DECLARATIVE AND PROCEDURAL MEMORY IN CHILDREN WITH DEVELOPMENTAL DYSLEXIA

Vishnupriya M.S

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ALL INDIA INSTITUTE OF SPEECH AND HEARING

MANASAGANGOTHRI,

MYSORE – 570006

May, 2017

CERTIFICATE

This is to certify that this dissertation entitled **"Declarative and Procedural memory in children with Developmental Dyslexia"** is a bonafide work submitted in part fulfillment for Degree of Master of Science (Speech-Language Pathology) of the student (Registration Number. 15SLP032). This has been carried out under the guidance of a faculty of the institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore,
May, 2017

Dr. S.R. Savithri,
Director,
All India Institute of Speech and Hearing,
Manasagangothri, Mysore-570006

CERTIFICATE

This is to certify that this dissertation entitled **"Declarative and Procedural memory in children with Developmental Dyslexia"** has been prepared under my supervision and guidance. It is also being certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore,

May, 2017

Dr.Jayashree C.Shanbal

Guide

Reader in Language Pathology

Department of Speech-Language Pathology

All India Institute of Speech and Hearing

Manasagangothri, Mysore-570006

DECLARATION

This is to certify that this dissertation entitled **“Declarative and Procedural memory in children with Developmental Dyslexia”** is the result of my own study under the guidance of Dr. Jayashree C. Shanbal, Reader in Language Pathology, Department of Speech-Language Pathology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore,

May, 2017

Register No. 15SLP032

Dedicated to all those children

with Developmental Dyslexia

for you are going to find the

STRENGTH IN YOU…

Acknowledgement

"*Acknowledgement and celebration are essential to fuelling passion, making people feel valid and valuable, and giving the team a real sense of progress that makes it all worthwhile"*

-Dwight Frindt

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CHAPTER 1: Introduction

Communication is defined as an active process of exchanging information and ideas between two participants which involves encoding, transmitting and decoding of intended messages (Shames & Wiley, 2000). Communication is one of the oldest human activities and involves a set of conventions or the use of complex arbitrarily agreed patterns of sounds called Language. The three main components of language are content (meaning), form (structure) and use (Bloom & Lahey, 1978). Each of these components involves one or more memory systems. For example, word learning (content) which requires the ability to learn and then store the information is often associated with the declarative memory. The ability to pick up those words from memory store, modify it and use the sound sequences permitted by the phonotactic rules of the language is attributed to the procedural memory system (Sengottuvel & Rao, 2013a).

Based on temporal and qualitative scale, memory can be divided into several categories. Sensory memory is capable of encoding enormous amounts of info.rmation which lasts for a duration of about 500ms for visual sensory memory and up to few seconds for auditory sensory memory. Short term memory is capable of retaining the information up to few minutes. This is often due to the intentional conscious effort an individual puts to remember the required information for some purpose of interest. On the other hand, Long term memory is different from the former owing to the capability of being limitless with regard to the amount of information which can be taken up, as well as for the duration to which the information can be retained. Declarative memory system deals with memories for facts, and procedural memory system deals with memories for skills (Cohen & Squire, 1980). Declarative memory encompasses two different forms of explicit memory; episodic memory (memory for personal experiences) and semantic memory (memory for facts, concepts or "world knowledge"; Tulving, 1972, 2002). Declarative memory is often associated with rapid learning that can even occur with a single exposure of the stimulus (Squire, 2004). For the purpose of learning as well as for computation of rules and sequences, procedural memory plays a predominant role (Aldridge & Berridge, 1998; Willingham, Salidis & Gabrieli, 2002). The declarative system has involvement in many other cognitive functions which include statistical learning, working memory, probabilistic classification learning, reinforcement, working memory as well as retrieval from declarative memory (Ullman, 2004). Previous researches also indicate that the procedural memory system is involved in aspects of grammar learning and processing across syntax, morphology and phonology (Ullman & Pierpont, 2005; Conway & Pisoni, 2008).

The researches dating back in 90s suggest that storage deficits are the underlying cause for developmental language disorders. However, after the Declarative – Procedural (DP) model was proposed (Ullman, 2004), majority of the language errors associated with developmental language impairments (Nicolson & Fawcett, 1990; Nicolson et al., 2001; Ullman & Pierpont, 2005; Squire, 2004) were attributed to the deficits in either of these (declarative/procedural) memory system. The independency of these memory systems has been proved by research on developmental language disorders, which are characterised by intact declarative learning and deficits in procedural learning and vice versa. To achieve optimal learning on a given task these two memory systems interact (compete: e.g., Foerde, Knowlton, & Poldrack, 2006, cooperate: e.g., Willingham, 1989) and incompetence in one system may result in enhancement of the other intact system (Ullman, 2004; Ullman & Pullman, 2015).

It is reported that though Declarative memory is often associated with rapid learning, based on the type of paradigm used for the assessment of Declarative system, the demands on the frontal lobe dependent executive functions can be increased or decreased (Hedenius, 2013). These include encoding strategies as well as recall of information. For example, for intentional encoding there is a huge demand on working memory and executive functions in comparison to incidental encoding. The same is the case with free recall as compared to recognition (Stuss & Knight, 2002). The old/ new recognition memory paradigm is the one which is most commonly used for measuring the aspects of Declarative memory. This paradigm involves the presentation of a list of items in an initial encoding session. After a specific time interval the participants are asked to indicate if they had encountered the same stimuli during the encoding session. The two cognitive subcomponents that influence the performance on recognition memory tasks are familiarity and recollection (Mandler, 1980; Jacoby, 1991; Yonelinas, 1994).

A plethora of studies have been conducted studying the memory systems of children and adults with various language impairments. The literature so far has unveiled the memory systems of developmental language disorders such as Autism, Specific Language Impairment, Developmental Dyslexia, Acquired language disorders and disorders in which cognition is affected (Kuppuraj & Prema, 2014; Sengottuvel & Rao, 2014; Ullman & Pullman, 2015). However, there are still several aspects of the complex memory system which remain undiscovered.

Written word recognition and phonological decoding are the typical difficulties presented in children with Developmental Dyslexia (DD) (Bishop & Snowling, 2004; Catts & Kamhi, 2005). However, DD has also been associated with many other deficits such as working memory, motor function, executive functions and implicit sequence learning (Smith-Smark, 2007; Fernandez et al., 2011). The link between an impaired Procedural memory system and DD was first suggested by Nicolson and Fawcett (Nicolson & Fawcett, 1990; Nicolson et al., 2001). According to them, children with DD used "conscious compensation" to overcome the deficits in automatization that they exhibited. They proposed a "Neural systems view" of developmental language disorders including DD and Specific Language Impairment (SLI) and suggested that these children may have an impaired Procedural memory system in contrast to an intact Declarative memory system (Nicolson & Fawcett, 2007).

The "Procedural Deficit Hypothesis" (PDH) proposed by Ullman and Pierpont in 2005 served as an explanatory account for SLI (Ullman & Pierpont, 2005). This hypothesis is in consonance with Nicolson and Fawcett's approach. PDH accounts for a variety of linguistic, motor and cognitive deficits in the form of an underlying impaired Procedural Memory system. The PDH hypothesis is based on the Declarative and Procedural model of language proposed by Ullman (2001, 2004). Holding on to the assumption of the DP model, an association between Procedural memory and grammar was predicted in the PDH. No association was predicted between procedural memory and vocabulary as this was hypothesised to be influenced by Declarative memory system. Thus, it was predicted that in a group of children with SLI, procedural memory deficits are found in children who exhibit grammatical impairments, but not in the children who exhibited vocabulary deficits. However, in

Developmental Dyslexia, the Procedural memory system is hypothesized to be the underlying cause for reading problems. This can be due to the impairment in automatization skill (direct) or the problems in phonological processing (indirect). This means that the deficits in the Procedural memory system are predicted to have a detrimental effect on the phonological processing skills, which is further considered to be essential for intact reading development. Considering this view, the effect of Procedural memory on reading can be said as partly mediated by the phonological processing skills.

One important aspect of the PDH framework is the prediction that Declarative memory is capable of taking over the functions that normally relies on the Procedural memory system. It is said that in the absence of an intact memory system, (here procedural memory) the other memory system (declarative memory) is capable of adopting and performing the functions of the impaired memory system. It is hypothesized that this compensatory mechanism accounts for the improvements seen in children with SLI and DD over time. For example, children with DD have difficulties in phonological encoding. It is hypothesized that these children try to compensate for this difficulty through memorization. They attempt to memorize the entire word or a part of word as segments or “chunks”. Based on the predictions of PDH, better reading abilities can be associated with better declarative memory in children with impaired procedural memory system. This implies that a positive correlation could be drawn between reading and Declarative memory in children with DD, but not in typically developing children where both the Declarative and Procedural memory systems are assumed to be intact.

Studies carried out in the past to explore the Procedural memory have reported an impaired performance on the Serial Reaction Time (SRT) Task by children with

DD (Vicari, Marotta, Menghiai, Molinari & Petrosini et al., 2005). Though there are studies focusing on the functions of Declarative memory in children with DD, no consistent findings are reported (Vicari et al., 2003; Jimenez-Fernandez et al., 2011). On the contrary, there are few studies which revealed intact Declarative memory in children with DD and few others which revealed impaired Declarative memory. Majority of these studies were done in the younger age group. Thus, there is a dearth of evidence that may throw some light on the trade off between Declarative memory and Procedural Memory in older children with DD. It can also be deduced from the literature that most of these studies focussed on the cognitive functions which were impaired in DD. The cognitive functions which are intact or preserved in this population still remain unexplored. Thus, it has been found that most of the studies have investigated just one of the memory systems (declarative or procedural), and few which focussed on both were conducted mostly in the younger age groups. The association between the linguistic skills and memory processes still remain unclear. Few investigators used artificial grammatical learning as a measure to assess linguistic processing, while few others used non-word repetition task. However, findings from both the measures are found to be inconclusive. This highlights the need of research investigations exploring both the declarative and the procedural memory skills in older children with DD and their linguistic abilities. Since DD is viewed as a continuum of SLI by many researchers, it would be interesting to probe into the trade off between Declarative and Procedural memory (if any) in children with DD and its association with their linguistic skills.

Hence, the aim of the present study was to understand the nature of Declarative and Procedural memory in children with Developmental Dyslexia.

CHAPTER 2: Review of Literature

"Memory is the process of maintaining information over time" (Matlin, 2005). It can be defined as the process where what is experienced or learned is established in the Central Nervous System (CNS). In the CNS it continues with a changing degree of permanence (retention) and can be recollected or retrieved from the storage at will (recall). There are four main processes that are significantly important for storage to take place and they are:

a) Encoding: Information is gathered from all the sensory systems and is deciphered in to the necessary form to be remembered and stored. The association cortices and other areas are predominantly important for this.

b) Consolidation: Converting the information encoded in t permanently storable form. The hippocampus with the surrounding areas plays a major role for this.

c) Storage: Actual deposition of the memories in to the final resting places. This is thought to be accomplished in the association cortex.

d) Retrieval: The process of accessing the already coded information when needed.

According to Multi-store Model of Memory (Atkinson & Shiffrin, 1971), the human memory system consists of memory structures as well as control processes. Memory structures are defined as the built in processes that are unvarying across situations. Control processes are defined as the process that are selected, constructed and used at the option of the individual and might vary across tasks. Understanding memory as sequence of discrete steps, is the crust of this model. Sensory stores, short term memory and long term memory are considered to be the major physical structures of the system.

Based on a temporal scale and on qualitative scale, memory can be divided into several categories. Sensory memory is capable of encoding enormous amounts of information which lasts for a duration of about 500ms for visual sensory memory and up to few seconds for auditory sensory memory. Short term memory is capable of retaining the information up to few minutes. This is often due to the intentional conscious effort put by the individual to remember the required information for some purpose of interest (Gazzaniga, Ivry & Mangun, 2009).

On the other hand, Long term memory is different from the former owing to the capability of being limitless with regard to the amount of information which can be taken up as well as for the duration to which the information can be retained. Long term memory can be divided into Declarative memory (explicit) and non-Declarative memory (implicit). Declarative memory is performed with awareness and non declarative memory does not require conscious awareness (Squire, 2004) (See figure 2.1).

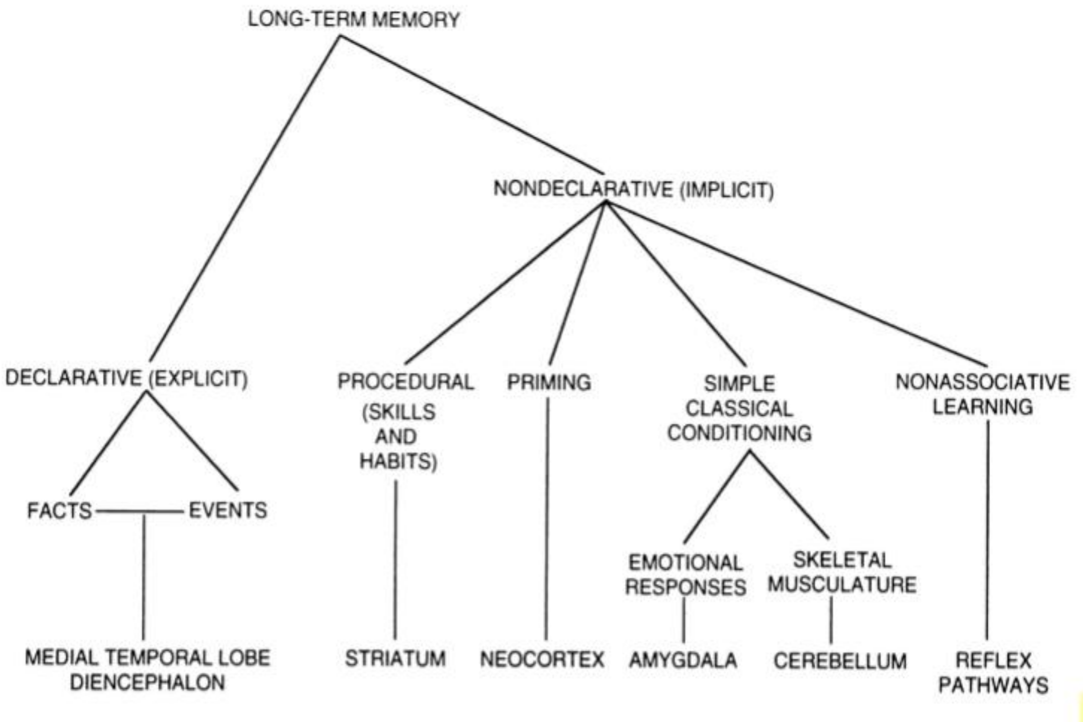

Figure 2.1. Declarative and non-declarative memory systems. The figure indicates the brain structures thought to be especially important for each type of declarative and non-declarative memory. *Source:* Squire, L. (2004) Memory systems of the brain: A brief history and current perspective, 171-177,47.

2.1 The Declarative Memory System

The learning in Declarative Memory System (DM) is rapid and sometimes can occur with just a single exposure of the stimulus (Squire, 2004). DM typically encompasses two forms of explicit memory; episodic and semantic memory. Episodic memory is the memory for individualised experiences whereas semantic memory is for facts, concepts or "world knowledge" (Tulving, 1972, 2002). Apart from the differences in the processed information, the associated experience encountered with these memories is distinct. Episodic memory is sometimes called as "mental time-travel" as it takes an individual back to a circumstance that happened in the past. One can re-visit and re-live the experiences in their minds. Remembering always involves a mental time travel and hence Tulving (2002) labelled the quality of episodic memory as “self –knowing”. In contrast, a memory which is independent of any definite context or circumstance is the Semantic memory. This includes knowledge about word meanings or knowledge about the general facts (e.g: Delhi is the capital of India).

Performance in recognition memory tasks are based on two cognitive subconstituents; Familiarity and Recollection. (Jacoby, 1991;Yonelinas, 1994). Familiarity is the sensation of having encountered an item before but without any knowledge of the context or situation in which it appeared (Yonelinas, 2002). In contrast to this, recognition of an item with the sensation of having been encountered before along with the understanding of the context in which it occurred is Recollection (Yonelinas, 2002). Familiarity is referred as item memory and recollection is referred as source memory (Henson, 2005). A very common example which explains the peculiarity of recognition and recall is the feel of recognizing a person as familiar but still being unable to identify the situational information as to how, where and when one has met the person.

Familiarity is sometimes called as a “subrecollective memory” as per the single process view of recognition memory. According to this view, recognition memory, recollection and familiarity are proposed to be different points on a continuum of an individual specific reliance suggesting quantitative difference in the memory strength (Squire & Wixted, 2011). However, the dual-process theories consider recollection and familiarity as two distinct processes (Eichenbaum & Lipton, 2008; Yonelinas, 2002) having at least partly different neural foundation.

The literature vastly reviews the association of declarative memory with the neuroanatomic substrates. It is proposed that the declarative memory depends on the medial temporal lobe structures (MTS). These structures include the regions of hippocampus such as the dentate gyrus and the subicular complex, perirhinal cortex and parahippocampal cortex (Squire & Knowlton, 1993). It is proposed that the medial- temporal complex is responsible for various functions related to memory such as encoding, consolidation and retrieval of memories (Squire & Knowlton, 1993). These memories over the period of time become mostly independent of the MTS and show more dependence on the neocortical regions with major dependence exhibited on the temporal lobe (Squire, Clark, & Knowlton, 2001).

There are several performance based tasks that assesses the declarative memory. These tasks either look in to incidental learning or intentional learning. In the incidental learning the participants are not informed in prior about the recall task that succeeds, however in the intention learning the participants are informed about the recall/recognition task that follows. Thus the participants make conscious efforts in learning making in intentional. California Verbal Learning test- Second edition (CVLT-11) (Delis, Gramer, Kaplan & Ober, 2000) is widely used for intentional learning. There are both child and adult version of the same. In this task, the participants are instructed to remember words from a list after 20minutes duration. The task is the same for both adult and child version. The variations are only for the words entitled in the study list. LLAMA-B language aptitude test is a test for incidental declarative learning and assesses the verbal declarative memory and vocabulary learning abilities (Meara, 2005). In this task the participants are asked to memorize the words which will be paired with pictures of imaginary entities. The participants are asked to learn these object pair for a time period of 2 minutes. This is followed by a test phase where the participants are cued with the given words and are asked to pick the respective object images. Visual Paired Associate Task (VPA)

(Vakil & Herishanu, 1998) is another task tapping in to intentional declarative memory. This test has an encoding phase where the participants are exposed to abstract shape and colour associations. In the recall phase that follows the participants are asked to recall the associations accurately.

The Recognition Memory after Incidental Encoding (RMIE) (Hedenius, 2013) is an incidental encoding task that tests the declarative memory. The RMIE task has 3 sub sessions, the encoding, recognition of the items encoded after 10 minutes and recognition of items after 24 hours. The items presented include black and white line drawings of real objects and certain made up objects. In the encoding phase the participants are asked to categorize the pictures as to real vs made up. In the recognition phases following the participants are asked to categorize the presented line drawings as seen vs. unseen. This task explores the overnight consolidation of memory through the recognition after 24 hours task.

2.2 The Procedural Memory System

In contrast to declarative learning that is rapid, Procedural learning is slow and gradual. The procedural memory system is involved in the implicit learning (Gabrieli et al., 1988; Squire & Zola, 1996; Willingham, Salidis, & Gabrieli, 2002). Though earlier procedural memory was considered important only for motor learning the recent studies shows that this system is important for a series of perceptual, cognitive and linguistic skills. A vast literature proposes that PM system plays a predominant role in learning and computation of the rules and sequences (Knowlton, Mangels, & Squire, 1996; Willingham et al., 2002). The importance of PM system in statistical learning (Karuza, Newport, Aslin, Starling, Tivarus, & Bavelier, 2013; McNealy, Mazziotta, & Dapretto, 2010), probabilistic classification learning (Poldrack et al., 2001; Poldrack & Rodriguez, 2004), reinforcement learning (Frank, 2005), working memory (Dahlin, Neely, Larsson, Backman, & Nyberg, 2008; McNab & Klingberg, 2008) and retrieval from declarative memory (e.g. lexical retrieval; Ullman, 2004) has been widely reviewed in the literature. The recent trend in literature reveals involvement of PM in domains of grammatical learning and processing, across the various sub-sections of language such as syntax, morphology and phonology (Conway & Pisoni, 2008; Christiansen, Conway & Onnis, 2012; Ullman, 2001, 2004; Ullman & Pierpont, 2005).

Though PM is less explored and understood than the DM, the functional traits and the neural underpinnings are widely being explored and are beginning to be unveiled. The functional aspect of the procedural memory may be attributed to facets of the learning and processing of the "stimulus response rule-like relations" that are context dependent (Packard & Knowlton, 2002; Poldrack, Prabhakaran, Seger, & Gabrieli, 1999; Wise, Murray & Gerfen, 1996)

The learning in the procedural memory system is slow and an online process which takes place across multiple presentations of the stimulus as well as the responses. The associations are rule like, which means they are firm, inflexible and uninfluenced by other mental systems, making the system "informationally encapsulated" (Squire & Zola, 1996).Since the rules are applied swiftly as well as habitually, the responses are set off by the stimulus rather than the conscious control.

It is proposed that the procedural memory system consists of a complex network of brain structures. The system is entrenched in the basal-ganglia circuits along with parts of parietal cortex, superior temporal cortex and the cerebellum (Rizzolatti, Fogassi, & Gallese, 2000; Schacter & Tulving, 1994; Squire & Zola, 1996). The basal ganglia involve a set of sub-cortical structures. This involves the striatum, globus pallidus, sub-thalamic nucleus and the substantia nigra (Wise et al., 1996). The striatum is further divided in to putamen and the caudate nucleas where the former is important for motor function and the latter for aspects of cognitive functions (Middleton & Strick, 2000). The dorsal aspects of these striatal structures are proposed to play a predominant role in procedural memory and the ventral portions are vital in affective memory (Packard & Knowlton, 2002).

The cerebellum has conventionally been associated in the balance control, synchronization of skilled movement and in motor learning (Ivry & Fiez, 2000). Recent evidences propose that certain portions of the cerebellum are responsible for procedural memory (mainly motor sequencing) (Ivry & Fiez, 2000; Mostofsky, Goldberg, Landa, & Denckla, 2000). For learning the motor sequences parts of the cerebellar hemispheres and the vermis plays a predominant role (Desmond & Fiez, 1998). These regions are also proposed to be responsible for verbal working memory (Desmond & Fiez, 1998).

The most extensively used task as a measure of Procedural Memory is the Serial Reaction Time (SRT) task (Nissen & Bullemar, 1987). In this task the participants are shown four boxes that are horizontally arranged across a computer screen. Whenever a stimulus (a picture or colour) appears in any one of the four positions participants are supposed to press the corresponding keys quickly and accurately as possible. In an implicit version of the task, the participants are not informed that the stimulus will be presented according to a fixed sequence. This is in contrast to the explicit version of the same task, where the pattern (sequence) is verbalized and memorized prior to the performance of the task.

Sequence learning is observed as enhancements in the accuracy and/or reaction times (RTs) of responses when compared to a randomly ordered sequence which is set up as a control condition at the end of practice. Learning in the SRT task is majorly incident and without the conscious awareness when it is administered as an implicit task (Howard & Howard, 1992; Willingham, Nissen, & Bullemer, 1989).On the SRT task, though the blocks or patterns of sequences are not indicated to the participant, it is possible that the sequence that is repeated can be learned through the declarative system by memorizing them. These could be of more possibility in children with SLI or in children with developmental language disorders (Kuppuraj & Prema, 2014). However, Robertson (2007) reported that the type of learning is not the aspect that determines the involvement of the declarative system, but the computational complexity of the sequences used. The sequences in SRT tasks can vary on to what extent elements in a given location bear first-order conditional (FOC) or second-order conditional (SOC) (and so on) statistical information. FOC sequences are considered lower order sequences, in which each element (i.e., n) in the sequence can be at least partially predicted from the preceding element, that is, just requiring the knowledge of the preceding event [i.e., (n − 1)]. In contrast, SOC sequences are considered higher order sequences, where in predicting the subsequent event within a high-order sequence requires knowledge of the two immediately preceding events [i.e., (n − 2) plus (n − 1)]. Evidences suggest that while performing an SRT task with FOC sequences basal ganglia and frontal circuits (i.e., underlying procedural) are activated (Pascual-Leone et al., 1993; Robertson, Pascual-Leone & Miall, 2004; Torriero et al., 2004), whereas the medial temporal structures are roped in while performing higher order sequences like SOC (Chun & Phelps, 1999; Poldrack et al., 2001; Schendan, Searl, Melrose & Stern, 2003).

The other task for procedural memory is the Mirror tracing (Gabreili et al., 1993; Milner et al., 1962). In this task the participants should simultaneously watch their hands in the mirror and trace the outline of a six sided star. The participants are given a practise trial initially followed by tracing four times. After performing other tasks for duration of about 30 minutes, participants should trace the outlines for five more times. The measures of total time taken for completion and the accuracy will be considered as the dependent measure.

2.3 Interaction between the two memory systems

Although contribution to learning by both declarative memory system and procedural memory system is different, an emerging line of work shows that these systems do not work in isolation. There are studies which show an intensive complex “cooperative” and ‘competetive” interaction between the two systems (Foerde & Shohamy, 2011; Poldrack & Packard, 2003; Ullman, 2004).

The studies conducted on animals revealed that damage to one system may actually augment the learning by the other system (Chang & Gold, 2003; Mitchell & Hall, 1988; Schroeder, Wingard, & Packard, 2002). The effect shown was bidirectional, where a lesion in the striatum showed an enhanced learning by the MTL and a lesion in the MTL showed an enhanced learning by the striatum (Lee, Duman, & Pittenger, 2008), thus serving as evidence to the relationship between both the systems. On this line of thought, the augmented performance of the intact system might reflect the deletion of competitive intrusion by the damaged system (Chang & Gold, 2003). Evidence from the neuroimaging studies revealed an analogous competitive mechanism in the human being as well. During the SRT task in a healthy individual it was observed that with practise, the striatal activity increased and the MTL activity decreased (Lieberman, Chang, Chiao, Bookheimer, & Knowlton, 2004).

Ullman in 2004 developed the Declarative-Procedural model (DP). According to this model, the brain structures underlying the declarative memory and procedural memory are also responsible for domains of mental lexicon as well as mental grammar. The functional roles of both these brain systems are comparable across language and non-language domains. This is further dependent on the shared anatomical, physiological, and biochemical substrates (Ullman, 2004).

As per the DP model, the brain structures underlying the declarative memory system also underlies the mental lexicon. This system facilitates acquisition and utilizes the comprehension of facts, events and words. Arbitrary word meanings and abstract representation such as categories are also stored in this system (Ullman, 2004). It includes bound morphemes, irregular morphological forms, and idioms. This system is also responsible for memory based generalization. The brain system that sub serves the declarative memory has an equivalent function in lexical memory as well. Thus MTL sub serves encoding, consolidation and access of novel memories. Non-linguistic conceptual knowledge and word meanings are represented in the inferior and ventral temporal regions of MTL (Damasio et al., 1996).

The brain system that underlies the procedural memory system is responsible for mental grammar. This system is accountable for learning new, and the computation of already learned procedures that are rule based especially items that are probabilistic and possesses hierarchical relations (Ullman, 2004). Thus, procedural memory is predicted to have a predominant role in aspects of grammar including syntax, inflectional and derivational morphology (Pinker, 1999), Phonology and compositional semantics. The channels that run through the basal ganglia to the thalamus and to frontal cortex are responsible for processing and learning of grammar (Ullman, 2004).

The Procedural Deficit Hypotheses (Ullman & Pierpont, 2005) was derived from the concepts of DP model and served as an explanatory account for Specific Language Impairment (SLI). According to this theory, the profile of compromised grammar and comparatively intact word learning were attributed to the procedural memory and declarative memory respectively. Intact word learning is assumed to be sub-served by the declarative memory and impaired performances in grammatical domains were attributed to the procedural memory system. This theory that served as an explanatory account for SLI proposed that an impairment in the procedural memory system leads to an enhanced performance in the declarative memory system thus assisting is learning.

2.4 Procedural memory and Declarative memory in neurodevelopmental disorders

There have been a number of studies on SLI revealing intact declarative memory (Ullman, 2004; Hedenius, 2013) as well as an impaired declarative memory (Kuppuraj & Prema, 2014; Sengottuvel & Rao, 2013). Use of semantic scores as a covariate however nullified the impairment in declarative memory and showed similar performance across both the groups. It is hypothesised that individuals with SLI uses compensatory strategies such as chunking for compensating for the grammatical impairment. In a typically developing individual, computations of complex forms (morphological variations) are assumed to be dependent on the procedural memory system (Ullman & Gopnik, 1999; Ullman & Pierpont, 2005). However, in individual with SLI, memorization of the complex structures as chunks are observed which is a function of the Declarative memory (Ullman & Pierpont, 2005). Evidence from the electrophysiological studies also reveals a wider dependency on the declarative memory systems in children with SLI (Fonteneau & Van der lely, 2008). Further previous studies also reveal that superior grammatical ability in children with SLI was well correlated with the declarative memory systems and not with the procedural memory systems (Lum et.al, 2014). Thus, the researches done so far yielded inconsistent findings were most of the studies suggested of an intact declarative system and an impaired procedural system though few studies did not find any significant difference in both the systems.

Evidence from the studies suggests that children with Autism rely on declarative memory to compensate for a variety of language, pragmatic and social issues in the disorder. Children with autism use formulaic speech which recompense for the linguistic shortfall in these children (Dobbinson et.al, 2003). For problems in relation to social deficit it is assumed that children with autism memorize the rules to the applied, and event related to schemas to counterweigh the social deficits (Norbury & Bishop, 2002). When typically developing relies on the procedural memory for grammatical category learning, children with autism uses declarative memory explicitly for this (Knowlton & Squire, 1993).

2.4.1 Developmental Dyslexia

Development dyslexia (DD) is a developmental language impairment typified by obscurity with literacy growth in the context of undamaged intellectual skills (Lyon, & Shaywitz, 2003). Phonological encoding and difficulties with written word recognition are the typical features exhibited in children with DD (Bishop &

Snowling, 2004; Catts & Kamhi, 2005). DD has also been associated with several other deficits like working memory, motor function and implicit sequence learning (Robertson, 2007). Current evidence from several studies reveals that DD is related to the underlying deficit in phonological processing (Catts & Kamhi, 2005; Goswami, 2000, 2008; Lundberg et.al, 1998; Snowling et.al, 2000). This impairment includes impaired phonological processing skills (Non word repetition, phonological awareness, rapid automatised naming) (Vellutino, Fletcher, Snowling, & Scanlon, 2004). A fundamental role for phonological skills in learning to read was put forward by the researches done in preschool training showing phonological skills to facilitate reading and writing development at a later stage (Lundberg, Frost and Petersen, 1988).

However, there are several studies that has found impairment in other domains such as impediment of working memory (Smith-Spark & Fisk, 2007; Swanson, Xinhua, & Jerman, 2009), motor function (Nicolson, Fawcett, & Dean, 2001), and implicit sequence learning (Howard, Howard, Japikse, & Eden, 2006; Jimenez-Fernandez, Vaquero, Jimenez, & Defior, 2011; Vicari, Marotta, Menghiai, Molinari, & Petrosini, 2003). However these could not be explained in relation to impaired phonological skills.

An association between an impaired procedural memory and DD was initially put forward through the Procedural Deficit Hypothesis (PDH) (Nicolson & Fawcett, 1990; Nicolson et al., 2001). The authors also proposed the "dyslexic automatization deficit" which suggests an impediment in the automatization of the skills, thus being an explanatory account for the types of impairments in the disorder. They also proposed of a "conscious compensation" that children with DD use in order to surmount the automatization deficits. The cerebellar deficit hypothesis which is discussed as an automatization deficit hypothesis at the cognitive level contributes to the automatization of the skilled behaviour (Nicolson & Fawcett, 2011). As per this view, deficit deficit in procedural memory may affect reading both directly and indirectly, directly through problems in skilled automatization and indirectly through problems in phonological processing (Nicolson & Fawcett, 2011) (see figure 2.2). The authors also put forward a “neural system view” of disorders like DD and SLI where an impaired procedural system is compared with an intact declarative memory system (Nicolson & Fawcett, 2007). The cerebellar deficit hypothesis is also compatible with the magnocellular deficit theory (Stein, 2001). The magnocellular deficit account holds that the reading problems spring from impaired sensory processing, caused by abnormal auditory and/or visual magnocellular pathways. Further this faulty input via the magnocellular pathways was attributed to cerebellar impairment. Cerebellar impairments are closely associated with impairments in skilled automatization which is a functional aspect of the procedural memory.

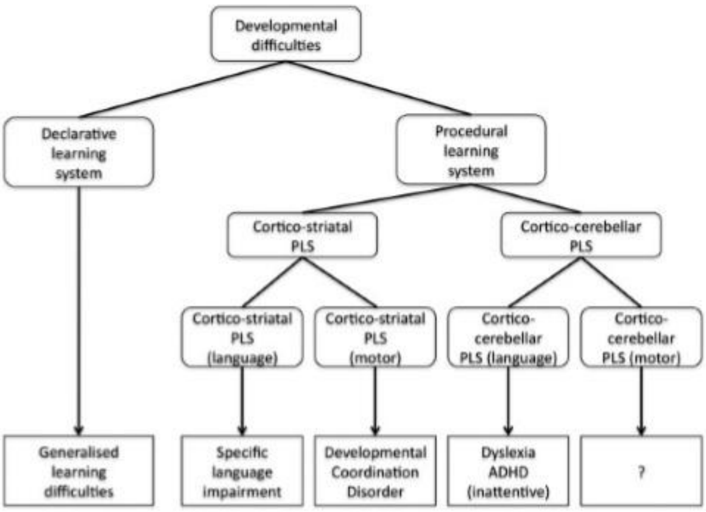

Figure 2.2 The Nicolson and Fawcett (2007) typology of learning disabilities in terms of neural systems.

Source: Nicolson, R. I., & Fawcett, A. J. (2007). Procedural learning difficulties: reuniting the developmental disorders?.,*TRENDS in Neurosciences*, *30*(4), 135-141.

PDH is developed from Declarative Procedural (DP) which is a dual-system model language however, Nicolson and Fawcett's domain general method and PDH has similar base. It mainly deals with areas of procedural memory system dysfunction specialised in a range of cognitive, linguistic and motor deficits (Ullman, 2001). Distinct cognitive/linguistic systems supports the aspects of rule governed language and idiosyncratic knowledge. Its assumed to be in the mental lexicon that idiosyncratic knowledge is memorised which includes arbitrary sound meaning associations and sporadic word forms like teach, taught etc. A distinct mental grammar supports rule-governed language which helps in combining words to phrases, sentences and complex words. The D-P model proposes that distinction between brain's declarative and procedural memory systems are mapped by distinguishing mental lexicon and mental grammar (Squire, 2004). It specifically explains that mental lexicon depends on declarative memory system constituted by the brain structure network and that mental grammar depends greatly on procedural memory brain network (Ullman, 2004).

The PDH claims that there is no link between procedural memory and vocabulary however, it predicts the impairment of both language and non-language functions and claims the association between grammar and procedural memory. Declarative memory accredits the link between vocabulary and memory system. In DD, impaired automatization skills and issues in phonological processing, directly and indirectly, underlies reading problems.

Studies that used implicit versions of the SRT task revealed an impaired performance at the procedural memory task associated with DD (Howard, Howard, Japikse, & Eden, 2006; Jimenez-Fernandez, Vaquero, Jimenez, & Defior, 2011;

Vicaria, Menghini, Hagberg, Caltagirone, & Petrosini, 2005). However, several studies also report of an intact procedural memory as well (Kelly, Griffiths, & Frith, 2002; Russeler, Gerth, & Munte, 2006). These weakened functioning in children with DD has been reported in studies that used artificial grammar learning paradigms (Pavlidou, Kelly, & Williams, 2009). It was also reviewed in the literature that towards the final sequence block, there is a significant increase in the reaction time scores in children with dyslexia as well as typically developing children implying that learning and consolidation of the sequences are taking place in both the groups, though the performance was poor in children with DD (Henderson & Warmington, 2017; Hedenius et al., 2011). In addition, structural and functional imaging studies in DD revealed not just an improvement in reading abilities after the behavioural interventions but also changes in structural and functional neuroanatomy (Eden et al., 2004; Temple et al., 2003).

Though there are studies that tested the functions of declarative memory directly, however inconsistent findings were reported. An intact performance in DD group was reported when an explicit version of the task was used task (Jimenez-Fernandez et al., 2011; Vicari et al., 2003). An enhanced performance in children with DD was attributed to a "neuronal recycling hypothesis" as described by Hedenius (2013). As per the hypothesis, children while learning to read, exhibit a trade off between building up a sight word lexicon and visual skills. According to the author, the enhanced performance shown by children with DD was because of a trade off exhibited as children develop reading ability. Using the categorization task with binary choice for response would also result in an inability to accurately inhibit the incorrect responses (Marton, Kelmenson, & Pinkhasova, 2007). It is proposed that as there is advancement in reading there could be a decline in the declarative memory as well (Dehaene et al., 2010). On the other hand, these differences in group that emerged disappeared when phonological impairments were manipulated, thus revealing that this impairment might not be in relation to an impairment in declarative memory but an underlying phonological problem. In contrast to this, there were also studies reporting an impaired declarative memory in children with dyslexia (Vellutino & Scanlon, 1985; Kramer et al., 2000; Swanson et al., 2009)

There are studies which proposed that the presence of a phonological decoding problem in individuals with DD may be attributed to an augmented dependence on "chunking" and "whole word memorizations" for reading (Shaywitz & Shaywitz, 2008; Van der Leij & Van Daal, 1999). Thus the present study aimed to explore the nature of declarative and procedural memory in children with DD.

CHAPTER 3: Method

The primary aim of the current study was to investigate the nature of Declarative and Procedural memory in children with Developmental Dyslexia (DD).

The objectives of the study were as follows:

- To compare the performance of children with Developmental Dyslexia (DD) and typically developing children in recognition memory after incidental encoding (RMIE) task as a measure of declarative memory.
- To compare the performance of children with Developmental Dyslexia and typically developing children in serial reaction time (SRT) task as a measure of procedural memory.
- To study if there is a trade off between declarative memory and procedural memory in children with Developmental Dyslexia
- To study the relationship between linguistic processes and Memory systems (Declarative and Procedural).

The present study followed a standard two group comparison research design to compare the declarative and procedural memory in children with Developmental Dyslexia (i.e., clinical group) and typically developing children (i.e., control group).

3.1 Participants

Participants were classified into two groups – the clinical group and the control group.

Clinical group: The clinical group included a total of 10 children with Developmental Dyslexia in the age range of 10-15 years. Clinical group= $10 \leq A \leq 15$ years.

Control group: The control group included 20 typically developing children; age and gender matched with the participants in the clinical group. Participants in the clinical group were matched to two participants each in the control group. Control group= $10 \leq A \leq 15$ years.

Participant selection criteria

All the participants in the study had Kannada as their first language and English as their second language. An informed consent was obtained from the caretakers with advance information on the purpose of the current study and maintenance of privacy. Children with Developmental Dyslexia as diagnosed by a qualified Speech-Language Pathologist and a Clinical Psychologist based on standardized tests were included in the study. All the participants were undergoing Speech and Language Therapy during the study.

None of the participants had any neurological, sensory or gross motor impairment as on the ICF-CY checklist (WHO work group, 2004). All Participants with Performance Intelligence quotient (PIQ) >80 as per Raven's Progressive Coloured Matrices were included in the study. Linguistic Profile Test (LPT) (Suchitra & Karanth, 1990, 2007) was administered to all the participants as a measure of their phonological, semantic and syntactical abilities in Kannada.

3.2 Stimulus Material

The stimulus material was adapted from the AIISH Research Fund Project "Nature of Non- Explicit Declarative and Procedural Memory Systems in Specific Language Impaired: Examining the Post Scripts of Procedural Deficit Hypothesis" (Kuppuraj & Prema, 2014). The material consisted of stimuli for measuring the recognition memory after incidental encoding (RMIE) as a measure of declarative memory (DM) and serial reaction time (SRT) as a measure of procedural memory (PM). The RMIE task consisted of 120 black and white line drawings of objects (60 real and 60 made up) with a total of 3 sets devised for each phase of the task. The SRT task consisted of stimulus (a coloured block) appearing on any of the four horizontally aligned blocks.

3.3 Instrumentation

A 14 inch screen HP laptop was used to conduct the experiment. The software Psychopy, version 1.83.00 (Peirce, 2007) was used for programming the stimulus for both RMIE and SRT tasks. Psychopy is an open based application and was programmed to give reaction time measures and accuracy.

3.4 Procedure

The testing was carried out in a quiet environment under normal lighting conditions during day time. The participants were seated comfortably and the distance between the participant and the laptop screen was approximately 50cm for all the experiments. As mentioned above, the stimulus presentation was controlled by Psychopy software (version 1.83.00).

The RMIE task included the presentation of visual objects as black and white line drawings of real objects and made-up objects of the size of 351*481px. After each stimulus, a crosshair (X) appeared in the centre of the screen for 1000 ms, to prime the occurrence of stimulus followed by the item (object image) for 500 ms in the centre. The item remained on the screen for 500 ms despite the response of the participant, to equalize presentation duration across stimulus and subjects. The total response window was up to 4500 ms including the presentation time of 500ms as depicted in Figure 3.1. Irrespective of the accuracy of the response the next stimulus appeared preceded by the cross hair. The order of presentation of items was randomized for each participant.

The RMIE task was carried out in three phases; an Encoding phase, where the participants had to classify the displayed item as real vs made up followed by two recognition phases (after 10 minutes and 1 day). In the encoding phase, the participants were asked to press the corresponding keys in the key board ("1" if the object is real and press "0" if the object is made up). The participants during the encoding phase were not informed about the recognition phase following, making the phase incidental. For the following recognition tasks (after 10 minutes and 1 day) new objects and already seen objects were shown to the participants. The task of the participant during these phases was to indicate if the object was seen or unseen during the encoding phase. The participants were instructed to press "1" if seen, and "0" if unseen.

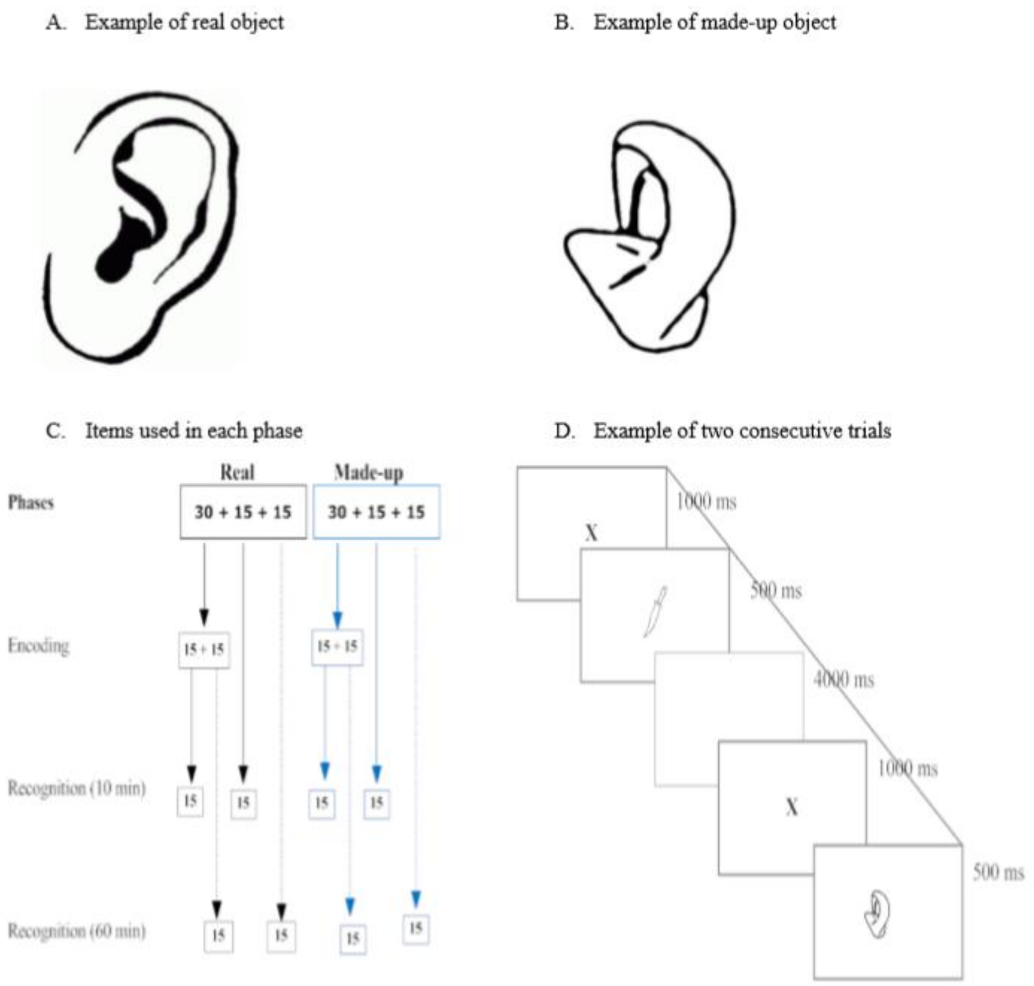

Figure 3. 1: Figure shows the set up of RMIE task.

Taken with permission from Kuppuraj, S. & Prema, K.S. (2014). Nature of Non-explicit Declarative and Procedural Memory Systems in Specific Language Impaired: Examining the Post Scripts of Procedural Deficit Hypothesis. *Unpublished Independent Projec*t, AIISH, Mysore

In the SRT task, participants traced the stimulus (a block filled with colour) appearing in any one of the four horizontally aligned locations/rectangles (location '1' is left most rectangle and location '4' is right most) on screen using spatially corresponding response keys on the key board ('Z', 'X', 'N', & 'M') as rapidly and accurately as possible. The participants were asked to use the left middle finger and index finger to respond for locations 'Z' and 'X' and right index and middle finger to respond for 'N' and 'M'. At the beginning of each trial a cross mark appears on all four locations for 250 ms to prime the appearance of the stimulus, followed by the stimulus in any of the four locations (one at a time) for as long as a correct button is pressed (see figure 3.2) . The time gap between stimulus appearance and button press was measured in milliseconds (ms) as reaction time (RT) for a single trial. The participants were given practise set of about 25 trials prior to the actual task to ensure easiness. Visual feedback was given if the button press was incorrect. The task consisted of four blocks; two random (R1 and R2) and two sequences (S1 and S2). On the random blocks (100 trials in each), the stimulus appeared randomly on any of the four locations. On the sequence phases, stimulus locations followed a pre-determined 12 item first order sequence (FOC). The sequence used was ‘421323413412’, in which all the locations have equal probability of occurrence (i.e., 25). Twelve sequence sets were repeated 20 times comprising each sequence blocks (12 item x 20 times= 240 trials per block). The participants were asked for a free recall if they had observed any particular pattern of occurrence of the colour on the block leading to easy performance.

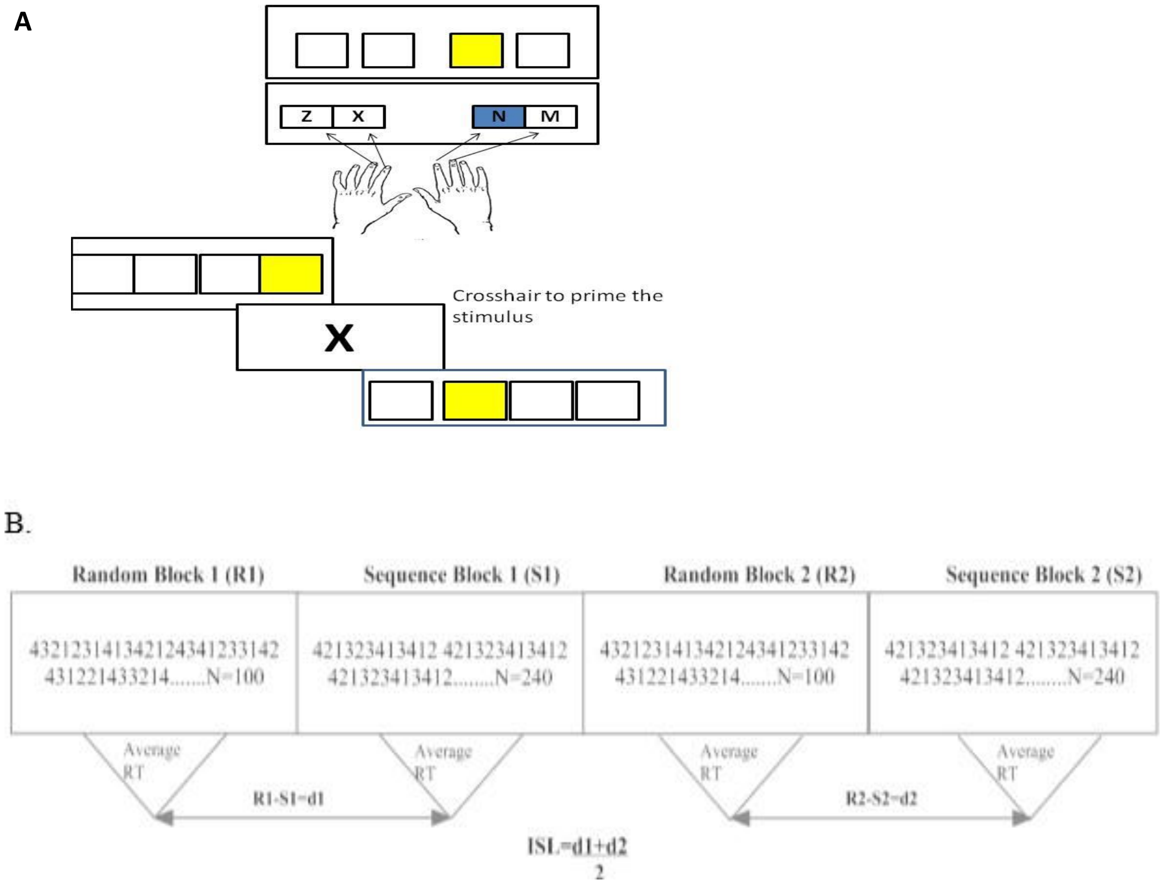

Figure 3.2: A) Shows the SRT task set up. The figure illustrates the stimulus appearing on one the squares and the corresponding key board press ie “N”. B) Random and sequence blocks with the number of trials.

Recreated from Kuppuraj, S., & Prema, K.S. (2014) Nature of Non-explicit Declarative and Procedural Memory Systems in Specific Language Impaired: Examining the Post Scripts of Procedural Deficit Hypothesis. *Unpublished Independent Projec*t, AIISH, Mysore

3.5 Scoring and Analysis

The responses for RMIE and SRT were computed by the Psychopy software (Peirce, 2007). For the encoding phase of RMIE task the accurate response and the averaged reaction time of each participant was calculated. Similarly, RT and the number of accurate responses were calculated for the immediate recognition phase. In the later recognition phase the accurate responses for real objects and made up objects out of the total accurate responses given were obtained. For the serial reaction task

(SRT) the mean reaction time in each block were calculated (R1 S1 R2 S2). The data was tabulated and subjected to statistical analysis using Statistical Package for Social Sciences (SPSS) version 17.0.

CHAPTER 4: Results

The aim of the present study was to investigate the nature of Declarative and Procedural memory systems in children with Developmental Dyslexia. The study also aimed to compare the performance of typically developing children and children with Developmental Dyslexia in the age range of 10 – 15 years across Recognition Memory after Incidental Encoding (RMIE) task, Serial Reaction Time task (SRT), to investigate if there is any trade-off between declarative memory and procedural memory in children with Developmental Dyslexia and also to study the relationship between linguistic processes and the two memory systems. The data obtained from both the groups i.e., TDC and DD group were analysed on measures of accuracy and reaction time for RMIE task and reaction time alone for the SRT task.

The data was subjected to statistical analysis for measures of accuracy and reaction time for the three subtasks of RMIE task. The RMIE subtasks included Encoding (Enc), Recognition after 10 min (Rec10) and Recognition after 24 hours (Rec24). For the SRT tasks, reaction time measures across four blocks [two random (R1rt, R2rt) and two sequences (S1rt, S2rt)] were measured and analysed. Reaction times greater than 3000ms and less than 300ms were eliminated for the reaction time measures under both the tasks. The mean reaction time scores across each block were computed separately. As the data followed a normal distribution, Parametric tests were used for the analysis. The data was analysed using the following statistical procedures:

- Descriptive statistics was carried out to find the mean, median and standard deviation (SD) for performance of TDC and children with DD on RMIE and SRT task.

- Independent sample t-test was used to compare the performance on RMIE between TDC and children with DD.
- Mixed ANOVA was used to compare the performance of TDC and children with DD on the performance across the SRT task.
- Pearson's correlation coefficient was used to compare the RMIE measures and SRT measures and also to compare the linguistic processes and the two memory systems (DM and PM)

The results of the present study are explained under the following headings as follows,

4.1 Performance of TDC and children with DD on the task of Declarative memory (RMIE task)

4.2 Performance of TDC and children with DD on the task of Procedural memory (SRT task)

4.3 Relation between Declarative memory and Procedural memory.

4.4 Relation between linguistic processes and the two memory systems (Declarative memory and Procedural memory)

4.1 Performance of TDC and children with DD on the task of Declarative memory (RMIE)

The RMIE task was used as a measure of Declarative memory. The RMIE task was further divided in to three subtasks. They are: Encoding, Recognition after 10 minutes and Recognition after 24 hours. The data obtained was subjected to statistical analysis for measures of accuracy (Encoding accuracy-EncAcc; Recognition accuracy after 10 minutes-Rec10Acc; Recognition accuracy after 24 hours-Rec24Acc) and reaction time (Encoding reaction time-EncRt; Recognition after 10 minutes reaction time-Rec10Rt; Recognition after 24 hours reaction time-Rec24Rt) for all the three subtasks (Encoding-Enc; Recognition after 10 minutes-Rec10; Recognition after 24 hours-Rec24).The mean, median and standard deviation (SD) for accuracy and reaction time were calculated for all the RMIE subtasks. Table 4.1 shows, mean, median and SD values for accuracy and reaction time in TDC and in children with DD.

Table 4.1

Mean, Median and Standard deviation values on accuracy measure and reaction time (in secs) on RMIE subsessions.

Sub sessions	**TDC**			**DD**		
	Mean	Median	SD	Mean	Median	SD
EncAcc	56.10	56	1.51	55.40	55.00	2.06
EncRt (in secs)	0.92	0.94	0.26	0.90	0.66	0.43
Rec10Acc	45.90	45.50	4.95	48.60	47.50	3.23
Rec10Rt (in secs)	0.90	0.89	0.14	0.98	0.89	0.24
Rec24Acc	48.65	49.00	2.00	47.90	48.00	3.28
Rec24Rt (in secs)	0.76	0.73	0.15	0.81	0.75	0.16

Note: Note: EncAcc=Encoding Accuracy, EncRt=Encoding reaction time, Rec10Acc=Recognition after10minutes accuracy, Rec10Rt=Recognition after 10minutes Reaction time, Rec24Acc=Recognition after 24 hours accuracy,Rec24Rt=Recognition after 24 hours

The analysis of results as indicated in table 4.1 for comparison of the mean scores in terms accuracy and reaction time across the subtasks of RMIE showed similar performance between TDC and DD. Analysis of the results in table 4.1 on the EncAcc tasks showed similar performances between TDC (Mean=56.10, SD =1.51) and in children with DD (Mean=55.40, SD=2.06). Analysis of the EncRt showed similar performances in TDC (Mean=0.92, SD=0.26) and in children with DD (Mean=0.90, SD=0.43). Analysis of Rec10Acc showed similar performances in TDC (Mean=45.90, SD=4.95) and DD (Mean=48.60, SD=3.23) and Rec10Rt did not show much difference in the mean values obtained in TDC (Mean=0.90, SD=0.89) and in children with DD (Mean=0.98, SD=0.89). Further the analysis of Rec24Acc showed similar performances in TDC (Mean=48.65, SD=2.00) and in children with DD (Mean=47.90, SD=3.28). Analysis of Rec24Rt also showed the same performance in TDC (Mean=0.76, SD=0.15) and children with DD (Mean=0.81, SD=0.16). Figures 4.1 and 4.2 indicate similar performance across subtasks between TDC and DD for accuracy and RT measures respectively. Since there was no difference found between the two groups the number of accurate responses for made up objects and real objects out of the total accurate responses were not computed for Rec24Acc.

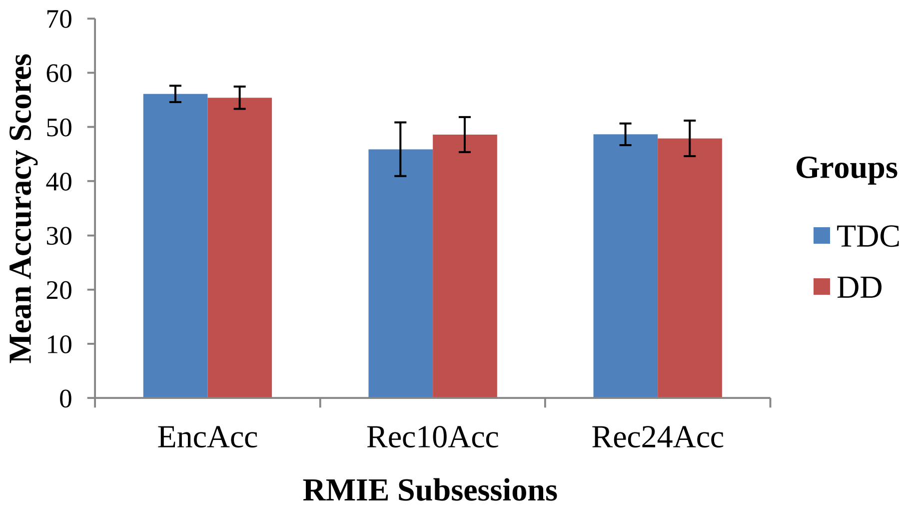

Figure 4.1 : Comparison of performances on Accuracy measures of RMIE subtasks in TDC and children with DD

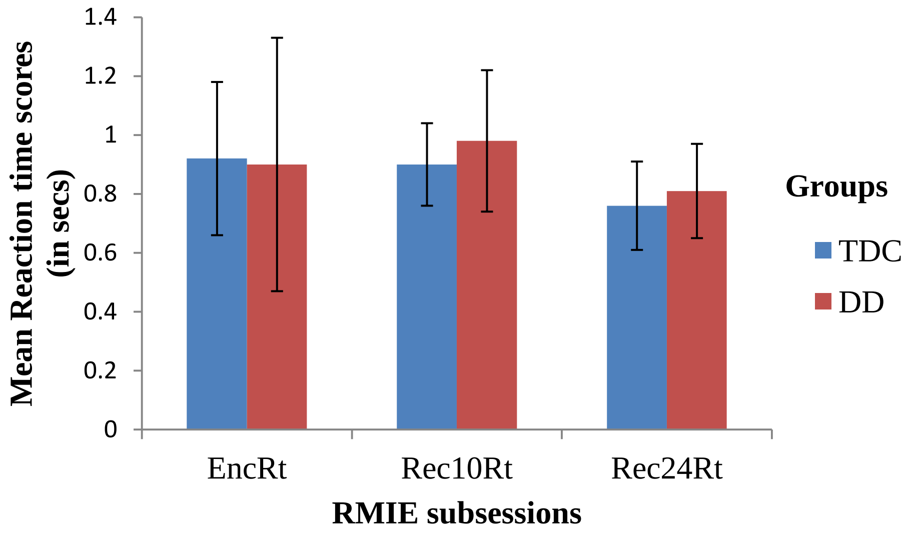

Figure 4.2 Comparison of Reaction time scores of RMIE subtasks in TDC and in children with DD.

Data was subjected to statistical analysis to test for significance of the differences between the two age groups. Independent sample t test was used to investigate the differences across the two groups for accuracy and reaction time measures across the subtasks. Analysis of results using the Independent sample t test showed that there was no significant difference ($p>0.05$) across all the parameters [EncAcc ($t(28)=1.05$, $p>0.05$), EncRt ($t(28)=0.19$, $p>0.05$), Rec10Acc ($t(28)=-1.5$, $p>0.05$), Rec10Rt ($t(28)=-1.2$, $p>0.05$) , Rec24Acc ($t(28)=0.77$, $p>0.05$)].

In summary, analysis of the results of performance on RMIE task indicated similar performances across all the subtasks of RMIE. However, the mean reaction time scores of children with DD were longer than that of the TDC (Table 4.1).

4.2 Performance of TDC and children with DD on the task of Procedural memory (SRT task)

The data obtained were analyzed for measures of reaction time. Table 4.2 shows the mean, median and standard deviation of the reaction time measures for both the groups on the SRT task as a measure of procedural memory.

Table 4.2

Mean, Median and SD values for reaction time (in secs) on SRT task

Components	**TDC**			**DD**		
	Mean	Median	SD	Mean	Median	SD
R1rt	0.63	0.63	0.09	0.78	0.79	0.11
S1rt	0.63	0.65	0.10	0.80	0.76	0.19
R2rt	0.64	0.65	0.08	0.80	0.76	0.21
S2rt	0.60	0.63	0.09	0.72	0.72	0.13

Note: R1rt= Random block 1, S1rt= Sequence block 1, R2rt=Random block 2, S2rt= Sequence block 2.

Analysis of the results obtained for reaction time measures on SRT task (Table 4.2) revealed significant differences across the two groups. Comparison and analyses of the mean scores of R1rt as shown in table 4.3 indicated that the mean reaction time scores were longer in children with DD (Mean=0.78, SD= 0.11) than in TDC (Mean= 0.63, SD= 0.09).

Analysis of the results of reaction time measures on S1rt as shown on table 4.2 revealed an increased reaction time measure for children with DD (Mean=0.80, SD= 0.19) than TDC (Mean=0.63, SD= 0.10).Analysis of the results of reaction time measures on R2rt as shown on table 4.2 indicated a longer reaction time score of children with DD (Mean=0.80, SD=0.21) than TDC (Mean=0.64, SD= 0.08).Analysis of the results of reaction time measures on S2rt as shown on table 4.2 indicated an increased reaction time scores for children with DD (Mean= 0.72, SD=0.13) than TDC (Mean=0.60, SD=0.09)

Analysis of the reaction time measures across all the blocks indicated a faster reaction time in the S2rt block in both TDC and in children with DD (figures 4.3)

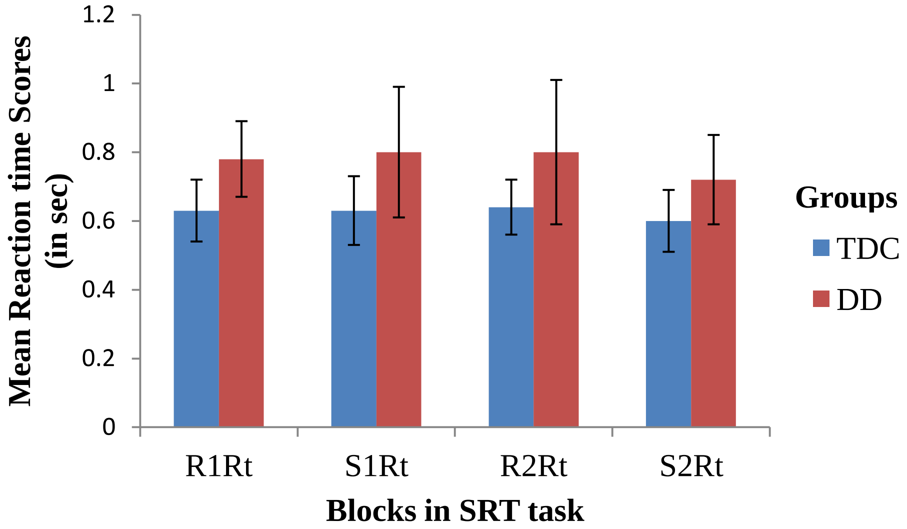

Figure 4.3: Performance of TDC and children with DD on task of Procedural Memory (SRT task).

The analogous analysis was done after the completion of SRT task. The participants were asked if they had observed any specific pattern in the blocks. None of the participants except two in the typically developing group could identify the pattern. The pattern said by the two participants in the TDC was partially correct. However there were no significant differences noted in their reaction time scores in comparison with other participants in the group.

The data obtained as shown on the table 4.2 was further subjected to statistical analysis. Since the data followed a normal distribution, parametric test was used. Mixed ANOVA within and across group was used to compare the performance of SRT task across the groups. The results of the statistical analysis were compared across main effect of conditions (S1, R1, S2, and R2), groups (TDC, DD) and interaction effect between conditions and groups.

Analysis of results on Mixed ANOVA revealed, significant main effect across conditions, $F(3, 84) = 8.45, p < 0.05$. Further pair wise comparison was done to analyse the differences across the tasks. Analysis of the results of pair wise comparison for R1 reveals significant difference across S1. That is there is a significant difference between the Random 1 block and the Sequence 2 block ($p < 0.05$). There was no notable difference across the other blocks in comparison with R1.Analysis of the results for S1 indicated significant difference across S2. That is there is a significant difference between the Sequence block 1 and the Sequence block 2 ($p < 0.05$) Analysis of the results of pair wise comparison for R2 indicated significant difference across S2. That is there was a significant difference between Random block 2 and the Sequence block 2 ($p < 0.05$).Analysis of the results of pair wise comparison for S2 indicated significant difference across all the other three blocks i.e., R1, S1 and R2. There was a significant difference between S2 and R1 ($p < 0.05$), S2 and S1 ($p < 0.05$) and S2 and R2 ($p < 0.05$). Thus among the four blocks the mean reaction time was fastest in Sequence 2 block for both TDC and DD (as shown in table 4.2).

Analysis of results on Mixed ANOVA indicated a significant difference between TDC and DD ($F(1,28)=11.4, p < 0.05$)).This shows that the reaction times (R1, S1, R2, S2) are significantly slower for DD compared to TDC (as shown in table 4.2).

Analysis of the results on Mixed ANOVA revealed no significant interaction effect across the conditions and groups, ($F(3,84)=1.08, p>0.05$). This shows that the trend in learning is the same in TDC and in DD. Though learning is happening in both the groups reaction time is longer in children with DD. Both the groups showed faster reaction time for S2 block (as shown in table 4.2).

In summary, Descriptive statistics were carried out initially and mean, median and mode were computed for all the SRT blocks (R1, S1, R2, S2) (Table 4.2). Analysis of the results as shown in table 4.2 showed a faster reaction time scores for TDC across all the subtasks. The reaction time scores of children with DD were longer in comparison to the TDC but the trends across different blocks were similar. Both the groups had the fastest reaction time in S2 block i.e. block 4 (Sequence 2 block) which showed that the learning is happening. Further the data was subjected to statistical analysis. Since the data followed a normal distribution, parametric test was used. Repeated measures ANOVA was used to compute the difference in performance across the two groups. The analysis of main effect of condition revealed significant difference across all the conditions. A pair wise analysis revealed significant difference across S2 and other blocks (R1, S1, R2). This shows that the mean reaction time obtained for S2 was significantly different across the other blocks. Analysis of main effect of groups also showed significant difference across the two groups. Analysis of main effect of interaction did not show any significant difference across the group meaning though the learning happening in both the groups the trend in the learning is same across the groups.

4.3 Relation between Declarative memory and Procedural memory

The present study also aimed to explore the relation between the Declarative memory and Procedural memory in both the groups. Data obtained for Rec10Acc, Rec10rt of RMIE and S1 and S2 of SRT task was considered for determining the relation between Declarative memory and Procedural memory. The Pearson's correlation coefficient (r) was calculated for the variables.

4.3.1 Relation between RMIE and SRT in TDC and DD

The data obtained for accuracy and reaction time scores of Recognition after 10minutes (Rec10Acc and Rec10rt) of RMIE and the reaction time scores (S1 and S2) of SRT task was considered for determining the relation between DM and PM respectively. The Pearson's correlation coefficient (r) was calculated for the variables. The table 4.5 shows the Pearson's correlation coefficient for Rec10Acc and Rec10Rt (RMIE) compared across S1 and S2 (SRT) in TDC

Table 4.3

Correlation values(r) for the comparison of RMIE task and SRT task in TDC

Components	Rec10Acc	Rec10Rt
S1	-0.04	0.42
S2	0.04	*0.42*

Note: S1=Sequence block 1 , S2=Sequence block 2, Rec10Acc= Accuracy measures of recognition after 10minutes,Rec10Rt=Reaction time measures of recognition after 10minutes.

Analysis of the result as shown in table 4.3 indicated that there was no significant correlation between Declarative memory and Procedural memory for TDC, i.e., the performances on RMIE task is not significantly related to performances on SRT tasks in TDC.

The data obtained for accuracy and reaction time scores of Recognition after 10minutes (Rec10Acc and Rec10rt) of RMIE and the reaction time scores (S1 and S2) of SRT task were considered for determining the relation between Declarative memory and Procedural memory respectively. The Pearson's correlation coefficient (r) was calculated for the variables. The table 4.4 shows the Pearson's correlation coefficient (r) for Rec10Acc and Rec10Rt (RMIE) compared across S1 and S2 (SRT) in children with DD.

Table 4.4

Correlation coefficient(r) across RMIE task and SRT in DD

Components	Rec10Acc	Rec10Rt
S1	-0.34	-0.06
S2	-0.53	*-0.29*

Note: S1=Sequence block1, S2=Sequence block 2, Rec10Acc= Accuracy measures of recognition after 10minutes, Rec10Rt=Reaction time measures of recognition after 10 minutes

Analysis of the results as shown in table 4.4 indicated that there was no correlation between Declarative memory and Procedural memory, i.e., performances on RMIE tasks is not significantly related to performances in SRT tasks in children with DD.

4.4 Relation between linguistic processes and the two memory systems (Declarative memory and Procedural memory)

Final scores obtained in the Linguistic Profile test (LPT) for each of the subsections (Phonology, Syntax, Semantics) were computed and compared across the performance in RMIE subtask (Rec10Acc, Rec10Rt) and SRT subtask (S1, S2) to find out the correlation between the Declarative memory ,Procedural memory and the linguistic processes. The table 4.5 shows the Mean and Standard deviation values on performance in the LPT subsections across children with DD and TDC.

Table : 4.5

Mean and Standard deviation scores on performance on LPT by children with DD and TDC

LPT Subsections	**TDC**		**DD**	
	Mean	SD	Mean	SD
Phonology	98.4	2.83	99.40	1.07
Syntax	90.95	2.76	85.80	4.15
Semantics	95.20	2.76	89.40	3.47

Analysis of the results as shown in table 4.5 shows similar performance across both the groups under LPT subsections. Analysis of the mean scores across phonology subsection revealed similar performance in both TDC (Mean=98.4, SD=2.83) and in children with DD (Mean=99.40, SD=1.07). Analysis of the total scores obtained in the syntax sections also indicated similar performance in TDC (Mean=90.95, SD=2.76) and in children with DD (Mean=85.80, SD=4.15). Analysis of scores of Semantics subsection was also carried out and revealed a similar performance across TDC (Mean=95.20, SD=2.76) and in children with DD (Mean=89.40, SD=3.14)

Bivariate analysis was carried out and Pearson's correlation coefficient (r) was computed. Table 4.6 shows the correlation coefficient for the LPT scores across the two memory systems.

Table 4.6

Correlation coefficient(r) across LPT subsections, RMIE and SRT.

LPT subsections	Rec10Acc	Rec10Rt	S1	S2
Phonology	0.06	0.026	-0.01	0.002
Syntax	-0.22	-0.23	-0.20	-1.69
Semantics	-0.15	-0.12	-0.18	-0.19

Note: Rec10Acc= Accuracy scores of Recognition after 10minutes, Rec10Rt=Reaction time scores of recognition after 10minutes, S1= Sequence block one of RMIE, S2= Sequence block 2 of RMIE,LPT=Linguistic Profile Test

The analysis of the results as shown in the table.4.6 indicated that the performances in the tasks for Declarative memory and Procedural memory are not significantly related to the performance in the Linguistic Profile Test.

In summary there was no correlation between the Declarative memory and Procedural memory in both the groups i.e., TDC and children with DD. There was no significant dependence observed between the linguistic processes and the two memory systems.

CHAPTER 5: Discussion

The aim of the present study was to investigate the nature of declarative and procedural memory in children with Developmental Dyslexia (DD). Performance of the children with DD was compared with TDC on measures of accuracy and reaction time for RMIE task (Declarative memory) and reaction time measures were considered for SRT task (Procedural memory).

Findings of the present study are discussed under the following sections:

5.1 Comparison of performance of TDC and children with DD on the task of Declarative memory (RMIE)

5.2 Comparison of performance of TDC and children with DD on the task of Procedural memory (SRT task)

5.3 Trade off between Declarative and Procedural memory in children with DD

5.4 Relation between the linguistic processes and the memory systems.

5.1 Comparison of performance of TDC and children with DD on the task of Declarative memory (RMIE)

The findings of the current study revealed that TDC and DD showed a similar performance on the RMIE task implying that both TDC and DD have comparable explicit learning. However, there have been studies quoted in literature of impaired declarative memory in children with DD (Vellutino & Scanlon, 1985; Kramer et.al., 2000; Swanson et al., 2009). These initial studies carried out to explore the incidental learning in children with DD used a different paradigm than the current study and revealed an impaired performance in DD on Declarative memory. The paradigms used to assess the declarative memory in the earlier studies as mentioned above are LLAMA B language aptitude test that assesses the verbal declarative memory and vocabulary learning abilities (Meara, 2005), Wide Range Assessment of Memory and Learning (WRAML; Adams & Sheslow, 1990) that assesses phonological, semantic, and visual STM, along with LTM.

However depending on the specific paradigm used, to assess declarative memory, the relative demand on executive functions underlying encoding strategies and recall of information may be increased or decreased (Hedenius et.al., 2013). The earlier tests used to measure the declarative memory were mostly tapping on to the intentional encoding where as the current study focussed on incidental encoding. Moreover the previous paradigms used required greater cognitive processes such as phonological, semantic, and visual short term memory which could make the task difficult to perform for a child with DD when compared to TDC. In yet another study by Hedenius et.al (2013) using similar incidental learning paradigm as in the current study, showed not just an intact declarative memory but an enhanced declarative memory in children with DD. Previous studies done to explore the incidental learning using various other paradigms such as DD is often associated with several linguistic and non linguistic deficits. The previous studies on cognitive functions revealed an intact or an enhanced performance on other cognitive functions such as visuospatial skills (Karolyi et al., 2003). The present finding might suggest of an intact cognitive function in children with DD. An enhanced performance in the declarative memory in the study by Hedenius et.al (2013) was suggestive of a superior ability for children with dyslexia in creating semantic associations for the made up objects. This kind of semantic substitutions compensates for the issues in lexical retrieval deficits faced by children with DD and might create associations for the entities that are difficult to describe. Though in the present study, the statistical analysis did not reveal any significant difference for performance on real and made up objects between the two groups, an observation of the performance of the tasks by few participants (two out of ten participants) in the DD group did reveal an ability to create a semantic association for made up objects. A longer reaction time measure in the DD group for all the subsections of the task could be because of a semantic association that is taking place (see figure 4.2). The limited sample size of the current study would have nullified this effect. However a decline in the performance in declarative memory as reported by the previous studies (Vellutino & Scanlon, 1985; Kramer et al., 2000; Swanson et.al., 2009) was contradicted by the present study which showed an intact declarative memory.

Kuppuraj & Prema in 2013 studied the performance on declarative memory task in children with SLI using a similar memory paradigm and revealed impaired declarative memory in children with SLI. PDH maintains that certain facets of lexical retrieval are underlined by procedural memory mainly because of the anatomical overlap between structures involved in procedural memory and lexical retrieval (Lum et al., 2012; Ullman & Pierpont, 2005). Since procedural memory is affected in children with DD in the current study (see results on SRT), their potential to recognise would have been affected (Kuppuraj & Prema, 2013). This could be a possible reason why they did not show an enhanced performance in the declarative memory task though they showed similar trends of TDC. Using the categorization task with binary choice for response would result in an inability to accurately inhibit the incorrect responses (Marton, Kelmenson, & Pinkhasova, 2007). Since the present study also used a binary choice paradigm (“seen” vs “unseen”) the inability to efficiently inhibit the incorrect responses would be a reason why there was no enhanced performance in children with DD.

An enhanced performance in children with DD was attributed to a "neuronal recycling hypothesis" as described by Hedenius (2013). According to the hypothesis, children while learning to read, exhibit a trade off between building up a sight word lexicon and visual skills. In the study by Hedenius, 2013 the participants in the DD group were mostly in the younger age group (Mean age: 11). Owing to the fact that in western countries enrolment to formal education takes place after 6 years of age, the enhanced performance that the participants showed could be a trade off. However in the present study the participants were of a higher age group (mean age :13) and since formal education in India starts at the age of four, the participants in the present study would have attained a superior ability in reading in comparison to the participants in the above mentioned study. It is proposed that as there is advancement in reading there could be a decline in the declarative memory as well (Dehaene et al., 2010). Thus, the intact and no enhanced performance in the RMIE task in the current study by children with DD can be attributed to a developing ability in their reading skills.

5.2 Comparison of performance of TDC and children with DD on the task of Procedural memory (SRT task)

The findings of the present study showed that the children with DD performed poorer than TDC on the task of procedural memory (SRT task). This indicates that the children with DD have an impaired implicit sequence learning skills/procedural memory. Overall, the findings support the notion of a link between procedural memory and DD. The findings of the current study was in line with several other studies that reported an impaired procedural memory or an implicit sequence learning in children with DD (Jimenez-Fernandez et al., 2011, Vicari et al., 2003, 2005) . A similar pattern of findings were also reported in a study by Hedenius et al (2011) in children with Specific Language Impairment.

Though children with DD were slower in performance on the SRT task, both the groups showed faster reaction time measures on the sequence blocks (S1, S2) than random trials. Out of the two sequence trials, reaction time was faster for the second sequence block. This shows that the learning and consolidation of the sequences are taking place in both the groups, though the performance was poor in children with DD (Henderson & Warmington, 2017; Hedenius et al., 2011). In the current study, the practise effect (which could be attributed to the increase in reaction time in the Sequence block 2) was however, eliminated by obtaining the difference between the random block 2 and the sequence block 2 which revealed a large difference. If the increase in reaction time was due to the practise effect, the random block preceding the sequence block 2 would have also shown a faster reaction time and the difference between the reaction times of both the blocks would have been minimal (Hamrick, 2015).

There are few previous studies that reported an intact implicit sequence learning (procedural memory) in children with DD (Deroost et.al, 2010; Menghini et.al., 2010). However these studies have focussed on reduced practice intervals for sequence trials ranging about 24 to 104 repetitions comparing to the 240 practise sessions for sequence trials in the present study. Thus the group difference that emerged in the current study was a result of over 200 trials for the sequence blocks. Further idea about the consolidation and group differences could have been inferred if there was a wider practice interval.

The findings of the current study are in line with the procedural memory deficit view of DD (Nicolson et al., 2001, 2010; Ullman, 2004). The findings of the current study are also compatible with the magnocellular theory of DD (Stein, 2001). The magnocellular deficit account holds that the reading problems derive from impaired sensory processing, caused by abnormal auditory and/or visual magnocellular pathways. Further this faulty input via the magnocellular pathways was attributed to cerebellar impairment. Cerebellar impairments are closely associated with impairments in skilled automatization which is a functional aspect of the procedural memory.

Though several studies show an association between an impaired reading and procedural memory, the relationship between both is unknown. The impairment in reading and procedural memory in children with DD might just reflect one of the several possible relationships (Hedenius, 2013). One possibility is that the general deficit in procedural memory in children with DD underlies the core phonological problems in DD as well as several cognitive functions including implicit sequence learning impairment as in the current study (Nicolson et.al, 2010). This sub served as a proposal for the procedural deficit memory view (Nicolson et.al, 2001, 2010)

The cerebellar deficit hypothesis which is discussed as an automatization deficit hypothesis at the cognitive level contributes to the automatization of the skilled behaviour.(Nicolson & Fawcett, 2011). As per this view, procedural deficit may affect reading both directly and indirectly, directly through problems in skilled automatization and indirectly through problems in phonological processing (Nicolson & Fawcett, 2011).An alternative possibility is that the procedural memory and the phonological deficits may be causally unrelated, but the co existence of both of these together may lead to the reading problems severe enough to draw clinical focus. Also the learning in a particular system might suppress the functionality of the other system (Ullman, 2004). Since declarative memory system is intact in children with DD in the current study, the use of declarative memory system widely would have suppressed the procedural memory system resulting in an impaired performance in children with DD in the SRT task.

Another explanation for an impaired procedural memory is in association with the structural organization in the brain. It has been proposed that the corticostriatal circuits and the corticocerebellar circuits are reported to be responsible for different facets of procedural learning. The corticostriatal circuits are to certain extend important for motor sequence learning and corticocerebellar circuits are engaged in motor adaptation (Doyon et al., 2009). Further the previous studies also revealed a co-existing thalamic anomaly that might explain for a range of sensory and motor impairments in DD. Thus, suggesting a possibility that such secondary thalamic anomalies may extend to affect the function of the cortico-striato-thalamo-cortical circuit which is presumed to cause the type of implicit sequence learning looked in by the SRT task in DD (Hedenius et al., 2013).

5.3 Trade off between Declarative and Procedural memory in children with DD

The declarative memory system and procedural memory system are hypothesised to interact in several manners (Ullman, 2004). Damaged to the declarative system is expected to enhance the learning and the processing by the procedural system and vice versa. Also the learning in a particular system might suppress the functionality of the other system (Ullman, 2004). The findings of the current study showed an intact declarative memory system and an impaired procedural memory system, however no correlation or trade off was found. A study by Hedenius (2013) using similar learning paradigm found an impaired procedural learning and not just intact but an enhanced performance in declarative memory in children with DD. The current study did not reveal an enhanced performance but similar performance across TDC and DD. Analysis of the results of individual participants did reveal higher scores on declarative memory tasks for few of the participants in the DD group. Since the sample size of the current study was less probably this could have nullified the effect.

As per the PDH compensation of the declarative memory system can take place only if this system remains normal (Ullman, 2005). Although the principles of PDH makes powerful predictions only about the procedural system, it is argumentative as to if their structures and functions remains intact (Ullman, 2005). The authors of the PDH hypothesis also hypothesize that the declarative structures and other structures may also be affected as development attains. Thus evidence suggests that a dysfunction which is at first restricted to one structure can lead to problems in others during development, partly due to their inter-connectivity (Neville & Bavelier, 2000; Sur & Leamey, 2001). In Procedural language disorders such as DD and SLI, this uncharacteristic development might be intense in the procedural system which is due to the high interconnectivity among its structures (Ullman, 2005). Owing to these facts though the current study did not show a statistically significant correlation across declarative memory and procedural memory, it was observed that there was impairment in the procedural memory system and an intact declarative memory system in children with DD which is in line with the PDH.

5.4 Relation between the linguistic processes and the memory systems

The study also aimed to find out the relation between linguistic processes and the two memory systems. However there was no significant correlation obtained between the parameters. The participants in TDC and the DD group had age adequate language skills. Analysis of the scores of LPT subsections in both the groups showed a similar performance scores in the subtasks (Table 4.5). Previous studies done to explore the declarative and procedural memory in children with SLI also used LPT as a tool for the assessment of linguistic processes (Kuppuraj & Prema, 2014; Sengottuvel & Rao, 2013a, 2013b, 2013c). These studies were carried out in Kannada language and LPT and according to the authors it was reported that LPT was used because, it was the only tool that was available which provided information on the semantics and syntax in Kannada speaking children (Kuppuraj & Prema, 2014). The authors used LPT as a tool to obtain the combined language scores of children with SLI and TD. The scores of the subsections mainly of semantics were further used as covariates to control for processing effects. In these mentioned studies when covariates were used, children with SLI did not differ from TD children on the performance of specific tasks such as the Visual Paired Association Task, which is a task considered for examining performance on incidental declarative learning.

Summary and Conclusions

The PDH framework is the prediction that Declarative memory is capable of taking over the functions that normally relies on the Procedural memory system. It is said that in the absence of an intact memory system, (here procedural memory) the other memory system (declarative memory) is capable of adopting and performing the functions of the impaired memory system and is hypothesized that this compensatory mechanism accounts for the improvements seen in children with SLI and DD over time.

Thus the present study aimed to explore the nature of declarative and procedural memory in children with DD. The current study considered two groups: clinical group (children with DD) and age, gender and education matched control group (TDC) in the age range of 10-15 years. The children diagnosed to have developmental dyslexia by a qualified Speech-Language Pathologist and a Clinical Psychologist based on standardised test was included in the study. Recognition Memory after Incidental Encoding (RMIE) task was used as a measure of Declarative memory and Serial Reaction Time (SRT) task was used as a measure of Procedural memory in both children with DD and TDC. Measures of accuracy and reaction time were computed and analysed for the sub sessions of RMIE task and measures of reaction time alone was obtained and analyzed for the SRT task.

The objectives of the study were to compare the performance of children with DD and TDC on RMIE task as a measure of declarative memory, SRT task as a measure of procedural memory, to study if there was a trade off between declarative memory and procedural memory and to study the relationship between linguistic processes and memory systems.

It was inferred from the current study that both children with DD and TDC had similar performance across the RMIE task implying an intact declarative memory system in both the groups. This suggests of an intact cognitive process in children with DD. The increased reaction time scores across the RMIE sub-sessions would be an indication of semantic association that was taking place. The enhanced performance in children with DD was attributed to the "neuronal recycling hypothesis" (Hedenius, 2013).

Findings of the current study revealed impaired performance in children with DD on the procedural memory task (SRT) in comparison with TDC. This finding is in line with the Procedural Deficit Hypothesis. Though children with DD were slower in performance in the SRT task, both the groups showed faster reaction time measures on the sequence blocks (S1, S2) than random trials indicating that learning and consolidation of the sequences are taking place in both the groups. However, the performance was poorer in children with DD. The findings are consistent with the Cerebellar deficit hypothesis (Nicolson & Fawcett, 2011) and the Magnocellular theory (Stein, 2007). One possibility for the impairment of procedural memory is that the procedural memory and the phonological deficits may be causally unrelated, but the co existence of both of these together may lead to the reading problems severe enough to draw clinical focus. Another explanation for an impaired procedural memory is in association with the structural organization (Levitt, 2000; Neville & Bavelier, 2000;Sur & Leamey, 2001) where in a dysfunction which is at first restricted to one structure can lead to problems in others during development, partly due to their inter- connectivity. Thus the uncharacteristic development in DD might be intense in the procedural system which is due to the high interconnectivity among its structures.

The current study also aimed to explore the correlation or trade off between declarative memory and procedural memory system. Though the study revealed an intact declarative memory system and an impaired procedural memory system, the correlation between both the memory systems were not statistically significant. The analysis of data of individual participants did reveal an enhanced performance in few of the participants in the DD group; however the limited sample size of the current study might have nullified this effect. The authors of the PDH hypothesis also propose that the declarative structures and other structures may also be affected as development attains. Thus evidence suggests that a dysfunction which is at first restricted to one structure can lead to problems in others during development, partly due to their inter-connectivity (Levitt, 2000; Neville & Bavelier, 2000; Sur & Leamey, 2001)

The present study also aimed to find out the correlation between declarative memory system, procedural memory system and the linguistic processes. However there was no significant correlation between the subtests of LPT and the two memory systems. This could be possibly because all the participants in the study had age adequate language skills and no group difference was exhibited in terms with the language scores.

The procedural memory system is hypothesized to be the underlying cause for the reading problems in DD due to impairment in automatization skill as well as problems in phonological processing. The PDH framework predicts that the Declarative memory is capable of taking over the functions that normally rely on the Procedural memory system and it is this compensatory mechanism that accounts for the improvements seen in children with DD over time. Thus the present study explored the nature of both the memory systems (declarative and procedural) and supported the view of intact declarative memory and an impaired procedural memory in children with DD.

Implications of the study

The findings of the current study on children with DD and TDC showed an intact declarative memory in both the groups and an impaired procedural memory in children with DD. Though there are several studies done to find out the cognitive skills in children with DD, majority of these studies focus on the impaired cognitive functions in them. The present study confirmed the presence of an intact cognitive skill (declarative memory) in children with DD which was less explored in the earlier studies. A thorough knowledge about the intact skills in these children such as an intact declarative memory in the current study will further pave way for advanced researches which in future may help in the development of novel intervention methods. The intact cognitive skill that is preserved in these children can be maximally utilised to bring about improvements rather than just using the residual abilities of an impaired skill.

Limitations of the study

The current study included a small sample size and future studies are warranted to generalise the results of the present study considering a larger sample size. The intentional declarative learning was not explored in the current study. The present study did not analyze the relation between the memory systems and domain specific linguistic processes which are assumed to underlie the procedural learning such as artificial grammar learning, Rapid automatization naming etc.

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