Nature of Non-explicit Declarative and Procedural Memory Systems in Specific Language Impaired: Examining the Post Scripts of Procedural Deficit Hypothesis.

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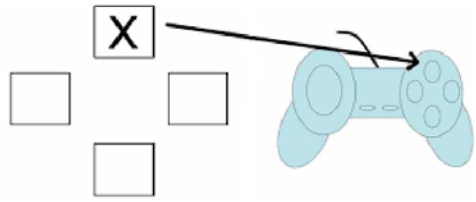

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Abstract

The declarative compensatory hypothesis (DCH) is an extension of the procedural deficit hypothesis (PDH) that is often addressed in children with specific language impairment (SLI) in the recent years. DCH claims that the relatively intact declarative system in SLI compensates for their procedural loss commensurately, therefore, we predicted a see-saw relation between these memory systems in children with SLI. Thirty children each in the age range of 8-13 years with and without SLI were the participants. First, we ensured an intact non-verbal declarative system in SLI group despite past inconsistencies on findings across non-verbal declarative tasks. We predicted that the nature of encoding and retrieval procedures used in the earlier studies as a reason for such inconsistencies. To investigate that we used two non-verbal declarative tasks that differed at the level of encoding and retrieval, i.e., retrieval through recognition after incidental encoding (recognition memory after incidental encoding –RMIE task) and retrieval through recall after intentional encoding (visual paired associate-VPA task). The retrieval was examined after 10 minutes and 60 minutes of encoding on both the tasks. On RMIE, children with SLI though poorer than TD at 10 minute delay, lost lesser made-up objects after the 60 minutes delay; however, TD children lost significant made-up items. We construed that as declarative advantage in SLI. On VPA, though SLI performed poorer than TD on both the retrieval sessions, the differences disappeared after using co-variates. On the contrary, RMIE's findings did not change with the inclusion of co-variates. Within the two types of retrieval, the TD children performed equally well on both but the SLI performed better on the recognition task than on the recall task. The findings are discussed in light of the effects of capacity limits on different declarative tasks.

The study also examined the procedural memory in the participants using a serial reaction time task with first order conditional sequences in order to minimize the declarative contribution. The procedural memory was affected in SLI despite some learning. Partial correlation between procedural and declarative scores showed a positive relation between these potentials. The correlation results did not support a see-saw relation between the potentials of these two memory systems. The findings are explained using a Generalized Context Model which advocates single mechanism exemplar based learning for procedural and declarative learning.

1. Introduction

Communication refers to the process of sharing information between two or more persons, or more specifically, 'the transmission of thoughts or feelings from the mind of a speaker to the mind of a listener' (Borden, Harris, & Raphael, 1994, p. 174). All the creatures in this world have some means of communication; however, human communication is more complex and unique with its arbitrary usage of a system called language. Language has two main components: content (meaning) and form (structure) (Bloom and Lahey, 1978). Memory systems have been implicated to different extent to either of these components. For instance, the ability to learn and store information which is the hallmark of declarative memory is linked to word learning (i.e., content) and the ability to pick words from this store and make word (or sound) sequences as per the probability rules of a specific language is the linguistic hall mark of procedural memory (i.e., form). However, one might not oversee the role of working memory - a term that is often considered as equivalent to short term memory. It supports the temporary storage and processing or manipulation of information, eventually for language purpose as well as for transferring the desired information into either declarative or procedural memory (long term memories).

Research in late 90s attributed the developmental language problems in children to temporary storage deficits (for detailed review see Kuppuraj & Prema, 2013a), however, after the Declarative – Procedural (DP) model (Ullman, 2004) for language came in to existence, majority of language errors in children with developmental language impairments are now accountable to one of these (declarative/procedural) deficits in long term memory system. The present study is on children with specific language impairment (SLI), one of the developmental disabilities affecting language alone. It aims to examine the memory systems of interest (i.e., declarative and procedural) in children with SLI to understand their memory strengths and inspect the trade-off between these memory systems in them.

2. Review of literature

Our memories are organized into separate and distinct systems-declarative and procedural (e.g., Ashby & Crossley, 2010). Declarative memory system deals with memories for facts and procedural memory system deals with memories for skills (Cohen & Squire, 1980). The independency of these systems has been demonstrated by disorders that are characterized by declarative learning deficits with relatively spared procedural learning and vice versa (e.g., Willingham, Salidis, & Gabrieli, 2002) . To achieve optimal learning on a given task these two memory systems interact (compete: e.g., Foerde, Knowlton, & Poldrack, 2006, cooperate: e.g., Willingham, 1998). And, incompetence in one system may result in enhancement of the other intact system (Ullman, 2004; Ullman & Pullman, 2015). In language domain, declarative system mediated by the medial temporal lobe wins the competition for word learning and procedural system mediated by the frontal-striatal structures wins the competition for acquiring knowledge about sequencing of elements (e.g., phonotactics and grammar) (e.g., Ullman, 2004). These two memory systems are implicated in children with specific language impairment (SLI), a neurodevelopmental condition characterized by language impairment with no associated neural, sensory and non-verbal intelligence issues (American Psychiatric Association, 2013; Leonard, 2014). Children with SLI show compromised procedural memory with an intact declarative memory capacity (e.g., Lum, Conti-Ramsden, Page, & Ullman, 2012) which confirms with their hallmark phenotype - poor grammar (e.g., Bishop, 2014) and intact word learning (e.g., Bishop & Hsu, 2015). Such language and memory phenomenon of children with SLI has been consistent with the claims of procedural deficit hypothesis (PDH) (Ullman & Pierpont, 2005) which owes their profile of compromised grammar and relatively intact word learning to their affected procedural memory system and preserved declarative system.

While there is consensus on procedural memory deficits in SLI (Lum & Conti-Ramsden, 2013), consensus is not seen for declarative potential in children with SLI (enhanced- Lukács, Kemény, Lum & Ullman, under review; unaffected non-verbal- Bishop & Hsu, 2015; affected verbal- Lum et al., 2012; affected non-verbal- Poll, Miller, & Van Hell, 2015) mainly due to the methodological differences across studies (e.g., processing load, see Lum & Conti-Ramsden, 2013). The present study addresses the inconsistency in the findings on declarative performance in children with SLI by comparing non-verbal declarative tasks that differ at encoding (incidental versus intentional) and at retrieval (recognition and recall) (see below). Further, the present study examines one of the extensions of the declarative compensatory hypothesis (DCH) (Ullman & Pullman, 2015), that is the trade-off between declarative and procedural memory system in children with SLI.

2.1.Declarative memory in SLI

Cabeza & Moscovitch (2013) view declarative memory system as one that principally underlies encoding, storing, consolidating, and retrieving knowledge or memory pertaining to personal events (for example, knowing particular events that occurred at a birthday party i.e., episodic memory), and general information (for example, knowing the arbitrary association between a word “chair” and its attributes, i.e., semantic knowledge). (e.g., and Learning (encoding) via the declarative memory system can be fast, even after a single exposure to the information. Retrieval of information from declarative system is often conscious through the processes of recognition and recall (Squire & Knowlton, 1995). A word or picture association task that requires the participants to remember as many associations as possible during later retrieval is a typical declarative task.

Studies that examined declarative memory in SLI found evidence for spared declarative memory in SLI on non-verbal tasks (Baird, Dworzynski, Slonims, & Simonoff, 2010; Bavin, Wilson, Maruff, & Sleeman, 2005; Lum, Gelgic, & Conti-Ramsden, 2010; Riccio, Cash, & Cohen, 2007). However, they performed poorer than TD on verbal declarative tasks (Baird, Dworzynski, Slonims, & Simonoff, 2010; Dewey & Wall, 1997; Duinmeijer, de Jong & Scheper, 2012; Lum et al., 2010; Lum et al., 2012; Nichols, 2004; Records, Tomblin & Buckwalter, 1995; Riccio, Cash, & Cohen, 2007; Shear, Tallal, & Delis, 1992), probably because of the poor information processing in SLI (Lum et al., 2012; Ullman & Pierpont, 2005). This is backed up by studies that reported of typical like performance in children with SLI on verbal declarative tasks after controlling for their working memory (statistically, Lum et al., 2012; experimentally, Lum, Ullman, & Conti-Ramsden, 2015) and phonological short term memory (PSTM) deficits (Lum et al., 2010)[1]. Recently, Bishop and Hsu (2015) studied the declarative system using intentional procedure in a group of children with SLI, age matched controls and grammar matched controls using auditory-visual paired associate learning task (analogous tasks for verbal materials, i.e., vocabulary learning and nonverbal materials, i.e., meaningless patterns and sounds) and confirmed the declarative strengths in SLI across verbal and non-verbal learning modalities. Nevertheless, non-verbal declarative tasks did not always support declarative strengths in SLI (see Collisson et al. 2014; Poll et al. 2015). Collisson et al's and Poll et al's study used Visual Paired Associate Task (VPA) (Vakil & Herishanu-Naaman, 1998) which has an encoding phase that exposes the participants to abstract shape and color associations and a recall phase where they are required to recall the associations accurately. The inconsistencies within nonverbal declarative tasks suggest that there are factors beyond the modality of tasks that might contribute to the variation in findings across declarative studies in SLI.

The answer may lie in the nature of encoding and retrieval invoked in the declarative tasks in SLI. First, whether the encoding phase is incidental or intentional. That is whether (intentional) or not (incidental) the participants are informed about the subsequent retrieval phase. Intentional tasks require the participants to consciously plan the strategy to store the item for later retrieval whereas incidental tasks are free from such conscious processing demands (Stuss & Knight, 2002). Second, whether the retrieval is examined through recall or recognition (through tasks designed for judgments on familiarization) (see Haist, Shimamura, Squire, 1992). Recalling an item from memory requires more information in storage than recognizing an item (e.g., Postman, Jenkins, & Postman, 1948). In other words, recall requires greater reinstatement

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[1] For more details on declarative performance of children with SLI, see Lum and Conti-Ramsden (2013).

of the learning event compared to recognition (Haist et al., 1992; Roediger, Weldon, & Challis, 1989). All the studies discussed above used intentional encoding and recall type of retrieval.

We are not aware of any published study that used recognition after incidental encoding in children with SLI as a measure of their declarative memory. Hedenius et al. (2013) first used a recognition memory task after incidental encoding (RIME) procedure in children with developmental dyslexia (DD), who share common underlying cognitive deficits with SLI (Bishop & Snowling, 2004). They found that children with DD learned and consolidated the information better than their typical peers via declarative system. A recent study (Lukács et al., under review) used a similar procedure with non-verbal and verbal items in two separate tasks to investigate declarative memory in SLI. In the encoding phase, participants categorized pictures (non-verbal task) or words (verbal task), as real or novel (made up). Participants during the encoding stage were not told that there would be recognition task following; hence, the encoding was incidental. During recognition tasks (delay of 10 minutes, i.e., short and 24 hours, i.e., long), participant had to say if s(h)e had or had not seen or heard the picture or word presented. The number of items accurately recognized and the speed of recognition (RT) indicated the declarative ability in participants. Children with SLI showed evidence of superior consolidation compared to the TD children on the non-verbal task. On this task, the children with SLI improved significantly on both real and novel objects between the short and long delays, with no significant changes for the TD children. Moreover, at the long delay the children with SLI did not differ from the TD children at remembering nonverbal information, though an impairment at remembering verbal items was still observed. Overall, the findings were the first to be reported suggesting an enhanced consolidation in declarative memory in children with SLI. In sum, there is a gap in the literature with regard to whether the encoding and retrieval type of the non-verbal tasks used contributed to the difference among the declarative findings in SLI. Further, the inclusion of the RMIE task in the trade-off experiment gives the best opportunity to detect any enhancement in their declarative potential.

2.2.Procedural memory in SLI

The procedural memory system underlies implicit acquisition, storage and use of knowledge (e.g., Squire & Zola, 1996) while it also mediates a variety of perceptual, motor and cognitive skills such as sequencing (Fletcher et al., 2005; Willingham, Salidis, & Gabrieli, 2002), and probabilistic categorization (e.g., Poldrack et al., 2001). Learning through procedural memory is gradual (unlike declarative memory) after several repeated exposures. Nevertheless, once skill/knowledge is acquired, they can be executed rapidly without awareness. For instance, learning to ride a bicycle is largely a procedural skill.

The serial reaction time (SRT) task (Neissen & Bulliemer, 1987) has been used to study motor sequence learning in children (e.g., Lum et al., 2012), which taps the visuo spatial domain of procedural memory (Howard, Mutter, & Howard, 1992). On an SRT task, participants are presented with four horizontal circles on the screen. Participants are told to trace the location of the stimulus (e.g., picture of a dog) that appears in one of the circles using the spatially corresponding button on the response pad as fast and accurately as possible. The stimuli follows random locations on certain blocks and a predetermined location sequences on certain blocks, however, without any indication to the participant, hence the learning is incidental. The reaction time (RT) gets swifter for sequential blocks producing a significant fall between random and sequence blocks. The extent of difference is considered the index of sequence learning (ISL), a measure of procedural memory (Nissen & Bullemer, 1987; Cleeremans & Jiménez, 1999; Sengottuvel & Prema, 2013a). Studies that examined procedural memory in SLI using motor sequence learning showed that children with SLI learned sequences poorer than their TD peers (Conti-Ramsden, Ullman, & Lum 2015; Desmottes, Meulemans, & Maillart, 2016; Gabriel et al., 2013; Lum et al., 2010; Lum et al., 2012; Tomblin, Mainela-Arnold, & Zhang, 2007). The findings were persistent even after controlling for attention and general motor speed difficulties (Kuppuraj & Prema, 2013a; Lum et al., 2010). The findings were consistent across verbal sequence learning (through Hebb effect: Hsu & Bishop, 2014) and artificial language learning tasks (Evans, Saffran & Robe-Torres, 2009; Mayor-Dubois, Zesiger, Van der Linden & Roulet-Perez, 2012; Plante, Gomez & Gerken, 2002). However, Gabriel et al. (2011) reported of intact procedural memory in SLI in SRT. Nevertheless, when they increased the complexity of the sequences (second order sequences-see below) they agreed with the poor sequence learning in SLI (e.g., Gabriel et al., 2013).

In view of the findings from the earlier studies, one of the objectives of the present study is to examine the declarative compensation for procedural loss in children with SLI (see the section on trade-off), which requires evaluation of the procedural memory independent of declarative memory's contribution. In what follows, we explain how a SRT task design could minimize declarative contribution.

On the SRT task, even though the sequencing blocks are not indicated to the participant (i.e., incidental), it could be argued that the repeating sequence could be learned through declarative system by applying explicit strategies (i.e., memorizing them), especially in children with SLI who tend to struggle with their procedural memory. Robertson (2007) reported that it is not the type of learning in SRT (implicit or explicit) that decides the engagement of 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 next 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, Tormos, Maeda, & Pascual-Leone, 2001; Torriero et al., 2004), whereas the medial temporal structures are roped in while performing higher order sequences like SOC (Chun & Phelps, 1999; Curran, 1997; Poldrack et al., 2001; Schendan, Searl, Melrose & Stern, 2003). Therefore, to evaluate the procedural capacity independent of declarative system the present study uses 12 item FOC repeating sequence.

2.3.Declarative-procedural trade off

Review on memory systems in SLI favors at least one major claim of PDH, i.e., children with SLI have attenuated procedural system. Further, it offers evidence for PDH’s second statement that children with SLI have intact declarative system[2]. Another integral argument of PDH that has not been examined extensively is the declarative compensatory hypothesis (DCH). DCH posits that the powerful and flexible declarative memory system which is capable of learning and retaining multiple types of information, functions and tasks (Squire & Wixted, 2011; Ullman, 2015) should play compensatory role for procedural impairments as long as the system remains functional (Ullman & Pullman, 2015).

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[2] however inconsistent, the present study aims to offer more insights about their declarative potential

There are evidences from language learning research for such declarative compensation. The computation underlying the addition of tense marker with a regular verb is typically a procedural skill (e.g., Kuppuraj & Prema, 2015). Evidence of frequency effects for regular verbs in children with SLI shows that they chunk and store the root plus bound morpheme together as a single unit in their declarative system (i.e., walk+-ed) (Oetting & Horohov, 1997; Poll et al., 2015; Thordardottir & Ellis Weismer, 2002; Ullman & Gopnik, 1999; Ullman & Pierpont, 2005; van der Lely & Ullman, 2001). Electrophysiological evidence showed an increased reliance on declarative system for grammatical processing in SLI (Fonteneau & van der Lely, 2008; Neville, Coffey, Holcomb, & Tallal, 1993; Ullman & Pierpont, 2005), and correlational findings showed that better declarative memory is associated with better compensation in grammar in SLI (Lum et al., 2012; Conti-Ramsden et al., 2015). Even though, Poll et al's study ran a correlation between memory systems, the declarative findings in SLI in their study failed to satisfy the basic criteria for declarative compensation, i.e., normal declarative system (see earlier discussion for the possible reasons). Also, note that that Poll's study was not designed to examine the trade-off at memory level. Lukács and colleagues (under review) have found some evidence that children with SLI have enhanced declarative potential at the consolidation level. This might well be a reflection of reduced procedural memory in SLI. However, none of the studies have investigated the trade-off between the two memory systems.

2.4.The present study

The present study is designed to reinvestigate the potential of the declarative system in SLI. The study compares procedures that vary at two levels: encoding (incidental versus intentional) and retrieval (recognition versus recall). The objective of comparison of the two procedures is twofold. First, to evaluate the reason for differences between the non-verbal declarative tasks (see prediction below). Second, two different procedures increase the probability of finding an intact declarative system (See PDH) in at least one of these procedures in SLI. Intact declarative system is the essential criteria for trade-off. The present declarative tasks are different from earlier tasks that measured declarative memory in SLI with respect to delay time for retrieval (for both the procedures). The present study places the retrieval sessions one at ~10 minutes and other at ~60 minutes after the encoding (compared to usual interval of ~10 minutes and ~24 hours after encoding, e.g., Lukács et al's; over weeks after encoding, e.g., Bishop & Hsu's). Evidence shows that the time required to show consolidation could vary depending on retrieval type, i.e., recognition or recall. Brown, Weighall, Henderson, and Gareth (2012) examined the retention in declarative memory in TD children and showed improved recognition of the novel non words after both short (3- to 4-h) and longer (24-h) delays. In contrast, recall improved only after longer delay and not after short delays. Examining the retrieval after 60 minutes of encoding was not investigated in the past, but it could give information from decay perspective (i.e., less decay is more detainment) as against the information from consolidation perspective (which happens only after sleep, see Lukács et al.). Further, the present study addresses the least understood phenomenon in memory research, i.e., can the overuse of declarative system in SLI lead to enhanced potential that is commensurate to the procedural loss?

2.5.Research questions and Predictions:

The present study addresses the question whether children with SLI have intact declarative system as examined using non-verbal materials. We predict as per the claims of PDH and evidence from the earlier studies that children with SLI will show intact declarative system. Specifically, a) children with SLI will perform similar to TD on RMIE. Because, the task employs incidental encoding (less demand on executive resources) and retrieval is through recognition (requires lesser reinstatement of events from storage). Further, children with SLI will perform poorer than TD on VPA because the task employs intentional encoding procedure and the retrieval is through recall. However, use of co-variates such as performance IQ and semantic scores (see method section) will negate the group (SLI and TD) difference in VPA, and such co-variates will not alter the findings in RMIE (because processing demand on RMIE is least). Further, when the two retrieval types are compared, children with SLI will perform recognition better than recall, where as TD will not show differences between the retrieval procedures. The study further asks, if there is a trade-off between declarative and procedural potentials in SLI. We predict a see-saw relation between declarative and procedural scores on the partial correlation (using IQ and semantic scores as covariates) analysis in the SLI group.

3. Method and Materials

3.1.Participants

Thirty children each with and without SLI participated in the study. All the participants were native speakers of Kannada language and were from middle to upper socio-economic background. Informed consent was obtained from the parents of the participants in addition to the approval for the conduct of the study by the AIISH ethical committee *Pretesting*

WHO 10 disability parental questionnaire (Singhi, Kumar, Malhi, & Kumar, 2007) was used to rule out any general disability in the participants. All the participants were administered the Gessell's drawing test (GDT) (Venkatesan, 2002) as a measure of their non-verbal IQ. GDT employs paper and pencil task, where the pictures are categorized in to preliminary domain (10 pictures-e.g., imitating horizontal and vertical strokes), intermediate copy domain (25 pictures-e.g., vertical and horizontal diamonds) and advance three dimensional drawing domain (10 items-e.g., transparent cubes and nested star). The pictures are shown to the participants for copying. The copying is not timed and scoring is done on all or none principle. Participants were also administered the Linguistic Profile Test (LPT) (Suchitra & Karanth, 1990) as a measure of their phonological, semantic and syntactical abilities in Kannada. LPT had sections such as phonology, semantics, syntax which were scored based on the ability to judge/name/repeat (as per the nature of the task) the orally presented stimuli. Each of the three sections had a maximum score of 100; thus, the combined language score (CLS) was 300. LPT has normative scores developed for the age range of 6-15 years (Suchitra & Karanth, 1990; Suchitra & Karanth, 2007). LPT is not evaluated for its sensitivity and specificity in detecting the language disorder; nevertheless, this is the only available detailed language test material in Kannada language. The LPT though examines some phonological and semantic aspects through expressive mode, does not examine expressive syntax. Hence, the present study does not rule out the fact that the SLI participants might have had expressive deficit (specifically grammatical). However, note that the dependent variables in the present study were expressive language free (i.e., procedural and declarative memory tasks- see below). We justify the validity of LPT in detecting SLI based on earlier published studies where the participants grouped under SLI based on LPT showed the hall mark clinical characteristics of SLI, i.e., poor non-word repetition (Kuppuraj and Prema, 2012), normal IQ (Sengottuvel & Rao, 2013a, b; Sengottuvel & Rao, 2014; Sengottuvel & Rao, 2015), sentence making (Sengottuvel & Rao, 2014), and poor sequence learning (Sengottuvel & Rao, 2013; Sengottuvel & Rao, 2014). The present study uses the IQ scores (raw) from GDT and semantic scores (raw) from semantics section of LPT as covariates in results section (referred as IQ scores, semantic scores henceforth) to account for difference between TD and SLI groups on lexical retrieval, vocabulary knowledge and executive functions (especially visuo-spatial loop of working memory). .

3.2.Inclusion of participants

None of the SLI or TD participants showed any hearing, visual, medical conditions as per the screening carried out using WHO 10 disability parental questionnaire. None of the participants in the SLI group had features of attention deficit hyperactivity disorder or autism on observation during the pretesting for their language and IQ. The study used the language score and IQ score to categorize the participants into TD or SLI groups confirming with Leonard's exclusionary criteria (2014) for SLI. That is, for inclusion as a participant in SLI group, s(h)e should have one of the language scores 1.25 SD lower than the standardized mean for that age group, accompanied by the IQ not lower than 85 in a standardized IQ test. In the present study, the CLS score of a participant on LPT was compared with the CLS standard mean score of that particular age group. And, participants who obtained a CLS of -1.25 SD or less were included in SLI group. For example, if the CLS for 8 year old child has the normative mean of 250 and SD of 20 in LPT, and the 8-year-old participants who scored 225 or less were included into SLI group. All the TD participants in the present study scored within 1 SD of CLS normative mean. Further, all the participants had an IQ score over 85 on GDT. See Table 1 for summary scores and comparison between SLI and TD groups on pretesting variables.

Table 1. Age, summary scores and comparison

Variables	**SLI**		**TD**		**Comparison**	
	Mean	**SD**	**Mean**	**SD**	**t(58)**	**p**
Age (months)	137.40	19.19	130.60	14.41	-1.55	0.13
Phonology	87.70	6.39	97.23	2.88	7.44	0.00
Semantics	82.72	6.21	92.57	4.48	7.04	0.00
Syntax	76.13	4.72	94.10	3.21	17.22	0.00
CLS	246.35	9.02	283.82	7.18	17.78	0.00
PIQ	93.90	5.88	97.46	5.76	2.37	0.02

Note: CLS is combined language score, given as summary score, which is the cumulative of phonology, semantic, and syntax scores. PIQ is performance IQ given as the summary score.

3.4. Experimental Tasks

The present study employed two declarative tasks that differ on encoding (incidental versus intentional) and retrieval types (recognition and recall) and a procedural (SRT task) task.

All the three experimental tasks were designed using trial version of the Paradigm software (www.paradigmexperiments.com/).

3.4.1. Recognition Memory after Incidental Encoding (RMIE). The study used RMIE as a measure of recognition of objects after incidentally encoding them. The RMIE task used in the present study was similar to the task developed at the Brain and Language Lab at Georgetown University by Ullman and colleagues (see Hedenius et al. 2013 for details). Similar task employed by Henson (2005), Kim and Cabeza (2009) has shown to engage the network of brain structures underlying declarative memory for both verbal and non-verbal stimuli. The present task included presentation of visual objects that were presented as black-and white line drawings of real objects and made-up objects (Figure 2 A, B) of the size of 351*481px. We excluded some objects (real and made-up) from original set used by Hedenius and colleagues, because investigators were of the opinion that Indian middle-class children would have been least exposed to some of the real objects that might, therefore, affect the categorization (they might think it as a made-up object) during encoding stage. Equal number of made-up objects was also excluded to balance the stimuli pool. A final set of 120 images (60 real and 60 made-up) were derived and resized for presentation. Three different sets of images were created –one each for a phase. First, for encoding phase 30 real and 30 made-up objects were considered. Because the recognition tasks required the objects from encoding phase to be used again, we added 30 of the objects from encoding phase (15 real and 15 made-up) and used another 30 new foils (15 real and 15 made-up) for each recognition phases (see figure 2 C).

Preceding each stimulus, a crosshair[3] (X) appeared in the center of the screen for 1000 ms, followed by the item (object image) for 500 ms in the center. The item remained on the screen for 500 ms despite the response (explained below) of the participant, to equalize

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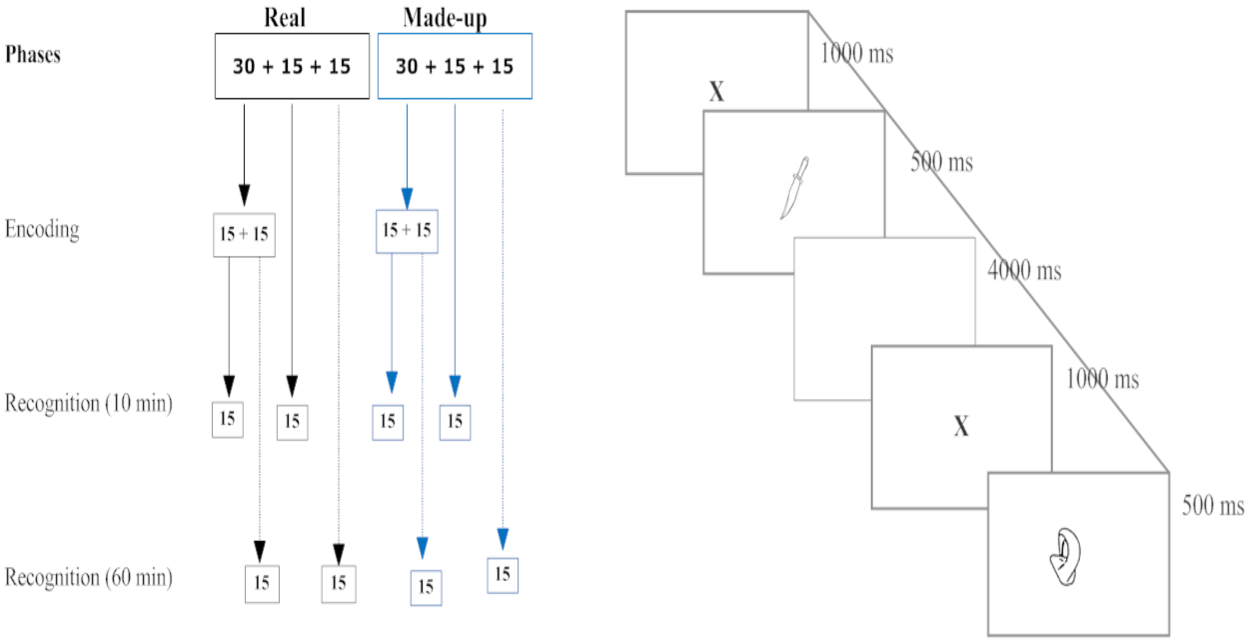
[3] One of the marks that aid in the positioning of overlaying images

presentation duration across stimuli and subjects. If the participant did not respond after 500 ms, an empty screen appeared on the screen until the participant responded or up to 4000 ms, i.e., including the 500 ms presentation time the response window was 4500 ms (see Figure 2 D). Irrespective of the accuracy of the response the next stimulus appeared preceded by the cross hair. Due to the technical limitations of the trial version of the Paradigm software, the items were presented in the same order to all the participants. Nevertheless, no more than three consecutive real or made-up objects were presented.

RMIE had three phases: an *encoding phase* where the participants categorize the shown objects as 'real' or 'made-up' (not nameable) and two *recognition phases* (after 10 & 60 minutes of encoding) where they categorized the objects as 'seen during encoding' or 'not seen during encoding'. During the encoding phase, participants were shown real and made up objects and were asked to categorize them (i.e., real vs. made-up). Participants had to press "1" if they feel the object is real and press "0" if they feel the object is unreal (i.e., made-up). Participants during the encoding phase were not told about the following recognition phases, hence this phase was incidental. The dependent measures were categorization accuracy and RT for correct responses. During recognition after 10 minutes and 1-hour phases that followed, new objects and already seen objects were shown to the participants. Here the participants had to indicate, if the object shown was 'seen' or 'not seen' during encoding phase ('seen'-press '1', 'not seen'-press '0'). There were no repeated objects between the recognition phases, therefore, command 'seen' stood for object seen during encoding phase. The dependent measures were categorization accuracy and RT for correct responses for the two phases separately.

A. Example of real object

B. Example of made-up object

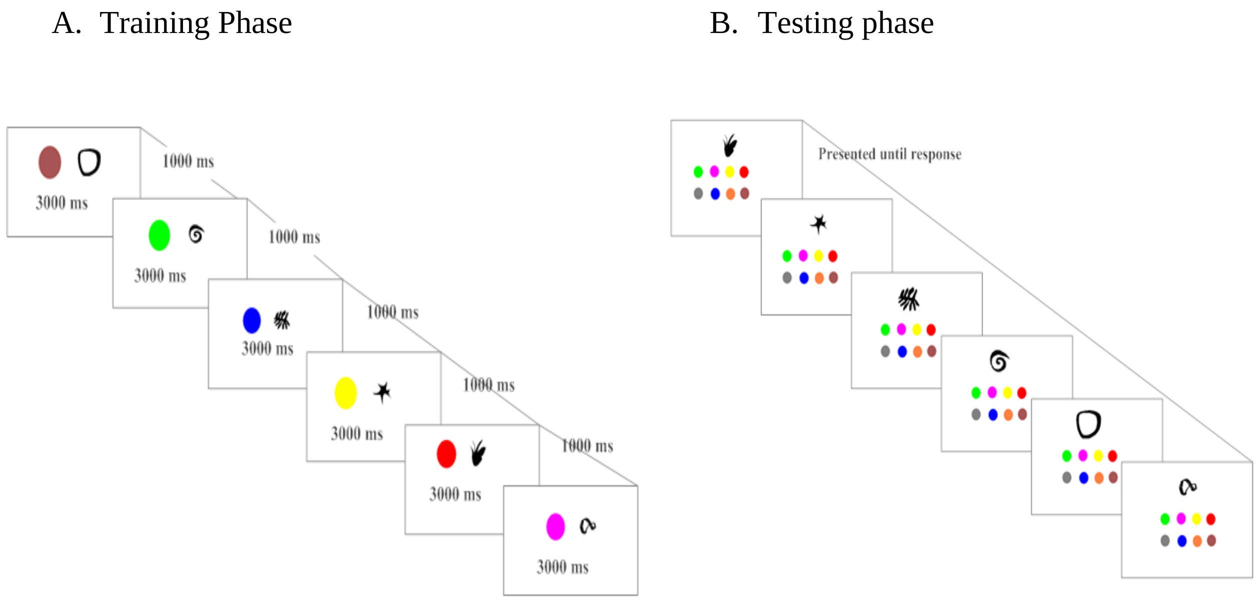


C. Items used in each phase

D. Example of two consecutive trials

Figure 2: A) Example of a real object images used in study. B) Example of a made-up object images used in the study. C) Showing objects selection. 120 items selected (60 real and 60 made-up). 30 each from real and made-up were shown during encoding for participants to categorize them in to "real" (press "1") or made-up (press "0"). After 10 minutes break, a recognition phase followed: 15 of real objects and 15 of made-up objects presented during encoding were presented again with 15 of new real objects and 15 of new made-up objects. Participants categorized them as "seen" or "not seen". After 60 minutes break, another recognition phase followed: 15 each from real and made-up objects presented during encoding (but not presented in 10 min recognition phase) were presented with 15 of new real objects and 15 of new made-up. Participants categorized them as "seen" or "not seen". D) Trial presentations.

3.4.2. Visual Paired Associate Task (VPA): We used a VPA task that resembled Vakil and Herishanu-Naaman (1998) to measure the recall from declarative memory after intentional encoding. VPA consisted of two phases: a training phase and two testing phases. In training phase (equivalent to the encoding phase in RMIE), participants were presented with 6 cards, each containing a color and then an abstract shape presented for 3000 ms each with the inter stimulus interval of 1000 ms (see Figure 3 A). These cards were presented three consecutive times in a different order with a time gap of 1000 ms between sets. The instruction for the participants was to remember as many pairs as possible, for later recall (hence intentional). Note, in RMIE, the participants were not told about later recognition phases.   Ten minutes after completion of the training phase, the testing phase followed (this is a recall phase, which is retrieval equivalent of recognition in RMIE) in which only the abstract shapes were presented (one at a time) along with the card with 8 colors (6 of which appeared already in training phase with two foils). Eight colors consisted of 5 other distracters from other pairs which were presented earlier and two other distracters. The participant’s task was to match the shape to the color (using computer mouse by clicking on the associate color). The cards were presented until a response was made (see Figure 3 B). After 60 minutes, another testing phase was conducted where the same procedure was repeated (delayed recall). Each correct association was given a score of ‘1’ (i.e., maximum score is 6). The accuracy and RT was measured by the software.



A. Training Phase

B. Testing phase

Figure 3: A) shows the presentation of items during training phase of VPA. Every shape and color association was presented for 3000 ms with ISI of 1000 ms between presentations. The association sets were presented thrice in different order. B) shows the testing phase (after 10 and 60 minutes of encoding).

VPA task is different from RMIE at the encoding as well as at the retrieval level. At the encoding level RMIE was incidental and VPA was intentional. And, RMIE used a recognition task for retrieval and VPA used recall. The final dependent measure on RMIE, i.e., the retrieval accuracy requires limited cognitive resources while encoding and only shallow reinstatement of stored information for retrieval (i.e., recognition). Therefore, if at all, an advantage in declarative system compared to TD in SLI, if present, is likely that it will be in RMIE.

3.4.3. Serial Reaction Task (SRT) task: The procedural memory in the participants was measured using a version of Nissen and Bullemer’s (1987) SRT task. On the SRT task, participants traced the stimulus (an image of a puppy) appearing in any one of the four horizontally aligned locations/circles (location ‘1’ is left most circle and location ‘4’ is right most on screen using spatially corresponding response keys on the key board (‘C’, ‘V’, ‘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 ‘C’ and ‘V’ and right index and middle finger to respond for ‘N’ and ‘M’ stimulus moved to the next circle only after a correct button press (self-paced task). 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 4 A). The time gap between stimulus appearance and button press was measured in milliseconds (ms) as reaction time (RT) for a single trial. The incorrect attempts in button press were accounted for by delayed RTs for a particular trial. Prior to the actual task, participants were given a practice set (about 25 trials) to ensure their easiness with the task. The task consisted of four blocks; two random (R) and two sequences (S) (i.e., 1st R-1st S-2nd R-2nd S). On the random blocks (100 trials in each), the stimulus appeared randomly on any of the four locations), therefore, left the participant with no scope for learning, except that RT could get better towards the end of the random trials due to general motor learning (Deroost & Soetens, 2006) (see Sengottuvel & Rao, 2013a for original version of the task). On the sequence phases, stimulus locations followed a pre determined 12 item first order sequence (FOC) (see introduction). The sequence used was ‘421323413412’, in which all the locations have equal probability of occurrence (i.e.., .25), hence there is no frequency information to extract. Nevertheless, some first order transitions occurred more often than others did in the sequence, for which the participant could respond faster. For instance, the transitional probability was 0.50 for some transitions (1&3, 3&4, and 4&1) and 0.33 for others (4&2, 2&3, 1&2, 2&4, 2&1, and 3&2), where as for some transitions, it was 0 (1&4, 3&1, and 4&3). Learning of FOC has been reported to minimize declarative contribution (see introduction). Twelve sequence sets were repeated 20 times comprising each sequence blocks (12 item x 20 times= 240 trials per block). A free recall task followed the SRT task in which participants were asked, if they observed any pattern and if so they had to try generating the observed sequence verbally.

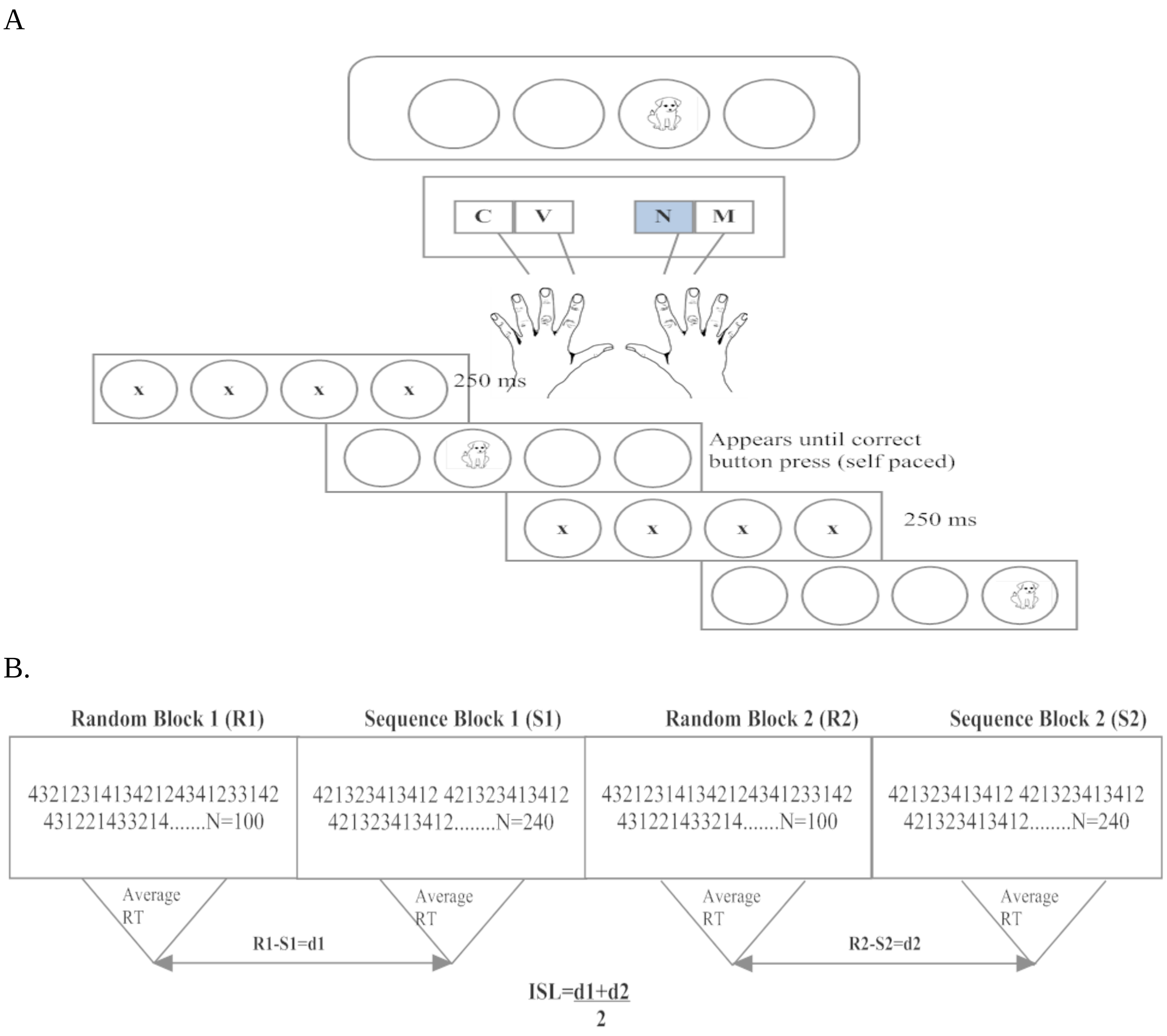


Figure 4. A) Showing the set up of SRT task, response buttons on the keyboard, and stimulus appearing in one of the location (and its correspondent button press, i.e., ‘N’). B) Random and sequence blocks, example of trials in each block and calculation of ISL.

3.5. Test environment and schedule

The participants were tested in a quiet room either in the school or at home under normal lighting conditions during day time. Experiments were run on a Compaq 510 notebook with 14” screen display and intel core 2 Duo Processor. The distance between the participant and the lap top screen was approximately 50 centimeters for all the experiments. The participant selection (language test and PIQ) and actual experimental task administration happened over two sessions. On the first session, participants were selected (took about 120 min approx) and on the second session they were first given the encoding and immediate recognition of RMIE task followed by the SRT task followed by delayed recognition of RMIE. The VPA’s encoding and recall sessions were done after that on the same day.

3.6. Data analysis

The present study intended to examine the non-verbal declarative and procedural memory in children with and without SLI. The objective was also to compare between two types of non-verbal declarative tasks (RMIE and VPA) across the groups and also to correlate the declarative scores with procedural scores. We analyzed the raw data in following way to complement the objectives.

On RMIE, for each participant we first calculated the number of accurate responses during encoding and averaged the RTs for them. From the immediate recognition phase, we calculated the number of accurately recognized responses (out of 60) and their RTs. In the follow-up analysis, we calculated out of total accurate responses given, how many were accurate for real objects (i.e., n/30) and how many were accurate for made-up objects (i.e., n/30) separately. Analogous analysis was done for delayed recognition phase as well. The variables extracted from RMIE were 12 and their abbreviations in text are given in the Table 2.

Table 2. The stages, scores derived, and their short forms used in running text.

Analysis stage	Description	In text
Encoding	Encoding accuracy	EncAcc
	Encoding RT	EncRT
Recognition	*After 10 minutes*	
	after 10 minutes- accuracy (collapsing real & made-up objects)	Rec10Acc
	after 10 minutes- RT (collapsing real & made-up objects)	Rec10RT
	after 10 minutes real objects- accuracy	10minRealAcc
	after 10 minutes real objects- RT	10minRealRT
	after 10 minutes made-up objects accuracy	10minMadAcc
	after 10 minutes made-up objects RT	10minMadRT
	After 60 minutes	
	after 60 minutes- accuracy (collapsing real & made-up objects)	Rec60Acc
	after 60 minutes- RT (collapsing real & made-up objects)	Rec60RT
	after 60 minutes real objects- accuracy	60minRealAcc
	after 60 minutes real objects- RT	60minRealRT
	after 60 minutes made-up objects- accuracy	60minMadAcc
	after 60 minutes made-up objects- RT	60minMadRT

On the VPA no measures were done during training (encoding) phase. In the recall stages, we calculated the accuracy and average RT for accurate responses. On SRT, for each participant, we calculated the mean of RTs in each block (R1, S1, R2, S2) after excluding the extreme values, i.e., RTs <300ms and >4500ms, because they were considered dubious (see Lum et al., 2012). And, the difference between R1 and S1 (d1), R2 and S2 (d2) were averaged [d1+d2/2] to derive the index of sequence learning (ISL, see Figure 3 B) (e.g., Willingham, Nissen, & Bullemer, 1989). The ISL could be a sole indicative of procedural sequence learning in the present SRT task (Sengottuvel & Rao, 2013a).

4. Results and discussion

4.1. RMIE

Two scores from encoding stage (EncAcc and EncRT) and six scores each from the recognition stages (e.g., Rec10Acc, Rec10RT, 10minRealAcc, 10minRealRT, 10minMadAcc and 10minMadRT; where Rec-recognition, Acc-accuracy, Mad-made-up) were derived after the analysis. Following outliers were removed from accuracy data, TD: data point excluded; scores type- 2; EncAcc,1;10minRealAcc, 2;60minRealAcc,2; 60minMadAcc and SLI: 1;EncAcc and a final set of data was derived.

4.1.1. Encoding

Group difference in encoding stage of RMIE was assessed using one way-ANOVA with and without co-variates. On accuracy, SLI were significantly lower than TD even after including IQ as co-variate. However, the difference between groups disappeared when semantic scores were used as co-variates. On RT, SLI were faster than TD, however the difference was not significant (see Table. 3). Speed Accuracy Trade-off (SAT) analyzed using correlation did not reach significance either across all children (r = 0.01) or within any of the two groups (TD r = 0.114, SLI r = -0.083), however, the negative correlation in SAT for SLI suggested that SLI traded their accuracy for speed.

4.1.2. Recognition memory

We ran a 2 (groups) x 2 (recognition sessions, 10 and 60 min) x 2 (object type, real and made-up) ANOVAs (one each for accuracy and RT) with and without co-variates. Considering the accuracy first without any covariates, the main effect of group was significant with SLI poorer than TD. The main effect of session was significant with recognition after 10min session better than recognition after 60 minutes. Further, the main effect of object type was also significant with real objects were responded to more accurately compared to made-up objects. The session and object type interaction was significant. Further, the 3-factor interaction (i.e., group x session x object type) was also significant. Although, the main effect of session and session x object type interaction disappeared once covariates were used, the group's main effect and 3-factor interaction persisted even after controlling for IQ, semantic scores or both (Table 3).

Table.3. Mean, SD for variables from RMIE task and comparisons

Encoding			**Mean**	**SD**		**Partial η2**			
TD	EncAccuracy		54.72	5.45		Covariates			
	Enc RT		1114.02	192.17		None	IQ	Semantics	Both
SLI	EncAccuracy		51.40	6.25	EncAccuracy	.07**	.06*	.04	.04
	Enc RT		1059.69	238.46	Enc RT	.016	.017	.001	.001
Recognition	**Recog Session**	**Obj type**			**Main effect of**	**None**	**IQ**	**Semantics**	**Both**
Accuracy									
TD	10 min	Real	25.78	2.72	Group	.208***	.180***	.219***	.215***
		Made-up	22.25	2.63	session	.111**	.022	.028	.003
	60 min	Real	26.32	2.01	Object Type	.718***	.002	.002	.000
		Made-up	18.28	3.12	Group x session	.027	.038	.010	.008
SLI	10 min	Real	23.30	4.67	Group x Object type	.024	.018	.001	.001
		Made-up	19.00	3.85	Session x Object type	.212***	.007	.057	.064
	60 min	Real	23.13	4.53	Group x session x Object type	.107**	.082**	.068*	.066*
		Made-up	17.93	3.77					
RT					**Main effect of**	**None**	**IQ**	**Semantics**	**Both**
TD	10 min	Real	1120.06	238.30	Group	.485***	.466***	.273***	.272***
		Made-up	1043.30	240.68	session	.009	.003	.014	.017
	60 min	Real	952.76	162.57	Object type	.001	.002	.012	.013
		Made-up	1019.59	444.04	Group x session	.020	.014	.003	.004
SLI	10 min	Real	1540.83	494.60	Group x Object type	.003	.004	.014	.015
		Made-up	1471.43	409.33	Session x Object type	.104**	.038	.009	.014
	60 min	Real	1464.77	496.55	Group x session x Object type	.002	.012	.015	.020
		Made-up	1464.77	496.55					

We investigated the 3-factor interaction as follows. First, we ran a 2 (sessions) x 2 (object type) repeated measures ANOVA for each group separately. Analysis on TD groups showed a main effect of session F(1,27)=13.16,p=.001, **η2**=.328 with recognition after 10 minutes better than 60 minute session, main effect of object type F(1,27)=113.62,p=.000, **η2**=.808 with real object better than made-up object, and a significant interaction F(1,27)=31.82,p=.000, **η2**=.541. Findings of

SLI groups showed main effect of session F(1,29)=.721,p=.403, **η2**=.024 with 10 min performed better than 60 minute session, main effect of object type F(1,29)=47.95,p=.000, **η2**=.623, with no significant interaction between them F(1,29)=.647,p=.428, **η2**=.022. Note that, interaction was present in TD and absent in SLI. That is, SLI performed both the object type similarly across sessions but TD tends to lose information on specific object type. To have a clear understanding, we made paired-t-test comparison across sessions and object types for both the groups separately. Findings after the delay showed that on real object recognition, TD performed marginally better, but SLI lost non-significant information. On the made-up objects, TD children lost the information significantly, but SLI did not show significant loss (see Table. 4).

Table 4. Pair wise comparisons delineating group x session x object type interaction 3-factor interaction

Pairs	SLI			TD		
	On comparison	t(29)	p	On comparison	t(29)	p
Real10Acc - Mad10Acc	real > made-up	4.921	.000	real > made-up	4.464	.000
Real60Acc - Mad60Acc	real > made-up	5.802	.000	real > made-up	12.042	.000
Real10Acc - Real60Acc	10 min > 60 min	.163	.871	10 min < 60 min	-.855	.329
Mad10Acc - Mad60Acc	10 min > 60 min	1.332	**.193**	10 min > 60 min	6.026	**.000**

Note: Acc-accuracy; Mad-made-up; 10- after 10 minutes; 60-after 60 minutes

RMIE's RTs variables (similar 2x2x2 ANOVA with and without covariates) showed main effect of group with TD performing faster than SLI. The betterment remained even after controlling for IQ, semantic scores or both. Further, a session x object type interaction also was significant. However, the significance faded once covariates were added. Interaction was followed up with paired t-tests after collapsing across groups and making a single group. Findings showed that

Real10RT was faster than Mad10RT (ns: p=0.078), Real60RT was better than Mad60RT (ns: p=0.121), Real10RT was better than Real60RT, (p=0.038) and Mad10RT was better than Mad60RT (ns: p=0.489).

4.1.3. Discussion: The present findings showing affected incidental encoding is in line with Lukács et al. (under review) who using similar task showed that SLI were significantly poorer than TD on incidentally encoding verbal (word vs. non-word) as well as non-verbal (real vs. made-up) information. The group difference on encoding faded when co-variates were included in to the analysis. For instance, including IQ reduced the significance level of the difference and inclusion of semantic scores nullified the difference. Therefore, it is more likely that the semantic knowledge contributed to the group difference in encoding in the RMIE task. Note that Hedenius et al. (2011) used covariates (IQ and semantic scores) in their study that showed better performance in children with DD. In sum, SLI tends to show performance comparable to their TD counterparts on the incidental encoding task, if the semantic abilities are controlled for.

On immediate recognition (i.e., after 10 minutes of encoding), children with SLI were poorer than TD. Lukács et al. and Hedenius et al. also showed similar findings on immediate recognition on RMIE task. Further, both the groups performed real objects better than made-up objects. The better performance for real objects at recognition after 10 minutes (in both the groups) could be attributed to the advantage the real objects have over made-up objects with regards to labeling and representation (e.g., Dickinson, 1999). The reason for SLI performing poorer than TD may not be readily attributable to their poor lexical retrieval skills (for poor lexical retrieval in SLI, See Sheng and McGregor, 2010b) which are often linked to their poor vocabulary level (e.g., Sheng & McGregor, 2010a). Because, if poor lexical retrieval had been the reason, the group difference would have disappeared after using semantic scores as covariates but our findings did not support this premise. . We found that the group difference remained after using semantic scores as co-variates, so was the session x group x object type interaction. Therefore, an alternative explanation is proposed within the framework of PDH. PDH maintains that some aspects 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 SLI in the present study (see results on SRT task), their recognition potential would have been affected. Further, as the present study used a categorization task with a binary choice for response (‘seen’ or ‘not seen’), the inability to efficiently inhibit the incorrect responses in SLI (Marton, Kelmenson, & Pinkhasova, 2007) would also have affected their performance. ·

After the delay of 60 minutes (delayed recognition session), both the groups lost information (information decay) compared to immediate retrieval stage. However, TD children lost significant information on made-up objects (but retained real objects well) but children with SLI did not lose significant information on either of the object types. More importantly, the interaction between session, group and object type remained even after using co-variates, suggesting that real/made-up difference across groups are not explicable by short-term memory processing or word knowledge skills. Lukács et al’s study reported of better consolidation for novel (made-up in the present study) objects after 24 hours compared to 10 minutes session. In contrast, in the present study we are not looking at the consolidation per se, during which the medial temporal lobe recapitulates the pattern of activation that happens during learning (McClelland, McNaughton, & O'Reilly, 1995; Wilson & McNaughton, 1994), and also largely during sleep (Ellenbogen, Payne, Stickgold, 2006; Takashima et al., 2009;). The delayed recall in the present study was conducted after 60 minutes of encoding. Without sleep factor, it would be inappropriate to conceive of an idea from consolidation point of view to explain the findings. Rather, we could consider discussing it from losing of information perspective (i.e., decay). That is, within the one hour period from encoding children with SLI lost lesser information on made-up objects. Literature do not highlight lesser decay as a memory advantage, however, the present study considers lesser decay on made-up objects as an enhanced declarative potential in SLI, with the specification that children with SLI do show declarative advantage, if a) the information is encoded incidentally, b) processed through the mechanism that is less phonologically demanding (made-up objects), and c) if retrieval was examined through recognition task (see also Lukács et al). Further, the RT in SLI contradicts general speed of processing deficit in SLI proposed by Leonard et al. (2007) and Miller (2001).

4.2. VPA.

A 2 (group-between subject factor) x 2 (session, 10 minutes and 60 minutes-within subject factor) ANOVA with and without co-variates was run for accuracy and RT measures separately. For accuracy, the main effect of group was significant with TD performing better than SLI. This main effect of group remained even after controlling for IQ, but the effect disappeared when semantic scores were controlled for. The main effect of session was also significant, with immediate recall better than delayed recall; the effect disappeared after controlling for IQ and semantic scores separately or together. The interaction between group and session did not reach significance (see Table 5). On RT, the main effect of group was significant with performance of children with SLI being faster than TD children- the effect persisted after controlling for IQ. The main effect of session was also significant with 60 minutes faster than 10 minutes-the effect diminished once covariates were added. The interaction between group and session was significant, even after controlling for IQ differences. We further assessed the group x session interaction using t-test. Independent sample t-test showed that on 10 minutes recall session both TD and SLI performed similarly (p=.514), but on 60 minutes recall session SLI was significantly faster than TD (p=.001). Paired t –test showed that TD performed both the sessions at same speed (p=.078), but SLI performed recall after 60 minutes significantly faster than 10 minutes session (p=.000).

Table 5. Descriptive statistics and comparisons between the variables of VPA

Accuracy

Group	**Session**	**Mean**	**SD**	**Main effect of**	**Partial η2**			
					Covariates			
					None	**IQ**	**Semantics**	**Both**
Accuracy								
TD	10 min	4.89	1.20	Group	.167***	.145**	.014	.013
	60 min	4.03	1.37	Session (immediate better than delayed)	.354***	.023	.009	.000
SLI	10 min	3.70	1.34	Group x session	.006	.011	.007	.006
	60 min	3.00	1.55					
RT				**Main effect of**				
TD	10 min	4364.02	1457.91	Group	.089**	.072**	.006	.031
	60 min	3898.92	1076.11	Session (immediate better than delayed)	.307***	.006	.005	.000
SLI	10 min	4157.51	916.34	Group x session	.076**	.008**	.006	.008
	60 min	2990.26	859.66					

4.2.1. Discussion: First considering the findings on comparison between groups without covariates. The present accuracy finding showing poor performance in children with SLI on intentional declarative task is similar to Collisson et al. (2014), who using VPA (akin to the present study) showed affected declarative memory in SLI. We put forth two explanatory perspectives for poor accuracy in SLI on VPA in the present study (while no co-variates were used). Firstly, the nature of encoding. Though we did not measure the encoding in VPA, children with SLI might have encoded the information (i.e., abstract shape and color association) less accurately, because the task was intentional. Intentional tasks are bound by capacity limits for information processing (for evidence on processing capacity limits in SLI, see Bishop,2005; Castellanos, Sonuga-Barke, Milham, , & Tannock, 2006; Hill, 2004; Im-Bolter, Johnson, Pascual-Leone, 2006; Mainela-Arnold & Evans, 2005; Morton & Schwartz, 2003; Vissers et al., 2015). That is, on the intentional task, the whole capacity is divided for attending to the stimuli (attentional constrains), to allot working mental space to register the association (working memory space constrains), and select the appropriate strategy (e.g., rehearsal) for it (executive constrains), therefore, constrains on total capacity may affect the intentional tasks (e.g., Marois & Ivanoff, 2005). One obvious constrain that demanded the participants to act quickly is temporal limitation on exposure duration of association during encoding (note that the exposure was only 3 sec each). Temporal limitation of exposure duration means, even before children with SLI decided a specific strategy to remember the association; the pictures were removed from their sight. Within this time window they had to decide on the best strategy to store the association. Studies have shown that it is most often the strategy the children with SLI use is inefficient (e.g., Thordardottir & Ellis Weismer, 2002). This type of encoding could be discriminated from the error less learning procedure enabling richer encoding adapted by Bishop and Hsu (2015). Not surprisingly, Bishop and Hsu's study showed typical like performance in their SLI participants on intentional declarative task (i.e., novel picture and sound association learning), considering that the recall type of retrieval requires greater reinstatement in storage. Second, it is worth a note that all the studies that showed intact intentional declarative performance used materials that are non-verbalizable (except Baird et al., that used semi-verbalizable geometric forms). In contrast, the present study had stimuli that are verbalizable, i.e., colors to which the abstract shapes are to be associated. Verbalizable items demand the phonological loop of working memory, which is often compromised in SLI (e.g., Graf Estes, Evans, & Else-Quest, 2007). Further, note that use of co-variates as predicted nullified the difference across the groups and sessions which strengthens the claim by Stuss and Knight (2002) who stated that intentional task is prone to processing difficulties. Collisson et al. also found similar results but did not analyze the data with co-variates. This finding is compatible with earlier studies in children with SLI that did not differ from TD children on performing VPA task neither on accuracy nor on RT after using the co-variates to control for processing effects (see Dewey & Wall, 1997; Lum & Conti-Ramsden, 2013; Lum et al., 2012; Lum et al., 2015; Ullman & Pierpont, 2005).

The RT for children with SLI was better than TD on VPA and the findings disappeared after using co-variates, but the effect size was small. Bavin et al's (2005) was the only study that reported of significantly better RT for children with SLI compared to TD on pattern recognition and spatial recognition task (where the participants had to remember and recognize previously seen spatial pattern on the screen) of declarative memory subtasks. Note that in the study by Bavin and colleagues, children with SLI were slower than TD on motor latency. Overall, though we will not consider the better RT as declarative strength in the present study, it is obvious that RT of the present study and RT of recognition subtasks of Bavin et al. are in contradiction to Kail's (1994) hypothesis of generalized slowing in SLI.

4.3. Type of retrieval effect

We compared the two groups on recognition (RMIE) and recall (VPA) type of retrieval. The comparison was applicable only for retrieval type and not for encoding, because the encoding in VPA was not measured. Further, the comparison was done only for accuracy scores for two types of retrieval and not for RT as the procedures used for measuring RT varied across RMIE and VPA. The accuracy scores were converted in to percentages to match the scores (note-the maximum scores were different for RMIE and VPA). The percentage score was then log 10 transformed (due to huge within subject variation and lack of normality). We first ran a 2 (group: TD & SLI) x 2 (session: immediate and delayed) x (retrieval type: recognition and recall) ANOCA with (IQ and semantic scores) and without co-variates. When no covariates were used all the three main effects were significant (Group: TD better than SLI; Recall session: Immediate better than delayed, Retrieval type: incidental better than intentional). To evaluate the group and retrieval type interaction we collapsed the sessions (i.e., averaged in to one) and ran independent and paired comparisons. Independent sample t-test across groups showed that children with SLI were poorer than TD on incidental average (TD mean: 1.88, SD=.039, SLI mean: 1.84, SD: .068, t (58) =2.77, p=.008), as well as on intentional average, but the difference just approached significance (TD mean: 1.80, SD=.23, SLI mean: 1.67, SD: .27, t(58)=1.98, p=.053). Within group paired comparison between incidental and intentional scores showed that TD group performed similarly on incidental and intentional tasks (incidental average mean: 1.88, SD:.039, intentional average mean : 1.80, SD=.23, (29)=1.83, p=.78) but for SLI, the incidental was better than intentional (incidental average mean: 1.84, SD=.06, intentional average mean: 1.67, SD=.27, t(29)=3.43, p=.002).To evaluate the session and retrieval type interaction (which had small effect size), we removed the group factor by considering all the participants as a single group and ran t-tests. The recognition was better than retrieval at 10 minutes (t (59)=2.51,p=.015) as well as on 60 minutes (t (57)=4.48,p=.000). Within both the retrieval types 10 minutes session was performed better than 60 minute session (Recognition: t (59)=2.81, p=.007; Recall: t (57)=5.07, p=.000). When IQ was used as co-variate only the main effect of group persisted, which later disappeared when semantic scores were controlled for. Other significant effects disappeared when either one of the co-variates were used (See Table. 6)

Table 6. Mean, SD across retrieval types, groups and comparison between them with and without covariates for accuracy

						Partial η2 Covariate			
Group	**Recall Session**	**Retrieval Type**	**Mean**	**SD**	**Main effect of**	**None**	**IQ**	**Semantic Score**	**Both**
TD	10 min	Incidental	1.90	.046	Group (TD > SLI)	.194***	.166**	.040	.037
		Intentional	1.89	.122	retrieval type (recog > recall)	.225***	.004	.019	.015
	60 min	Incidental	1.87	.049	session (immediate >delayed)	.410***	.018	.019	.003
		Intentional	1.79	.185	Group x retrieval type	.071**	.062	.000	.000
SLI	10 min	Incidental	1.86	.080	session x retrieval type	.167***	.014	.002	.008
		Intentional	1.77	.153	Group x session	.004	.001	.035	.032
	60 min	Incidental	1.83	.081	Group x session x retrieval type	.002	.000	.000	.000
		Intentional	1.65	.243					

4.3.1. Discussion: Considering the findings without covariates first. TD children performed both the type of retrievals similarly, children with SLI performed recognition better than recall, and immediate retrieval was better than delayed retrieval across retrieval type. If the learning was matched between the retrieval types recalling is difficult compared to recognition (see introduction). And, within short intervals only recognition task is capable of showing better retrieval (Brown, Weighall, Henderson, & Gaskell, 2012). The TD participants in the present study performed similarly in both recognition and recall because the task that employed recall type of retrieval employed greater exposure of items (3 seconds each and thrice) than the task that employed recognition type of retrieval (500ms each and once). That could have nullified the recognition advantage in TD. Despite greater learning for recall task SLI performed recognition better than recall. To our knowledge none of the past studies compared these two types of retrieval in children with SLI. Since, the SLI might be poor at processing intentionally; the greater exposure did not act in favor of retrieval through recall in SLI (see Stuss & Knight, 2005). Remember, that the recall requires stronger storage compared to recognition. Further, the performance after delay cannot be compared to Brown et al's as they were done after the 3-4 hours of delay. As with the present study we have considered it from decay perspective, and the finding is both the groups lost information across sessions similarly. When covariates were used the type of retrieval discrepancy with in SLI and the discrepancy between TD and SLI disappeared suggesting the role of processing and capacity demands in the differences (see also earlier discussion under VPA task).

4.4. Procedural memory

The present study did not probe the accuracy, because accuracy in the present SRT paradigm is taken care of by increased RTs (self-paced task, see also Kuppuraj & Prema, 2013 for similar design). We first calculated the mean RT from each block for all the four blocks for all the participants. Then we transformed the values in to log 10 (because of non-normality). First, we ran a non-parametric test for comparing the groups on ISL, because the SD was bigger than mean and the data did not follow normal distribution. The Mann-Whitney U test showed that SLI was significantly poorer than TD (TD mean rank: 38.67, SLI mean rank: 22.33; U=205, p=.000). Findings of 2-way ANOVA (groups- SLI, TD as between subjects) x 4 (blocks' RT as within subjects) showed no significant main effect of blocks [F (1, 58) = 1.088, p=.356] showing that the change in difference between random and sequence blocks were not significant. The main effect of group was significant [F(1,58)=4.61, p=.03, E2=.07] with minimal effect size showing that overall the RTs of TD group was significantly better than SLI group. The interaction between blocks and group did not reach significance [F (1, 58) =.000, p=.98]. Though, the interaction was absent we went on to run a repeated measures ANOVA separately for both the groups to see how well the participants learnt the sequences across blocks. Significance values on the pair wise comparison was, TD: R1 to S1 change: p=.367, S1 to R2 change: p=.007, R2 to S2 change: p=.021; SLI: R1 to S1 change: p=.418, S1 to R2 change: p=1.00, R2 to S2 change: p=1.00.

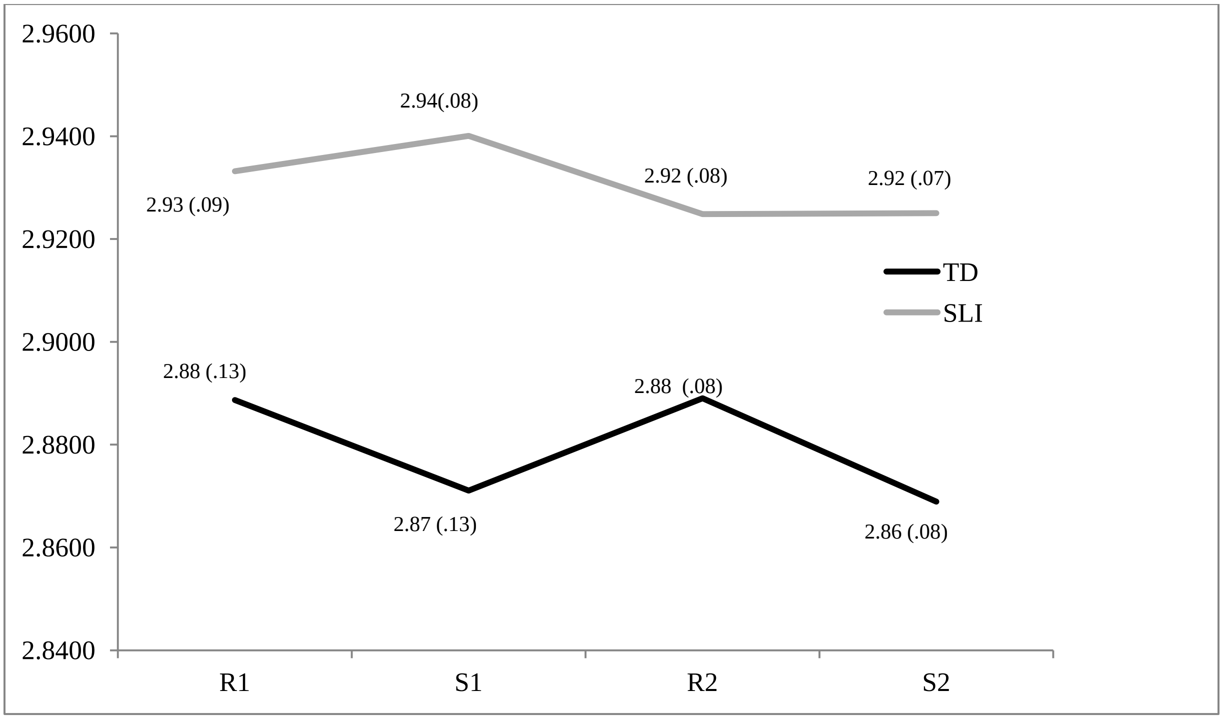


Figure 4
Log 10 RT across blocks for TD and SLI groups

On the explicit recall, 4 of the SLI and 6 of the TD participants reported that they felt on some of the blocks there was a pattern in the stimulus locations. However, none of them could repeat more than two of the consecutive locations that appeared in sequence blocks.

4.4.1. Discussion: The index of sequence learning (quantity of sequence learning) showed that children with SLI did not learn the first order conditional (FOC) sequences as good as TD children. This has largely been in support of previous studies that used SRT task and showed poor procedural memory in SLI (e.g., Lum et al., 2012). The children with SLI did show some amount of sequence learning, which is in support of the meta analysis of Lum et al (2014) who also reported that children with SLI might show some amount of sequences (see also Mayor-Dubois, Zesiger, Van der Linden, & Roulet-Perez, 2012). However, ISL which considers the average of learning across blocks shows that SLI were significantly poorer than TD which reiterates the major claim of PDH that children with SLI have procedural sequence learning deficit.

4.5. Tradeoff

To examine whether or not the potentials of memory systems are commensurate with each other, we ran a partial correlation (with IQ as co-variate) between the two mean scores of the sequence block (S1 and S2), the ISL, and the variables of declarative tasks (RMIE and VPA) (See Table.7). Note that S2 was indicative of sequence learning after several trials, therefore considered here as habitual procedural score and S1 is considered initial procedural score.

When the groups were combined, S2 travelled in same direction as accuracy scores of RMIE. In the TD group, S2 travelled in the same direction as RMIE's RT at encoding as well as at immediate recognition. In the SLI group, S2 travelled in the same direction as accuracy at 10 minutes as well as 60 minutes sessions of RMIE. Note that neither of TD or SLI's procedural scores correlated with VPA's scores. If we just consider the direction, ignoring the significance, procedural capacity is traded off with RMIE in TD (but only sparsely traded with VPA). However, the findings are otherwise in SLI. Nevertheless, none of the correlations were suggestive of significant trade-off between procedural and declarative capacities in either of the groups; rather they indicate these potentials to be driven in the same direction.

Table. 7. Correlation between procedural and declarative scores. Given are ‘r’ values, outside parenthesis is ‘p’ value

Groups	Procedural Scores	Declarative Scores									
		Recognition after incidental encoding						Recall after intentional encoding			
		RMIEencAcc	RMIEencRT	RMIE10Acc	RMIE10RT	RMIE60Acc	RMIE60RT	VPA10Acc	VPA10RT	VPA60Acc	VPA60RT
Both	S1	**.002**	.180	-.194	.014	-*.330* *(.01)*	.099	-*.238* *(07)*	.130	-.212	**-.098**
	S2	-.007	*.229* *(.08)*	-*.395* *(.001)*	.152	-*.361* *(.001)*	.179	-.088	.100	-.176	-.164
	ISL	.215	**.087**	.075	**.104**	.090	**.127**	.113	**.110**	.140	**.114**
TD	S1	**.157**	.230	-.294	.180	-.269	.158	**.150**	.157	**.007**	.086
	S2	**.295**	*.416* *(.02)*	-.192	*.380* *(.04)*	-.181	.275	**.180**	.142	**.052**	.055
	ISL	.234	**.112**	**-.140**	**.118**	**-.114**	**.160**	**-.038**	**.112**	.017	-.081
SLI	S1	**.043**	.212	-.071	.000	-.283	.111	-.326	.176	-.241	**-.038**
	S2	-.120	.156	-*.440* *(.02)*	.092	-*.374* *(.05)*	.184	-.086	.109	-.227	**-.146**
	ISL	**-.099**	-.060	.149	-.064	.179	-.020	**-.075**	**.082**	.126	**.003**

Note: Bold values suggest trade-off. Italic values suggest a significant correlation. Bolded italic suggests trade-off (none in the table). The negative sign should not be interpreted as evidence for trade-off, because the relation between the variables, i.e., Accuracy (more is more) and RT scores (less is more) originally share an opposite relation.

4.5.1. Discussion: The present correlation data fails to support the compensatory hypothesis of PDH (Ullman and Pierpont, 2015) despite showing intact declarative memory in SLI and even a glimpse of enhancement. The evidence also contradicts ample literature that supports dual-learning mechanism in human (Clahsen, Sonnenstuhl, & Blevins, 2002; Klein, Cosmides, Tooby, & Chance, 2002; Squire, 1992; Pinker, 1999; Pinker, & Ullman, 2002; Zola-Morgan, Squire, & Mishkin, 1982). One reason for the variables shown to travel in the same direction could be the single mechanism underlying both the learning. For studies supporting single mechanism models underlying learning, see Nosofsky, (1988), Nosofsky, Kruschke, and McKinley, (1992), and Nosofsky and Zaki, (1998). Nosofsky and Zaki, (1998) explained both classification learning (procedural type) as well as recognition learning (declarative type) using a single generalized context model (GCM). GCM argues that both the learning is accomplished by comparing the incoming probe with stored exemplars, which is stored in single system. Further, the setting of parameter determines how successful particular learning is. For instance, on sequence learning, every time a sequence trial is presented the stored exemplar strength is increased by a constant amount, leading to faster responses after several trials. The parameter here is the response scale that quantifies the magnitude of increment (based on summed similarity between stored exemplar and incoming probe see Nosofsky, Kruschke, and McKinley, 1992). On the other hand, recognition happens simply by comparing the incoming probe with stored exemplar. The similarity between the stored exemplar and incoming probe is participant’s memory sensitivity- the parameter that decides how well an object is recognized (see Maddox & Ashby, 1993; McKinley & Nosofsky, 1995; Nosofsky & Zaki, 1998 for details). The present correlation data suggests sub-optimal parameter setting of both summed similarity (procedural memory) and memory sensitivity (declarative memory) in SLI participants. Such differential parameter setting allows us to explain why one type of system is less affected compared to others as in the present study. However, generalized context model does not offer scope to explain trade-off, nor did the present study show significant trade-off between these two types of learning. As per the present findings (that agrees with GCM), weak exemplar learning forms the core of the deficit in SLI (Hsu & Bishop; 2010; Tomasello, 2000; 2003); however, the deficit manifests more on learning probabilistic sequences than learning the association. More research is needed in order to understand why sequence learning is more adversely affected in SLI under GCM. However, there are atleast two recent evidences to support that increasing the summed similarity parameter will facilitate procedural learning, thus fostering the discussion on the grounds of GCM. First, Lum et al. (2014) in their meta-analysis of SRT studies showed that increasing the number of trials in SRT task improves the sequence learning in SLI. Second, Torkildsen et al. (2013) showed that increasing the variability among the exemplars (therefore, making the stimulus pool high variable, i.e.., easily contrastable) facilitated the learning in children with SLI, i.e., SLI learned the items from high variability exemplars set and not from the low exemplars set. We also construe that increasing the trials and variability set strengthen the summed similarity.

Caution must be applied before accepting the findings of correlation in the present study because there could be a common confounding factor (such as attention) influencing both the variables measured, therefore, leading to correlation findings showing the variables to move in same direction. Note that only IQ and semantic scores were used as co-variates in partial correlation, there could still be attention and working memory factors common for both the declarative and procedural scores influencing the correlation findings. Studies have endorsed the role of attention in unconscious learning (assuming atleast SRT and RMIE partly involved implicit processing) (see Jiang & Chun, 2001; Jimenez, 2003; Nissen & Bullemer, 1987; Turk-Browne, Junge, & Scholl, 2005,) and working memory in procedural and declarative processing. Oberauer (2010) claims in his argument challenging the traditional model of working memory (Baddeley, & Baddeley, 2007) that both declarative and procedural memory has working memory space which are prone to processing limitations. The working memory deficits that are likely to be associated with children with SLI in the present study could therefore be a confounding variable in masking the negative relation between procedural and declarative memory.

5. Concluding remarks

The present study examined predictions made by PDH and its compensatory hypothesis. Unlike the past studies that used single declarative task in SLI, the present study compared their performance across two declarative tasks that varied at the level of encoding and at retrieval. The study also explored the procedural memory in a fashion that is less dependent on declarative system and looked for behavioral trade-off between procedural and declarative memory potentials. The following findings were in support of the predictions made: a) children with SLI have declarative capacity comparable to TD children on VPA after using co-variates b) children with SLI showed advantage (compared to TD) in storing on declarative memory with RMIE task (though only for made-up objects), c) the co-variates used changed only the VPA performance and not the RMIE, e) children with SLI showed better performance on recall type of retrieval compared to recognition, f) children with SLI have poor procedural memory. Predictions that failed to gather evidence from findings are a) Trade-off between declarative and procedural potentials. The findings showed no support for trade-off between the potentials and alternatively single mechanism view is strengthened, b) we had predicted no group difference on RMIE, however, the findings showed poor performance in SLI compared to TD (even after using co-variates). However, a closer look at the findings showed that the difficulties associated with real objects (poor phonological short term memory in SLI) could have resulted in the difference.

The study offers clinical implications with reference to choice of therapy techniques. Therapy techniques that target teaching some declaratively learnable (see open question section) language aspects could employ behavioral strategies that depend on “chunking” of complex forms as well as techniques that would improve learning via declarative system, such as “spaced” as opposed to “massed” presentation (Conti-Ramsden et al., 2015; Ullman & Pullman, 2015). Second, the evidence showing that SLI are as good as (on verbalizable items)/better than TD (if non-verbalizable items are used) within one hour has its implications in vocabulary andlanguage teaching. For instance, using least verbalizable visual symbols for teaching abstract language rules, rehearsing (frequency enhancement) , and increasing the duration of exposure (with spaced approach) would be ideal for children with SLI.

The present study has limitations that could be addressed in future studies examining compensation. First, while examining trade-off, the present study should have considered the consolidation scores in procedural memory as well (for studies reporting procedural consolidation deficits in children with SLI, see Hedenius et al. 2011; Desmottes et al., 2016). Second, the encoding of VPA was not measured in the present study. Having a measure of intentional encoding would have resulted in more concrete findings, such as where in the process is the deficit in intentional declarative tasks in children with SLI. Finally, we would rather be more inclined to interpret the correlation data from a common confounding variable point of view, that is, attention and working memory. In which case, we urge that future studies minimizes the interpretation of correlation findings and encourage imaging and electrophysiological studies in this area (see Poldrack et al. 2001 for evidence of see-saw in Parkinson's disease).

5.1. Open questions for future research

Insight gained from the present study poses three questions for future investigation. First, **i**f examining the systems exclusively, that is without engaging them competitively as in the present study does not reveal behavioral trade-off, what could be the better alternative for that? One possibility is to engage the systems simultaneously in a single task (such as artificial language learning), therefore, they compete for learning and the outcome will quantify the contribution of each of the learning process of interest (i.e., declarative and procedural). In that case, a negative correlation could emerge as a more feasible measure of trade-off. Poll et al. (2015) attempted that with some success by designing an experiment that engaged both the systems in natural language.

Second, what is the next step in developmental language research if the declarative strength and successful compensation is confirmed? This is an acceptable prospect and definite challenge for future research as most language elements share low conditional probability (CP) (i.e., probability of 'b' occurring given the previous element is 'a') between them (see Hunt & Aslin, 2001). For Instance, in natural language 'I want to go running' could have many variations of '*want*' such as '*wanted, have been wanting,* and *had been wanting*' (all legitimate in this frame). Thus, predicting one morpheme from preceding morphemes in natural language often involves low CP, therefore, are highly procedural (or impossible by declarative strategy) compared to relations such as adding –s to form plural (which is far more predictable, i.e., high CPs; possible by declarative strategy). Therefore, how could an enhanced declarative system which despite its flexibility in learning vast associative information could be expected to help in natural language scenarios? All the research showing better learning through explicit instructions (declarative) (e.g., Finestack & Fey, 2009) have used very high CP elements in their experiments and ignored the real challenge ahead.

Third, the present finding not showing enhanced declarative potential could be language specific. It could be that in order to show enhancement, the declarative system must be pushed to its extreme limits. The study used Kannada, an agglutinating language where the rules can be simplified. For instance, for the 'want' example above, all the forms illustrated for English could be incorporated by using a single 'verb plus past tense'. Simply, the Kannada language may not push the declarative system to its limits. A cross linguistic investigation is warranted to address this issue.

Supplementary materials:

The task with associated pictures used for the SRT and RMIE tasks can be accessed from the CD submitted with the project report. Materials for VPA has been given in the method section (or see Vakil & Herishanu-Naaman, 1998).

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Author contributions:

Kuppuraj S: Conceived the idea, helped designing the experiments, did the statistical analysis, wrote the draft.

Prema Rao: Conceived the idea, inputs in designing the experiments, read the draft and suggested changes. Both the authors read and finalized the manuscript.

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