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Long-term memory: A review and meta-analysis of studies of declarative and procedural memory in specific language impairment

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Abstract

This review examined the status of long-term memory systems in specific language impairment (SLI), in particular declarative memory and aspects of procedural memory. Studies included in the review were identified following a systematic search of the literature and findings combined using meta-analysis. This review showed individuals with SLI are poorer than age matched controls in the learning and retrieval of verbal information from the declarative memory. However, there is evidence to suggest that the problems with declarative learning and memory for verbal information in SLI might be due to difficulties with verbal working memory and language. The learning and retrieval of non-verbal information from declarative memory appears relatively intact. In relation to procedural learning and memory, evidence indicates poor implicit learning of verbal information. Findings pertaining to nonverbal information have been mixed. This review of the literature indicates there are now substantial grounds for suspecting that multiple memory systems may be implicated in the impairment.

The idea that memory impairments may cause or contribute to the language problems characterizing specific language impairment (SLI) has been the focus of much research and debate in the field (e.g., Gathercole & Alloway, 2005; Gathercole & Baddeley, 1990; Joanisse & Seidenberg, 1998; Van der Lely, 2005). An important development in this area has been the identification of working memory impairments in SLI (for reviews see Alloway & Gathercole, 2012; Montgomery, Magimairaj, & Finney, 2010). From this literature, it appears that individuals with SLI have problems with the short-term storage and manipulation of verbal information, but not necessarily with visual (and not easily verbally coded) information (Archibald & Gathercole, 2006a; Archibald & Gathercole, 2006b; Lum, Conti-Ramsden, Page, & Ullman, 2012a). In relatively more recent times there has been growing interest in the memory systems that support the learning and long-term storage of information (Evans, Saffran, & Robe-Torres, 2009; Hsu & Bishop, 2011; Ullman & Pierpont, 2005). This review summarizes research investigating two long-term memory systems in SLI; the declarative and procedural memory systems.

Multiple Memory Systems in the Brain: The Declarative and Procedural Systems

It is widely accepted that humans' ability to learn, store, and retrieve information is supported by separate memory systems (Squire, 2004). In this review, the term 'memory system' refers collectively to the learning, storage and retrieval of information. The declarative and procedural systems differ with respect to supporting brain structures and cognitive processes that underlie learning and memory (Eichenbaum, 2000; Packard & Knowlton, 2002; Squire, Stark, & Clark, 2004). However, although distinct systems have been identified, it is important to recognize that different memory systems cooperate and compete to support learning and memory (Packard & Knowlton, 2002; Poldrack et al., 2001a). Subsequently, the knowledge and skills that we learn, including language, can be thought of as the product of interacting memory systems rather than a set of systems working independently.

A widely accepted taxonomy of memory systems differentiates between declarative and non-declarative memory (Squire, 1992). Procedural memory is one of a number of systems that comprise the non-declarative system. Both declarative and procedural systems have the capacity to store information from minutes to years. This can be contrasted with working memory, which holds information in an active state for use in cognition for a short period of time (Baddeley, 2003). Collectively, the declarative and procedural systems allow us to learn and use information and skills across the life span. It is known that disruption to the declarative or procedural system significantly reduces the ability to learn, even if working memory is intact (e.g., Corkin, 2002; Heindel, Butters, & Salmon, 1988).

An Overview of the Declarative Memory System

The declarative memory system principally supports learning, storage, and retrieval of knowledge or memory pertaining to personal events, referred to as episodic memory, and general information, referred to as semantic memory (Squire, 1992; Squire et al., 2004; Tulving & Markowitsch, 1998). Examples of episodic memory include knowing particular events that occurred at a dinner party. An example of semantic memory includes knowing that the word 'dog' corresponds to the object or concept of a dog. Learning via the declarative memory system is achieved through binding arbitrarily related pieces of information together (Mayes, Montaldi, & Migo, 2007). In the case of episodic memory, learning might occur after witnessing which person told an anecdote at a dinner party. For semantic memory, this might be learning the association of a particular sound pattern or orthography to its referent.

Learning via the declarative memory system can be fast. In some cases only a single exposure to the information is required in order for information to be learned. However, repeated exposures to the information will increase the propensity that learning will take place and also the speed at which it can be retrieved (Alvarez & Squire, 1994). Retrieval of information from the declarative memory system occurs through the processes of recall and recognition (Knowlton & Squire, 1995). In many contexts, but not all, the learning and retrieval of information requires awareness. That is, cognitive effort is required to learn

(e.g., studying for an exam) and retrieve the information (e.g., responding to a question on an exam). The learning and retrieval processes of the declarative memory systems are supported by the medial temporal lobes, in particular the hippocampus (Eichenbaum, 2000, 2004; Squire et al., 2004).

An Overview of the Procedural Memory System

The procedural memory system underlies the implicit learning, storage and retrieval of skills and knowledge (Gabrieli, 1998; Squire & Zola, 1996). The main neural structures that support this memory system are a collection of subcortical structures referred to as the basal ganglia and cerebellum as well as the prefrontal cortex (Packard & Knowlton, 2002; Parent & Hazrati, 1995). The learning and retrieval of information from the procedural memory system is said to be implicit because conscious awareness is not required.

Unlike declarative memory, procedural memory is better suited to learning sequentially or learning probabilistically structured information (Packard & Knowlton, 2002). This includes learning new motor and perceptual skills (Nissen & Bullemer, 1987) and forming associations between pieces of verbal or visual information that are probabilistically or statistically structured (Conway & Pisoni, 2008; Karuza et al., 2013; Knowlton, Squire, & Gluck, 1994). The neurological architecture of the procedural memory system permits implicit learning, storage, and retrieval processes to be carried out on visual, verbal, cognitive, and also linguistic information (Alexander & Crutcher, 1990; Alexander, DeLong, & Strick, 1986; Ullman, 2006).

Learning via the procedural memory system is often slow, with repetition or repeated exposures to the information required in order for a skill or knowledge to be learned (Packard & Knowlton, 2002). However, once information has been acquired, new knowledge and skills may be used without awareness and sometimes only following the presence of a preceding stimulus. An often-cited example is our ability to learn and then automatically execute new motor skills without awareness. The act of repeating a motor skill (e.g., reaching for an object) will come to be performed rapidly and without awareness.

Declarative and Procedural Memory Functioning in SLI

At present there are empirical and theoretical grounds to suspect that language learning is supported by both declarative and procedural memory systems. Ullman (2001, 2004) has proposed that the declarative and procedural memory systems support different aspects of language. In the case of language development in non-impaired populations, the proposal is that the procedural memory systems support the use and learning of grammar, and the declarative memory system, lexical knowledge (for exceptions see Hartshorne & Ullman, 2005). In SLI, Ullman and Pierpont (2005) argued that the grammatical impairments in this group are primarily caused by neurological problems that underlie the procedural memory system. It is also proposed that the learning and memory functions of the declarative memory system are relatively intact. Subsequently, lexical knowledge and other aspects of language hypothesized to be dependent on this memory system should not be key areas of impairment in SLI.

A number of studies have been conducted that have investigated the learning and memory functions of the declarative and procedural memory systems in SLI. In this literature, findings concerning the status of these two memory systems in SLI has been mixed. Specifically, contrasting data have been presented showing declarative and procedural memory systems are intact (Gabriel, Maillart, Guillaume, Stefaniak, & Meulemans, 2011; Mayor-Dubois, Zesiger, van der Linden, & Roulet-Perez, 2012) and impaired (Evans et al.; Kemény & Lukács, 2010; Lum, Gelgec, & Conti-Ramsden, 2010). Thus consensus is yet to be reached whether declarative and procedural memory systems are impaired in SLI.

In this report, research investigating these long-term memory systems in SLI is reviewed. To provide a concise and objective review of the literature, studies were identified using a systematic search of databases and their results synthesized using meta-analytic techniques.

Method

Database Searching

Articles that were published or 'in press' up to December 2012, were identified following a systematic search of CINHALL, ERIC, Medline, and PsycInfo electronic databases.

Databases were accessed via EBSCOHost. Two sets of searches were undertaken. The first identified studies that investigated declarative memory for verbal or visual information in SLI using standardized tests (for a review of the performance of individuals with SLI on experimental declarative memory tasks see Ullman and Pierpont 2005). A description of the search strategy and keywords used to identify these studies is presented in Supplemental Digital Content A.

The second search identified studies that had investigated procedural learning and memory in SLI. In keeping in line with the declarative memory studies, the search strategy was designed to identify studies that have investigated procedural memory for verbal or visual information in this group. It should be noted that there are very few standardized tests that assess procedural memory (Baron, 2004). However, a number of validated experimental tasks have been developed that are known to tap the procedural memory system (e.g., Aslin, Saffran, & Newport, 1998; Karuza et al., 2013; Nissen & Bullemer, 1987; Poldrack et al., 2001b). The search strategy aimed to identify studies that had presented such tasks to individuals with SLI. A description of the search strategy and keywords used in this search is presented in Supplemental Digital Content B.

We note that research also has been undertaken investigating procedural learning of visuo-motor information (e.g., Gabriel et al., 2011; Lum et al., 2012a; Tomblin, Mainela-Arnold, & Zhang, 2007). For systematic reviews and meta-analyses of this literature with respect to neurodevelopmental disorders such as SLI, see the work by Lum et al. (Lum, Conti-Ramsden, Morgan, & Ullman, under review; Lum, Ullman, & Conti-Ramsden, 2013).

Study Inclusion Criteria

Studies were included in the meta-analysis if they met two inclusionary criteria. First, the study was required to be published or be 'in press' in a peer-review journal (written in any language) that reported on an original study. Data reported in literature reviews,

dissertations, or book chapters were not included in this meta-analysis. Second, the study needed to present a task that assessed the declarative or procedural memory system using verbal or visual stimuli to one group of individuals with SLI and a control group comprising individuals of comparable age without language impairments. The search that aimed to identify studies investigating declarative memory in SLI initially returned 1724 records. After duplicates were removed and inclusionary criteria applied, a total of 11 studies were identified. The search that aimed to identify studies investigating procedural memory initially identified 250 records. A total of four studies were identified after applying the inclusionary criteria.

Meta-Analytic Methods

Results from each individual study were summarized using the effect size Cohen's d along with 95% confidence intervals and significance test. Cohen's d describes differences between groups in standard deviation units (for an introduction to effect sizes see Durlak, 2009). For all comparisons, Cohen's d was calculated so that positive values indicated that the control group performed better than the SLI group on the memory task. The 95% confidence interval accompanying each Cohen's d value provides an estimate of the precision of the study's effect size. Larger confidence intervals denote poorer precision (for an introduction to interpreting confidence intervals see Cumming & Finch, 2005). In some cases it was possible to combine the results of several studies investigating the same aspect of memory and compute an average effect size for a group of studies. Averaging of effect sizes was undertaken using a random effects model (Hedges & Vevea, 1998).

Results & Discussion

Results from the meta-analysis investigating learning and memory functions of the declarative memory system in SLI are reviewed first.

Verbal Learning via the Declarative Memory System in SLI

Learning verbal information by the declarative memory system in SLI has been investigated using list learning/retrieval tasks. These tasks assess both learning and retrieval of verbal information from declarative memory (Baron, 2004; Lezak, 2012). The learning component of the task assesses how well an examinee can encode arbitrary pieces of verbal information given multiple exposures. The pieces of information in the task are individual words or pairs of words (e.g., nurse-fire) that are presented in a list. During the learning component, the complete list of words is repeatedly presented. Depending on the test, the list may be repeated three or four times. After each presentation the examinee is asked to recall the entire list. Declarative learning for verbal information on these tasks is quantified by summing the total number of words correctly recalled over the learning trials (e.g., Cohen, 1997; Sheslow & Adams, 1990) or the number of words correctly recalled on the final learning trial (e.g., Delis, Kramer, Kaplan, & Ober, 1994). In both scoring methods, the assumption is that as more words are encoded into declarative memory, the number of words correctly recalled increases.

Figure 1 summarizes results from studies investigating verbal learning in SLI using list learning/retrieval tasks in a forest plot. Forest plots show individual study effect sizes and their confidence intervals as well as the overall average effect size. As is standard practice, data points showing results from individual studies are presented as circles and the weighted average as a diamond (for an introduction to forest plots see Lewis & Clarke, 2001). All studies in Figure 1 reported children with SLI recalled significantly fewer words during the learning trials than age-matched control groups. The effect sizes observed in each study are consistent; the smallest effect size was found to be 0.769 (Riccio, Cash, & Cohen, 2007) and the largest 1.150 (Dewey & Wall, 1997). The average effect size computed using all studies in Figure 1 was found to be 0.899 and statistically significant. Thus on average, the literature shows that verbal learning is significantly poorer in children with SLI than in typically developing children of the same age.

The studies summarized in Figure 1 suggest that children with SLI learn fewer pieces of verbal information than non-language impaired children of the same age. These findings might indicate impairments related to the learning mechanisms of the declarative memory system in SLI. Based on similar observations, Lum, Gelgec and Conti-Ramsden (2010) suggested that declarative memory for verbal information might be impaired in SLI. This suggestion was forwarded after finding that children with SLI performed significantly more poorly on a composite measure of learning and recall on a list learning/retrieval tasks compared to age-matched controls.

Subsequent work (Lum & Bleses, 2012; Lum et al., 2012a) coupled with closer inspection of past research, appears to question whether declarative learning is impaired in SLI (e.g., Records, Tomblin, & Buckwalter, 1995). It has been found that the rate at which new words are learned from one trial to the next in list learning/retrieval tasks is similar between participants with SLI and their age-matched counterparts. For example, using a non-standardized list learning task, Lum and Bleses (2012) did not find a difference in the learning rate of new words between children with SLI and age-matched controls. This result was previously observed by Nichols et al. (2004) and Records, Tomblin and Buckwater (1995). These studies found that the number of new words learned between learning trials was not significantly different between children with SLI and age-matched controls. These findings suggest that differences between individuals with SLI and control groups on list learning/retrieval tasks might be due to difficulties with other memory, for example, difficulties in verbal working memory. There is some evidence to support this claim. Children with SLI have been found to recall significantly fewer words after the first trial on list learning tasks (e.g., Lum & Bleses, 2012; Nichols et al., 2004; Records et al., 1995; Shear, Tallal, & Delis, 1992). In the neuropsychological literature, performance on this part of the list-learning/retrieval tasks is considered to be an indicator of short-term memory (Lezak, 2012). Thus observed differences between children with and without SLI on verbal learning appear to reflect initial differences on the first trial only, which in turn suggest verbal short-term memory limitations.

Other evidence showing that poor working memory might underlie poor verbal learning in SLI was presented by Lum, Conti-Ramsden, Page, and Ullman (2012a). In that study, the performance of children with SLI and age-matched peers on verbal learning was compared

and differences in verbal working memory statistically controlled. Before controlling for verbal working memory, the observed value for Cohen's d on the measure of verbal learning was found to be .997 (see Figure 1). However, after controlling for verbal working memory, the effect size decreased to .263, and the difference between the groups was no longer found to be statistically significant. This study showed differences in verbal learning between SLI and control groups can be reduced once the influence of verbal working memory is removed. Third, there is also the influence of language level to consider. Having a higher level of language functioning may help children "see" connections between arbitrary words whilst this is likely to be more difficult for children with poor language. Better language can therefore help children to do better even from the first trial in recalling lists. Thus differences in the severity of the language problems in SLI may at least partly explain the lack of replication of findings across the studies described above.

Non-verbal Learning in the Declarative Memory System in SLI

The ability of children with SLI to learn information via the declarative memory system has also been investigated using non-verbal tasks. The results from these studies potentially shed light on the functioning of the declarative learning mechanisms in SLI. This is because non-verbal tasks place minimal demands on verbal working memory capacity. Subsequently, the difference between individuals with and without SLI on non-verbal learning tasks should be smaller; assuming declarative learning is relatively intact.

A number of standardized memory tests include subtests designed to probe the learning mechanism of the declarative memory system for non-verbal information. These tasks are designed to be non-verbal analogues of the list-learning/retrieval tasks described earlier. In these tasks, an examinee is repeatedly presented with a picture that cannot be verbalized easily. Following each presentation the participant is prompted to reproduce the picture or recognize elements of the picture from a set of distracters. Learning on the task is quantified by measuring whether there is an increase in non-verbal information recalled during the learning trials.

Lum et al. (2012a) and Riccio, Cash and Cohen (2007) presented the Dot Locations subtests from the Children's Memory Scale (CMS; Cohen, 1997) to children with and without SLI. On that task children are presented with a picture comprising randomly placed dots. The picture is shown multiple times and after each presentation, children aim to recreate the picture using small tokens. A measure of learning is obtained by summing how many tokens were placed in a position that matched their location in the stimulus picture. A variant of this task is for children to learn the spatial location of an abstract object over a number of trials. This ability is assessed by the Paired Associates Learning Subtest from the Cambridge Neuropsychological Test Automated Battery (Cambridge Cognition., 1996) and Visual Learning subtest from the Wide Range Assessment of Learning and Memory (Sheslow & Adams, 1990). The performance of children with SLI on these subtests compared to age-matched peers has been reported in several studies (Baird, Dworzynski, Slonims, & Simonoff, 2010; Bavin, Wilson, Maruff, & Sleeman, 2005; Lum et al., 2010). Results from studies investigating declarative learning of non-verbal information are summarized in

Figure 2. This figure shows that overall, there are no differences between SLI and age-matched control groups on tasks assessing declarative learning for visual information.

Figure 2 shows that no study identified in our literature search reported significant differences between children with and without SLI on the tests assessing learning of non-verbal information over multiple trials. In the studies by Riccio et al. (2007) and Lum et al. (2012a; Lum et al., 2010) the observed effect sizes were close to zero. That is, the SLI and control groups were statistically indistinguishable on the task. The average effect size computed from all the studies in Figure 2 was found to be 0.228, which although significant at $p = .048$, reflects a small effect size (Cohen, 1988). Thus, the literature on declarative learning in SLI indicates a small difference (just over 0.2 *SD*) between children with SLI and their typically developing peers. Overall, there is little evidence to suggest that learning of non-verbal information is impaired in SLI.

Retrieval of Information from the Declarative Memory System in SLI

The other component of the declarative memory system studied in SLI is the retrieval of information. There are two broad methods used to study the retrieval of verbal information from the declarative memory system. One method assesses how well an examinee can recall or recognize arbitrarily related information that has been learned over multiple trials. This method of investigating retrieval is typically assessed in an additional component of the list learning/retrieval tasks described earlier (e.g., Records et al., 1995; Shear et al., 1992). In the retrieval component of the task, after the learning phase has been completed, participants are asked to recall or recognize previously studied list of words. A second method assesses how well a verbally presented episodic event can be retrieved following a single exposure (e.g., Cohen, 1997; Sheslow & Adams, 1990). This type of retrieval is assessed in story recall/recognition Tasks. In these tasks the examinee is presented with a short story. At the end of the story the examinee is asked to either recall the entire story and/or recognize different elements.

The results from studies investigating retrieval of verbal information are summarized in Figure 3. To assist with interpretation, the computed effect sizes are averaged across recall and recognition conditions and across short and delayed recall retrieval conditions. In several studies, the processes of recall and recognition in immediate and delayed retrieval conditions have been found to be highly correlated (Baird et al., 2010; Lum et al., 2012a; Riccio et al., 2007). Thus for the purposes of this review, averaging over these conditions is not masking any process-specific effects.

Figure 3 shows that most of the studies have reported participants with SLI retrieve significantly less verbal information than children of the same age who are not impaired. There are some exceptions to this trend. Studies by Baird et al. (2010) and Records et al. (1995) observed small effect sizes and non-significant differences between participants with SLI and age-matched peers. Shear et al. (1992) also observed a non-significant difference between children with and without SLI. In that study the effect size was similar to those studies that did find a significant difference (e.g., Lum et al., 2012a; Nichols et al., 2004; Riccio et al., 2007). Consequently, insufficient statistical power most likely accounts for their non-significant results. Overall, significant differences have been found irrespective of

whether the information to be retrieved is a list of unrelated words, presented over multiple trials, or a short story presented once. This suggests that individuals with SLI retrieve less verbal information from declarative memory compared to typical children of the same age.

However, as with verbal learning, the apparent difficulty children with SLI have with retrieval might be due to other factors and not poor declarative memory. Initial evidence to support this claim comes from closer inspection of the study by Baird et al. (2010), who observed a small effect size. Memory functioning in that study was assessed using the WRAML (Sheslow & Adams, 1990). The measure of retrieval in the WRAML is calculated by finding the difference between the total number of words recalled in the learning and immediate retrieval conditions. In contrast, the instruments used in the other studies that found significant differences between SLI and controls (e.g., Lum et al., 2012a; Nichols et al., 2004; Riccio et al., 2007) did not directly control for performance in the learning condition. Rather the standardization of subtests scores from learning conditions aims to correct for performance on learning trials. It is also interesting to note that Records et al. (1995) adjusted participants' retrieval scores to account for learning and immediate retrieval conditions. After this calculation they found a non-significant trend in which the participants with SLI retrieved more words than children who were not impaired. Thus controlling for differences in verbal learning reduces differences between SLI and non-SLI groups on declarative memory retrieval tasks.

It was noted earlier that verbal learning problems in SLI might be due to poor verbal working memory. An interesting proposition that will need to be explored in future research is whether poor verbal working memory problems in SLI underlie learning and retrieval of verbal information from declarative memory in this group. Some evidence already supports this suggestion. Lum et al. (2012a) first observed significant differences between children with and without SLI on declarative memory retrieval tasks (see Figure 3). After controlling for verbal working memory, the average effect size across different retrieval tasks was found to be .23 and non-significant. Interestingly, a further reduction in the effect size was observed when both working memory and language abilities were simultaneously controlled. Thus the difference in the retrieval of verbal information in SLI may be secondary to both working memory and language problems. In sum, individuals with SLI struggle to retrieve verbal information. However, the difficulty observed in this area may be due to verbal working memory and language problems and not declarative memory deficits.

Data also exist concerning retrieval of non-verbal and visual information from declarative memory in SLI. This aspect of memory in SLI has been assessed with three different tasks. One task assesses retrieval of nonverbal or visuospatial information following multiple trials. This task is designed to be a visual analogue of the list learning/retrieval tasks. For example, on the Dot Locations task from the CMS (1997), the examinee is asked to recreate a previously shown picture depicting a random array of dots, using tokens, after a delay. Another commonly used non-verbal task assesses recognition of faces (e.g., Cohen, 1997). During the assessment the examinee is shown a number of faces that they are asked to commit to memory. Retrieval is examined by testing how accurately the faces previously studied can be identified from 'distracter' faces that were not previously shown. Finally, several standardized tests (Cohen, 1997; Sheslow & Adams, 1990) assess retrieval of

information from pictures that show common events (e.g., eating lunch at a picnic). In these 'Picture Tasks', the examinee is shown the picture once for a short period of time (e.g., 10 seconds), and then asked to retrieve specific information about the picture. The task is designed to be a visual analogue of the Story Recall/Recognition Task.

A summary of study findings from tests assessing retrieval of non-verbal or visual information in SLI is presented in Figure 4. On tasks assessing retrieval of non-verbal/visual spatial as well as faces most studies have observed small effect sizes and non-significant differences between groups. The average effect size observed on tasks assessing retrieval of abstract non-verbal information and faces is .198 and .157 respectively. These findings indicate that children with SLI are able to retrieve some types of non-verbal information from declarative memory with equal proficiency as non-language impaired children of the same age.

It is certainly not the case that children with SLI are proficient at retrieving all types of non-verbal/visual information from declarative memory. Figure 4 shows that in the Picture Tasks, children with SLI typically retrieve significantly less information than typical children of the same age. In two studies (Dewey & Wall, 1997; Lum, Conti-Ramsden, & Ullman, 2012b), the difference between the SLI and control groups was found to be statistically significant. In the remaining studies (Baird et al., 2010; Riccio et al., 2007), the differences between groups was not significant, but effect sizes were medium in magnitude. The average effect size for all studies using the Picture Task was found to be .526, which was statistically significant.

The difficulty children with SLI have with retrieving information from pictures showing everyday events may be related to verbal memory. In the adult neuropsychological literature, concerns have been raised about the validity of Picture Tasks as a test of visual memory. Studies have found that performance on this task in adults with neurological impairment can be best predicted by learning and memory for verbal information (Chapin, Busch, Naugle, & Najm, 2009; Dulay et al., 2002). One explanation for this association is that the events shown in Picture Tasks can be verbally encoded. Lum et al. (2012b) further observed that, in children with and without SLI, performance on the Picture Task could be predicted by verbal working memory. This association was found even after controlling for the effects of language and declarative memory skills. In light of these findings, there is evidence to suggest that verbal working memory may underlie the difficulty children with SLI have in retrieving information about pictures.

Is the Declarative Memory System Impaired in SLI?

Overall, the evidence on the declarative memory system in SLI mirrors the data on verbal working memory. Children with SLI perform poorly, relative to age-matched controls, on tasks that assess the learning and retrieval of verbal information from declarative memory. The analogous functions for visual/visuospatial information appear to be intact in SLI. An outstanding question to be addressed is whether declarative memory for verbal information is impaired in SLI or whether the problems are more closely tied to verbal working memory and/or language problems. Experimental work will be required to clarify this issue.

The Procedural Memory System in SLI—Unlike declarative memory, there are no standardized assessments tools that evaluate the learning and memory mechanisms of the procedural memory system. However, a number of experimental paradigms have been developed to investigate the implicit learning and retrieval of information in visual (Knowlton et al., 1994), auditory/verbal (Saffran, 2003; Saffran, Aslin, & Newport, 1996), and visuo-spatial-motor domains (Nissen & Bullemer, 1987).

Procedural Learning and Memory for Auditory/Verbal Information—Implicit statistical learning of auditory information in SLI has been investigated by Evans, Saffran, and Robe-Torres (2009) and Mayor-Dubois, Zesiger, van der Linden, and Roulet-Perez (2012). In both studies, children with SLI and age-matched peers listened to a continuous stream of nonwords or tones. The stimuli are constructed so that the adjacent probabilities between specific phonemes/tones within nonwords/phases are higher than those between nonwords/phases (Saffran, Newport, Aslin, Tunick, & Barrueco, 1997). During testing the stimuli are presented while the children are engaged in another activity (e.g., drawing a picture). This ensures that children are not actively attending to the verbal information and any learning that takes place is implicit. After the exposure period, knowledge of the phonemes or tones presented earlier is assessed using a recognition task. Recent evidence indicates that learning on this type of task draws upon the same neural networks that support other forms of procedural learning (Karuza et al., 2013). Thus the implicit learning of verbal information can be considered to engage the procedural learning system. Figure 5 presents a summary of individual study findings.

The results from both Evans et al. (2009) and Mayor-Dubois et al. (2012) showed children with SLI performed significantly more poorly than non-language impaired children of the same age in tasks that involved recognizing implicitly learned auditory information. Figure 5 shows that the observed effect sizes for both studies were around .8. The average effect size for these two studies is also statistically significant. Interestingly, Evans et al. (2009) also found that the magnitude of the difference between children in the SLI and comparison groups could be reduced by increasing the exposure period to the auditory stimuli. In one experiment children with and without SLI were presented with the auditory stimuli for 24 minutes and in another, 48 minutes. In the 24-minute exposure period the difference between the SLI and control groups was significant but not in the 48-minute exposure period. This pattern of results does not support the view that SLI is associated with an absence of implicit learning. Rather, it seems that implicit learning occurs in SLI, but these affected individuals require increased exposure to the target information.

Procedural Learning and Memory for Visual Information—Implicit learning in SLI in the visual domain has been investigated using probabilistic classification tasks. A considerable volume of research has shown these tasks are supported by parts of the brain that underlie the procedural memory system (Poldrack et al., 2001b; Poldrack & Packard, 2003). In these tasks, participants are seated in front of a computer display and different combinations of four cues appear on the screen. Participants are asked to work out which combinations of cues are associated with one of two outcomes. During testing, different cue combinations appear and the participant presses one of two buttons on a keyboard to

indicate a particular outcome. Feedback is provided on each trial. The association between the cues and outcomes are probabilistic. For example, one set of cues will be associated with one outcome 75% of the time and another set of cues 25% of the time. At the start of the task, participants' accuracy is around chance level. However, following more trials, accuracy increases. The learning on the task is implicit because participants are unable to articulate the relationship between cues and outcomes. However, evidence that participants have learned associations is observed as accuracy increases over trials.

Two studies have investigated probabilistic classification in SLI. Results from these two studies are also summarized in Figure 5. The available evidence on probabilistic classification in SLI has produced conflicting results. In the study by Kemény and Lukács, (2010) a significant difference between children with and without SLI was observed on the task. Specifically, after 150 training trials the children with SLI were not able to predict outcomes above chance level whereas children in the control group could. Also, as seen in Figure 5, the observed effect size in that study was large. In contrast, Mayor-Dubois, Zesiger, van der Linden, and Roulet-Perez (2012) found no significant differences in accuracy between children with and without SLI after 200 trials. In that study both groups of children were able to learn the association between the cues and outcomes.

In accounting for the discrepant findings, one suggestion forwarded by Mayor-Dubois et al. (2012) is that differences in study findings on the probabilistic classification task might reflect differences in declarative memory. They point out that the relationship between cues and outcomes used in Kemény and Lukács' (2010) study were simple and participants may have obtained explicit awareness of the association. If this were the case, learning on the task by the SLI and control group participants might have been supported by the declarative memory system. Given previous research showing intact declarative memory for visual information in SLI, it would be reasonable to expect comparable performance between the two groups. Another possibility is that children with SLI require more trials in order to implicitly learn associations with equal proficiency to non-language impaired children. As noted earlier, in the study by Kemény and Lukács participants received 150 trials, whereas in the study by Mayor-Dubois et al. participants received 200 trials. To address these issues, additional research will be required to test these alternative explanations.

Is the Procedural Memory System Impaired in SLI?

At present the available data indicates that auditory/verbal aspects of procedural memory are likely to be impaired in SLI. The two studies involving auditory statistical learning both report poor implicit learning in SLI. However, when visually based probabilistic classification tasks are used, findings have been inconsistent. The difficulty in making general statements about these aspects of procedural memory is that the evidence is very sparse. Nonetheless, one trend that is emerging from this literature is that children with SLI appear to require more exposures to information, irrespective of whether the information is verbal or visual. Thus, at this stage it does not seem appropriate to characterize SLI as a developmental disorder whereby information cannot be implicitly learned. Rather, it seems individuals with SLI require more exposures to the information. Consequently, detecting

differences between children with and without SLI on measures assessing the procedural memory system may require tasks that assess implicit learning rather than retrieval.

Concluding Remarks and Clinical Implications

This review examined research investigating the declarative memory system and aspects of the procedural memory system in SLI. From this literature it appears that in children with SLI, learning is affected by functioning in long-term memory systems in addition to known deficits in working memory. In the case of declarative memory, there is some evidence to suggest that problems with learning and retrieval in SLI may be secondary to working memory problems and/or language difficulties and do not reflect declarative memory deficits. Indeed, it appears that declarative memory functioning is similar in children with and without SLI. With respect to the procedural memory system, implicit learning of verbal information appears to be affected SLI. Thus, in terms of future research directions, to further our understanding about the relationship between memory and language problems in SLI, it may be beneficial to broaden our focus beyond working memory to other memory systems.

There is a history of identifying underlying deficits in children with developmental disorders such as SLI. This has informed and will continue to inform clinical practice in speech and language pathology. In this review, we identify potential difficulties in long-term memory, such as implicit learning of verbal material via the procedural memory system which clinically adds to our existing knowledge about short-term and working memory difficulties in SLI. This review, in addition, identifies declarative memory as a system that appears to function relatively well in SLI. Declarative memory is a powerful and flexible long-term memory system that can have a compensatory role in language learning (Ullman & Pierpont, 2005). This information provides an evidenced-based rationale for existing clinical practice, i.e., the use of explicit learning strategies in therapeutic intervention. For example, when talking about yesterday put –ed on the verb, like *played*, if talking about today it is –ing, like *playing*. The evidence reviewed here also implies that clinical interventions which harness the declarative memory system but also incorporate approaches that are effective in learning through that system, for example, spaced presentations, imageable items, deep encoding, should result in more effective language outcomes in children with SLI (Ullman & Pullman, under review).

A trend emerging from investigations into the procedural memory system in SLI highlights a potential benefit in increasing the amount of language to which children with SLI are exposed, presumably above that encountered by typically developing children. However, given that research into declarative and procedural memory systems is still very much in its infancy, more experimental work and then randomized controlled trials of interventions are required before translating findings into treatments.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations: CMS = Children's Memory Scale; CVLT-C = California Verbal Learning Test for Children; RAVLT = Rey Auditory Verbal Learning Test; WRAML = Wide Range Assessment of Learning & Memory; Notes: **p* < .05; ***p* < .001.

Figure 1. Effect sizes of studies examining declarative learning for verbal information in SLI using list learning/retrieval tasks.

Figure 2. Effect sizes of studies examining declarative learning for non-verbal information in SLI using learning/retrieval tasks.

Notes: ^aAverage effect size for recall and recognition in immediate and delayed conditions. ^bAverage effect size for recall in short and delayed conditions. **p* < .05; ***p* < .001.

Figure 3. Effect sizes of studies examining retrieval of verbal information from declarative memory in SLI.

Notes: ^aAverage effect size for short and delayed recall conditions. **p* < .05; ***p* < .001.

Figure 4. Effect sizes of studies examining retrieval of non-verbal information from declarative memory in SLI.

Notes: ^aAverage effect size for verbal and tonal stimuli in Experiment 1 and 2.

Figure 5. Effect sizes of studies investigating implicit learning and memory of verbal and non-verbal information.