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RESEARCH REPORT

Challenges in skill acquisition and memory retention in children with developmental language disorder

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Abstract

Background: Understanding memory retention in children with developmental language disorder (DLD) compared with their typically developing (TD) peers enhances our knowledge of memory processes.

Aims: To examine long-term memory consolidation of a declarative object-location task and a procedural symbol-writing task, along with grammatical and lexical skills, in 5-year-old children with DLD and their age-matched peers.

Methods & Procedures: A total of 23 children with DLD and 30 TD peers participated. For procedural memory, children practiced writing a new symbol and were assessed 4 hours and 2 weeks post-practice. For declarative memory, they practiced locating cards until they achieved 75% correct responses and were assessed again 4 hours and 2 weeks post-practice.

Results & Discussion: Children with DLD had fewer correct responses on the declarative-memory object location task with the gap widening significantly from 4 hours to 2 weeks post-training. On the procedural symbol-writing task, children with DLD showed overall lower accuracy. Furthermore, only their TD peers exhibited delayed gains 4 hours post-training in production times, while they narrowed the gap two weeks later. A speed–accuracy trade-off was observed during their symbol-writing practice. These results highlight atypical long-term declarative memory retention and procedural knowledge acquisition in DLD. Consistent with previous studies, declarative memory correlated with lexical scores in both groups, while procedural memory correlated with grammatical scores only in TD peers. Interestingly, long-term procedural learning was linked to lexical abilities in children with TD. Characterizing child performance in short and long intervals following practice may aid clinicians in supporting children with DLD beyond the clinical setting.

KEYWORDS
procedural memory, declarative memory, DLD, long-term memory, lexical and grammatical skills, motor skill learning, object location memory task

WHAT THIS PAPER ADDS

What is already known on the subject

- Current studies emphasize the role of long-term memory in language learning, particularly procedural memory for grammar and declarative memory for lexical knowledge but often overlook longer term performance and non-sleep memory consolidation. Additionally, most research focuses on older children, with few studies addressing younger children at critical language acquisition ages, a gap this study aims to fill.

What this paper adds to the existing knowledge

- The study shows that children with DLD exhibit atypical patterns in declarative and procedural memory post-training. It also establishes correlations between memory types and language skills, highlighting distinct memory challenges in children with DLD compared with their TD peers.

What are the potential or actual clinical implications of this work?

- The clinical implications of this study highlight the need for targeted interventions to address post-practice memory deficits in children with DLD. The findings indicate that children with DLD struggle with both declarative and procedural memory tasks at different post-training intervals, suggesting the necessity for early, ongoing support. Personalized educational and clinical strategies that consider each child's unique memory profile can enhance language acquisition and overall learning outcomes, making tailored interventions crucial.

INTRODUCTION

Understanding how children with developmental language disorder (DLD) acquire and retain skills compared with their typically developing (TD) peers is crucial for designing effective interventions. DLD involves delayed or disordered language learning not caused by hearing loss, developmental delay, neurological issues, or environmental deprivation (Bishop, 2017; Leonard, 1995). About 7% of kindergarten children have DLD (Tomblin et al., 1997), leading to poor academic achievement, self-esteem, social and emotional development, and future employment (Conti-Ramsden et al., 2013).

The mechanisms behind language learning difficulties in DLD are still debated. Research has traditionally focused on phonology and grammar, with many children characterized by grammatical-SLI (G-SLI) or syntactic-SLI (Sy-SLI) (Friedmann & Novogrodsky, 2008; Van der Lely, 2005). Current studies highlight the role of long-term memory (LTM) in language learning, emphasizing procedural memory in grammar and declarative memory in lexical knowledge (Hamrick et al., 2018; Lammertink et al., 2020). While Hamrick et al. (2018) focus on the earlier phase of LTM learning, later performance, which critically relies on LTM mechanisms, was not systematically addressed, particularly not in children with DLD (e.g., Hedenius et al., 2011; Lucaks et al., 2017; Lum et al., 2012). For example, for procedural learning delay periods that enable memory consolidation but do not include sleep were not studied before, whereas for declarative memory delay periods of more than 24 hours were not addressed. Furthermore, most studies focus on school-aged children or older participants, while only a few studies focus on younger children at the critical age of language acquisition (Adi-Japha et al., 2011; Adi-Japha & Abu-Asba, 2014). This study aims to fill this gap by examining declarative associative memory and procedural motor memory at 4-hours and 2 weeks post-training as well as grammatical and lexical skills in kindergarten children with DLD and their TD peers.

International Journal of Language & Communication Disorders

DECLARATIVE AND PROCEDURAL LTM SYSTEMS

Our memories are thought to be organized in two separate and distinct LTM systems: a declarative system, which retains singular experiences and memories of facts and events; and a procedural system, which addresses repeated experiences and memories of skills and habits (Squire, 2004). Short-term memories in these two memory systems are transformed into longer term memories via processes known as memory consolidation (Dudai et al., 2015). Memory consolidation is a hypothetical family of processes that stabilize a memory trace after its initial acquisition. These processes take place both during wakefulness and during sleep at multiple levels of organization and function in the brain. The initial steps of memory consolidation occur at a cellular level within minutes to hours, a process known as synaptic consolidation. Besides this rapid synaptic consolidation, systems consolidation processes further extend to days, months and years leading to LTM (Dayan & Cohen, 2011; Gais et al., 2007).

Studies of the declarative memory system have shown that sleep contributes to the stabilization of memories in both verbal and non-verbal tasks (for a review, see Rasch & Born, 2013). Developmental studies have shown maturation effects but also a similar protective effect for sleep on the retention of declarative information for children and adults (Wilhelm et al., 2008).

Studies of procedural motor skill learning tasks have shown in adults, school-aged children, and kindergarten children, that significant training-dependent gain in performance following a training experience can appear 24 hours post-training, presumably reflecting consolidation processes (for a review, see Adi-Japha & Karni, 2016). More recent studies have shown developmental differences whereby a period of sleep is required in adults, but not in children, to develop post-learning gains (Adi-Japha & Karni, 2016; Adi-Japha et al., 2019; Ashtamker & Karni, 2013).

LTM systems and linguistic skills in children with DLD and peers

Research on declarative memory in children with DLD is relatively limited, with only a few studies examining this aspect (Bishop & Hsu, 2015; Lucaks et al., 2017; Lum et al., 2012). Existing studies generally suggest that children with DLD exhibit largely unimpaired declarative memory when the tasks involve non-verbal stimuli, such as abstract visual and spatial information (Bishop & Hsu, 2015), or verbalizable stimuli where working memory demands are controlled (Lum et al., 2012). These findings indicate that declarative memory may remain intact in DLD, especially in controlled contexts. Additionally, most studies on the post-learning phases of verbal and non-verbal declarative memory have found no impairments in delayed recall tasks (30 min post-training) or retention after 24 hours, a period that includes overnight sleep (Baird et al., 2010; Bishop & Hsu, 2015; Lucaks et al., 2017), or that impaired recall stemmed from deficits in working memory (Lum et al., 2012, 2015). For example, Lucaks et al. (2017) observed that children with DLD performed similarly to their TD peers on a non-verbal task that included both immediate recognition and a 24-hour retention interval, with children with DLD showing unique improvements from the recognition phase to the 24-hour retention phase. Studies involving adults with DLD, however, suggest potential age-related differences in declarative memory processing; for instance, adults with DLD have shown impairments in an overnight enhancement on the same non-verbal declarative memory task where children with DLD demonstrated gains (Earle & Ullman, 2021). Extended delay periods beyond 24 hours have yet to be explored in children with DLD, leaving questions about longer term retention unanswered. These longer delay periods are of importance due to further contributions to LTM consolidation processes during periods of days, weeks and months.

Correlation analyses of non-verbal declarative learning measures with lexical knowledge and grammatical skills indicated that unlike verbal declarative learning that correlated with both lexical knowledge and grammatical skills in TD individuals (Hamrick et al., 2018), and in children with DLD (Conti-Ramsden et al., 2015; Lum et al., 2012); non-verbal declarative learning did not correlate with either lexical knowledge or grammatical measures in children with DLD or their TD peers (Baird et al., 2010; Lum et al., 2012). Delayed memory recall (verbal and non-verbal tasks) of 20–30 minutes was not correlated with lexical knowledge (Baird et al., 2010). To the best of our knowledge, there are no studies testing the association of declarative learning following delay periods of more than 30 minutes with lexical knowledge, or studies of associations between performance following any delay period of declarative memory with grammatical skills.

Regarding procedural memory, systematic research has identified impairments among children with DLD in learning to execute a repeated sequence of fine motor movements (acquired via the procedural memory system). Furthermore, there is emerging evidence that individuals with DLD do not consolidate (24-hours post-training) and retain (few days or weeks post-training) sequence knowledge as effectively as their TD peers (Adi-Japha et al., 2011; Desmottes et al., 2016; Hedenius et al., 2011). A recent study in adults found impaired (evening) learning but intact retention following a 12-hour delay (morning session) (Earle & Ullman, 2021). Shorter delay periods that do not include sleep following motor sequence learning have not been tested so far in individuals with DLD. The literature on TD adults shows that 4 hours are sufficient for the stabilization of procedural memory to withhold interference and the depiction of performance gains 24 hours post-training (Brashers-Krug et al., 1996). In a period of 4 hours post-training, adults do not show performance gains, but children can develop such gains (Adi-Japha et al., 2019; Ashtamker & Karni, 2013).

Correlation analyses have been undertaken to unfold associations of procedural LTM with lexical knowledge and grammatical skills. The Procedural Deficit Hypothesis (PDH) (Ullman & Pierpont, 2005), which connects the atypicality of procedural memory functioning in children with DLD to abnormalities in brain regions related to procedural memory, notes the role of these brain regions in the acquisition of aspects of language, in particular grammar. In line with the PDH, correlation analyses tended to show that procedural memory sequence learning is associated with grammatical knowledge in TD individuals (Hamrick et al., 2018, but see Lammertink et al., 2020), but not in those with DLD. Associations between later phases of sequence learning and language measures were less often studied. Nevertheless, Desmottes et al. (2016, 2017) reported an association between the later phases of sequence learning and grammatical abilities in children with TD. No consistent pattern of association emerged for children with DLD in these studies. More importantly, sequence learning or later retention was not associated with lexical knowledge in children with TD or DLD in these studies.

THE CURRENT STUDY

Research gap

There is limited research on LTM consolidation in children with DLD, particularly concerning the retention of procedural and declarative memory over different post-training intervals. While previous studies have examined the role of procedural and declarative memory in grammar learning and lexical knowledge (Hamrick et al., 2018), they have not systematically addressed post-training memory consolidation in children with DLD at both short-term and extended delay intervals. Specifically, procedural memory performance has not been examined at intervals less than 24 hours post-training (in periods that do not include sleep). Declarative memory performance has not been tested beyond 24 hours post-training, leaving questions about longer term retention unanswered. Most studies focus on school-aged children, whereas kindergarten-aged children, a critical period for language acquisition, remain understudied. By addressing these gaps, the present study provides insights into how declarative and procedural memory consolidate information over different post-training periods and examines their association with linguistic abilities in young children.

Hypotheses

Children with DLD and their TD peers are assumed to exhibit comparable declarative memory performance. Verbal Declarative memory (the declarative task here used, the object location task, is based on verbalized items, see Methods) is expected to correlate with lexical knowledge in both groups and with grammatical knowledge in children with DLD (Baird et al., 2010; Lum et al., 2012). Children with DLD are predicted to show initial learning of procedural motor skills but may not exhibit performance gains at either 4 hours or 2 weeks post-training. In TD children, procedural memory should correlate with grammatical skills (Hamrick et al., 2018), whereas no such association is expected in children with DLD (Lammertink et al., 2020).

Objectives

To systematically investigate the consolidation of declarative and procedural memory in children with DLD, this study aims to examine memory retention at both a short-term interval (4 hours) and a long-term interval (2 weeks) post-training. It compares the performance of DLD and TD children in a declarative memory task (object-location game, based on verbalized items) and a procedural memory task (invented letter writing task). Additionally, the relationship between memory performance and linguistic skills is analysed, focusing on lexical knowledge and grammatical judgment. Finally, the assessment of potential compensatory mechanisms, particularly whether declarative memory compensates for procedural deficits in children with DLD, as suggested in prior studies (Ullman & Pullman, 2015) is investigated.

This study employs a 4-hour post-training interval, allowing for the examination of early memory consolidation effects that occur without sleep (Adi-Japha et al., 2019; Ashtamker & Karni, 2013). It also uses a 2-week post-training interval, assessing long-term consolidation, including the cumulative effects of sleep and memory stabilization over time. By exploring previously unexamined timeframes in memory consolidation for children with DLD, this study aims to provide insights into tailored clinical and educational interventions for improving language learning in this population.

TABLE 1 Background information.

	TD ($N = 30$)	DLD ($N = 23$)			
	M (SD)	M (SD)	Z	p	r
Age (months)	69.30 (3.54)	69.04 (3.90)	0.05	0.957	0.01
Language proficiency	1.12 (0, 95)	−2.92 (1.99)	6.19	0.000	0.85
Non-verbal intelligence	102.57 (11.43)	97.34 (14.38)	1.25	0.210	0.17
Vocabulary Index	11.97 (1.56)	7.00 (2.25)	5.54	0.000	0.76
Grammar Index	0.67 (0.79)	−1.41 (0.64)	5.77	0.000	0.79
Number Recall	12.03 (3.72)	6.52 (3.39)	4.43	0.000	0.61
Hand movement	9.50 (3.57)	7.61 (2.62)	1.92	0.054	0.26

Note: Language proficiency is based on the Goralnik test (Z score); non-verbal intelligence was measured by Raven Standard Scores ($M = 100$, SD = 15); basic drawing level was measured on a 1–4 scale; vocabulary was tested by WPPSI ($M = 10$, SD = 3); grammar was tested by Shatil Grammatical judgment sub-test (Z score); number recall and hand movement were measured with Kaufman ABC subtests ($M = 10$, SD = 3); $r = Z/\sqrt{N}$.

METHOD

Participants

A total of 53 native Hebrew-speaking children aged 5–6 ($M = 69.92$ months, SD = 3.49 months) participated in the study. A total of 23 children (11 female) with DLD were recruited from a language kindergarten and 30 children (16 female) with TD were recruited from a kindergarten in the same municipal area. In terms of gender, the groups were similarly composed ($\chi(1) = 0.16, p = 0.69$). Groups were further matched for age and non-verbal intelligence (Table 1).

All participants had a nonverbal IQ of 80 or above, as measured with the Raven's Coloured Progressive Matrices (Raven, 2003). The children with DLD were diagnosed with significant language impairment, normal nonverbal intelligence, and sound adaptive behaviour skills. The placement committee (comprised of the special education kindergarten district supervisor, municipal kindergarten psychologist, and special education therapists) assessed eligibility based on standardized cognitive assessments, speech-language pathologist referral, and information from previous kindergarten teachers and caregivers. All children referred to the placement committee are administered the Wechsler Preschool and Primary Scale of Intelligence (WPPSI; Wechsler, 1967). Children are referred to the placement committee after being diagnosed as having a language disorder based on a score of more than 1 SD below the mean in at least two language tests that are used in clinics and have normal performance IQ (Friedmann & Novogrodsky, 2004). Children were included in the DLD group if they performed at or below 1.25 SD on the Goralnik Screening Test for Hebrew (Goralnik, 1995) including six subsections vocabulary, sentence repetition, comprehension, oral expression, pronunciation, and story-telling and did not have a diagnosis of other developmental disorders. Table 1 provides the background information for all children participating in the study. Parental consent was secured, and the study was approved by the IRB and by the Ministry of Education (287/8918/2015).

MATERIALS

Memory tasks

Children performed two LTM tasks, the (declarative) object location task and the (procedural) symbol writing task (invented letter task—ILT). In the present study, declarative memory is operationalized using the object location task in three time points: initial performance (collection of immediate short-term memories for card location), 4 hours post (a delay period without sleep) and 2 weeks post (LTM with sleep). We operationalized procedural memory using the ILT in four time points: pre (collection of short-term memories of a given new movement) and post-training (assessment of immediate practice effects), 4 hours post-training and 2 weeks post-training.

Object location memory task

The two-dimensional object location task resembles the game 'concentration' (adapted from Rasch et al., 2007) and consists of 16 card pairs showing coloured pictures of different well-known animals and everyday objects. The experimenter has a set of 16 cards randomly ordered. The matching 16 cards are laid face up on a game board, in a constant 4 × 4 array. Children are requested to memorize card locations. When the child is ready (not longer than 30 second duration), cards are turned face down. The experimenter then presents a card, and the child is requested to locate the matching card. If the response is correct, the card is turned face up and then face down again. If the response is incorrect, the child is shown the correct loca-

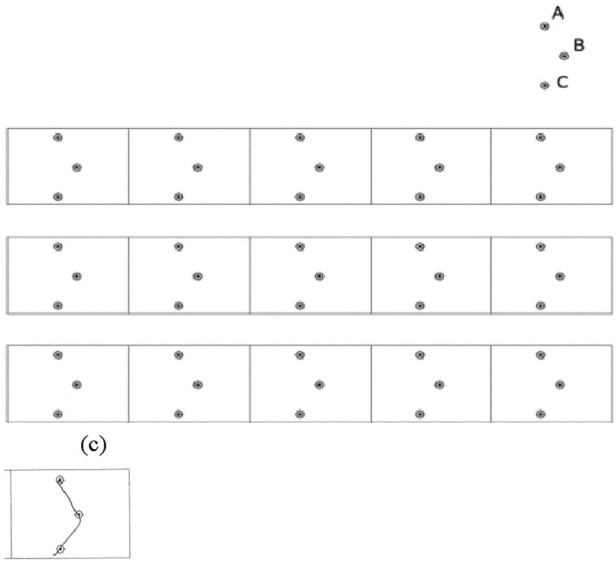

FIGURE 1 The invented letter task: (a) one letter; (b) one block; and (c) one drawn letter. Each ILT block is coded for completion time and accuracy. ILT, invented letter task.

tion. This cued recall procedure is repeated until a criterion of 12/16 correct responses is reached (75%). At retrieval testing, all card pairs are tested once. If the response is correct cards are turned face up, and then face down. Incorrect responses are ignored, and the next card is presented. Children had three retrieval testing sessions: (a) immediately following the training procedure, (b) 4 hours post-training and (c) 2 weeks post-training.

Invented letter task (ILT)

The ILT (Adi-Japha et al., 2011) was used to study the time-dependent course of motor skill acquisition. The task consists of point-to-point planar movements (Figure 1a: A → B → C, segment length 1.2 cm, circle outer diameter 3 mm, shape width 6 mm) to form an invented letter. Movement progression within a block (Figure 1b) was from right-to-left (as in Hebrew writing). Participants perform a writing-like task using HB pencil. Overall, 20 blocks of the task were performed: 12 on the first (training) day, four blocks 4 hours post-training, and four additional blocks on the 2-week post-training session. Blocks were printed on a half A4 sheet. Each block contained 15 repeats of the same pattern. Blocks were separated by 15–30 seconds (Julius & Adi-Japha, 2015). Before training and before each test, participants practiced pattern production for 2–6 rows (4–6 in the first day, 2–3 rows in the other training days) until the correct performance of a full row and the move to the next row were achieved. Note that similar amount of practice was given to children with a developmental coordination disorder (DCD), who performed similarly to typical developing peers (Adi-Japha & Brestel, 2020).

Language tasks

To assess proficiency in Hebrew the *Goralnik Screening Test for Hebrew* (Goralnik, 1995) was administered. In addition, children were assessed using a grammatical judgment task and a lexical knowledge task.

The Goralnik screening test for Hebrew

The Goralnik screening test (Goralnik, 1995) includes subtests for vocabulary, sentence repetition, comprehension, oral expression, pronunciation and story-telling. The scores are raw scores, with a total of 180 points (30 for each subtest). The Goralnik manual enables the calculation of a standardized z-score based on age-appropriate norms, used for identifying DLD (Goralnik, 1995). Children with DLD scored $\leq$ 1.25 SD below the mean, while TD children scored $\geq$ 0.9 SD below the mean.

The grammatical judgement task

The task used to assess grammatical abilities was the Shatil and Share (2003) grammatical correction task (20 items). Children were presented with an ungrammatical sentence which they had to correct by providing a grammatical alternative. Ungrammaticality included various reasons: incorrect word order, no agreement between gender and number, no tense agreement, wrong conjugation used and inappropriate preposition use. An example of an ungrammatical sentence may be: 'The parents came to **we**' where the child had to correct it to 'The parents came to **us**'.

The lexical task

The lexical expressive language task was the vocabulary subtest of the Hebrew version of the Wechsler Preschool and Primary Scale of Intelligence (WPPSI-III-HEB) (24 items). The child is asked to express what each word means. For example, the child was given the word 'hat' and he had to define what it meant. There was an answer key indicating a satisfactory meaning.

Sequential STM tasks

Two subtests of the Kaufman Assessment Battery for Children (K-ABC; Kaufman & Kaufman, 1983), the number recall and the hand movement tasks, were used. In the number recall task, the experimenter reads out a string of numbers and the child is asked to repeat the number string in the same order. The strings vary from 2 to 9 digits. In the hand movement task, the child is asked to imitate a series of taps that the experimenter makes on the table with the fist, palm or side of the hand. This version of the K-ABC was adapted for Hebrew and has been standardized (M = 10, SD = 3 for each subtest; M = 100, SD = 15 for the overall score). On average, test-retest and internal consistency reliabilities of the K-ABC subtests have been reported as 0.85 and 0.62, respectively (Phizer et al., 1995).

Procedure

Children were first tested for background measures, the Raven test, the Language tests and the sequential STM tests in one to two meetings depending on child progress. Children were then tested on the ILT and 2 weeks later, on the object location task. The ILT and the declarative object location tasks were administered on separate days. All children were assessed in a designated room in their kindergarten.

Data analyses

The object location task involved 3 sessions. The first time the task was administered, the children practiced until the criterion of 12/16 correct cards was reached. The number of cards correctly identified in the criterion round represents session 1. The number of cards correctly identified 4 hours post-training and 2 weeks post-training represent session 2 and session 3, respectively. With a power of 0.80 and a two-tailed $\alpha = 0.05$, $n = 22$ per group is sufficient to detect medium effects ($f = 0.25$) (G*Power 3.1; Faul et al., 2009).

Each ILT block was coded for completion time and accuracy. Completion time was measured using a stopwatch, from the first touch of the pencil on the page until the pencil was put down on the table. An ILT shape was evaluated as accurate if it was drawn in one continuous line and went through the midpoint. Accuracy was evaluated as the number of correct shapes per block. Four testing sessions were used in the analyses: (a) pre-training session (blocks 1–4 on day 1); (b) post-training session (blocks 9–12 on day 1); (c) 4 hours post-training (4 blocks, blocks 13–16); and (d) retention session (4 blocks) assessed 2 weeks later. An α level of 0.05 was adopted. With a power of 0.80 and a two-tailed $\alpha = 0.05$, $n = 18$ per group is sufficient to detect medium effects ($f = 0.25$).

Preliminary distribution analyses of the object location task and the ILT data (|Skewness| < 1.6, max. Kurtosis = 2.7) indicate acceptable Skewness levels (−2:2, Cohen, 2013), while for Kurtosis, values between 2 and 4 are typically acceptable (Tabachnick et al., 2013). The parametric and non-parametric procedures yielded the same pattern of significance. Here we report the non-parametric analyses.

Note that the object location task involves 3 time points (initial/4 hours post/2 weeks post-training) while the ILT involves four time points (pre/post/4 hours post/2 weeks post-training). Therefore, a 3 (time point = initial/4 hours post/2 weeks post-training) × 2 (groups = DLD/TD) and a 4 (time point = pre/post/4 hours post/2 weeks post-training) × 2 (groups = DLD/TD) generalized linear model analysis for repeated measures with robust estimator were applied to the Object location data and ILT completion time and accuracy data, respectively. Sequential Bonferroni correction was used for post-hoc comparisons.

Results

In order to test differences in declarative memory, we present the accuracy results for the declarative, object location, task among children with TD and those with DLD. These are followed by the results of the procedural memory ILT in terms of accuracy and completion times. Impairments in the formation of long-term memories may be the result of failure at the encoding phase due to short-term memory (STM) deficits. In the current study, we reanalysed LTM tasks beyond STM related abilities. Finally, the results of the two language tasks are presented and correlations between the procedural, declarative and language tasks are reported.

Declarative memory

On pretesting, children used 1–6 practice trials to get to the criterion of at least 12/16 cards correctly located. No group difference emerged in the number of practice trials to criteria (Wilcoxon $Z = 1.39$, $p = 0.162$, $r = 0.19$). The generalized linear model analysis indicated an overall group difference (Table 2). While, overall accuracy level was reduced (time point main effect) (Table 2 and Figure 2), the findings indicate an overall time point × group interaction such that significant group differences emerged only 2 weeks post-training (Table 2; for descriptive task statistics and detailed analysis, see Appendix A, Tables A1–A4) due to a larger decrease in performance from 4 hours post-training to 2

TABLE 2 χ^2 scores and group difference significance levels at different time points for the object location task.

					Post-hoc group difference, *p*		
	Wald χ^2	**d.f.**	***p***	**Cramer's *V***	**Init**	**4 hours post**	**2 weeks post**
Time point	13.823	1	< 0.001	0.51			
Group	92.717	2	< 0.001	0.93	0.070	0.155	0.002
Time point × Group	7.631	2	0.022	0.29			
With STM-NR as a covariate							
Time point	10.388	1	0.001	0.44			
Group	92.762	2	< 0.001	0.91	0.169	0.185	0.004
Time-point × Group	7.648	2	0.022	0.27			

Note: Group = TD/DLD (TD, $n = 30$; DLD, $n = 23$); time point = Init, 4 hours post, 2 weeks post; STM-NR = short-term memory—number recall (Verbal STM). Cramer's $V = \sqrt{\chi^2/(N^*\text{d.f.})}$; post-hoc sequential Bonferroni was used (see Appendices A and B).

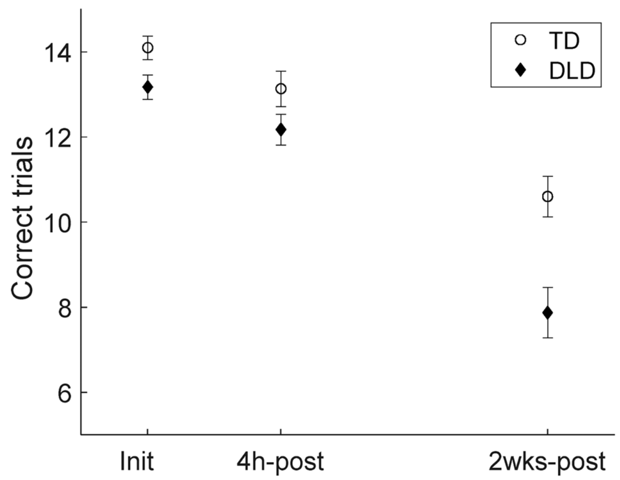

FIGURE 2 The Declarative task (concentration game): the number of cards correctly identified (of 16). mean values and SE are depicted. See Table A1 for descriptive statistics.

weeks post-training (retention period) for children with DLD ($Z = 2.48$, $p = 0.013$, $r = 0.34$).

Declarative memory with sequential verbal STM controlled

Due to the large group differences in sequential verbal STM, as in previous studies, we ran the analysis once more while controlling for this variable (Lum et al., 2012). Controlling for the verbal STM test (i.e., STM—number recall test), the significance pattern in the generalized linear model analysis without the covariate was replicated (Table 2 with STM-NR as a covariate; for more details, see Appendix B, Tables B1–B3). In particular, the overall time point × group interaction was significant, even after controlling for verbal STM, stressing the larger decrease in performance from 4 hours post-training to 2 weeks post-training in children with DLD (Table 2). No main effects of verbal STM emerged in the analysis of the object location task data (see Appendix B, Table B1).

Procedural memory

In terms of Accuracy (Figure 3a), although overall accuracy level was high (above 12.7/15 shapes correctly drawn at all time points) the data indicates that children with DLD perform significantly less accurately than their peers at all time periods (Wald $\chi^2(1) = 9.40$, $p = 0.002$, Cramer's $V = 0.42$). Furthermore, the data indicates a main effect of time point (Wald $\chi^2(3) = 10.12$, $p = 0.018$, Cramer's $V = 0.25$; for descriptive task statistics and more and detailed analysis, see Appendix C, Tables C1–C4). Post-hoc analysis of the ILT time point main effect indicated an overall (i.e., across both groups) reduction in accuracy from pre- to post-training ($p = 0.010$, sequential Bonferroni correction; see Appendix C, Table C4), but an increase in accuracy later with a return to pre-training levels of accuracy at the 4 hour and 2 weeks post-training assessments (p's = 0.745 sequential Bonferroni correction; see Appendix C, Table C4). No time point × group interaction emerged (Wald $\chi^2(3) = 5.98$, $p = 0.113$, Cramer's $V = 0.19$, for more details, see Appendix C, Table C3).

In terms of completion time (Figure 3b) the generalized linear model analysis indicated that there was an overall improvement in performance with an interaction between group and time (Table 3; for descriptive task statistics and detailed analysis, see Appendix C, Tables C5–C8). While groups showed a similar performance level at the onset and end of the training (pre and post: $p = 1.000$) (Table 3 using post-hoc sequential Bonferroni correction; for more details, see Appendix C, Table C8), only the group of children with TD improved from post-training to 4 hours post-training (mean difference = 4.05, $p = 0.000$, post-hoc sequential Bonferroni correction; see Appendix C, Table C8) while the performance of children with

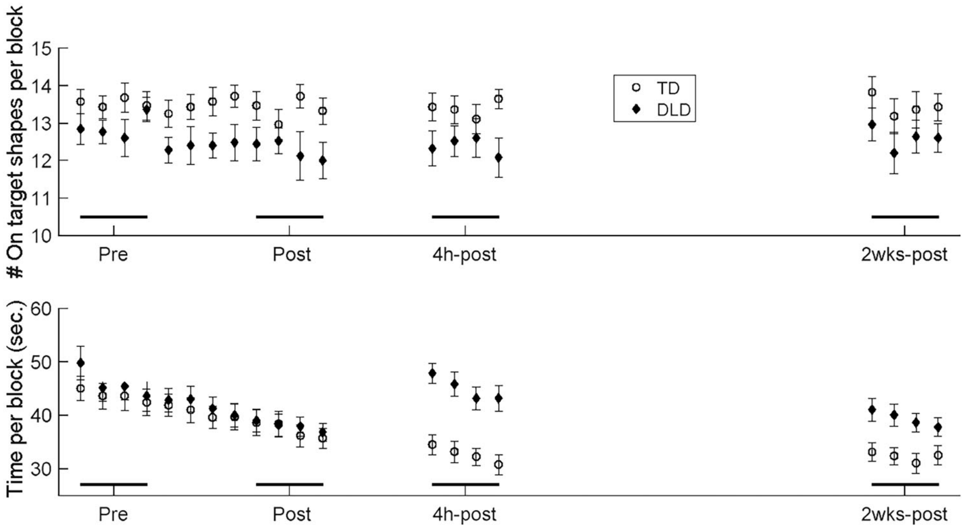

FIGURE 3 The procedural memory task: (a) number of accurately produced shapes (of 15); and (b) completion time. The figure depicts the mean value per block and SE. See Appendix C, Table C1, for descriptive statistics. See Table C11 for the correlation between completion time and accuracy across participants.

TABLE 3 ILT completion times: χ^2 scores and group difference significance levels at different time points.

	Wald χ^2	d.f.	*p*	Cramer's *V*	Post-hoc group difference, *p* Pre	Post	4 hours post	2 weeks post
Group	3.931	1	0.047	0.27				
Time point	182.342	3	< 0.001	1.07	1.000	1.000	0.000	0.089
Time point × Group	68.702	3	< 0.001	0.68				
With STM-HM as a covariate								
Group	3.624	1	0.057	0.26				
Time point	182.583	3	< 0.001	1.45	1.000	1.000	0.000	0.118
Time point × Group	68.747	3	< 0.001	0.65				

Note: Group = TD/DLD (TD, $n = 30$; DLD, $n = 23$); time point = Init, 4 hours post, 2 weeks post; STM-HM = short-term memory—hand movement test (Motor STM); Cramer's $V = \sqrt{\chi^2/(N^* \text{d.f.})}$; post-hoc sequential Bonferroni was used (see Appendices C and D).

DLD slowed down (mean difference = −6.58, $p = 0.000$, post-hoc sequential Bonferroni correction; see Appendix C, Table C8), resulting in a significant group difference ($p = 0.000$) (Table 3; for more details, see Appendix C, Table C8). However, while TD children retained their speed at retention testing, 2 weeks later, children with DLD improved their performance (mean difference = 5.54, $p = 0.000$, post-hoc sequential Bonferroni correction; see Appendix C, Table C8), and reduced the gap between the two groups ($p = 0.089$) (Table 3; for more details, see Appendix C, Table C8).

To test for within group speed–accuracy trade-off, reduction in accuracy was tested per group. A within group generalized linear model analysis indicated a reduction in accuracy only for the group of children with DLD (Wald $\chi^2(3) = 11.12$, $p = 0.011$, Cramer's $V = 0.26$, with accuracy at pre-training higher than that of post-training ($p = 0.006$, sequential Bonferroni correction), and returns to pre-testing level at the 2 weeks post-training session ($p = 0.873$) (see Appendix C, Tables C9 and C10). Given that the two groups improved their completion time to the same extent from pre- to post-training (Figure 3 and Table 3), these data suggest that completion time improvement during training in children with DLD reflects speed–accuracy trade-off. No change in accuracy level throughout the experiment was noted for children with TD (Wald $\chi^2(3) = 0.66$, $p = 0.883$, Cramer's $V = 0.06$).

The ILT controlling for motor sequential STM

The ILT is a long-term motor skill learning task. Studies of motor skills in children with DLD (Hill, 2001; Zelaznik & Goffman, 2010) indicate that children with DLD struggle with fine motor coordination, which may confine their performance in procedural tasks. In order to focus on long-term learning effects, the analysis was repeated while controlling for Motor STM (i.e., the STM—hand movement test).

The analysis of ILT accuracy data while controlling for Motor STM (i.e., STM—hand movement test) indicated that the significance pattern that appeared in the analysis without the covariate was replicated. Specifically, the analysis indicated the advantage of the TD over the DLD group (Wald $\chi^2(1) = 10.09$, $p = 0.003$, Cramer's $V = 0.43$). as well as the time point main effect (Wald $\chi^2(3) = 8.55$, $p = 0.018$, Cramer's $V = 0.23$; for a detailed analysis, see Appendix D, Tables D1–D3). Post-hoc analysis indicated an overall reduction in accuracy from pre- to post-training ($p = 0.010$, sequential Bonferroni correction; see Appendix D, Table D3), but an increase in accuracy later with a return to pre-training levels of accuracy at the 4 hour and 2 weeks post-training assessments (p's = 0.748 sequential Bonferroni correction; see Appendix D, Table D3). No time point × group interaction emerged (Wald $\chi^2(3) = 5.97$, $p = 0.113$, Cramer's $V = 0.19$, for more details see Appendix D).

The significant pattern in the generalized linear model analysis for completion times were mostly replicated (Table 3), in particular the time point × group interaction was replicated even after controlling for motor STM, indicating a-typical learning of children with DLD characterized by slowing from post-training to 4 hour post-training while their peers were improving, but closing the gap from 4 hours to 2 weeks post-training. No main effects of motor STM emerged in the analysis of ILT accuracy and completion time data (see Appendix D, Tables D4–D6).

Correlations between grammatical and lexical skills and declarative and procedural performance

Table 4 presents correlations between grammatical and lexical knowledge and LTM measures. For TD children, declarative memory showed an initial significant positive correlation with lexicon at 4 hours post-training ($r = 0.426$), yet this diminished over time, as indicated by a lack of correlation at 2 weeks post-training ($r = -0.062$). Procedural memory became more prominent as time progressed. Faster completion times on procedural tasks at 4 hours and 2 weeks post-training were significantly associated with better grammar outcomes (at 4 hours post-training, $r = -0.336$; at 2 weeks post-training, $r = -0.319$). Similar correlations were observed with the lexicon, with significant negative correlations between the lexicon and the procedural task at 4 hours ($r = -0.458$) and 2 weeks ($r = -0.517$) post-training, suggesting that faster task execution aligns with stronger lexical abilities. Procedural memory accuracy also showed significant positive correlations with both grammar (4 hours post: $r = 0.496$; 2 week post: $r = 0.384$) and lexicon (4 hours post: $r = 0.439$; 2 weeks post: $r = 0.634$). Verbal STM further supported grammar and lexicon outcomes in the TD group, with significant positive correlations for both grammar ($r = 0.536$) and lexicon ($r = 0.634$).

Among children with DLD, Table 4 shows a significant positive correlation between declarative memory at 2 weeks post-training ($r = 0.562$) and the lexicon. In contrast, procedural memory completion times and accuracy showed no significant correlations with grammar or lexicon, highlighting a limited role in language outcomes for this group. Verbal STM displayed a trend-level positive correlation with grammar at 2 weeks post-training ($r = 0.398^{\wedge}$), suggesting a potential, albeit weaker, contribution to the grammatical task performance.

DISCUSSION

The current study tested the learning over time of a declarative associative memory task as well as of a procedural motor-skill learning task in kindergarten children with DLD and their TD peers. While the long-term declarative memory system stores individual experiences and factual memories, the long-term procedural memory system operates repeated experiences and memories related to skills and habits (Squire, 2004). Verbal STM was controlled in the declarative task to reduce the effect of possible verbal effects of task stimuli during task performance, Motor STM was controlled in the procedural task, to enhance the effect of sequence learning. The design was intended to fill two gaps in the literature of LTM abilities in DLD by testing twice after the practice: 4 hours and 2 weeks post-practice. Studies of declarative memory did not address retention periods longer than 24 hours post-training. In addition, procedural memory was not tested in delay periods of less than 24 hours post-training. The time points were chosen to build on prior LTM studies in TD individuals that emphasize the importance of these delay intervals to memory consolidation and retention in typical and atypical development (Adi-Japha, Fox et al., 2011; Adi-Japha et al., 2019; Ashtamker & Karni, 2013; Dudai et al., 2015). The extension of time helped reveal the window of opportunities that children with impairments use in closing the procedural gap and opening the declarative performance gap 2 weeks post-training.

The main findings of the current study suggest that declarative and procedural learning are both atypical in their post-training phase in children with DLD. For declarative memory, the recall of information 2 weeks post-training while for procedural memory accuracy levels and the 4-hour post-training phase of completion times,

TABLE 4 Spearman correlations between long-term performance on declarative and procedural memory tasks and grammatical and lexical abilities.

Group		Declarative memory (object–location task, verbalized items)			NV procedural memory: completion times			NV procedural memory: accuracy			
		Initial	4 hours post[a]	2-weeks post[b]	Post training	4 hours post	2-weeks post	Post training	4 hours post	2-weeks post	Verbal STM
TD	Grammar	−0.021	0.108	−0.287	−0.034	−0.336	−0.319	0.251	**0.496*** **	**0.384** **	**0.536*** **
	Lexicon	0.272	**0.426** **	−0.062	−0.307	**−0.458** **	**−0.517*** **	0.194	**0.439** **	**0.380** **	**0.634*** **
DLD	Grammar	−0.019	0.004	0.268	0.137	0.088	0.039	−0.233	−0.122	−0.174	**0.398**^
	Lexicon	0.129	0.362	**0.562*** **	−0.143	−0.218	−0.215	.033	.048	0.058	0.211

Note: Raw scores were used.

[a]4 hours post = 4 hours post-training.

[b]2 weeks post = 2 weeks post-training.

^$p = .06$, *$p < .05$, **$p < .01$, ***$p < .001$.

showed relatively poorer performance for children with DLD compared with peers with TD. While for the declarative memory performance, as expected in this task, there was a relative decline with time for both groups, more so 2 weeks post-training for children with DLD; for procedural memory the change in performance duration for children with DLD 4 hours post-training was opposite in direction of children with TD who improved, with some gap closure 2 weeks post-training. These findings may shed light on the relatively deficient procedural memory in children with DLD, in line with previous studies (e.g., Lum et al., 2012) and demonstrate a deficit in long-term declarative memory, extending previous contrasting results (Earle & Ullman, 2021; Lucaks et al., 2017). Furthermore, long-term declarative memory was linked with lexical scores in TD and DLD groups. Long-term procedural memory correlated with language scores only in TD children: accuracy correlated with grammatical and lexical scores whereas completion times correlated with lexical scores. This highlights the role of declarative memory in lexical knowledge in TD children and in children with DLD, and procedural memory in language acquisition in TD only, extending the understanding of relationships to kindergarten children with DLD (Hamrick et al., 2018; Lum et al., 2012; Ullman & Pierpont, 2005). The following discussion will focus on declarative memory, procedural memory and the link between them and language ability via grammatical and lexical tasks.

DECLARATIVE MEMORY

The declarative memory system is responsible for encoding, storing and retrieving facts and events. While only a few studies on declarative memory tasks in children with DLD exist, it has been reported that declarative memory of children with DLD is unimpaired (when the stimuli included abstract visual and spatial information, Bishop & Hsu, 2015; or when the stimuli are easily verbalized but working memory is controlled for, Lum et al., 2012, 2015). Therefore, it has been suggested that declarative memory deficit does not construct a core impairment in DLD and can play a compensatory role for abnormalities of brain structures underlying their procedural memory associated with impaired acquisition of grammatical skills in DLD (Ullman & Pierpont, 2005; Ullman & Pullman, 2015).

Our findings challenge the perspective of intact long-term declarative memory by demonstrating poorer performance in children with DLD, particularly at longer retention intervals. Based on previous results, we expected that children with DLD will benefit from overnight declarative memory consolidation (Lucaks et al., 2017). The results for the declarative object location task, however, showed that children with DLD scored lower than their peers, with a decrease in performance from 4 hours post-training to 2 weeks post-training. This performance decline highlights the importance of extending the retention interval beyond typical durations in declarative memory research (Poll et al., 2015).

The finding of a long-term decline in declarative memory aligns with recent studies on adults with DLD (Earle & Ullman, 2021), showing a deficit in overnight memory retrieval enhancement on a declarative task (12 hours post-training, after sleep) compared with TD adults, despite similar learning after encoding. This suggests that declarative memory consolidation may be impaired in adults with DLD. Our study supports the presence of a consolidation deficit following a delay period that includes sleep, extending this effect to kindergarten children and up to 2 weeks post-training. Sleep has a protective effect on the consolidation of declarative memory. Recent studies highlight sleep problems in children with communication disorders (including children with language impairments) as well as an association between sleep behaviour and language skills (Botting & Baraka, 2018; Earle et al., 2018).

PROCEDURAL MEMORY

Procedural memory underlines a set of skills involved in completion of a wide range of tasks: from writing to composing grammatically correct sentences. Our study examined repeated letter writing and its relation to language skills. Numerous studies have documented procedural learning impairments in children with DLD (e.g., Adi-Japha, Strulovich-Schwartz et al., 2011; Lum et al., 2012), though these deficits can vary based on task attributes. For example, some research indicates that performance on procedural tasks is influenced by task complexity, and children with language impairments may not exhibit deficits on simpler procedural tasks (Gabriel et al., 2011). It is also suggested that children with DLD exhibit impairments 24 hour post-learning on a serial reaction time task. However, initial procedural learning appears to be similar between children with DLD and their peers (Hedenius et al., 2011).

The procedural task here studied, the ILT, has two outcome measures, completion times and accuracy. For grapho-motor skill learning tasks, the retrieval of task elements that affect the shape of the trajectory (i.e., accuracy) is related to the more attentive-, or planning-related abilities. This is in contrast to lower level motor execution processes that are expressed in the mean duration of shape performance (Sosnik et al., 2014). The ILT task was designed to minimize accuracy demands, because accuracy in young children is associated with attention abilities, for example, as shown in children who were trained on a visual-motor sequences learning task (Janacsek et al., 2012).

The current results indicate that children with DLD exhibited a distinct pattern in procedural memory consolidation, particularly in completion time for the ILT task. While TD children improved their performance between the post training and 4-hour post-training assessments, children with DLD showed a counterintuitive increase in task completion time at the 4-hour post-training interval. This suggests that procedural memory stabilization processes in DLD follow an atypical trajectory, diverging from the expected consolidation pattern seen in TD peers.

One possible mechanism underlying this increase in completion time could be related to inefficient encoding and early-stage consolidation. Prior studies indicate that children with DLD often experience difficulties in stabilizing new procedural knowledge shortly after training (Adi-Japha et al., 2011; Adi-Japha & Abu-Asba, 2014; Zwicker et al., 2011). This might manifest as an increased cognitive load when attempting to retrieve and execute the motor sequence, resulting in slower performance at the 4-hour mark. Additionally, the observed speed–accuracy trade-off pattern during training suggests that children with DLD may have initially prioritized speed over accuracy, leading to ineffective learning that required additional cognitive effort during the early post-training phase. Instead of exhibiting efficient execution, children with DLD may have engaged in deliberate, effortful reconstruction of the movement sequence after the delay, thereby prolonging task completion time. Interestingly, the DLD group showed subsequent improvement at the 2-week post-training interval, suggesting that longer term consolidation processes may compensate for initial inefficiencies. This aligns with findings that children with DLD often require extended timeframes to integrate procedural knowledge (Desmottes et al., 2016; Hedenius et al., 2011).

Another possible explanation for the increase in completion time 4 hours post-training in children with DLD might be related to the grapho-motor component of the task. Motor coordination deficits common in DLD (Zelaznik & Goffman, 2010) could have contributed to increased cognitive-motor interference when attempting to recall and execute the ILT task after a short delay. Future studies should test whether there was a reduction in motivation toward the end of the first day (4 hours post) explaining slower production, as found in studies of handwriting in children with DLD (Brouwer, 2012).

The speed–accuracy trade-off observed in DLD children provides an opportunity to explore adaptive learning strategies that optimize skill acquisition. Given that children with DLD struggled with accuracy immediately after training but showed some recovery 2 weeks later, interventions could be designed to gradually increase task complexity while maintaining accuracy standards. Prior research suggests that breaking down practice into smaller, distributed sessions—rather than long, intensive training—may enhance retention and reduce cognitive overload in children with learning challenges (Adi-Japha et al., 2019; Fox et al., 2016). Alternatively, implicit learning strategies may reduce cognitive load (Plante et al., 2010). Additionally, structured feedback and reinforcement strategies (Zwicker et al., 2011) could help guide children toward a balance between speed and accuracy in procedural learning. Future studies should investigate whether adjusting training duration, feedback frequency, or reinforcement strategies can help mitigate the initial trade-off observed in DLD children and improve their procedural memory consolidation.

In analysing the results of the procedural task, we conclude that children with DLD struggle to consolidate new procedural skills shortly after training (within a 4-hour delay), indicating that impaired post-training performance may not be dependent on sleep. A previous study using the same task and age group showed a deficit 24 hours post-training (Adi-Japha et al., 2011), which was partially mitigated 2 weeks later. These results suggest a benefit from extending the assessment period to 2 weeks post-training in children with DLD, possibly due to additional practice.

DECLARATIVE AND PROCEDURAL MEMORY—LEXICAL AND GRAMMATICAL ASPECTS

Recent research indirectly highlights the role of procedural and declarative memory mechanisms in language skills, differentiating between verbal and non-verbal declarative memory. It concludes that both procedural and verbal declarative memory are crucial for grammar learning, while no associations were found with non-verbal declarative memory (Baird et al., 2010; Lum et al., 2012). In line with previous studies in older children (Hamrick et al., 2018; Lum et al., 2012), in the current study the declarative task showed significant correlations with lexical tasks in both groups: TD children at 4 hours post-training and DLD children at 2 weeks post-training; however contrary to our expectations no correlation with grammar skills in children with DLD emerged. The object-location-task critically merges non-verbal (visual stimuli) and verbal (verbalization of stimuli cards representing objects with varying word frequency, for example, giraffe versus dog) components, indicating that it can be regarded as a verbal task. If so, the findings support the notion that acquiring lexical, but not grammatical skills, heavily relies on declarative memory, as theoretically expected for verbal declarative memory. Future studies should utilize tasks that are more clearly categorized as either verbal or non-verbal.

In TD children, as the association between lexicon and declarative memory weakened at the 2-week post-training assessment, a simultaneous correlation emerged between lexical knowledge and both the speed and accuracy of the procedural task. This finding, although not reported before in the literature, may reflect the nature of the lexical knowledge task, which requires children to define words rather than simply recognize them. Unlike receptive vocabulary tasks (e.g., Altman et al., 2017, 2018); this task placed greater cognitive demands on retrieval and verbal expression. Furthermore, age may also affect associations between memory tasks and language abilities. While declarative memory undergoes maturation, procedural memory in children is similar or even superior to that of adults (Adi-Japha et al., 2014, 2019; Adi-Japha & Karni, 2016; Dorfberger et al., 2007) and may support lexicon development.

For children with DLD, long-term declarative knowledge seems to support lexical skills. In the current study, DLD children depicted an overall lower declarative knowledge as well as overall lower lexicon than their TD peers. Higher speed and better accuracy in the procedural task among TD children may align with better learning of lexical items by these children. Impaired procedural learning in DLD may explain why a correlation between lexical knowledge and procedural performance is missing in these children. The role of declarative memory in DLD emphasizes its potential as a target for interventions focused on vocabulary acquisition.

In TD children, but not in those with DLD, procedural memory plays a central role in the long-term development of grammar (Hamrick et al., 2018). Procedural memory is associated with learning rules and patterns, such as syntax and morphosyntax, which are fundamental for grammar acquisition (Ullman, 2004). The significant correlations found in the current study between procedural memory accuracy (which was overall lower in DLD) and grammar at 4 hours and 2 weeks post-training in TD children, but not in those with DLD, are consistent with the PDH and with Desmottes et al. (2016, 2017)'s studies. Research by Hedenius et al. (2011) and Hamrick et al. (2018) reinforce the idea that efficient procedural learning underpins typical grammar development. Further support is provided by results by Conti-Ramsden et al. (2015) that understanding content with varying grammatical complexity is related to procedural memory abilities in TD children. The findings of this study illustrate the reliance of TD children on procedural systems for mastering grammatical rules over time. Studies by Desmottes et al. (2016, 2017) reported a connection between the later phases of procedural sequence learning and grammatical abilities in TD children, but no consistent pattern emerged for children with DLD, which aligns with our study's findings. It should be noted that in the current study, the lack of correlation in children with DLD between accuracy measures of the procedural task and grammar, could have evolved due to the planning demands related to the accuracy of correct shape performance (Sosnik et al., 2014). Children with DLD are known to be challenged by motor planning demands more than TD peers (Hsu & Tseng, 2024) and this may have determined their accuracy scores, however, motor planning may not correlate with grammar.

Children with DLD performed poorer than their peers in consolidating procedural knowledge aligning with the PDH hypothesis. However, according to the declarative compensatory hypothesis (Ullman & Pullman, 2015), verbal declarative memory should compensate for procedural impairments in children with DLD. However, the ability to compensate for language deficits would be expected to increase with age as the declarative memory system matures (Ullman, 2004). The findings of the current study indicate that (verbal) declarative memory may not support grammatical skills in kindergarten children with DLD. Therefore, the declarative compensatory hypothesis regarding grammar learning in DLD cannot be confirmed by the current study. Additionally, children with DLD showed poor long-term retention of the declarative task, reducing their reliance on declarative LTM. It is possible that a purely verbal declarative task would yield different results (e.g., Lum et al., 2012).

CLINICAL IMPLICATIONS AND LIMITATIONS

The clinical implications of this study highlight the need for tailored interventions to address the specific memory retention deficits observed in children with DLD. By demonstrating that children with DLD exhibit poorer performance in both declarative and procedural memory tasks at different post-training intervals, this research suggests that early and continued support targeting these areas could mitigate long-term academic and social challenges. Moreover, the study emphasizes the importance of personalized educational strategies that consider the unique procedural and declarative memory profiles of each child, potentially enhancing language and learning outcomes.

Intervention protocols may differ in their instructional methods, suited for promoting declarative or procedural skills, as well as in their scheduling. Literature on preferred intervention methods in children with DLD may include different instruction methods that involve feedback, explicit (Ukrainetz, 2024), or implicit (Plante et al., 2010) instruction. These studies may support the distinction between teaching approaches based on the type of memory deficit. While grammatical abilities may benefit from implicit, immersion-style interventions, vocabulary growth may be reinforced with explicit instruction. Tailoring intervention strategies to the needs of children can optimize outcomes. Intervention may be applied to support initial practice, retention or generalization.

Scheduling of practice may significantly affect training results. For example, individuals with ADHD show a reduction in accuracy levels during training on a motor task (Fox et al., 2016; Goulardins et al., 2015). Furthermore, 24 hours post-training their accuracy level is reduced while that of TD peers increases, a gap that diminishes 2 weeks post-training. These individuals were found to benefit from a shorter practice session, as long practice resulted in decreasing accuracy rates due to inattention. The shorter training not only increased the accuracy levels at post-training, but also decreased the performance gap 24 hours post-training (Fox et al., 2016). Combining different methods may further enhance practice effects as skill learning commonly involves an initial explicit instructional session followed by periods of trial-and-error learning which may yield a new strategy with better results (Adi-Japha et al., 2008).

The findings of the current study should be considered within its limitations as focusing on a small age range including a small sample size. In addition, while the tasks used in this study are well-established, it is important to introduce new tasks to minimize potential task-dependent effects and to include an assessment of verbal declarative memory. In terms of procedure, all participants first performed the procedural task, and 2 weeks later performed the declarative task. Thus, future studies should examine whether there is an order effect. Furthermore, although age-appropriate, the procedural task involves many repetitions of task stimuli, which could contribute to the longer duration required for task completion 4 hours post-training. It should be noted, however, that a similar situation would regularly occur in procedural learning tasks, especially those that involve transfer tasks, which again show deficiencies in young children with language deficits (DeVeney et al., 2024). Future studies should refer to multiple practice lengths (Fox et al., 2016; Ghanamah et al., 2020, 2022, 2023).

CONCLUSIONS

The findings of the current study reveal that children with DLD performed poorly on both declarative and procedural memory at different time points in consolidation: 4 hours post-training in completion time of procedural memory and 2 weeks retention in declarative memory accuracy. Additionally, overall lower accuracy was reported for declarative as well as for procedural learning in children with DLD. Thus, overall, TD children showed better performance compared with their DLD peers on both tasks. While the results of the procedural task concur with previous studies pointing to impaired delayed performance, the results of the declarative task point to a long-term deficit and may explain why previous findings regarding declarative memory were mixed. Furthermore, correlation analyses confirmed that, as found in previous studies (see Hamrick et al., 2018), the declarative memory task correlated with lexical scores in both DLD and TD peers, and procedural memory accuracy correlated with grammatical scores only in peers. However, unlike previous studies, in the current study, the long-term phases of procedural learning completion time were associated with lexical abilities in the TD group, possibly due to the specific characteristics of the task.

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The authors have nothing to report.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

CONSENT STATEMENT

Informed consent of parents and child assent was obtained from all individual participants included in the study.

PERMISSION TO REPRODUCE MATERIAL FROM OTHER SOURCES

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APPENDIX A: GENERALIZED LINEAR MODEL—REPEATED DATA—STATISTICAL ANALYSIS OF THE OBJECT LOCATION TASK

TABLE A1 Descriptive statistics correct card locations on the object location task.

Group	Time point	Mean	STD	95% CI	
				Lower	Lower
TD	Init	14.10	0.27	13.58	14.64
	4 hours post	13.13	0.41	12.35	13.96
	2 weeks post	10.60	0.47	9.73	11.55
DLD	Init	13.17	0.28	12.64	13.73
	4 hours post	12.17	0.36	11.49	12.89
	2 weeks post	7.87	0.58	6.81	9.09

Note: Group = TD/DLD (TD, $n = 30$; DLD, $n = 23$); CI = Wald confidence interval.

TABLE A2 Goodness of fit.

Quasi-likelihood under independence model criterion (QIC)	18.253
Corrected quasi-likelihood under independence model criterion (QICC)	19.584

TABLE A3 Model effects.

	Wald chi-square	d.f.	*p*	Cramer's *V*
(Intercept)	15361.112	1	< 0.001	
Group	13.823	1	< 0.001	0.51
Time point	92.717	2	< 0.001	0.93
Group × Time point	7.631	2	0.022	0.29

Note: Group = TD/DLD (TD, $n = 30$; DLD, $n = 23$); time point = Init, 4 hours post, 2 weeks post; Cramer's $V = \sqrt{\chi^2}/(N^{*}\text{d.f.})$.

TABLE A4 Pairwise comparisons (sequential Bonferroni correction).

Group, time point	Group, time point	Mean difference	STD (mean)	d.f.	Sequential Bonferroni *p*	95% CI	
						Lower	Upper
TD, Init	TD, 4 hours post	0.967	0.433	1	**0.077**	−0.071	2.004
	TD, 2 weeks post	3.500	0.520	1	0.000	2.024	4.976
	DLD, Init	0.926	0.390	1	**0.070**	−0.048	1.900
	DLD, 4 hours post	1.926	0.449	1	0.000	0.699	3.153
	DLD, 2 weeks post	6.230	0.639	1	0.000	4.356	8.105
TD, 4 hours post	TD, Init	−0.967	0.433	1	0.077	−2.004	0.071
	TD, 2 weeks post	2.533	0.505	1	**0.000**	1.116	3.951
	DLD, Init	−0.041	0.496	1	0.935	−1.013	0.932
	DLD, 4 hours post	0.959	0.544	1	**0.155**	−0.259	2.178
	DLD, 2 weeks post	5.264	0.709	1	0.000	3.215	7.312
TD, 2 weeks post	TD, Init	−3.500	0.520	1	0.000	−4.976	−2.024
	TD, 4 hours post	−2.533	0.505	1	0.000	−3.951	−1.116
	DLD, Init	−2.574	0.543	1	0.000	−4.080	−1.068

(Continues)

TABLE A4 (Continued)

Group, time point	Group, time point	Mean difference	STD (mean)	d.f.	Sequential Bonferroni *p*	95% CI Lower	95% CI Upper
	DLD, 4 hours post	−1.574	0.587	1	0.036	−3.085	−0.063
	DLD, 2 weeks post	2.730	0.742	1	**0.002**	0.734	4.727
DLD, Init	TD, Init	−0.926	0.390	1	0.070	−1.900	0.048
	TD, 4 hours post	0.041	0.496	1	0.935	−0.932	1.013
	TD, 2wkd post	2.574	0.543	1	0.000	1.068	4.080
	DLD, 4 hours post	1.000	0.282	1	**0.002**	0.257	1.743
	DLD, 2 weeks post	5.304	0.565	1	0.000	3.658	6.951
DLD, 4 hours post	TD, Init	−1.926	0.449	1	0.000	−3.153	−0.699
	TD, 4 hours post	−0.959	0.544	1	0.155	−2.178	0.259
	TD, 2wkd post	1.574	0.587	1	0.036	0.063	3.085
	DLD, Init	−1.000	0.282	1	0.002	−1.743	−0.257
	DLD, 2 weeks post	4.304	0.598	1	**0.000**	2.592	6.016

Note: Group = TD/DLD (TD, $n = 30$; DLD, $n = 23$); time point = Init, 4 hours post, 2 weeks post; mean difference = mean group difference; CI = Wald confidence interval. Italics/non-Italics *p* bold values reflect within/between group differences, respectively.

APPENDIX B: GENERALIZED LINEAR MODEL—REPEATED DATA—STATISTICAL ANALYSIS OF THE OBJECT LOCATION TASK WITH VERBAL STM AS A COVARIATE

TABLE B1 Goodness of fit.

Quasi-likelihood under independence model criterion (QIC)	19.471
Corrected quasi-likelihood under independence model criterion (QICC)	21.584

TABLE B2 Model effects.

	Wald chi-square	d.f.	*p*	Cramer's *V*
(Intercept)	3481.159	1	< 0.001	
Group	10.388	1	0.001	0.44
Time point	92.762	2	< 0.001	0.91
Group × Time point	7.648	2	0.022	0.27
STM-NR	0.011	1	0.918	0.01

Note: Group = TD/DLD (TD, $n = 30$; DLD, $n = 23$); time point = Init, 4 hours post, 2 weeks post; STM-NR = short-term memory—number recall; Cramer's $V = \sqrt{\chi^2/(N^{*}\text{d.f.})}$. A preliminary analysis indicated no interaction effects of STM-NR with the object location task scores.

TABLE B3 Pairwise comparisons (sequential Bonferroni correction).

Group, time point	Group, time point	Mean difference	STD	d.f.	Sequential Bonferroni *p*	95% CI Lower	95% CI Upper
TD, Init	TD, 4 hours post	0.966	0.434	1	***0.105***	−0.119	2.050
	TD, 2 weeks post	3.496	0.520	1	0.000	2.019	4.973
	DLD, Init	0.897	0.470	1	**0.169**	−0.229	2.022
	DLD, 4 hours post	1.898	0.502	1	0.001	0.525	3.271
	DLD, 2 weeks post	6.209	0.707	1	0.000	4.135	8.282
TD, 4 hours post	TD, Init	−0.966	0.434	1	0.105	−2.050	0.119
	TD, 2 weeks post	2.530	0.502	1	***0.000***	1.121	3.938
	DLD, Init	−0.069	0.523	1	0.895	−1.094	0.956
	DLD, 4 hours post	0.932	0.554	1	**0.185**	−0.309	2.174
	DLD, 2 weeks post	5.243	0.748	1	0.000	3.100	7.385
TD, 2 weeks post	TD, Init	−3.496	0.520	1	0.000	−4.973	−2.019
	TD, 4 hours post	−2.530	0.502	1	0.000	−3.938	−1.121
	DLD, Init	−2.599	0.590	1	0.000	−4.234	−0.964
	DLD, 4 hours post	−1.598	0.617	1	0.048	−3.188	−0.007
	DLD, 2 weeks post	2.713	0.789	1	**0.004**	0.631	4.795
DLD, Init	TD, Init	−0.897	0.470	1	0.169	−2.022	0.229
	TD, 4 hours post	0.069	0.523	1	0.895	−0.956	1.094
	TD, 2wkd post	2.599	0.590	1	0.000	0.964	4.234
	DLD, 4 hours post	1.001	0.283	1	***0.003***	0.239	1.764
	DLD, 2 weeks post	5.312	0.556	1	0.000	3.691	6.933
DLD, 4 hours post	TD, Init	−1.898	0.502	1	0.001	−3.271	−0.525
	TD, 4 hours post	−0.932	0.554	1	0.185	−2.174	0.309
	TD, 2wkd post	1.598	0.617	1	0.048	0.007	3.188
	DLD, Init	−1.001	0.283	1	0.003	−1.764	−0.239
	DLD, 2 weeks post	4.310	0.589	1	***0.000***	2.609	6.012

Note: Group = TD/DLD (TD, $n = 30$; DLD, $n = 23$); time point = Init, 4 hours post, 2 weeks post; mean difference = mean group difference; CI = Wald confidence interval. Italics/non-Italics p bold values reflect within/between group differences, respectively.

International Journal of Language & Communication Disorders

APPENDIX C: GENERALIZED LINEAR MODEL—REPEATED DATA—STATISTICAL ANALYSIS OF THE ILT

TABLE C1 Descriptive statistics: ILT accuracy data.

Group	Time point	Mean	STD	95% CI	
				Lower	Lower
TD	Pre	13.39	0.17	13.06	13.73
	Post	13.27	0.17	12.95	13.61
	4 hours post	13.36	0.18	13.00	13.73
	2 weeks post	13.42	0.26	12.92	13.93
DLD	Pre	12.90	0.24	12.44	13.38
	Post	12.16	0.30	11.59	12.76
	4 hours post	12.33	0.27	11.80	12.87
	2 weeks post	12.49	0.29	11.93	13.08

Note: Group = TD/DLD (TD, $n = 30$; DLD, $n = 23$); CI = Wald confidence interval.

TABLE C2 Goodness of fit: Accuracy data.

Quasi-likelihood under independence model criterion (QIC)	17.712
Corrected quasi-likelihood under independence model criterion (QICC)	17.936

TABLE C3 ILT-accuracy: Model effects.

	Wald chi-square	d.f.	*p*	Cramer's *V*
(Intercept)	51354.850	1	< 0.001	
Group	9.397	1	0.002	0.42
Time point	10.121	3	0.018	0.25
Group × Time point	5.980	3	0.113	0.19

Note: Group = TD/DLD (TD, $n = 30$; DLD, $n = 23$); time point = Pre, post, 4 hours post, 2 weeks post. Cramer's $V = \sqrt{\chi^2}/(N^*\text{d.f.})$.

TABLE C4 ILT-Accuracy: Pairwise comparison (sequential Bonferroni correction).

Time point	Time point	Mean difference	STD	d.f.	Sequential Bonferroni	95% CI	
					p	Lower	Upper
Pre	Post	0.438	0.139	1	**0.010**	0.070	0.805
	4 hours post	0.313	0.141	1	0.132	−0.050	0.676
	2 weeks post	0.200	0.173	1	0.745	−0.215	0.615
Post	Pre	−0.438	0.139	1	0.010	−0.805	−0.070
	4 hours post	−0.125	0.128	1	0.**745**	−0.417	0.167
	2 weeks post	−0.238	0.174	1	0.684	−0.672	0.196
4 hours post	Pre	−0.313	0.141	1	0.132	−0.676	0.050
	Post	0.125	0.128	1	0.745	−0.167	0.417
	2 weeks post	−0.113	0.144	1	**0.745**	−0.427	0.201

Note: Mean difference = difference between time points; CI = Wald confidence interval.

TABLE C5 Descriptive statistics: ILT completion time data.

Group	Time point	Mean	STD	95% CI	
				Lower	Lower
TD	Pre	44.42	1.66	41.29	47.79
	Post	38.27	1.63	35.20	41.60
	4 hours post	34.22	1.49	31.43	37.26
	2 weeks post	33.41	1.37	30.84	36.19
DLD	Pre	45.47	2.12	41.50	49.82
	Post	37.74	1.46	34.99	40.70
	4 hours post	44.32	1.54	41.41	47.44
	2 weeks post	38.78	1.42	36.10	41.66

Note: Group = TD/DLD (TD, $n = 30$; DLD, $n = 23$); CI = Wald confidence interval.

TABLE C6 Goodness of fit: Completion time data.

Quasi-likelihood under independence model criterion (QIC)	25.621
Corrected quasi-likelihood under independence model criterion (QICC)	24.733

TABLE C7 ILT-Completion time: Model effects.

	Wald chi-square	d.f.	*p*	Cramer's *V*
(Intercept)	19,503.388	1	< 0.001	
Group	3.931	1	0.047	0.27
Time point	182.342	3	< 0.001	1.07
Group × Time point	68.702	3	< 0.001	0.68

Note: Group = TD/DLD (TD, $n = 30$; DLD, $n = 23$); time point = Pre, post, 4 hours post, 2 weeks post. Cramer's $V = \sqrt{\chi^2}/(N^*\text{d.f.})$. A preliminary analysis indicated no interaction effects of STM with the ILT scores.

TABLE C8 ILT—Completion time: Pairwise comparison (sequential Bonferroni correction).

Group, time point	Group, time point	Mean difference	STD	d.f.	Sequential Bonferroni *p*	95% CI	
						Lower	Upper
TD, pre	TD, post	6.147	0.776	1	***0.000***	3.748	8.547
	TD, 4 hours post	10.198	1.066	1	0.000	6.870	13.527
	TD, 2 weeks post	11.010	1.093	1	0.000	7.608	14.412
	DLD, pre	−1.051	2.691	1	**1.000**	−6.731	4.629
	DLD, post	6.681	2.206	1	0.037	.204	13.157
	DLD, 4 hours post	0.097	2.259	1	1.000	−4.365	4.559
	DLD, 2 weeks post	5.641	2.180	1	0.106	−0.546	11.827

(Continues)

TABLE C8 (Continued)

Group, time point	Group, time point	Mean difference	STD	d.f.	Sequential Bonferroni *p*	95% CI Lower	95% CI Upper
TD, post	TD, pre	−6.147	0.776	1	0.000	−8.547	−3.748
	TD, 4 hours post	4.051	0.863	1	***0.000***	1.483	6.618
	TD, 2 weeks post	4.863	0.952	1	0.000	1.969	7.756
	DLD, pre	−7.198	2.675	1	0.090	−14.907	0.510
	DLD, post	0.533	2.187	1	**1.000**	−3.950	5.016
	DLD, 4 hours post	−6.051	2.241	1	0.090	−12.527	0.426
	DLD, 2 weeks post	−0.507	2.161	1	1.000	−4.928	3.914
TD, 4 hours post	TD, pre	−10.198	1.066	1	0.000	−13.527	−6.870
	TD, post	−4.051	0.863	1	0.000	−6.618	−1.483
	TD, 2 weeks post	0.812	0.552	1	***0.989***	−0.672	2.296
	DLD, pre	−11.249	2.589	1	0.000	−18.899	−3.600
	DLD, post	−3.518	2.080	1	0.727	−9.206	2.171
	DLD, 4 hours post	−10.101	2.136	1	**0.000**	−16.492	−3.711
	DLD, 2 weeks post	−4.558	2.053	1	0.264	−10.319	1.204
TD, 2 weeks post	TD, pre	−11.010	1.093	1	0.000	−14.412	−7.608
	TD, post	−4.863	0.952	1	0.000	−7.756	−1.969
	TD, 4 hours post	−0.812	0.552	1	0.989	−2.296	0.672
	DLD, pre	−12.061	2.522	1	0.000	−19.645	−4.477
	DLD, post	−4.329	1.996	1	0.271	−9.865	1.206
	DLD, 4 hours post	−10.913	2.055	1	0.000	−17.184	−4.642
	DLD, 2 weeks post	−5.369	1.967	1	**0.089**	−11.102	0.363
DLD, pre	TD, pre	1.051	2.691	1	1.000	−4.629	6.731
	TD, post	7.198	2.675	1	0.090	−0.510	14.907
	TD, 4 hours post	11.249	2.589	1	0.000	3.600	18.899
	TD, 2 weeks post	12.061	2.522	1	0.000	4.477	19.645
	DLD, post	7.732	1.289	1	***0.000***	3.779	11.684
	DLD, 4 hours post	1.148	1.544	1	1.000	−2.366	4.661
	DLD, 2 weeks post	6.692	1.388	1	0.000	2.494	10.889
DLD, post	TD, pre	−6.681	2.206	1	0.037	−13.157	−0.204
	TD, post	−0.533	2.187	1	1.000	−5.016	3.950
	TD, 4 hours post	3.518	2.080	1	0.727	−2.171	9.206
	TD, 2 weeks post	4.329	1.996	1	0.271	−1.206	9.865
	DLD, pre	−7.732	1.289	1	0.000	−11.684	−3.779
	DLD, 4 hours post	−6.584	0.998	1	**0.000**	−9.656	−3.512
	DLD, 2 weeks post	−1.040	0.850	1	1.000	−3.282	1.202

(Continues)

TABLE C8 (Continued)

Group, time point	Group, time point	Mean difference	STD	d.f.	Sequential Bonferroni *p*	95% CI Lower	Upper
DLD, 4 hours post	TD, pre	−0.097	2.259	1	1.000	−4.559	4.365
	TD, post	6.051	2.241	1	0.090	−0.426	12.527
	TD, 4 hours post	10.101	2.136	1	0.000	3.711	16.492
	TD, 2 weeks post	10.913	2.055	1	0.000	4.642	17.184
	DLD, pre	−1.148	1.544	1	1.000	−4.661	2.366
	DLD, post	6.584	0.998	1	0.000	3.512	9.656
	DLD, 4 hours post	5.544	0.688	1	***0.000***	3.410	7.677

Note: Group = TD/DLD (TD, $n = 30$; DLD, $n = 23$); time point = Init, 4 hours post, 2 weeks post; mean difference = mean group difference; CI = Wald confidence interval.

TABLE C9 Testing within groups: ILT accuracy data for the TD and DLD groups. Preliminary analysis for speed–accuracy trade-off.

	Wald chi-square	d.f.	*p*	Cramer's *V*
(Intercept) TD	47412.574	1	< 0.001	
Time point (TD)	0.656	3	0.883	0.06
(Intercept) DLD	17308.226	1	< 0.001	
Time point (DLD)	11.122	3	0.011	0.26

Note: TD, $n = 30$; DLD, $n = 23$; time point = Pre, post, 4 hours post, 2 weeks post. Cramer's $V = \sqrt{\chi^2/(N^* \text{d.f.})}$.

TABLE C10 Pairwise comparison for the time point main effect (in Tabe C9) within the DLD group for the ILT accuracy data (sequential Bonferroni correction).

Time point	Time point	Mean difference	STD	d.f.	Sequential Bonferroni *p*	95% CI Lower	Upper
Pre	Post	0.739	0.225	1	**0.006**	0.147	1.332
	4 hours post	0.576	0.234	1	0.069	−0.026	1.178
	2 weeks post	0.413	0.254	1	0.417	−0.222	1.048
Post	Pre	−0.739	0.225	1	0.006	−1.332	−0.147
	4 hours post	−0.163	0.210	1	**0.873**	−0.633	0.307
	2 weeks post	−0.326	0.238	1	0.511	−0.896	0.243
4 hours post	Pre	−0.576	0.234	1	0.069	−1.178	0.026
	Post	0.163	0.210	1	0.873	−0.307	0.633
	2 weeks post	−0.163	0.209	1	**0.873**	−0.632	0.306

Note: Maen difference = difference between time points; CI = Wald confidence interval.

TABLE C11 Correlation analysis of completion time and accuracy of the ILT across participants ($N = 53$) at each time point.

Time point	Spearman *r*	*p*
Pre	−0.09	0.521
4 hours post	0.17	0.225
2 weeks post	−0.33	0.018
Pre	−0.18	0.196

APPENDIX D: GENERALIZED LINEAR MODEL—REPEATED DATA—STATISTICAL ANALYSIS OF THE ILT WITH MOTOR STM AS A COVARIATE

TABLE D1 Goodness of fit: Accuracy data.

Quasi-likelihood under independence model criterion (QIC)	21.153
Corrected quasi-likelihood under independence model criterion (QICC)	19.935

TABLE D2 ILT-accuracy: Model effects.

	Wald chi-square	d.f.	*p*	Cramer's *V*
(Intercept)	8054.174	1	< 0.001	
Group	10.094	1	0.003	0.43
Time point	8.552	3	0.018	0.23
Group × Time point	5.966	3	0.113	0.19
STM-HM	0.063	1	0.801	0.03

Note: Group = TD/DLD (TD, n = 30; DLD, n = 23); time point = Pre, post, 4 hours post, 2 weeks post; SHM-HM = short-term memory—hand-movement test; Cramer's $V = \sqrt{\chi^2/(N^*\text{d.f.})}$. A preliminary analysis indicated no interaction effects of STM with the ILT scores.

TABLE D3 ILT-accuracy: Pairwise comparison (sequential Bonferroni correction).

Time point	Time point	Mean difference	STD	d.f.	Sequential Bonferroni *p*	95% CI Lower	95% CI Upper
Pre	Post	0.437	0.139	1	***0.010***	0.070	0.805
	4 hours post	0.313	0.141	1	0.133	−0.051	0.676
	2 weeks post	0.200	0.173	1	0.748	−0.215	0.615
Post	Pre	−0.437	0.139	1	0.010	−0.805	−0.070
	4 hours post	−0.125	0.128	1	***0.748***	−0.417	0.168
	2 weeks post	−0.238	0.174	1	0.686	−0.672	0.196
4 hours post	Pre	−0.313	0.141	1	0.133	−0.676	0.051
	Post	0.125	0.128	1	0.748	−0.168	0.417
	2 weeks post	−0.113	0.144	1	***0.748***	−0.427	0.201

Note: Mean difference = mean difference between time points; CI = Wald confidence interval; Cramer's $V = \sqrt{\chi^2/(N^*\text{d.f.})}$.

TABLE D4 Goodness of fit: Completion time data.

Quasi-likelihood under independence model criterion (QIC)	31.833
Corrected quasi-likelihood under independence model criterion (QICC)	26.733

TABLE D5 ILT-Completion time: Model effects.

	Wald chi-square	d.f.	*p*	Cramer's *V*
(Intercept)	2374.017	1	< 0.001	
Group	3.624	1	0.057	0.26
Time point	182.583	3	< 0.001	1.45
Group × Time point	68.747	3	< 0.001	0.65
STM-HM	0.003	1	0.953	0.01

Note: Group = TD/DLD (TD, n = 30; DLD, n = 23); time point = Pre, post, 4 hours post, 2 weeks post; SHM-HM = short-term memory—hand-movement test; Cramer's $V = \sqrt{\chi^2}/(N^*\text{d.f.})$. A preliminary analysis indicated no interaction effects of STM-HM with the ILT scores.

TABLE D6 ILT—Completion time: Pairwise comparison (sequential Bonferroni correction).

Group[a], Time-point[b]	Group, Time-point	Mean difference[c]	*SD*	*df*	Sequential Bonferroni *p*	95% *CI* Lower	95% *CI* Upper
TD, Pre	TD, Post	6.146	.775	1	***.000***	3.750	8.541
	TD, 4 hours post	10.193	1.062	1	.000	6.877	13.510
	TD,2 weeks post	11.005	1.093	1	.000	7.603	14.407
	DLD, Pre	−1.088	2.780	1	**1.000**	−6.957	4.781
	DLD, Post	6.646	2.300	1	.058	−.106	13.399
	DLD, 4 hours post	.059	2.363	1	1.000	−4.593	4.711
	DLD, 2 weeks post	5.606	2.265	1	.147	−.822	12.034
TD, Post	TD, Pre	−6.146	.775	1	.000	−8.541	−3.750
	TD, 4 hours post	4.048	.861	1	***.000***	1.457	6.639
	TD, 2 weeks post	4.859	.952	1	.000	1.953	7.766
	DLD, Pre	−7.234	2.763	1	.118	−15.244	.776
	DLD, Post	.501	2.279	1	**1.000**	−4.150	5.152
	DLD, 4 hours post	−6.086	2.343	1	.118	−12.835	.662
	DLD, 2 weeks post	−.540	2.245	1	1.000	−5.138	4.059
TD, 4 hours post	TD, Pre	−10.193	1.062	1	.000	−13.510	−6.877
	TD, Post	−4.048	.861	1	.000	−6.639	−1.457
	TD, 2 weeks post	.812	.552	1	***.990***	−.673	2.296
	DLD, Pre	−11.282	2.685	1	.000	−19.217	−3.346
	DLD, Post	−3.547	2.184	1	.834	−9.518	2.424
	DLD, 4 hours post	−10.134	2.251	1	**.000**	−16.827	−3.441
	DLD, 2 weeks post	−4.587	2.148	1	.327	−10.617	1.442
TD, 2 weeks post	TD, Pre	−11.005	1.093	1	.000	−14.407	−7.603
	TD, Post	−4.859	.952	1	.000	−7.766	−1.953
	TD, 4 hours post	−.812	.552	1	.990	−2.296	.673
	DLD, Pre	−12.093	2.606	1	.000	−19.888	−4.298
	DLD, Post	−4.359	2.087	1	.331	−10.146	1.429
	DLD, 4 hours post	−10.946	2.155	1	.000	−17.494	−4.397
	DLD, 2 weeks post	−5.399	2.050	1	**.118**	−11.371	.573

(Continues)

International Journal of Language & Communication Disorders

TABLE D6 (Continued)

Group[a], Time-point[b]	Group, Time-point	Mean difference[c]	*SD*	*df*	Sequential Bonferroni *p*	95% *CI* Lower	95% *CI* Upper
DLD, Pre	TD, Pre	1.088	2.780	1	1.000	−4.781	6.957
	TD, Post	7.234	2.763	1	.118	−.776	15.244
	TD, 4 hours post	11.282	2.685	1	.000	3.346	19.217
	TD, 2 weeks post	12.093	2.606	1	.000	4.298	19.888
	DLD, Post	7.735	1.290	1	**.000**	3.781	11.689
	DLD, 4 hours post	1.147	1.544	1	1.000	−2.367	4.661
	DLD, 2 weeks post	6.694	1.391	1	.000	2.490	10.899
DLD, Post	TD, Pre	−6.646	2.300	1	.058	−13.399	.106
	TD, Post	−.501	2.279	1	1.000	−5.152	4.150
	TD, 4 hours post	3.547	2.184	1	.834	−2.424	9.518
	TD, 2 weeks post	4.359	2.087	1	.331	−1.429	10.146
	DLD, Pre	−7.735	1.290	1	.000	−11.689	−3.781
	DLD, 4 hours post	−6.587	.999	1	**.000**	−9.662	−3.513
	DLD, 2 weeks post	−1.040	.850	1	1.000	−3.282	1.201
4 hours post	TD, Pre	−.059	2.363	1	1.000	−4.711	4.593
	TD, Post	6.086	2.343	1	.118	−.662	12.835
	TD, 4 hours post	10.134	2.251	1	.000	3.441	16.827
	TD, 2 weeks post	10.946	2.155	1	.000	4.397	17.494
	DLD, Pre	−1.147	1.544	1	1.000	−4.661	2.367
	DLD, Post	6.587	.999	1	.000	3.513	9.662
	DLD, 4 hours post	5.547	.692	1	**.000**	3.401	7.693

Note: [a]Group = TD/DLD (TD, n = 30; DLD, n = 23); [b]Time-point = Init, 4 hours post, 2 weeks post; [c]Mean difference = mean group difference; CI = Wald confidence interval. p bold values are related to the adjacent time-points analyses discussed in this article.