in the current study are also partly in consonance with the suggestion that this period is characterized by asymmetry in the relative control and activation of motor effectors and that during the stage of flexible coupling (9-14 months), communication by gesture is predominant and there is a lag in verbal communication (Iverson & Thelen, 1999). The supposition is that in the transition phase that leads to synchronous production of gestures and speech, children will show a preference towards well practiced manual behaviours than newly learned verbal behaviours, and so children may not establish new co-ordinations with novel behaviours (Zanone & Kelso, 1991; Bates et al., 1979). The same was the case for even non-manual gestures. This assumption was true in the case of verbal utterances and symbolic hand gestures in this study. Both these behaviours were novel for this time period and they co-occurred with only few other well practiced behaviours. There were also instances where novel behaviours did not co-occur with other frequently occurring behaviours. However, the data from the present study suggests that not all the early behaviours produced by these infants decrease by the end of the first year. This was especially true in the case of vocalic and syllabic behaviours, as well as hand gestures. These were frequently produced even during this transition phase and they continued to co-ordinate with each other; i.e. with less frequently or frequently occurring behaviours. Abney et al. (2014) recently observed that particular changes in the dynamics of a modality usually preceded or coincided with the onset of significant developmental milestones in another modality. Therefore, it is possible that the co-occurrence of novel behaviours with only established ones is paving way for their frequent occurrences further in development, especially in the case of verbalizations.

In the current study, the raw data did suggest that there were instances where girl infants produced more coordinated bouts of behaviours. This was especially seen in the co-occurrence of vowelizations and hand gestures. However, a previous study by Fogel and Hannan (1985) reported that there were no gender differences seen in the phenomenon of co-occurrence. Perhaps, it must be kept in mind that the ages of infants that were studied were different in their study. Nevertheless, they did document a laterality bias in the co-occurrence of hand gestures. Other accounts have also hinted that infants do show a preference for the co-production of speech with right hand gestures. For example, a study on 6 to 9 month old infants has documented that infants coordinated a higher proportion of rhythmic speech behaviours with right arm movements (Iverson & Fagan, 2004). In the current study, conversely, there was no laterality biases observed in the co-occurrence of speech with hand gestures. This was true even for the raw data. A possible explanation for the same could be the differences in the methodologies and number of participants considered in each of these studies.

During the annotation of co-occurring bouts, it was also observed that there were instances where some of these gestures were synchronously produced with speech. For example, there were instances of ‘vowelizations’ and ‘gaze at person’ co-occurring simultaneously. However, since the current study followed an event-based approach to code these behaviours, these instances were not subjected to further analysis. But, these might suggest that even before the age of 1 year, infants may have synchronous gesture-speech coupling systems in place, although these might be very in-frequent and may possibly occur only for highly well-practiced behaviours. A time-based analysis approach will enable one to study this phenomenon in a better fashion.

Additionally, it was seen that apart from speech, the various gestural behaviours were also seen to co-occur with each other, even in the absence of speech. This was especially seen in the cases of head movements and gaze behaviours. Since the current study focused on the co-occurrence of speech with different types of gestures, the co-occurrences of behaviours within the gestural modality were not recorded for further analysis, but, it might be interesting to study this further.

In summary, true to the hypothesis of the study, speech and gestures were found to exhibit coordination from the age of 3 months, with certain coordinated bouts showing significant developmental influences. It was also seen that differential patterns of co-occurrence were exhibited by behaviours of both modalities, across the developmental time frames. For most part, when speech and gestures co-occurred with each other, this seemed to depend on the occurrence rates of these behaviours. Moreover, it was noted that there were instances of a lack of co-occurrence between novel speech (verbal utterances) and hand movements (symbolic hand gestures). This possibly suggests that novel behaviours in both modalities of the same communication system may only co-occur as the infant's advance in age.

Summary

Overall, the results of this study on the development of gestures and speech in pre-linguistic infants indicates that most of the early behaviours were seen from the 3rd month of age, and towards the end of the first year of life, mature and communicative behaviours were found to be frequently produced. The results also suggested that many of these behaviours across the various systems within the two modalities demonstrated a significant developmental change; i.e. there was a change in their occurrence pattern (i.e. either increase or decrease in rates of occurrence) with age. The growth trajectories plotted for speech behaviours and gestures revealed that majority of these behaviours had a non-linear growth trend and a few of these even exhibited linear trends. This possibly suggests that development is subject to variation within a time period and skills achieved at one age are not maintained or consistently seen beyond this age, and that the occurrence of any behaviour is dependent on biological, motivational and environmental factors. The findings also revealed that a good number of these behaviours demonstrated unpredictable trends, possibly suggesting that the development of behaviours may not demonstrate a definite pattern within the first year of life. Further, the change point analyses revealed that that there were certain months within the first year of life wherein there was a robust change in the rate of occurrence of gestures. Therefore, even in the face of variability these systems do demonstrate some amount of stability. Perhaps, these may serve as sensitive periods to indicate the development of skills in these systems, and the lack of such a trend possibly suggests that development in those particular systems is not stabilized within the first year of life. However, this trend was not exhibited by speech behaviours. The data also provides ample evidence to support that both modalities robustly emerge in a parallel fashion in every infant, and that behaviours that are acquired early in life do not tend to disappear as the infant grows older.

Infants were also found to coordinate behaviours in both gestural and speech modalities from a young age, with some of these patterns showing a significant developmental change. This suggests that within the first year of life there are well-defined changes in the co-occurrences of certain behaviours. The findings revealed that for most part, the probability of co-occurrence depended on the frequency of occurrence of behaviours, i.e. a frequently produced behaviour possibly entrains another behaviour that may be either frequently or infrequently produced. However, this was applicable to only certain behaviours, as this criterion was not always satisfied. Another observation was that novel behaviours in one system did not co-occur with novel behaviours in another system, possibly suggesting that novel behaviours can only co-occur with previously established behaviours. Nevertheless, these patterns seem to provide support for the dynamic coupling of speech and gestural behaviours.

There were inter-subject variations seen in the production of individual behaviours as well as in co-production bouts. This finding suggests that development is marked by individual variability, due to various factors pertinent to each infant, e.g. caregiver interactional style or motivation. This coupled with the variable trends demonstrated by the behaviours under study, suggests that variability in development is a norm and this has to be taken into account while studying the development of infants with atypical development.

Overall, the results have led to interesting observations that point to the need for further research, specifically addressing the role of multimodal systems in the development of communication in typically developing older children, which may be further extended to children with atypical developmental patterns.

SUMMARY & CONCLUSIONS

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Gestures constitute the nonverbal aspect of communication. Gesture is used by all when they speak, irrespective of the age, culture and social backgrounds. Gesture is not only performed with hands, but by other parts of body, such as head, face or arms. Thus, gestures are defined as manual [e.g., waving to say goodbye], facial [e.g., lip pouting to show displeasure], or other body [e.g., miming an object or person] movements (Capone, 2010).

Many studies (Bates et al., 1979; Capone, 2010; Thelen, Kelso & Fogel, 1986; Trevarthen, 1977) report that by the end of the first year, the repetitive motor activities of young infants begin to give way to more articulated control and directed communication via the nonverbal mode. The same trend is seen even in the case of the verbal modality; children progress from pre-linguistic vocal productions that randomly occur to meaningful productions that aid in referential communication (Oller, 1980; Stark, 1980). Nonetheless, these two modalities are not independent and are coordinated with each other from birth. It has been hypothesized that children learn to communicate and interact with their environment using the nonverbal and verbal modes, with the nonverbal mode leading the way early in infancy and the verbal mode stemming from the non-verbal one (Luria, 1960). This is consistent with what has been documented previously, wherein some studies indicate that the gestural and vocal modalities are semantically and temporally integrated from the earliest stages (Caprici et al., 2005), while others report that asynchronous combinations of gestures and words are more frequent than synchronous ones during initial phases of development in typical children (Butcher & Goldin-Meadow, 2000; Kelly, 2014). Apart from this, there are several processes which are intrinsic (e.g. maturation, cognition) as well as extrinsic (e.g. environment) to an infant that aids in the process of development of communication skills (Gerhskoff-Stowe, 2002; Gogate, Walker-Andrews & Bahrick, 2001; Piaget, 1954; Rohlfing, 2008; Thelen & Smith, 2003). However, such conclusions are based on studies that have followed different methodologies and across different age ranges of children, which in itself necessitates further exploration.

The aim of this study was to investigate and compare the development of gestures and speech in infants from the age of 3 months till 12 months, during play/interaction with mothers using a longitudinal design, with the objective of comparing the following across age:

1) Gestural behaviours of face, gaze, head, leg, torso, whole body as well as hands
2) Speech behaviours which included pre-speech, vocalic, syllabic and verbal utterances
3) Emergence of gesture - speech coordination

It was hypothesized that both gestures and speech would exhibit similar growth trends within the first year of life, since these are two components of the same communication system, which is multimodal. It was also assumed that gestures and speech would exhibit coordination from the age of 3 months, although the patterns of coordination might vary with age.

Nine typically developing infants (three girls and six boys) participated in the study. Informed consent was obtained from the parents prior to their inclusion along with their infants in the study. All the participants were full term babies, with no major birth complications, and passed a hearing, vision and language screening before they were included in the study. They were also from Kannada speaking families with the mother as the primary caregiver.

Each infant and the mother were videotaped at their home, using a Sony HDR handycam (video and audio recorder). The first recording was done at 3 months of age. Each recording was done once a month for the duration of 1 hour, when the child was most playful and alert. The recordings were not continuous, since there were breaks when the child was fussy/ uncomfortable. The mothers were instructed to talk to/ stimulate/ play with their infant as they normally would, either when the infant was lying on the floor or when placed on the lap of the mother or sitting independently in the later months. The mothers were also provided with toys by the investigator in order to facilitate interactions. These infants were observed for a period of 10 months, with the first recording beginning at 3 months of age and this continued until they turned 1 year of age. The analysis reported in the study includes on an average 8 recordings per child, the reason being that not all the infants were recorded every month either due to ill-health or other reasons within the family. Therefore, complete data was only available for three months of study between the ages of 3 and 5 months. The videos were later edited and only those portions of the data that could be used for the analysis were retained. The average duration of the data used for the analysis was 10 - 15 minutes per recording for every infant, from the 3rd to 6th months and 20-25 minutes per recording for every infant for the later months.

All behaviours of the infants were coded using ELAN software (Lausberg & Sloetjes, 2009). A *key* for coding gestural and speech behaviours was developed by the principal investigator (Appendix 2) and the same was compiled based on the review of literature (Bates et. al, 1979; Fogel & Hannan, 1985; Oller, 1981). Apart from the ones listed in literature, new behaviours that were observed in the samples were also included in the coding. Taken together, the key described gestures of face (expressions and movements), gaze, head, torso, legs, whole body, hands and speech behaviours. Each item in the key thus developed was provided with an operational definition, in order to facilitate uniformity in the coding across coders. The coding of the samples was done by three independent coders (speech language pathologists), one being the investigator and two other coders who were trained in the use of the coding system using a video sample of an infant who was not included in the study.

Initially the investigator identified and labeled the behaviours exhibited by the infants in every second of the frame. The other coders were required to do this exercise on 13% of the samples, and they were asked to carry this out independently. The 10 videos that were coded for reliability were selected randomly from the data pool, keeping in mind that each month of study was represented in the reliabilities check. From these samples the mean percentage of agreement between the coders was calculated. After the primary annotation was done, the investigator also identified the speech and gestural behaviours that co-occurred in each of the samples using an event-based approach, in order to document the co-occurrence of these behaviours. Frequencies of occurrences and co-occurrences, as well as rates of occurrences and co-occurrences were calculated and appropriate non-parametric statistical analyses were carried out in order to document the growth trends and patterns of occurrences of these behaviours. The salient results of the study are summarized below.

Overall, the findings of this study does suggest that both verbal and non-verbal behaviours are robust in infants from the age of 3 months, and both these sets of behaviours continue to develop independently and harmoniously within the first year of life. However not all annotated behaviours were seen from the 3rd month of age. As the age of the infants progressed, it was seen that infants began producing mature behaviours in both modalities, although this did not indicate that the early behaviours disappeared. Both early and mature behaviours within each modality exhibited some common and different trends with age.

All categories of behaviours in both modalities demonstrated significant developmental changes across most months of study; i.e. there were differences in the rates of occurrence of gestures and speech behaviours with age. These were further corroborated with the presence of significant correlations between the rates of occurrences and age, in positive and negative directions, indicative of differential growth patterns with age for each of the systems studied. It was also interesting to note that many behaviours in both modalities exhibited coordinated patterns of development, in that, they seem to mutually contribute or aid in the production or lack of production of other behaviours within each developing system. Behaviours in the gestural systems demonstrated linear, non-linear and unpredictable trends, while speech behaviours exhibited non-linear and unpredictable trends. This suggests that development is variable, not predictable, and that the acquisition of a behaviour does not imply that the behaviour is stabilized. Therefore, development might be considered as a constant process of evolution and dissolution (Smith & Thelen, 2003).

All behaviours within the gestural system, except that of torso and symbolic hand movements, demonstrated a significant age at which change in the occurrence rates of behaviours in the system was predictable. This suggests that although the occurrence patterns of behaviours are variable, age at which change is foreseeable in the system is evident. It was also seen that post this age of change, the occurrence patterns of behaviours in the system was different when compared that seen before this particular age. It was interesting to note that this trend was not observed for speech behaviours, which contributed to the difference seen in the occurrence patterns of behaviours across the modalities. This might suggest that development in the speech modality may not be as stabilized when compared to the gestural modality. This was further supported by the observation that gestures were produced with higher frequency than speech behaviours throughout the study period, suggesting that both modalities develop in a parallel fashion within the first year of life.

Considering that gestures and speech are part of the same communication system, these trends suggest that both gestures and speech are seen from a very young age in infants. Although both modalities share the same growth characteristics, there were differences observed. Gestures were produced with higher frequency across all the months of study and speech behaviours did not demonstrate an age at which change in the system could be predicted. This possibly provides evidence to support earlier assumptions that gestures/nonverbal behaviours precede the development of speech/verbal behaviours (Corballis, 2012; Luria, 1960), and that possibly within the first year of life the child interacts with his/her environment predominantly using the gestural mode. Further, the trends demonstrated by both modalities suggests that development of the communication system is dynamic and subject to variability, similar to what has been observed for other systems in children that are undergoing development (Abney et al., 2014; Schmidt & Post, 2015; Smith & Thelen, 2003). These findings suggest that both typical and atypical development must be viewed as a multimodal process and that the understanding of the development processes cannot be limited to documenting the ages of acquisition of skills within just the verbal modality.

Co-occurrence of gestural and speech behaviours were seen from the age of 3 months, with certain combinations of these behaviours demonstrating significant developmental changes within the first year of life. Pre-speech and syllabic behaviours that were co-produced with gestures exhibited this trend, suggesting that with age there were changes in the frequency of co-occurrence with age. These differences were seen between the initial and final pre-linguistic developmental timeframes, with higher rates of co-occurrence observed in the initial phase. There were only minimal differences seen in the rates of co-occurrence of various categories of speech and gestures within each developmental timeframe, and these were not significant. When compared to other gestural behaviours across the time periods studied, hand movements co-occurred with all four types of speech behaviours at higher frequencies (percentage), although there was a decline in the co-occurrence in the middle and final phases. It was seen that facial gestures, leg and torso movements co-occurred with pre-speech, vocalic and syllabic utterances at higher percentage frequency between the ages of 3 and 4 months, while there was an overall reduction in their co-occurrence beyond the age of 8 months. The opposite trend was seen for whole body movements co-occurring with these types of speech behaviours. In the case of gaze behaviours, head and hand movements the percentage of co-occurrence with speech behaviours was similar across all the months. All gestures were found to co-occur with verbal utterances mostly after the age of 7 months, which possibly reflects the age at which the infants began to produce verbalizations, which were the only behaviour that co-occurred with gestures within this speech category.

To some extent, the probability of these coordination bouts seemed to be determined by the frequency with which each of the behaviours were produced, in that, more frequently produced behaviours in one modality seemed to entrain both less frequently and frequently produced behaviours in the other modality. However, this was not uniformly seen across all categories of behaviours within each modality. Moreover, it was interesting to note that novel behaviours in both modalities did not co-occur with each other, the only exception being 'verbalizations'. It is possible that since these are relatively less well-practiced behaviours, they are not frequently produced and subsequently contributes to a lack of coupling. There were also significant correlations, both positive and negative, seen in the occurrence of certain coordination bouts with age, suggesting patterns that herald the mutual development of both modalities.

The nature of the coordination of speech and hand movements observed also suggests that children are on the path towards developing a gesture-speech system like that seen in adults from very early on, and this aligns with what has been previously suggested (Butcher & Goldin-Meadow, 2000; Iverson & Thelen, 2004; Kelly, 2014). This suggests that the link between speech and gestures is special since these are seen from early on. However, the finding that there is a decrease in the frequency of co-occurrence of speech and hand behaviours towards the end of the first year of life needs to be looked into. It is possible that the lack of co-occurrence of novel and mature behaviours in both modalities could have contributed to this observation. Further, although not well-defined, infants do seem to plan and produce verbal and non-verbal components of behaviours as a single unit, which might be temporally synchronous and asynchronous within the first year of life. However, since this study adopted an event-based analysis, the exact nature of synchrony in the co-expression of behaviours cannot be understood from these results. It must also be kept in mind that behaviours across the various gestural systems (e.g. gestures 'frown' (facial gestures) and 'gaze at person' (gaze behaviours) were also produced as coordinated bouts. These findings do suggest that infant communication system is multimodal and that these modalities show patterns of co-development, essentially influencing development both within and across a modality. Therefore, it would be interesting to further study the temporal characteristics of co-occurrence of behaviours across and within both modalities in young infants.

It is also clear that development/co-development of behaviours in infants is marked by inter-individual variability. Factors, such as, caregiver interactional styles, biological and neuro-muscular maturation seemed to interact in multiple ways and these appeared to determine the production of these behaviours and even accounted for variability in the occurrence of these behaviours in each of the infants that were studied. Although these were not measured for in the present study, these observations align well with the understanding that development occurs in a multidimensional context with the contributions of intrinsic and extrinsic processes within any given child (Gerhskoff-Stowe, 2002; Gogate, Walker-Andrews & Bahrick, 2001; Rohlfing, 2008). Therefore, future studies following a controlled design can better explain the extent to which these factors play a role in development. For example, caregiver interactional styles could play an important role in heralding the development of communication differentially across modalities. This is especially true for a country like India, where these interactional styles may vary across cultures, linguistic, educational or even socioeconomic backgrounds. Documenting these influences would probably strengthen our understanding of the developmental process, particularly in atypical children.

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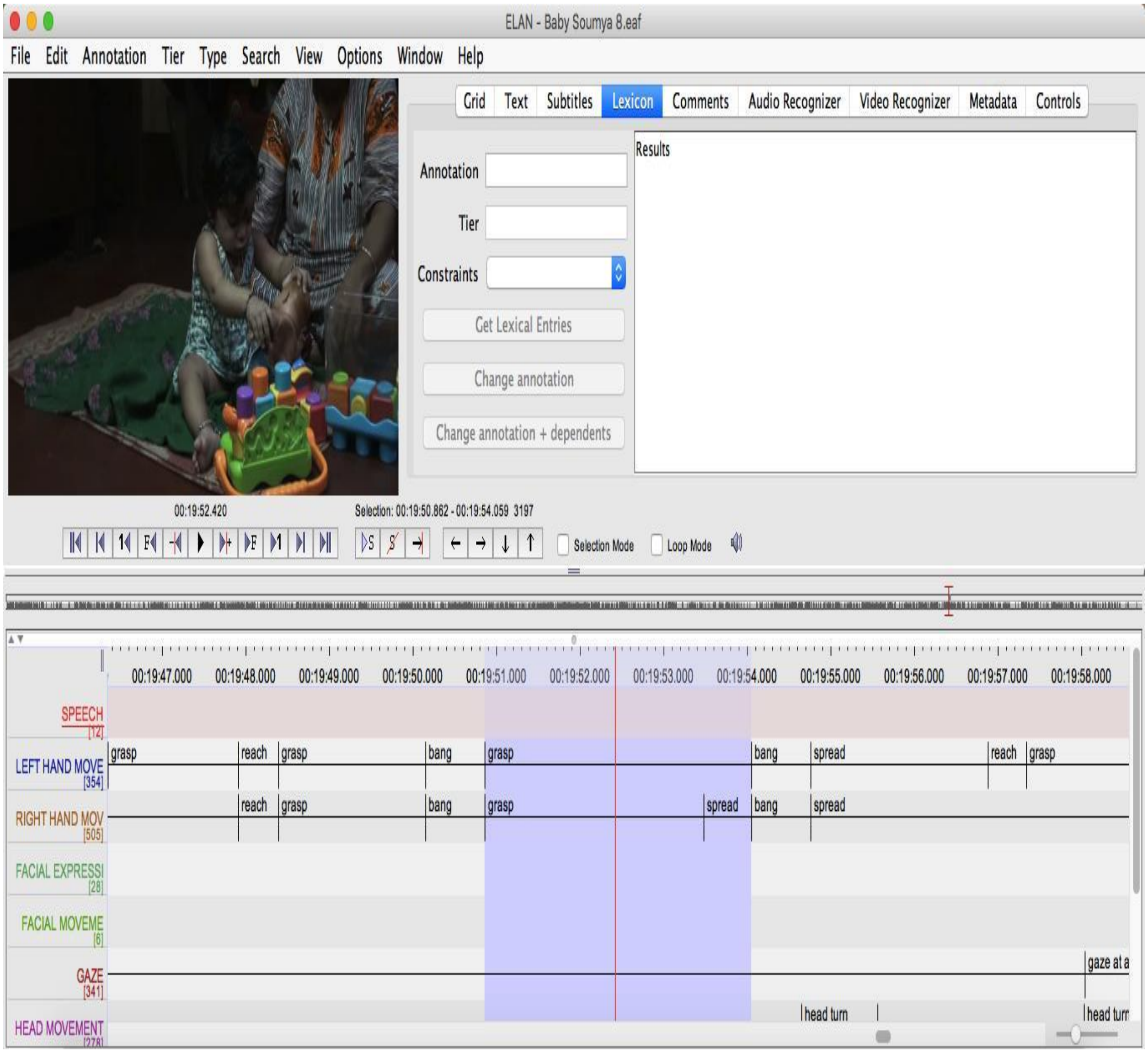
APPENDICES

APPENDIX 1

ELAN sample for participant 3.



APPENDIX 2

Key with the operational definitions of annotated gestural and speech behaviours used in the study.

Sl No:	Type	Behaviours	Operational definition
A.	***Gesture***		
1.	Facial gestures		
1.1.	Facial expression	Attention	Brows raised at centre of face and lowered at outside edges of face
		Displeasure	Furrowed brows towards eyes
		Discomfort	Furrowed brows with lip lifted and protruded
		Interest	Brows slightly raised
		Frown	Mouth slightly open with edges of mouth curved downward
		Startle	Multiple eye blinks
		Smile	Edges of mouth curved upward
1.2.	Facial movement	Tongue protrusion	Anterior extension of the tongue
		Lip/tongue play	Rapid and repetitive movements of lip/tongue
		Pout	Puckered lips with lower lip protrusion
		Mouthing	Lip, mouth or tongue movements similar to when one speaks
		Puckered lips	'Kiss-like' mouth formation
2.	Gaze behaviours	At person	Looking at mother's face
		At object	Looking at an object
		At action	Looking at the behaviours of self, others or objects
		Away	Eye's closed or gaze diverted
		Track	Visual tracking of object
		Shift	Shifting gaze quickly between objects or actions
3.	Head movements	Roll side to side	Lateral rotation of head (headshake)
		Roll front to back	Forward-backward movement (head nod)
		Extended	Head held high*
		Lowered	Head held low*
		Turn	Rotation of head to either side
4.	Leg movements	Both leg kicks	Flexion and extension of the two legs, either simultaneously or in alternation
		Single leg kick	Flexion and extension of one leg
		Foot rub	The medial surfaces of the foot rub against the ankle and foot of the opposite leg
		Feet in contact	Mutual contact of feet

5.	Movements of torso	Bounce	Torso moves up and down
		Rock	Back-and forth movement
6.	Whole body movements	Lean	Upper half of body moves forward or backwards
		Stand with support	Standing with help from adult or sturdy object
		Stand	Standing independently
		Turn	Rotation of upper half of body
		Crawl	Moves using both hands and legs
		Walk	Moves using feet
		Walk with support	Moves using feet with help from adult
		Roll over	Turns entire body in a lateral direction
7.	Hand Movements		
7.1.	Pre-Symbolic Bimanual gestures	Clasp	Any mutual contact of hands or fingers
		Clap	Brief, forceful and repeated contact of hands
		Up	Both arms extended towards an adult
7.2.	Pre-Symbolic movements	Curled	Fingers flexed either loosely, or in a fist
		Grasp	The hands / fingers are wrapped around something other than own hands
		Hand in mouth	Fingers placed in mouth
		Hand-held toy in mouth	Toy held in hand placed in mouth
		Index finger extension	Any clear sustained extension of the index finger
		Reach	Extending fingers towards an object in order to reach
		Spread	All fingers fully extended or spread apart
		Up	Both arms extended towards an adult
7.3.	Pre-Symbolic Rhythmic movements	Bang	Movement with the hand or object held in hand makes firm contact with a surface
		Cycling	Any movement by the fingers; rhythmic tapping, flexing and extending of fingers
		Flex	Bending and extending of wrist
		Shake	Vertical movement of the arm from the shoulder with an object in hand
		Swing	Vertical movement of the arm from the shoulder with no object in hand
		Twist	Rotation of wrist back and forth
7.4.	Symbolic movements	Give	Handing over an object to the adult
		Hand configuration	Conveys some aspects of the referent's meaning
		Point	Extending finger or palm towards a referent
		Request	Reaching with open hands while looking at caregiver or moving an adult's hand to the referent

		Show	Holding up an object in the listener's potential line of sight
		Take	Receiving an object with open hands from an adult
B.	***Speech***		
1.	Pre-speech utterances	Vocal play & vegetative sounds	Sounds that reflect the child's attempts at testing the vocal apparatus, such as laugh, shout, squeal, click, and vegetative productions such as grunt or cry.
2.	Vocalic utterances	Hum	Wordless nasal tone with the mouth opened or closed
		Vowelization	Vowel like sounds produced in one breath (prolonged)
3.	Syllabic utterances	Articulatory gesture with weak vocal element	Facial postures that resemble speech with weak or no voicing*
		Babbling (shapes)	Vowel- and consonant- like productions that approximate syllable (CV, VC, CVC, VCV etc.)
4.	Verbal utterances	Jargon	Short utterances unacceptable in adult speech (seen during interactions with caregivers)
		Verbalization	Long utterances that resemble speech with less intelligibility (seen during interactions with caregivers) *
		Word	Distinct meaningful word
5.	Prosodic alterations		Variations in intonation within an utterance *

Source: As adapted from Bates, et al., 1979; Fogel and Hannan, 1985; Oller, 1980; *Investigator

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Trends in the Development of Rhythmical Hand Behaviours in Infants

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Abstract

Infants are reported to produce large amounts of rhythmical behaviours, like kicking, banging, rocking, waving, bouncing, swaying and such. The present study examined the development of rhythmical hand behaviours, in order to understand the trends in the emergence of these behaviours. Participants included nine infants who were longitudinally studied for the duration of 10 months, between 3 and 12 months of age. The infants were observed for six types of rhythmic behaviours (cycling, bang, swing, shake, flex and twist) as they co occurred with speech behaviors, and a measure of rate of co-occurrence was calculated. Results indicated that rhythmical behaviours were present from the young age of 3 months, with changes in the occurrence rate as they grew older. There were also variations seen in the rates of occurrence with respect to hand preference and some indicators of cultural variations with respect to few of these rhythmical behaviours.

Key words: Rhythmical hand behaviours; longitudinal design; rate of occurrence; growth trends.

Introduction

Rhythmical stereotypes are a part of the behavioral repertoire of insects, fish, birds and is less common in mammals (Schleidt, 1974). In primates, these stereotyped behaviours are uncommon and are considered pathological. Among non-human primates, these have not been observed in free animals, but are seen in animals caged in small enclosures or those raised in social isolation (Berkson, 1968). In humans, stereotypy is usually associated with not-so-typical populations, like children with autism, individuals who are blind, and those who are emotionally disturbed (Berkson & Davenport, 1962).

When compared to other primates, stereotypy is the hallmark of typically developing human infants during a stage in the lifecycle (Kravitz & Boehm, 1971). Infants are reported to produce large amounts of rhythmical behaviours, like kicking, banging, rocking, waving, bouncing, swaying and such. These behaviours occur very frequently and infants are seen to enjoy and absorb these acts, though it is difficult to ascribe a purpose for these movements.

There has been considerable debate regarding the functions of these stereotypical behaviours seen in infants. Psychoanalysts have suggested that stereotypy could be a sign of emotional development, such as an attempt to recreate rhythmical prenatal experiences or as a result of an infant being confined to a small space (Kris, 1954; Levy, 1944). Piaget (1954) observed that the repetitive movement are 'secondary circular reactions' since an infant repeats activities that have an interesting effect on the environment, thus serving as a sign of cognitive development. It has also been noted that certain rhythmical behaviours are associated with particular stages of neuromuscular maturation, and therefore suggest that rhythmic patterns appear in the transition stages of motor development (Kravitz & Boehm, 1971).

Schleidt (1974) proposed that repetition of a signal could increase its potency for communication, since caregivers may consider these behaviours as intentional. A study on 'fussy' infants reported that the increased levels of arousal in a baby facilitated the release of rhythmic motor output, which in turn accentuated their cry for distress and received a hastened response from the caregiver (Thelen & Fisher, 1982). This result suggests that rhythmic movements may communicate infant affect.

Thelen (1979) observed 20 American infants between the ages of 4 and 52 weeks and concluded that there seemed to be multiple contexts that elicited rhythmical behaviours in the infants. These were categorized as interactions with caregivers, other people, interest in objects, feeding times, passive or active kinesthetic changes and non-alert states like that of drowsiness. Further, developmental trends in the interactions of these contexts and rhythmic movements were also observed. It was observed that in 3-5 month old infant's interactions with caregivers occurring frequently in object related interactions with older infants served as strong elicitors of stereotypy, . It was also seen that all types of contexts elicited stereotypy during6-7 months and showed a decline when the infants were approaching 12 months of age. Thelen (1979) also documented a wide range of rhythmical stereotypies that involved various parts of the body such as legs, head, torso, arms and face in infants. Among the movements of legs and feet, rhythmical kicking was observed in early age and was found to persist for a number of months. These bouts were often seen in infants between 6 and 14 weeks of age, when they were in prone or supine position. . The rhythmic movements seen were alternate-leg kicking, single-leg kicking, foot rubbing, both-legs-together kicking, foot flexion, foot stomping and foot rotation.

Movements of torso observed in the study included bouncing, swaying, rocking, hand-and-knees rock, hands-and-feet rock, rocking and bouncing while sitting, kneeling and standing. These stereotypies were observed while the infants were in prone, sitting, kneeling or standing positions as well as when they were supported on hands, knees and feet. These movements were observed in infants at various ages; abdomen movements by 16 to 34 weeks, hands and knees movements by 18 to 44 weeks, sitting movements by 18 to 48 weeks, kneeling movements by 30 to 50 weeks and standing movements by 22 to 44 weeks.

It was also documented that infants performed many bouts of stereotyped movements of the arms, hands and fingers, which were often found to incorporate objects as part of the movement itself. These behaviours included arm waving, arm banging, hand clapping, push-pull movement of elbow (bend), ear/hair rub, flexing of hands, rotating of hands and flexing of fingers. . It was also noted that flexing of fingers was not seen in all infants. Rhythmical movements of arms began by 6 to 22 weeks, movements of hands by 22 to 46 weeks and movements of fingers were seen by 4-16 weeks. Movements of head and face were reported to be infrequent when compared to the rest of the body. Head shake and head nod were seen along with tongue protrusions, tongue swipes, non-nutritive sucking and small rhythmic mouthing movements.

Thelen (1981) concluded that rhythmic stereotypies appeared to be under strong central control. The first evidence that points in this direction is the regularity seen in the age of onset of these behaviours and the close association of these ages to other aspects of neuromuscular maturation. Therefore, the production of these behaviours seem to be dependent on the maturation of the nervous system and these events are intrinsic to the infant. But this does not rule out the variability in the developmental course of these behaviours, which might reflect the influence of factors extrinsic to the infant. However, Thelen (1981) observed that despite the variability, these behaviours develop in an orderly manner. Evidence that also supports this view can be found in the appearance of these behaviours before the infant gains postural control over a new position. For example, rhythmical kicking may precede both the ability to support weight on legs as well as the use of legs for crawling or walking. This might suggest that simple motor patterning actually reflects some degree of functional maturity of a neuromuscular pathway, even though the pattern is not under complete voluntary control and there is imperfect goal-correction.

Thelen (1981) also suggested that these stereotypies could also be the result of an overload in the neural processing capacity, since the available pathways are immature to process heavy demands; implying that when maturation enhances the processing capacity of the system, the stereotypical behaviours will be replaced by variable and goal-corrected activity. This observation could be extended to human infants since their neuromuscular maturation is much slower when compared to infants of non-human primates. But, it can also be the case that these behavioural 'by-products' are used as per the opportunities by infants and may serve a variety of complex functions when mature behaviours are not available to them.

These views do suggest that there are various aspects of the development of rhythmical movements that are not clearly understood. Since infants are constantly engaged in producing these movements, tracing their development from a very young age could possibly shed some light on the factors that govern the emergence and in some cases there is decline in these behaviours with progress in age. Also, if these movements are a part and parcel of the process of neuromuscular maturation, then it must be deemed important to document the development and patterns of occurrence of these rhythmic movements. This is especially true for hand movements as they form a communicative system that develops in conjunction with the speech/linguistic system. Keeping this background in mind, this study has been undertaken to document the patterns of development of rhythmical hand behaviours in typically developing infants.

Aim of the Study

This study aimed to document the development of rhythmical hand movements in typically developing infants from the age of 3 to 12 months, using a longitudinal design.

Method

Participants

The study included nine typically developing infants, three female and 6 male infants. These infants were followed longitudinally for a period of 10 months, and the first recording was made at the age of 3 months and ended when the infants turned 1 year of age. On an average, there were 8 recordings per child. This was because of unavoidable circumstances where some infants could not be recorded for all the 10 months of the study period. All the participants were full term babies, with no major birth complications, and passed a hearing, vision and language screening test before they were included in the study. They were also from Kannada speaking families with the mother as the primary caregiver.

Procedure

The recordings were done in the homes of the infants while they were interacting with their mothers, using a Sony HDR video and audio recorder. Each recording was done once a month for the duration of 1 hour, when the child was most playful and alert. The recordings were not continuous, since there were breaks when the child was fussy/ uncomfortable. The mother was instructed to talk to/ stimulate/ play with the infant as normally as possible, either when the infant was lying on the floor or when placed on the lap of the mother or sitting independently in the later months. The videos were later edited and only those portions of the data that could be used for the analysis were retained. The average duration of the data used for the analysis was 10 - 15 minutes per recording, from the 3rd to 6th months and 20-25 minutes per recording for the later months.

Coding of Rhythmic Behaviours

The rhythmic behaviours of the infants were coded using ELAN software (Lausberg & Sloetjes, 2009), which provides a frame- by- frame analysis of the recording. A key for coding all the behaviours was developed by the principal investigator (Appendix 1) and the same was compiled based on a review of existing literature (Thelen, 1981). Each item in the key thus developed was provided with an operational definition, in order to facilitate uniformity in the coding across coders. The coding of the samples was done by three independent coders (speech language pathologists), one being the principal investigator and two other coders who were trained in the use of the coding scheme using the video sample of an infant who was not part of the main study.

Initially, the principal investigator identified and labelled the rhythmic behaviours exhibited by the infants. Then the two coders were instructed to go through the coded samples and indicate whether they agreed or disagreed with the annotations of the principal investigator. The coders were required to do this exercise on 10% of the samples, which were randomly selected, i.e.10 videos, and they were asked to carry out this independently. The 10 videos were selected from the data pool, keeping in mind that each month of study was represented in the reliabilities check.

The mean percentage agreement was calculated for both the coders for rhythmic hand behaviours, and this is as shown in Table 1.

Table 1: The percentage agreement between coders for gaze behaviours.

Month	Total number of rhythmic behaviours	Mean percentage of agreement (%)
3	66	94.97
4	71	88.67
5	71	86.71
6	98	89.45
7	87	93.49
8	69	91.11
9	61	88.61
10	45	93.73
11	43	91.19
12	54	93.59

Results

The aim of the study was to document the development and patterns of occurrence of rhythmic behaviours between the ages of 3 and 12 months in typically developing infants from Kannada Speaking families. The following hand behaviours were analyzed in the study: 'bang', 'cycling', 'shake', 'swing', 'flex' and 'twist'. These were annotated separately for the left and right hands. A measure of *rate of occurrence per minute* was computed. This rate was calculated in ELAN software for each month, and it is defined as the total number of individual rhythmic behaviours divided by the duration of the observational segment for that month.

The means and standard deviations for the rates of occurrence of pre-symbolic rhythmic gestures of the left hand are as shown in table 2 and figures 2 (a, b, c, d, e & f) show the mean rates and the quadratic growth models for each behaviour. Kruskal-Wallis test revealed a significant difference in the rates across the months for 'bang' [χ^2 (7, N=937)=47.150; p=0.000], 'shake' [χ^2 (8, N=789)=40.738; p=0.000] and 'swing' [χ^2 (9, N=1603)=28.355; p=0.001] at 0.001 levels of significance.

The post-hoc analysis revealed that for ‘bang’ gesture, the differences were due to the variations seen in the rates between the means of the 8th and 3rd, 4th and 5th months and in the case of ‘shake’ gesture variations were seen between the means for the 10th and 3rd, 4th and 5th months. For ‘swing’ gesture, the differences were noted between the means for the 4th month and all the months from the 6th month.

Table 2: Means & SDs for rates of occurrence of left hand rhythmic behaviours.

Month	Bang	Cycling	Shake	Swing	Flex	Twist
3	0 (0)	0.195 (0.163)	0 (0)	1.582 (0.807)	0 (0)	0 (0)
4	0 (0)	0.244 (0.338)	0.165 (0.48)	1.96 (1.35)	0 (0)	0 (0)
5	0.313 (0.538)	0.23 (0.176)	0.226 (0.195)	1.236 (0.433)	0 (0)	0 (0)
6	0.469 (0.427)	0.444 (0.674)	0.682 (0.367)	0.796 (0.305)	0.072 (0.205)	0.036 (0.102)
7	0.367 (0.179)	0.224 (0.263)	0.245 (0.202)	0.427 (0.265)	0.086 (0.16)	0 (0)
8	1.307 (1.391)	0.341 (0.406)	0.419 (0.311)	0.708 (0.624)	0 (0)	0.023 (0.048)
9	0.675 (0.626)	0.158 (0.133)	0.465 (0.46)	0.29 (0.148)	0.006 (0.015)	0 (0)
10	0.794 (0.59)	0.199 (0.326)	1.099 (1.138)	0.56 (0.668)	0.087 (0.194)	0.063 (0.099)
11	0.784 (0.425)	0.454 (0.557)	0.711 (0.363)	0.726 (0.569)	0.012 (0.021)	0.011 (0.021)
12	0.882 (0.781)	0.267 (0.291)	0.796 (0.507)	0.589 (0.422)	0.013 (0.024)	0 (0)
P	0.000***	0.915	0.000***	0.001***	0.326	0.089

Note: ***$p \leq 0.001$

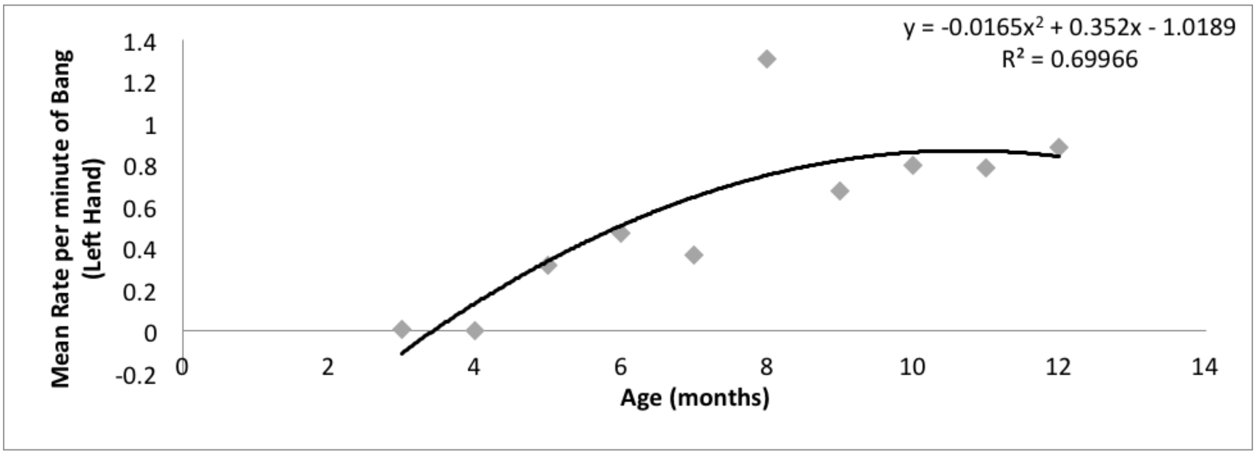

Figure 1(a): Mean rate and growth model for bang (left hand).

From the Figure 1(a), it can be understood that 'bang' gesture is only present from 5 months of age in these infants. The rate of occurrence was highest in the 8th month, beyond which there was a decrease seen between the 8th and 12th month. However, there was an overall increase in the production of this behaviour in this age group than when compared to that between 3rd and 7th month. Correspondingly, the quadratic growth model predicted a polynomial growth trajectory for this gesture, with the quadratic regression predicting a good fit for the model (R^2= 0.6996). This would then suggest that 'bang' is a hand movement that increases with a corresponding increase in age during infancy.

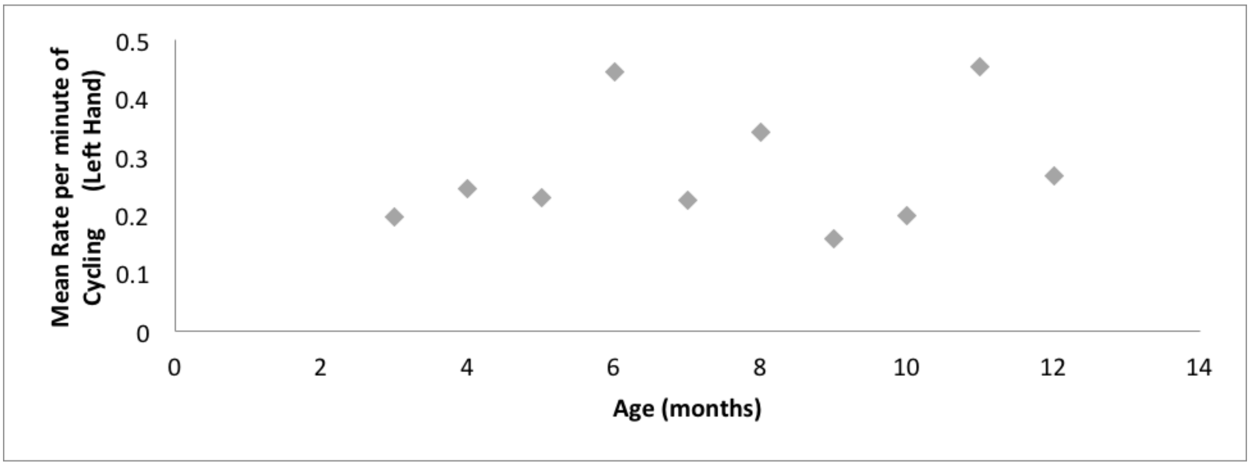

Figure 1(b): Mean rate and growth model for cycling (left hand).

From figure 1(b), it is evident that 'cycling' gesture was seen across all the months of study, although there is no clear pattern of increase or decrease in the rates. The highest rate of occurrence was noted in the 11th month. Correspondingly, the quadratic growth model revealed an unpredictable growth trajectory for this behaviour.

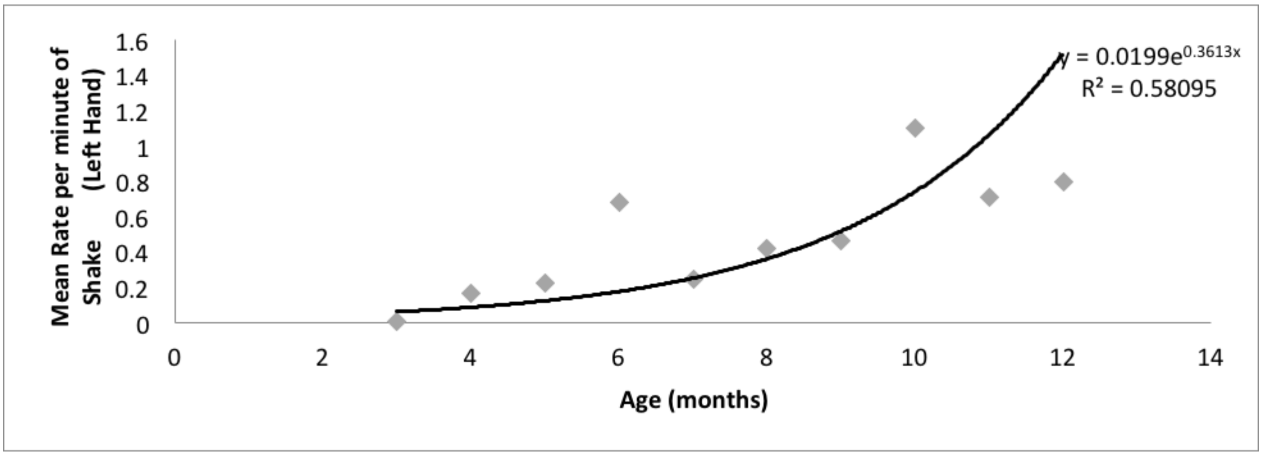

Figure 1(c): Mean rate and growth model for shake (left hand).

From figure 1(c), it can be observed that 'shake' gesture was noted from the 4th month onwards in the sample, with a near-steady rise till the 12th month. It was also clear that two months, namely, the 6th and the 12th recorded frequent instances of production of this behaviour, although, the highest rate was seen in the 10th month. Correspondingly, the quadratic growth model predicted an exponential growth trajectory for this gesture, with the quadratic regression predicting a low fit for the model (R^2= 0.5809). This would then suggest that the occurrence of 'shake' may vary with an increase in age during infancy.

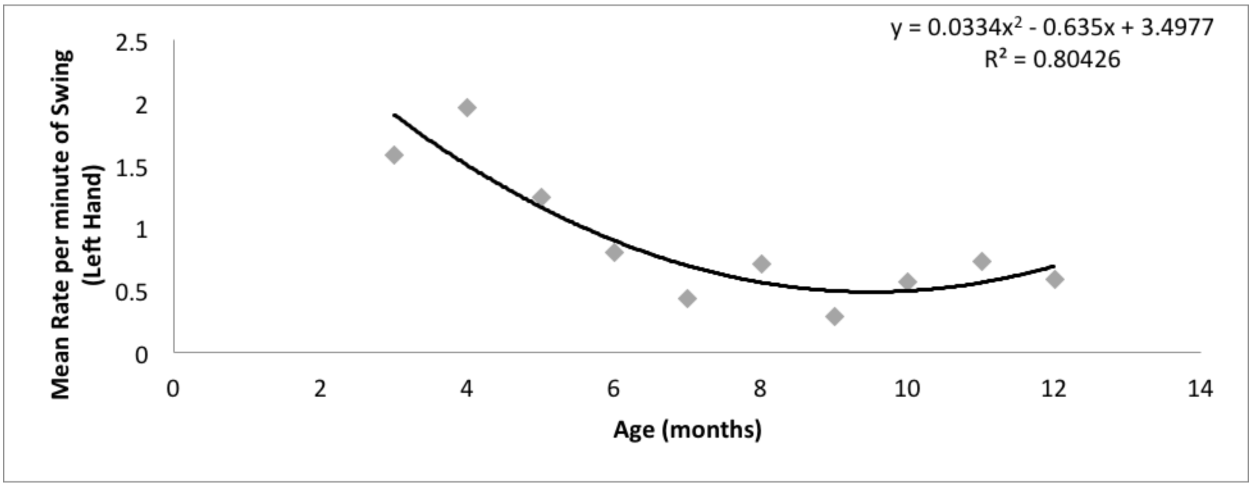

Figure 1(d): Mean rate and growth model for swing (left hand).

From the above figure, it is evident that 'swing' gesture was seen from the 3rd month in these infants, and the occurrences seem to reduce as age increases. The highest rate was noted in the 4th month, and thereafter the rates decreased between 5 and 7 months of age. There was also a slight increase in rates observed between 8 and 11 months. Correspondingly, the quadratic growth model predicted a polynomial growth trajectory for this gesture, with the quadratic regression predicting a good fit for the model (R^2= 0.8042). This would then suggest that 'swing' is a behaviour that decreases with a corresponding increase in age during infancy.

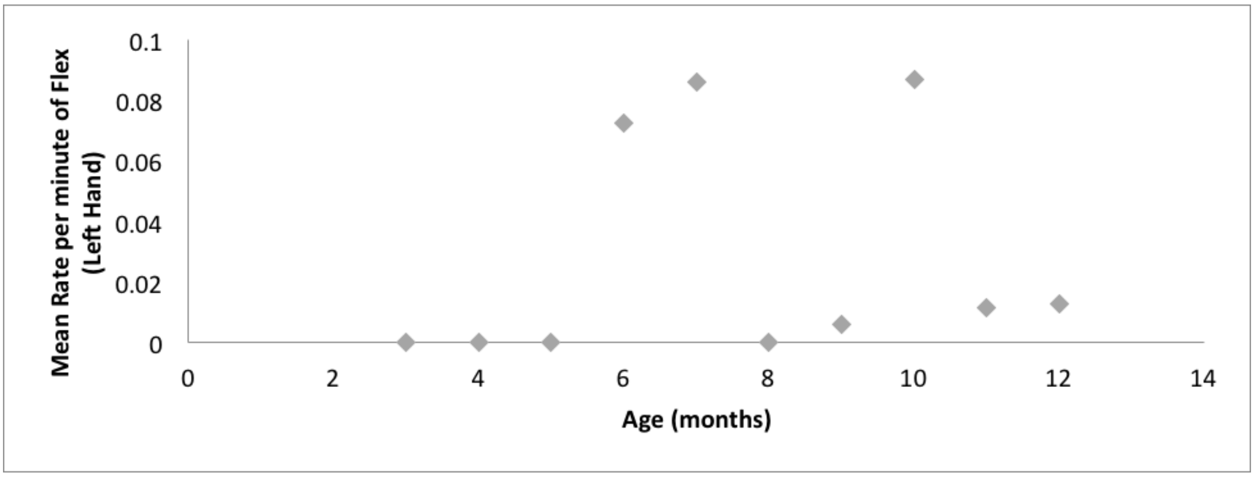

Figure 1(e): Mean rate and growth model for flex (left hand).

From figure 1(e), it is clear that 'flex' gesture was not produced frequently by the infants throughout the study period. It was observed only between 6 and 12 months, and there was a lot of variation seen in the occurrence within this age range. The highest rates were seen for both 7and 12 months of age. Correspondingly, the quadratic growth model revealed an unpredictable growth trajectory for this behaviour.

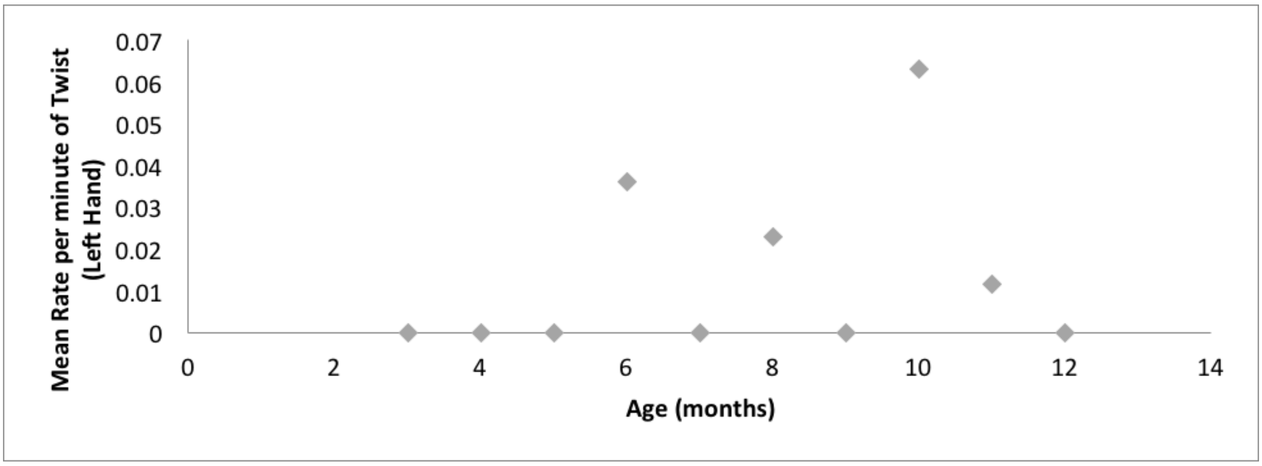

Figure 1(f): Mean rate and growth model for twist (left hand).

From the figure 1(f), it can be understood that infants rarely produced 'twist' gesture. It was noted to be present between 6 and 11 months of age, although there were variations in the rates of occurrences within these months. And the highest rate of occurrence was seen in the 10th month. Correspondingly, the quadratic growth model revealed an unpredictable growth trajectory for this behaviour.

The means and standard deviations for the rates of occurrence of pre-symbolic rhythmic gestures of the right hand are as shown in table 3 and figures 2 (a, b, c, d, e & f) which show the mean rates and the quadratic growth models for each gesture. Kruskal-Wallis test revealed a highly significant difference in the rates across the months for the gestures 'bang' [χ^2 (8, N=1789)=53.774; p=0.000], 'shake' [χ^2 (9, N=1191)=42.515; p=0.000] and 'swing' [χ^2 (9, N=1920)=31.332; p=0.000] at 0.001 levels of significance.

The post-hoc analysis revealed that for ‘bang’, the differences were due to the variations seen in the rates between the means for the 9th month and those below the 6th month, and in the case of ‘shake’ gesture, variations were seen between the means for the10th and all the other months. For ‘swing’ gesture, these differences were noted for the means of the 4th and 3rd months and all the months from the 8th.

Table 3: Means & SDs for rates of occurrence of right hand pre-symbolic rhythmic gestures.

Month	Bang	Cycling	Shake	Swing	Flex	Twist
3	0 (0)	0.207 (0.187)	0.036 (0.068)	1.941 (0.936)	0 (0)	0 (0)
4	0.006 (0.017)	0.269 (0.227)	0.143 (0.273)	2.033 (1.325)	0 (0)	0 (0)
5	0.449 (0.483)	0.228 (0.263)	0.323 (0.28)	1.656 (0.63)	0 (0)	0 (0)
6	0.486 (0.487)	0.428 (0.501)	0.459 (0.351)	0.75 (0.445)	0.066 (0.123)	0.01 (0.029)
7	0.853 (0.628)	0.326 (0.108)	0.469 (0.34)	0.631 (0.431)	0.226 (0.363)	0.027 (0.048)
8	2.28 (2.041)	0.611 (0.519)	0.883 (0.859)	1.072 (0.664)	0.037 (0.062)	0.032 (0.049)
9	1.998 (1.945)	0.272 (0.15)	0.878 (0.565)	0.272 (0.137)	0.012 (0.03)	0.006 (0.015)
10	2.192 (1.051)	0.331 (0.329)	2.306 (1.712)	0.746 (0.595)	0.079 (0.152)	0.036 (0.059)
11	1.317 (0.731)	0.498 (0.39)	1.035 (0.337)	0.884 (0.636)	0.005 (0.015)	0.016 (0.032)
12	1.525 (0.954)	0.353 (0.331)	1.094 (0.64)	0.81 (0.723)	0.012 (0.022)	0 (0)
P	0.000***	0.576	0.000***	0.000***	0.101	0.097

Note: ***p≤0.001

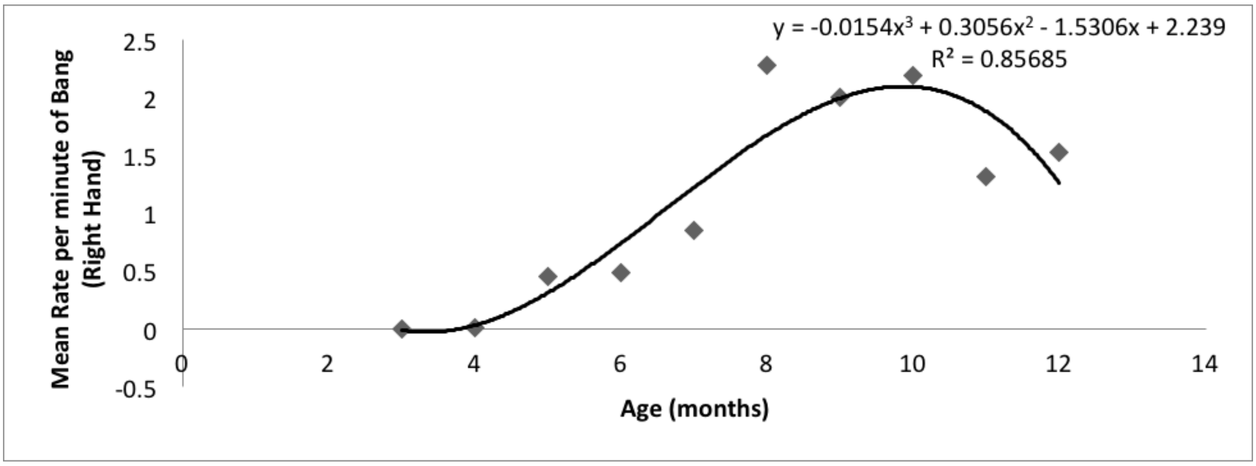

Figure 2(a): Mean rate and growth model for bang (right hand).

From the figure 2(a), it can be understood that 'bang' gesture is only present from 5 month of age in these infants. The rate of occurrence was highest in the 8th month, beyond which there is a decrease seen between the 8th and 12th month. However, there was an overall increase in the production of this behaviour in this age group than when compared to that between 3rd and 7th month.

Correspondingly, the quadratic growth model predicted a polynomial growth trajectory for this gesture, with the quadratic regression predicting a good fit for the model (R^2= 0.9344). This would then suggest that 'bang' is a behaviour that shows an increase as well as a decrease in occurrence with a corresponding increase in age during infancy.

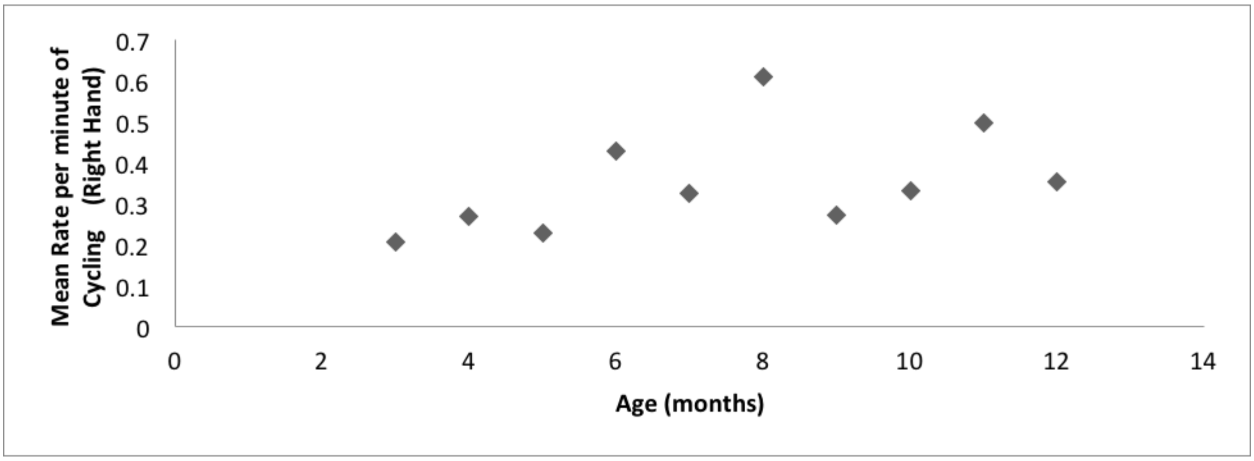

Figure 2(b): Mean rate and growth model for cycling (right hand).

From figure 2(b), it is evident that 'cycling' gesture was seen across all the months under study, although there is no clear pattern of increase or decrease in the rates. The highest rate of occurrence was noted in the 8th month. Correspondingly, the quadratic growth model revealed an unpredictable growth trajectory for this behaviour.

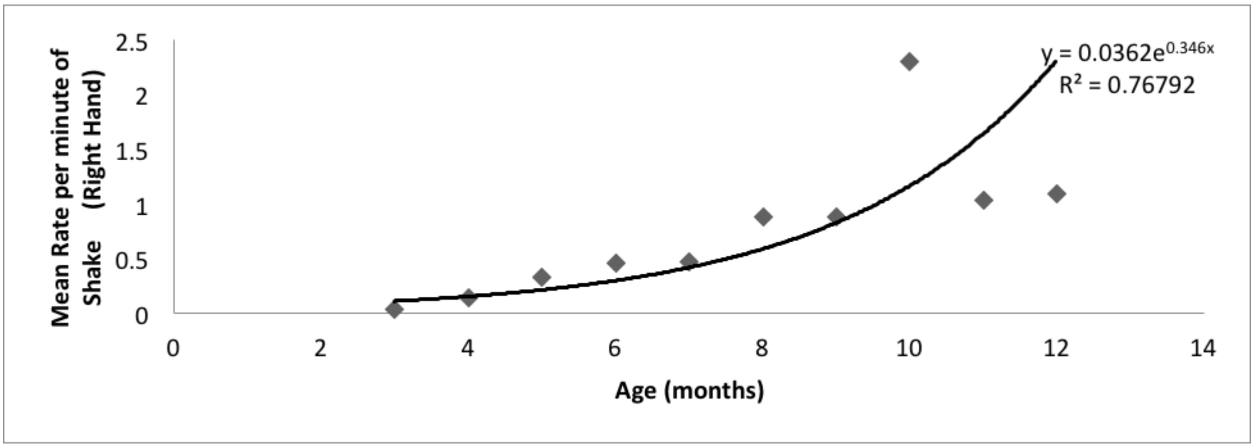

Figure 2(c): Mean rate and growth model for shake (right hand).

From figure 2(c), it can be observed that 'shake' was noted from the 4th month, with a near-steady rise till the 12th month. The highest rate of occurrence was seen in the 10th month. Correspondingly, the quadratic growth model predicted an exponential growth trajectory for this gesture, with the quadratic regression predicting a good fit for the model (R^2= 0.7679).

This would then suggest that the occurrence of ‘shake’ gesture increases with a corresponding increase in age during infancy.

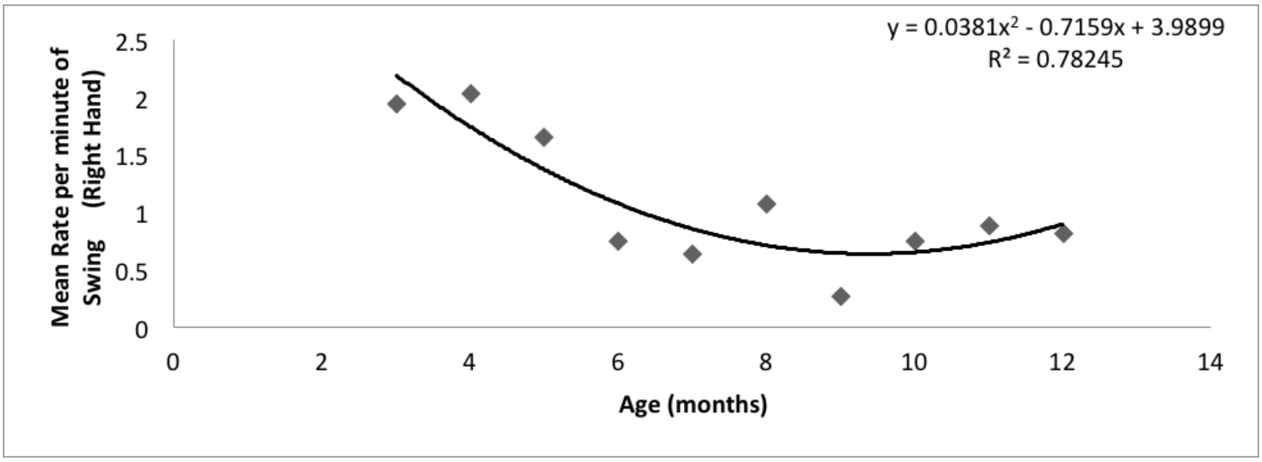

Figure 2(d): Mean rate and growth model for swing (right hand).

From the figure 2(d), it is evident that ‘swing’ gesture was seen from the 3rd month in these infants, and the occurrences seem to reduce as age increases. The highest rate was noted in the 4th month, and thereafter the rates decreased between 5 and 12 months of age, although variations were observed across this age range. Correspondingly, the quadratic growth model predicted a polynomial growth trajectory for this gesture, with the quadratic regression predicting a good fit for the model (R^2= 0.7824). This would then suggest that ‘swing’ is a behaviour that decreases with a corresponding increase in age during infancy.

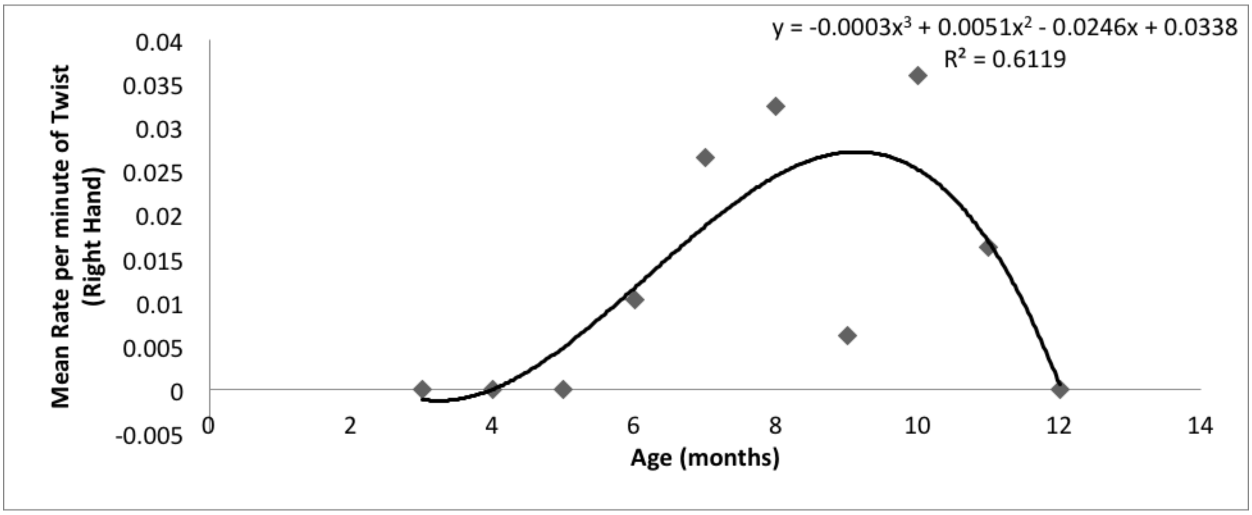

Figure 2(e): Mean rate and growth model for twist (right hand).

From the figure 2(e), it can be understood that 'twist' was only seen from the 6th month and it was not observed in the 12th month. There were also variations in the rates of occurrences between 6 and 11 months, and the highest rate was seen in the 10th month. Beyond this age there was a decrease seen in the rates between 11 and 12 months. Correspondingly, the quadratic growth model predicted a polynomial growth trajectory for this gesture, with the quadratic regression predicting a good fit for the model (R^2= 0.6119). This would then suggest that the occurrence of 'twist' increases and then decreases with a corresponding increase in age during infancy.

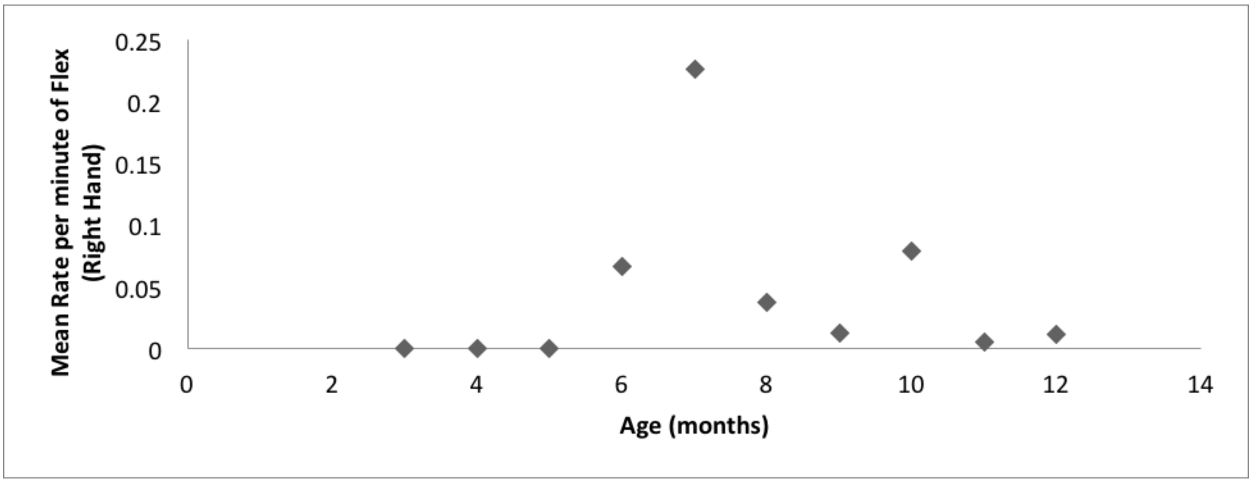

Figure 2(f): Mean rate and growth model for flex (right hand).

From figure 2(f), it is clear that this gesture was seen only from the 6th month and there was an overall decrease in the production as well as variations seen in the occurrence between 6 and 12 months. The highest rate was seen in the 7th month. Correspondingly, the quadratic growth model revealed an unpredictable growth trajectory for ’flex’.

Wilcoxon Signed-rank test was carried out to see if there were significant differences in the rate of occurrences for the rhythmic behaviours produced using the right and left hands. The results revealed that there were statistically significant differences in the usage of hands for bang in the 9th (Z=2.201; p=0.028), 10th (Z=2.023; p=0.043), 11th (Z=2.240; p=0.025), and 12th (Z=1.963; p=0.050) months, at 0.05 levels of significance. These differences were also seen for ‘shake’ gesture in the 7th (Z=2.201; p=0.028), 9th (Z=2.201; p=0.028), 10th (Z=2.023; p=0.043), and 11th (Z=2.100; p=0.036) months, whereas for ‘swing’ gesture, these were seen in the 5th (Z=2.666; p=0.008) and 11th (Z=2.201; p=0.028) months at 0.05 and 0.01 levels of significance respectively. The mean rates of occurrences for these behaviours were higher for the right hand for all these months.

Discussion and Conclusions

The present study looked into the emergence of rhythmic hand behaviours in typically developing children from Kannada speaking families, incorporated in a longitudinal design. There were some interesting trends observed for these behaviours in the study. Rhythmic gestures of fingers (cycling) and arms (swing & shake) were seen from the 3rd month, while other gestures of arms (bang) were seen from the age of 5 months and wrist (flex & twist) were seen from the 6th month of age. This goes on to suggest that infants are engaged in rhythmical activities of the hand throughout the first year, although there were some variations observed in the rates of occurrences of these behaviours.

Infants were observed to produce ‘cycling’ behaviours from the very beginning of the study period, i.e. 3 months of age and were seen throughout the study period. There was a peak in the occurrence of this behaviour produced by the left hand in the 6th and 11th month of age, and in the 8th month for the same behaviour produced using the right hand. However, these trends were not significant to suggest that there was a developmental influence on the occurrence of this behaviour. This finding is similar to that reported by Thelen (1979). In her study it was found that finger movements were produced with equally low frequency throughout the first year of life. In the present study, the growth model revealed an unpredictable growth trend for this behaviour, which provides further evidence to the lack of influence of age on the development of ‘cycling’.

‘Cycling’ was mostly observed when the children were idle, with the arms/hand in resting position or while either looking at object or the mother. Since this behaviour seemed to occur randomly and was not accompanied by purposeful actions, this could have attributed to the variations in the occurrence of these behaviours across the months. Also, it was interesting to note that there was a decline in the rate of occurrence of this behaviour with the emergence of ‘reach’ and ‘grasp’. Previously, Thelen (1981) had also suggested that cycling might precede grasping.

‘Swing’ was behaviour that was observed from the 3rd month of age in these infants. There was a clear trend, which suggested that the rates of occurrence of this behaviour produced by both hands peaked in the 4th month. It was also noted that there was a statistically significant developmental influence on the occurrence of this behaviour. However, this finding is not similar to that by Thelen (1979), where she reported that rhythmic stereotypies involving hands were seen at significantly higher frequencies at around 6 months of age. This could also point out to possible cultural variations in the development of this behaviour. In the present study, the growth model revealed a polynomial trend for ‘swing’, which suggests that this behaviour decreases from the 3rd month till the 7th month, after which there is a slight increase in the occurrence.

Infants were noted to produce ‘shake’ from the 3rd month of age in the study. There was a clear trend which suggested that the rates of occurrence of this behaviour produced by the left peaked in the 6th and 12th month, while that produced by the right hand peaked in the 10th month of age. It was also noted that there was a statistically significant developmental influence on the occurrence of this behaviour. Again, these findings are different from that reported by Thelen (1979). In her study rhythmic stereotypies involving hands were seen at significantly higher frequencies at around 6 months of age. This could also point out to possible cultural variations in the development of this behaviour. In the present study, the growth model revealed an exponential trend for ‘shake’, which suggested that this behaviour increases till the age of 10 months.

‘Bang’ was observed to be produced by infants from the age of 5 months in the study. There was a clear trend, which suggested that the rates of occurrence of this behaviour produced by both hands, peaked in the 8th month. It was also noted that there was a statistically significant developmental influence on the occurrence of this behaviour. These findings are different from that reported by Thelen (1979), where she suggests that rhythmic stereotypies involving hands were seen higher frequencies at around 6 months of life. This could also point out to possible cultural variations in the development of this behaviour. In the present study, the growth model revealed a polynomial trend for ‘bang’, which suggests this behaviour increases from the 5th month till around the 10th month, after which there is a slight decrease in the occurrence.

Lew and Butterworth (1997) have suggested that, during the early months, the ability of an infant to interact with their environment is limited. This is because infants are often confined to a supine position, even while being held by caregivers due to their poor posture and neuromuscular control. This would explain the early occurrence of behaviours such as ‘swing’, ‘shake’ and ‘bang’ that are easily produced with minimal muscular effort and their subsequent decline over the coming months, when infants are more capable of interacting independently with their surroundings. These may provide the infants with opportunities to explore their surroundings within the constraints of their physical system, and also might serve as trial and error behaviours that pave the way for more stable hand gestures.

It is also possible that the occurrence of these behaviours coincides with a shift in the interaction opportunities due to the maturation of the visual, tactile and neuromuscular systems (von Hofsten, 2007). From the 6th month, almost all the infants were able to sit independently and were able to manipulate and explore their environment effectively. It may be assumed that with age, these skills will get stable, as the child will have better control over these behaviours and will exhibit these movements with purposeful activities based on their internal motives. For example, the children were seen to produce ‘bang’ and ‘shake’ with objects held in their hands.

‘Flex’ and ‘Twist’ were gestures that were produced by infants from age of 6 months. The rates of occurrence of ‘flex’ produced by the left hand peaked in the 7th and 11th months, while that produced by the right hand peaked in the 7th month. However, these trends were not statistically significant to suggest that there was a developmental influence on the occurrence of this behaviour. The growth model revealed an unpredictable growth trend for 'flex', which provides further evidence to the lack of influence of age on development.

The rates of occurrence of 'twist' produced by both hands peaked in the 10th month, although, these trends were not statistically significant which suggests that there was no influence of development on the occurrence of this behaviour. The growth model for 'twist' produced using the right hand showed a polynomial trend, which suggests that this behaviour increases till the 10th month, after which there is a decrease in the occurrence. However, the same was not seen in the case of 'twist' produced using the left hand. The growth model showed an unpredictable trajectory.

Rhythmic movements of the wrist, namely, flexing and twisting of wrists were seen when the infant was idle and mostly observing their own hands. These were noted to have fewer instances of occurrence throughout the study and were produced only by few infants in the study. A possible explanation for the same could be that, since these were not associated with meaningful actions, the behaviours did not occur at regular intervals; however, their presence might indicate that these are needed for further motor development. Thus, although these behaviours emerged, there was relative instability seen across the months and a subsequent decline in these behaviours towards the end of the first year. This was evidenced in the variations in the rates of occurrences seen across the months.

With regard to handedness, significant differences were only seen for few of these behaviours, namely, 'swing', 'bang' and 'shake', with a notable right hand preference. Previously, Iverson, Hall, Nickel and Wozniak (2007) have reported that there was no shift in the arm preference for rhythmic stereotypes till the age of 9 months. The findings in this study show otherwise, as there were differences seen even in the younger months. However, one has to keep in mind that there were only few the instances of right hand bias recorded in the study.

Thus, it can be understood that infants were found to engage in rhythmical movements from the first 6 months of their life, although there were slight differences noticed in the ages of emergence of each of these behaviours. However, most of these movements showed a decline in the occurrence towards the end of the first year. Also, all the behaviours that were studied showed non-linear trends in the growth, although the growth trajectories were different for each behaviour. This would then suggest that every behavior in an infant follows a different growth trajectory and therefore, it is important that these are documented and understood especially in the case of atypical infants. Also, this might even suggest that development occurs in stage-like shifts.

Rhythmic stereotypes have been considered as transition or by product behaviours of the normal maturation process (Lourie, 1949; Thelen, 1981). These are assumed to be available to infants when higher-order complex behaviours are not available, although they are simple, repetitive, devoid of goals and are largely not under sensory regulation. This view would therefore propose that all rhythmic gestures are part and parcel of normal maturation and might pave the way for meaningful manual actions. The data from the present study also tends to lean towards this hypothesis. Most behaviours that were studied did have a developmental trend which seemed to vary based on the context and maturation of the neural mechanisms within the infants.

This data also points towards possible variations in the emergence of these behaviours based on culture, especially for movements of 'swing', 'shake' and 'bang'. The findings in this study suggest that children from American and Kannada speaking backgrounds may differ in the ages of acquisition of rhythmic hand movements. However, this could also point out to possible differences in the rearing practices seen in both cultures.

The findings in this study also seem to support the presence of hand preferences for rhythmic arm movements. However, one has to bear in mind that this study included only 9 participants, and therefore, it is suggested that further studies need on a larger population to substantiate these results. But the results of this study sheds light on the need to document the emergence of every skill in an infant which will further advance our knowledge into the understanding of the development of mature communication systems in an infant.

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Appendix 1

Appendix 1: The operational definitions of hand gestures as adopted in the study

Sl No.	*Gesture*	*Operational definition*
1	Flex	Bending and extending of wrist
2	Twist	Rotation of wrist back and forth
3	Cycling	Any movement by the fingers; rhythmic tapping, flexing and extending of fingers
4	Swing	Vertical movement of the arm from the shoulder with no object in hand
5	Shake	Vertical movement of the arm from the shoulder with an object in hand
6	Bang	Movement with the hand or object held in hand makes firm contact with a surface

Source: Thelen, 1981

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Development of Vocal and Motor Behaviours in an Infant: Preliminary Findings

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Abstract

Previous work has suggested that oral and manual systems co-emerge in a developing child which leads to the emergence of a more adult-like, precisely-timed coupling of gesture and speech (Iverson & Thelen, 1999). This study aimed to document the frequency of occurrence of vocalic and body movement gestures namely, hand, facial expression, facial movements and eye gaze in infants (using ELAN software) and to understand the emergence of vocal-motor link in a single typically developing child. The child was from a Kannada speaking family and the mother-infant dyad interactions were audio-video recorded once a month, from the 3rd to the 5th month. Results indicated that a typically developing infant is endowed with a repertoire of vocal, facial, and bodily signals and as young as 5 months there is a clear indication of strong vocal-motor linkage in expression.

Keywords

Non-verbal behaviours, vocal behaviour, motor behaviour, speech development, Case study

Introduction

Gestures constitute the nonverbal aspect of communication. Gesture is used by all when they speak, irrespective of the age, culture and social background. Gesture is not only performed with hands, but by other parts of body, such as head, face or arms. Thus, gestures are defined as manual [e.g., waving to say goodbye], facial [e.g., pouting to show displeasure], or other body movements [e.g., miming an object or person], (Capone, 2010).

McNeill (1992) documented four major characteristics of the gestures used by adults along with speech. First, although gesture and speech often convey complementary aspects of an underlying message, they do so simultaneously, temporally linked within the bounds of a single utterance. Second, when adults gesture while speaking, gestures consist primarily of hand, arm, and finger movements (manual). It is relatively uncommon for mature speakers to produce gestures that involve legs, feet or whole body (non-manual). Third, among right-handed speakers (majority of all speakers), coexpressive gestures tend to be unimanual and are produced primarily with the right hand (Kimura, 1973). Fourth, gestures and speech have a constant relationship in time, with the manual movements of gesture either slightly anticipated or occurring in synchrony with co expressive speech.

Connections between the vocal and gestural system has been suggested to be in place early in development in children. Iverson and Thelen (1999) suggested a model of vocal-motor development as an evidence for an integrated view of the origins of gesture-speech timing in infancy. This model suggests that although gesture and speech are produced in order to convey meaning, their co-production requires the ability to produce controlled, voluntary movements in the two effector systems, namely, the vocal tract and the manual system, and to coordinate these movements in time and space.

Iverson and Thelen (1999) suggested a possible developmental progression characterized by four phases based on the model proposed. The first phase is called *initial linkages*, where hand and mouth activity are loosely coupled from birth. The second phase is *emerging control*, where there is an increase in the adaptive use of hands and mouth marked by rhythmical and sometimes coordinated activities in both manual and vocal modalities. This phase is seen from 6 to 8 months of age. The third phase is *flexible couplings,* which is characterized by the emergence of coupled but not synchronous gesture and speech from 9 to 14 months of age. The last phase called *synchronous coupling,* has adult-like precisely-timed coupling of gesture and speech and is seen from 16 to 18 months of age.

Various researchers have supported the developmental progression as suggested in the model by Iverson & Thelen (1999). Lew and Butterworth (1997) observed that when newborns bring their hands to the facial area to introduce the fingers for sucking, they open the mouth as the hand is moving towards the facial area, in anticipation of its arrival. Trevarthen (1977), followed 5 children from 2 to 6 months of age, and observed that as early as 8 to 12 weeks, hand and finger movements were synchronized with prespeech facial movements such as tongue protrusion and lip contraction. The facial movements, which were usually produced without concurrent vocalization, were accompanied by hand, foot or trunk movements. Among these, hand and arm movements, especially hand waving, finger pointing, and fingertip clasping, were found to be finely synchronized with pre speech movements.

A study on a larger scale conducted with 28 children in the age range, 9 to 15 weeks, reported that manual actions such as index finger extensions, which resemble 'pointing' co-occurred with vocalization or mouthing movements even in this young group of infants. Hand action was found to be systematically organized into sequences with other infant actions (Fogel & Hannan, 1985). They also suggested that manual actions of infants as young as 9 weeks of age may occur in relation to their facial expressions, gaze directions and vocalizations. In a similar study, among older Japanese infants studied between 5 to 9 months, increased production of rhythmical upper limb movements were reported to be related to the age of onset of reduplicated babbling (Ejiri, 1998).

Iverson and Fagan (2004) also reported an age-related increase in frequency of vocal-gestural coordination, with greater coordination in arm (specifically right arm) than leg or torso movements, and a temporal pattern similar to that of adult gesture-speech co-productions, in 6- to 9-month old infants. They also documented that rhythmic vocalizations occurred more with rhythmic manual than non-manual activity in babblers.

Need for the Study

Few studies (Trevarthen, 1977; Fogel & Hannan, 1985; Iverson & Fagan, 2004) thus, have suggested that the vocal-motor system may be linked together, either tightly or loosely, during development in infants. In the Indian context, a previous study by Veena (2010) has addressed the development and communicative functions of gestures in Kannada speaking children from the age of 8 to 18 months. This study focused on hand gestures and found that there were no differences in the age of acquisition of communicative gestures in these children when compared to those reported in other cultures. However, the pre-linguistic development of vocal and motor behaviours has not been given considerable focus in India and it is in this context that this study has been undertaken.

Aim of the Study

This study aimed to document the frequency of occurrence of vocalic and body gestures namely, hand, facial expression, facial movements and eye gaze and also to understand the emergence of the vocal-motor link in a typically developing infant.

Method

Participant

One typically developing female infant was included in the study. She was recorded once every month, with the first recording beginning at 3 months of age and continuing till she turned 5 months. The participant was a full term baby, had no major birth complications, and passed a hearing, visual and language screening at 3 months of age. She was from a Kannada speaking family with the mother as the primary caregiver.

Procedure

The infant and the mother were videotaped at their home, using a Sony HDR video and audio recorder. Each recording was done once a month for the duration of 1 hour, when the child was most playful and alert. The recordings were not continuous, since there were breaks when the child was fussy/ uncomfortable. The mother was instructed to talk to/ stimulate/ play with the infant as the normally would, either when the infant was lying on the floor or when placed on the lap of the mother. The videos were later edited and only those parts of the data that could be used for the analysis was retained. The average duration of the data used for the analysis was 10 - 15 minutes for every month of recording.

Coding

All behaviours of the infant were coded using ELAN software (Lausberg & Sloetjes, 2009). The frame for the analysis was set for every second for the entire data per instance of recording. A key for coding the vocal and motor behaviours was made by the principle investigator (Appendix 1) and the same was compiled based on the review of literature (Fogel & Hannan, 1985; Oller, 1981).

Each item in the key thus developed was provided with an operational definition, in order to facilitate uniformity in the coding across coders. The coding of the samples was done by two independent coders (speech language pathologists), who were trained in the use of the coding system and the keys on a video sample of the infant who was not included in the study. The first coder (principal investigator) identified and labelled the vocal and motor behaviours exhibited by the infant in every second of the frame. The interjudge reliability check for coding was done on the sample of the 4^{th} month. The second coder went through the annotated sample and indicated whether there was an agreement or disagreement with the annotations of the principal investigator. Later, the percentage of agreement between the coders was calculated and it was found to be 86 (N= 377) for the 4^{th} month.

Analysis

The motor behaviours of the infant were categorized as movements of face, facial expressions, gaze, and hand movements. The vocal behaviours were categorized as vocalic, syllabic, vegetative and periods of silence. The frequencies of occurrence of both these behaviours were calculated. The frequencies of co-occurrence of oral and gestural behaviours were also calculated by noting the different body gestures that occurred during the production of vocal behaviours as well as during those periods when the infant was silent.

Results

The results of this study are presented with regard to the two aims of the study. The first aim of the study was to document the frequency of occurrence of motor and vocal behaviours in the infant for the observation period. The percentage frequencies of occurrence for these behaviours are as shown in Table 1.

Table 1: Percentage frequencies of body gestures and vocal behaviours.

MOTOR BEHAVIOURS	**MON 3**	**MON 4**	**MON 5**	**MOTOR BEHAVIOURS**	**MON 3**	**MON 4**	**MON 5**
Left Hand				**Right Hand**			
Curl	32	30	4	Curl	31	17	3
Grasp	16	10	17	Grasp	19	20	24
Reach	1	0	20	Reach	5	1	10
Spread	12	42	37	Spread	15	34	46
Hand in Mouth	5	3	3	Hand in Mouth	0	7	10
Swing	2	4	0	Swing	2	4	0
Bang	0	0	13	Bang	0	2	2
Shake	0	0	1	Shake	0	5	0
Index finger extension	14	8	4	Index finger extension	9	8	3
Clasp	17	4	1	Clasp	19	3	1
Gaze				**Facial Movement**			
Gaze at person	47	31	21	Lip/Tongue Play	33	3	7
Gaze at action	23	1	0	Mouth	24	60	57
Gaze away	11	32	26	Pout	2	1	0
Gaze at object	17	33	50	Tongue Protrusion	33	36	36

Gaze track	2	3	3	Puckered Lips	8	0	0
Facial Expression				**VOCAL BEHAVIOURS**			
Concentration	4	11	27	Vocalic	40	47	45
Smile	8	63	55	Syllabic	11	18	16
Distress	25	0	0	Vegetative	13	11	13
Interest	63	17	18	Silence	37	24	26
Startle	0	0	0				
Frown	0	9	0				

Note: MON= month

a) Frequency of occurrence of gaze behaviours

Across the three months, there were differences seen in the occurrence of gaze behaviours between the third and the fifth month. Gaze directed towards mother (46%) was found to be more in the third month, while gaze directed towards objects (50%) was found to be frequent in the fifth month. Gaze directed towards an action (23%) was only seen in the third month and gaze directed away (30%) was seen frequently in the fourth month, while gaze track was less frequently seen across all the months.

b) Frequency of occurrence of facial movements

During the third month random lip and tongue movements (33%) at play were observed, and these were not seen in the other months. Mouthing behaviour was found to vary across the months; 24% in the third month, 60% in the fourth month and 57% in the fifth month. Pouting (2%) and puckering of lips (8%) were mostly seen in the third month. Tongue protrusions were noted throughout the months and there were minimal differences seen in the percentage of occurrence (33% in the third and 36% in the fourth and fifth months).

c) Frequency of occurrence of facial expressions

Among the facial expressions, distress (25%) was seen only in the third month, while frown (25%) was seen only in the fourth month. Interest (63%) was observed frequently in the third month. Frequency of occurrence of smile (63%) was noted to be higher in the fourth month while the occurrence of concentration (27%) was high in the fifth month.

d) Frequency of occurrence of hand movements

During the third month, curling of fingers (32%), both in right and left arms, was observed to be more frequent than the other movements. Grasp was found to be more associated with the right arm, and there was an increase in the behaviour with an increase in age (24% in fifth month). Reaching behaviour was seen more in the fifth month (20% for left and 11% for right arms respectively). Spread was also found to increase in the fourth (42% for left, and 34% for right arms respectively) and fifth (37% for left, and 50% for right arms respectively) months,

Swinging of arms was found to be high in the fourth month (4% for both right and left arms), along with hand shaking (5% for right arm). Banging was not observed in the third and fourth months, but in the fifth month it was frequently seen for the left arm (13%). Clasping of hands was seen mostly in the third month (17%) and index finger extensions (14% for left and 9% for right arms respectively) were also frequently observed in the same month. Placing the right hand in mouth was seen in the fourth (7%) and fifth (11%) months.

d) Frequency of occurrence of vocal behaviours

Across all the three months, the frequency of occurrence of vocalic utterances (48%) and vegetative sounds (12%) remained steady. It was observed that there was a slight increase in the production of syllabic utterances with an increase in age (10% in the third month, 18% in the fourth month and 16% in the fifth month). Also, with an increase in age, it was seen that the periods wherein the infant remained silent decreased considerably from 37% in the third month to 18% in the fifth month.

The second aim of the study was to understand if there was evidence of the proposed vocal-motor synchrony in the behavious of infant for the observation period. For the purpose of providing a comprehensive picture, the instances of the different types of behaviours were collectively considered under each of the body gestures, namely, hand, face and gaze. Thus, the percentage frequencies of the types of body gestures that co-occurred with the various vocal behaviours and during periods of silence are as shown in Figure 1.

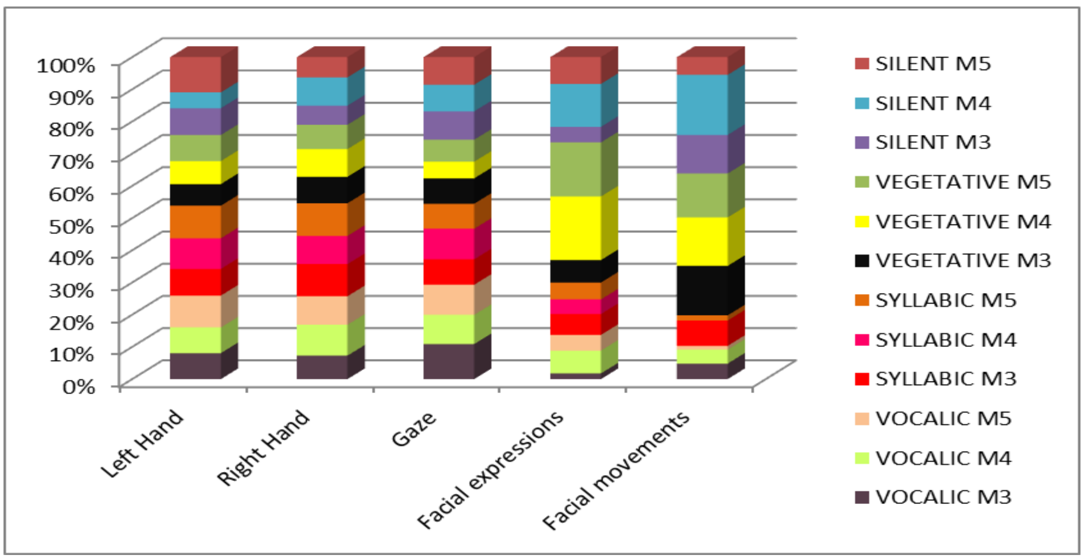

Figure 1: Percentage frequencies of co-occurrence of vocal-motor behaviours

It can be understood from figure 1 that, gestures occurred when the child was exhibiting a vocal behavior as well as when the child was silent across all the three months, although there were some variations in the patterns seen. On comparison between left and right hand gestures, there were not many differences seen in the instances of co-occurrence. In the fifth month, left hand movements (41%) were seen frequently when the child remained silent, while the right hand movements were seen more during periods of silence in the fourth month (27%) and during syllabic utterances (31%). Facial movements occurred more when the child was silent in the fourth month (18%) as well as during vegetative productions across all months (average 15%). Facial expressions co-occurred with vegetative productions during the fourth (12%) and fifth (10%) months. Gaze behaviours seemed to occur at similar frequencies, both during vocal productions and periods of silence for all the three months (average 27%).

Discussion

The findings of this study points out that an infant as young as 3 months old demonstrates a plethora of motor and vocal behaviours. This is similar to that reported in other studies on infants from different cultural backgrounds (Trevarthen, 1977; Fogel & Hannan, 1985). The results indicate that both motor and vocal behaviours of the infant showed different patterns of occurrence across the ages which were under study. Some behaviours were only seen during certain months while some others were seen across all the months, though with varied frequencies. It was also observed that the occurrences of some behaviours reduced as the age of the child increased.

During the third month, the infant was found to engage more with the caregiver, which is evidenced in the frequent gaze directed at the caregiver as well as towards observations of the caregivers' actions. Moreover by the fifth month, gaze was directed more towards objects, which indicates that as the infant grows there is the tendency to explore and observe objects around his/her environment. The infant was also found to track the path of objects to which she was exposed across the three months, though it was not a very frequent behaviour, possibly due to poor neuromuscular control. It was also observed that the instances of the infant looking away from object or person were found to be less in the third month and the fifth months. But, this behaviour was found to be more in the fourth month, where there is a corresponding decrease in gaze directed at caregiver and at any object.

Hand movements were among the most frequent behaviours observed in the infant, when compared to the other motor as well as vocalic behaviours. During the third month, curling and clasping of fingers were frequently observed, and these may correspond to the quiet physiological state of very young infant, where they remain idle for longer periods of time. Index finger extensions were also seen frequently in the same month, and there was a decrease seen in this behaviour for the other months. These were observed as random movements, with neither a stimulus to trigger the act nor a specified target for the behaviour to be purposeful. Thus, these did not resemble the mature 'points' as reported in the other studies on young infants (Fogel & Hannan, 1985).

As mentioned earlier, the child showed interest in the manipulation of toys during the later months, especially in the fifth month. This was also reflected in the increased occurrence of reaching for objects, grasping objects, and spreading of fingers etc. Rhythmic behaviours such as that of banging the object on a surface of contact, swinging of arms and shaking of toys held in hand were seen more during the fourth month, but these were not as frequent as the other hand behaviours.

With regard to facial movements, in the third month random lip and tongue movements were observed and these were not seen in the other months. Similar patterns were also seen for lip pouting and lip puckering. Tongue protrusions were seen across all the months with almost similar frequencies of occurrences. These might suggest that these are very early behaviours seen in an infant, and these may pave the way for mature speech-like movements as the child develops. Mouthing behaviours, which are considered as movements that resemble speech without accompanying vocalizations, were more frequent in the fourth and fifth months.

When compared to other body gestures, namely, gaze, hand and facial movements, the instance of occurrence of facial expressions were comparatively less. Distress was most frequently seen in the third month but it did not occur in the other months. The same pattern was observed for frown, which was again only seen in the fourth month. A reason for these behaviours to occur in the younger months could be the physiological state of the infant; she was found to be very fussy. Smile was seen when the infant was paying attention to the caregiver's actions or smile, and there was an increase in the occurrence of this behaviour with age. Concentration was seen frequently in the fifth month and this was noted while the child was observing an action or while looking at an object or caregiver.

Across all the three months, vocalic utterances and vegetative sounds were produced with similar frequency. It was observed that there was a slight increase in the production of syllabic utterances with increase in age, which again coincides with a similar pattern of increase in rhythmical hand gestures. As age increased, it was seen that the periods wherein the infant remained silent decreased considerably from the third month to the fifth month. Thus, as the infant developed, there seemed to be an increase in the occurrence of mature oral productions, namely, vocalic and syllabic utterances, and a reduction in reflexive utterances and periods of silence.

With regards to co-occurrence, both vocal and gestural movements co-occurred as early as the third month in the infant, however there were variations in the instances of co-occurrence across the months. During the third month it was observed that hand gestures (both left and right arms), gaze patterns, facial expressions and facial movements were seen during periods of silence and during vegetative productions. Even in the fourth month the same trend was noted. But during the fifth month, these body movements were seen to occur more during vocalic productions as well as periods of silence.

From the data, it was also understood that there were increased occurrences of synchronous vocal-motor behaviours, which could possibly reflect the maturity of both these systems. Motor movements such as hand gestures and gaze were seen to occur during syllabic and vocalic productions. This finding could provide evidence to an age-related increase in frequency of vocal-motor coordination as reported by Iverson and Fagan (2004). Also, the infant seemed to be in the first phase of 'initial linkages' from the third month of age. But, this finding has to be considered with some caution since a good percentage of motor behaviours also co-occurred during periods of silence.

There was also little evidence to support the progression to the next phase of 'emerging control' in the fifth month. This could be because the infant was found to exhibit fewer instances of rhythmical motor and vocal behaviours in the 5 months. Thus, the data of this study does suggest the presence of a coupled vocal-motor system, but it is not sufficient to understand the exact nature of entrainment in this coupled system.

Conclusion

From this study it can be observed that both whole body gestures and vocalic behaviours occurred frequently in an infant as young as three months of age. It can also be understood that across the three months there are variations in the behaviours exhibited by the infant, in that, some gestures like random lip and tongue movements, are seen more at a younger age, few others, like gaze track are seen during all the three months and some behaviours, like arm banging, were more frequent when the infant was five months old. This same trend was seen even for vocal productions. Since the data in this study is limited, one cannot draw conclusions regarding the growth trends for both these motor and vocal behaviours.

Co-productions of motor and vocal behaviours were also seen from the third month of age. There were instances of facial, hand and gaze gestures co-occurring with all types of vocal productions, namely, syllabic, vocalic and vegetative productions. However, there were variations seen between the third and the fifth months. With an increase in age, there was near-synchronous occurrence of body gestures with mature oral productions (syllabic and vocalic). But again, this conclusion is guarded since these behaviours were also frequently seen during periods of silence.

Thus, it can be reasoned that a typically developing infant is endowed with a repertoire of vocal, facial, and other bodily behaviours from a very young age and one can observe evidences of a strong link between vocal and motor behaviours as they co-emerge from the third month of life.

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Appendix 1

Appendix 1: Operational description of vocal and motor behaviours that were studied.

Motor behaviours		
Hand movements	Curled	Fingers flexed either loosely, or in a fist
	Index finger extension	Any clear sustained extension of the index finger
	Grasp	The hands / fingers are wrapped around something other than own hands
	Clasp	Any mutual contact of hands or fingers
	Spread	All fingers fully extended or spread apart
	Swing	Vertical movement of the arm from the shoulder with no object in hand
	Shake	Vertical movement of the arm from the shoulder with an object in hand
	Bang	Movement with the hand or object held in hand makes firm contact with a surface
	Hand in mouth	All fingers or any part of hand placed in the mouth

	Toy in mouth	Child places toy held in hand in the mouth
Facial movements	Pout	Puckered
	Puckered lips	'kiss-like' mouth formation
	Mouthing	Lip, mouth or tongue movements similar to when one speaks without phonation
	Tongue protrusion	Tongue extended and placed between lips
	Lip play	Rapid and repetitive movements of lips when at play
	Tongue play	Rapid and repetitive movements of tongue when at play
Facial expression	Smile	Edges of mouth curved upwards
	Distress	Furrowed brows towards eyes and pinched face
	Frown	Mouth slightly open with edges of mouth curved downwards
	Interest	Brows slightly raised
	Concentration	Brows raised at centre of face and lowered at outer edges of face
	Startle	Rapid and sudden blinking of eyelids
Gaze	Gaze at person	Looks at mothers/caregivers/speakers face
	Gaze at object	Looks at toy or any object
	Gaze at action	Looks at the behaviour of mother/object
	Gaze away	Looks at anything other than 'person' or 'object'
	Gaze track	Visual tracking of objects
Vocal behaviours		
	Silence	Periods where the child was not vocalizing
	Vegetative productions	Includes all reflexive productions such as cry, grunt, vocal play etc.
	Vocalic productions	All vowel productions
	Syllabic productions	All combinations of vowels and consonants

Source: Fogel & Hannan, 1985; Oller, 1981

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Patterns in the Emergence of Hand Actions in Typically Developing Infants

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Abstract

Purpose: The dynamic systems theory [1] regards the development of an infant as a complex and dynamic system. This study investigates the development of the hand system in typically developing infants, in the backdrop of this theory. Specifically, we wanted to document the growth trajectories exhibited by these behaviours within the first year of life and to determine a predictable age at which these hand actions would exhibit a change in occurrence, in the face of variability.

Method: Nine typically developing infants, 3 females and 6 males, were videotaped from the third month till they turned twelve months of age, while interacting with their mothers. Samples were coded for the occurrence of four categories of hand actions (actions during play/rest; actions with objects; actions towards adults; iconic actions) using ELAN.

Results: The hand actions we studied were marked by variability as evidenced in their growth trends, and some of these hand actions, especially those that help manipulate objects and those seen during play/rest demonstrated an age at which reliable change in the rate of occurrence was seen within the developmental period.

Conclusion: Our results demonstrate that the development of the hand system follows some principles of being a dynamic system.

Keywords Hand actions; Infants; Dynamic development; Growth curves; Change point analysis

Introduction

Many studies [2-5] have suggested that, by the end of the first year the repetitive motor activities of young infants begin to give way to more articulated control and directed communication. Infants are said to begin to communicate intentionally through gestures and vocalizations and later words. Gestures and speech are regarded as parallel modalities, as most often the communicative signals produced by children are in both of these modalities [6]. Some studies indicate that the gestural and vocal modalities are semantically and temporally integrated from the earliest stages [7], while others report that asynchronous combinations of gestures and words are more frequent than synchronous ones during initial phases of development in typical children [8].

Communicative gestures (hand and others) that begin around 7-9 months in children are assumed to be derived from a repertoire of vocal, facial and body signals that an infant is endowed with at birth [8-12,5]. Around 10 months of age, deictic and iconic hand gestures are pervasive in children's speech. Children produce deictic gestures and culturally derived gestural routines such as waving goodbye, before they begin to talk [10,8]. These behaviours are also referred to as prelinguistic gestures (and performatives) because their emergence is observed prior to spoken language. However, pointing continues to be used throughout development. Showing, giving, pointing and requesting emerge in this predictable sequence starting at approximately 10 months of age [2]. These behaviours show a marked increase in occurrence after 11 months, which coincides with a decline in more primitive gestures (e.g. reaching) and emotive gestures (e.g., moving body up and down).

The dynamic systems theory [1] suggests that development is a process of self-organization of multiple individual elements of a system. Coherent behaviours are a manifestation of relationships between the various components, with the constraints and opportunities of the environment. Change in any behaviour is said to occur over different time scales along with other collaborating elements (behaviours) of the same system or even other systems. Therefore, the coherence of time and the levels of the system imply that the dynamics of one time period will be continuous and nested within the dynamics of all the other time periods. That is, every event within or across systems lays the foundation for the next event to occur.

Further this theory states that when an infant achieves a milestone, one does not always see stability or a near-steady increase in the frequency or the rate at which this behaviour is produced at later ages. Therefore, the development of any behaviour could follow both linear and nonlinear paths depending on the changes that occur in one or more components of the system. This could be true if one considers development to be a dynamic and an evolving process.

Therefore, it would seem necessary to consider the developmental pattern of any behaviour and describe the dynamics of change that occurs over a given time frame. This will in turn predict when one can expect reliable change to occur in a developing system, thus aiding in behavioural and cognitive development. Very few studies have attempted to provide evidence for the variability seen in infant development, with the exception of limb movements [13-17]. A very recent study investigated the dynamic patterns of limb movements (e.g. sitting) and pre-linguistic vocalizations (e.g. canonical babbling) in a single infant and they were able to establish that variability preceded or coincided with the onset of mature developmental milestones across the two motor systems [18].

Drawing influences from the above literature, the aim of this study on hand actions was twofold; the first was to document the developmental trends of hand actions in infants by the means of growth curves. This was done in order to understand if these behaviours reflected linear or non-linear patterns of growth within the developmental period of 3-12 months of age. The second was to document the age at which there was a significant change in the occurrence of these hand actions, using a time series method such as change point analysis.

Method

Participants

Nine typically developing infants (three females and six male infants) participated in the study. They were followed for a period of 10 months, with the first recording taken at the age of 3 months and the last recording taken at 10 months of age. The analysis reported in the study includes on an average 8 recordings per child. This was because all the infants could not be recorded every month either due to ill-health or other reasons within the family. All the participants were full term babies, with no major birth complications, and passed a hearing, vision and language screening before they were included in the study. They were also from Kannada speaking families with the mother as the primary caregiver.

Procedure

Each infant and the mother were videotaped at their home, using a Sony HDR video and audio recorder. Each recording was done once a month for the duration of 1 hour, when the child was most playful and alert. The recordings were not continuous, since there were breaks when the child was fussy/uncomfortable. The mothers were instructed to talk to/stimulate/play with their infant as they normally would, either when the infant was lying on the floor or when placed on the lap of the mother or sitting independently in the later months. The videos were later edited and only those portions of the data that could be used for the analysis were retained. The average duration of usable data for analysis was 10-15 minutes per recording, from the 3rd to 6th months and 20-25 minutes per recording for the later months.

Coding of hand actions

Hand actions observed in the infants were coded using ELAN software [19], which allows a frame- by- frame analysis of the recording. A key for coding these behaviours was developed by the principal investigator (Appendix 1) and the same was compiled based on the review of literature [11,2]. The key described actions of fingers, palms and arms. Each item in the key thus developed was provided with an operational definition, in order to facilitate uniformity in the coding across coders. Annotation of the samples was done by three independent coders (speech language pathologists), one being the principal investigator and two other coders who were trained using a video sample of an infant who was not included in the study. The following categories of hand actions were annotated in the samples; (1) actions during play/rest which occur randomly while the infant is at play/observing adult/or vocalizing when at rest, (e.g. clap, clasp, hand in mouth, curl, index finger extension, flex, twist, cycling, spread, swing); (2) actions with objects that occur when the infant is manipulating objects during play (e.g. holding toy in mouth, reach, grasp, bang, shake); (3) actions towards an adult that occur while the child is interacting with adult to convey a need or information (e.g. up, point, show, request, give, take); (4) and actions that reflect iconicity and convey some aspect of the referent (e.g. hand configurations).

The principal investigator identified and labeled the hand actions exhibited by the infants in every second of the frame in all the samples. The coders were required to do this exercise on 10% of the samples, which were randomly selected, i.e, 10 videos, and they were asked to carry out the same exercise independently. These videos were selected randomly from the data pool, keeping in mind that each month of study was represented in the reliabilities check. Then the principal investigator went through all the coded samples and noted the instances of agreement and disagreement between the coders. The mean percentage agreement between all the three coders was calculated and this is as shown in Table 1. The cohen's kappa was found to be 0.84.

Month	Total number of hand actions	Mean percentage of agreement (%)
3	245	82.97
4	770	90.57
5	583	89.71
6	930	93.02
7	616	89.49
8	928	92.11
9	1125	92.75
10	1198	90.69
11	975	88.19
12	680	91.69

Table 1: The percentage agreement between coders for hand actions.

Analysis

In order to establish the frequency with which the participants produced these behaviours, a measure of rate of occurrence per minute was computed. This rate was calculated for each month, and it was defined as the total number of a hand action (e.g. clasp) divided by the duration of the observational segment for that month. The rates of occurrence were then used to plot growth curves based on quadratic regression analysis. This was done in order to determine the growth trend of behaviours, and we anticipated these trends to be either linear (constant increase or decrease in the rates of occurrence with a corresponding increase in age) or non-linear (polynomial: curvilinear relationship between rates of occurrence and age; or quadratic: exponential relationship between rates of occurrence and age). We carried out change point analysis (20), which is used with time series data in order to determine the age at which there is a significant change in occurrence of hand actions between 3 to 12 months of age.

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Results

The aim of the study was to document the trends exhibited by hand actions within the developmental period of 3-12 months in typically developing infants. The study also aimed to document the age at which there was a significant change in the occurrence of these behaviours in order to understand if their development is predictable in the face of variability.

In order to test our prediction regarding the dynamic growth trends of hand actions we plotted growth trajectories of each of the behaviours using quadratic regression analysis (see examples: Figures 1 & 2). We have summarized the growth trends exhibited by each hand action in Table 2 (Please note: supplemental files include mean rate of occurrence and growth curves for all hand actions). As can be seen, there are more instances of hand actions exhibiting a non-linear growth trend than a linear one. There were also few instances where the growth trend could not be predicted, either due to extremely variable occurrence across months (e.g. flex) or because of reduced frequency of occurrence of the hand action (e.g. hands up).

Categories of behaviours	Hand action	Growth trend	Level of significance
Hand actions during play/rest	Clap	Unpredictable	
	Clasp	Polynomial	R2=0.913 (F=345.21;p=.000)
	Hand in mouth	Polynomial	R2=0.779 (F=332.56;p=.015)
	Curl	Exponential	R2=0.879 (F=4211.53;p=.036)
	Index finger extension	Polynomial	R2=0.932 (F=140.03;p=.000)
	Flex	Unpredictable	
	Twist	Polynomial	R2=0.611 (F=30.03;p=.046)
	Cycling	Unpredictable	
	Spread	Linear	R2=0.859 (F=188.60;p=.000)
	Swing	Polynomial	R2=0.782 (F=3067.82;p=.001)
Hand actions with objects	Holding toy in mouth	Polynomial	R2=0.715 (F=998.03;p=.018)
	Grasp	Linear	R2=0.910 (F=1240.08;p=.000)
	Bang	Polynomial	R2=0.934 (F=1998.60;p=.001)
	Shake	Exponential	R2=0.767 (F=1732.66;p=.023)
	Reach	Linear	R2=0.962 (F=7568.10;p=.006)
Hand actions towards an adult	Up	Unpredictable	
	Point	Polynomial	R2=0.669 (F=71.24;p=.033)
	Request	Unpredictable	
	Show	Polynomial	R2=0.836 (F=19.06;p=.001)
	Give	Polynomial	R2=0.0822 (F=56.90;p=.044)
	Take	Unpredictable	
Iconic hand action	Hand configurations	Polynomial	R2=0.789 (F=185.43;p=.036)

Table 2: Growth trends for hand actions (per category).

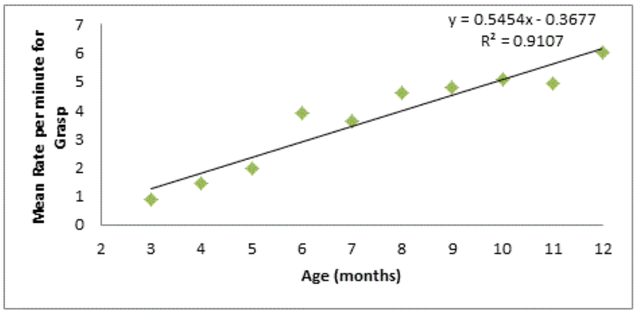

Figure 1: Growth curve (linear) for grasp.

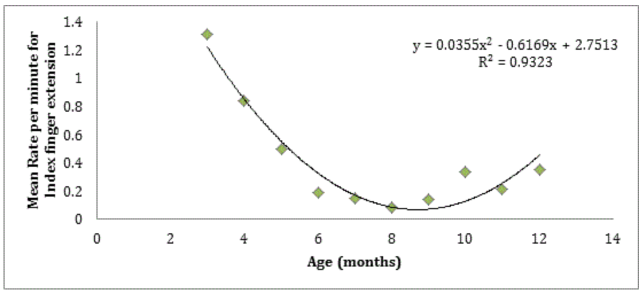

Figure 2: Growth curve (non-linear) for index finger extension.

Subsequently, change point analysis was carried out in order to understand the age at which there was a significant change in the rate of occurrence of each of these hand actions. We only found significant change for eight hand actions (see Table 3), under the categories of 'action with objects' and 'actions during/playrest'.

As can be seen the robust change for most of these hand actions occurs from the age of 6 months, except in the case of 'index finger extension', where the change occurs at an early age of 4 months. Post the age of significant change, there is a decrease in the occurrence of only three behaviours, namely, 'holding toy in mouth', 'swing' and 'index finger extension'.

Categories of hand behaviour	Hand action	Month of significant change	Confidence level (%)	Pattern of change in rate of occurrence post change
Hand actions with objects	Bang	8	95	Increase
	Grasp	6	97	Increase
	Reach	7	96	Increase
	Shake	10	96	Increase
	Holding toy in mouth	10	95	Decrease
Hand actions during play/rest	Swing	6	93	Decrease
	Index finger extension	4	92	Decrease
	Spread	6	92	Increase

Table 3: Change point data for hand actions.

Discussion

The current study documented the emergence of hand actions in typically developing infants, between the ages of 3 and 12 months, within the dynamic systems framework. The goals were to determine; (1) the growth trends of hand actions, (2) the age at which a significant change is seen in the occurrence of behaviours over time. We hypothesized that in order to be a dynamic system, hand actions that we studied would show mostly linear or non-linear growth trends, and would demonstrate an age at which reliable changes in occurrence could be predicted amidst variability. We find that the hand system does follow principles of being a dynamic system, which is similar to that demonstrated for the even other systems, such as the limb or both vocal and limb systems [13-18]. However, within this system not all the hand behaviours that were studied satisfied the principles of being dynamic.

Growth trends of hand actions

True to the predictions of dynamic systems theory [1], hand actions demonstrated non-linear (most frequent) and linear (less frequent) trends. Only few of these hand actions demonstrated unpredictable trends within two categories of behaviours that were studied, namely, 'actions during play/rest' (e.g. flex) and 'actions with adults' (e.g. up). A possible reason for this could be that the occurrence of these behaviours showed considerable variation across months. For example, 'up' was seen only during months 5, 6 and 10. Interestingly, linearity was demonstrated by mostly those hand actions that were seen from the age of 3 months itself, such as 'spread', 'grasp' and 'reach'. However, majority of the hand actions across different categories exhibited non-linear trends. Such patterns might indeed suggest that within the first year of life the hand system in undergoing re-organization constantly within a span of few months. This would then imply that variability is a norm during development. Future studies should consider including a larger age group in order to determine if there is an age at which these behaviours stabilize. It might also help if more participants are included, since this will help determine the contributions of intra- and inter-subject variability, especially since this will have implications when one looks at the developmental pattern in atypical children. Other factors, such as the role of caregiver's interaction and levels of exposure to environmental stimuli also might affect the production of these behaviours, and these need to be documented in future studies.

Significant change in the occurrence of hand actions

Since most behaviours showed evidence of variability (according to growth trends), we had assumed that most hand actions would demonstrate an age at which change in the occurrence of behaviour was predictable. On the contrary, the predictions of dynamic systems theory [1] held good only in the case of select hand actions. All actions of hands involving objects and few involving play/rest showed an explicit age within the developmental period where a significant change in the occurrence of behaviour is evident (based on change point analysis). This is similar to what has been reported for other developing systems in infants [13-18]. But, the results might also imply that not all behaviours of the hand system show significant changes, which would then contradict the expectation of a dynamic system. Alternatively, it is also possible that a change in these behaviours might occur beyond the age of 1 year. Therefore, it substantiates the need for testing this in future studies with older infants. Similarly, change was found to occur at various months for different hand actions, suggesting that within the hand system, behaviours do not exhibit similar trends in variability.

Interestingly, except in the case of 'bang', the age at which there was a reliable change in the occurrence of these hand actions did not coincide with those months that showed a peak in the occurrence of the same behaviours, possibly suggesting that reliable change in behaviour is not related to its frequency of occurrence. The predicted growth trends of each of these hand actions were also varied; it was a mix of linear and non-linear trends. This might then suggest that behaviour is characterized by a specific expectation for when a change will occur, irrespective of the type of variability seen.

Following the age at which a significant change was observed it was also noted that those hand actions which were seen in infants from the age of 3 months tended to show a decrease in the rates following the age at which there was a significant change in occurrence (e.g. holding toy in hand (action with object), swing and index finger extension (actions during play/rest)). Other hand actions with objects, (e.g. reach, bang) showed the opposite trend, and were found to increase. Such trends might suggest that these behaviours are still undergoing development, and that there could possibly be multiple points of change (reorganization) within the system, as the child continues to grow [17]. This is especially considering the observation that novel behaviours seen after the age of 7 months (e.g. point, hand configurations) did not suggest the presence of a predictable age of change within the time frame that we studied. Future studies looking at children above the age of 12 months will be able to provide evidence to either support or refute this.

Conclusions

This study tracking the occurrence of hand actions in nine infants demonstrates that development of the hand system seems to echo the characteristics of a dynamic system. We found that the growth trajectories of most hand actions were marked with variability and revealed both linear and non-linear trajectories. However, even in the face of this variability, we found that only 'hand actions with objects' and few 'hand actions during play/rest' demonstrated significant and reliable changes in the rates of occurrence within the first year of life. All these raise questions regarding our current understanding of infant development and the requirement that there must be a change in our outlook towards the assessment of communicative behaviours in atypical children. However, the current study has its limitations since it has included only 9 infants and has only studied the development of hand actions till the age of 12 months. Therefore, future work with a larger sample and over longer observational timeframes, which also includes other co-developing behavioural systems, such as the vocal system, is warranted. The results of future studies may also help us better understand the developmental processes in atypical children.

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