Learning, Forgetting, and Relearning: Skill Learning in Children With Language Impairment

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Purpose: The current study tested whether the difficulties of children with specific language impairment (SLI) in skill acquisition are related to learning processes that occur while practicing a new skill or to the passage of time between practice and later performance.

Method: The acquisition and retention of a new complex grapho-motor symbol were studied in 5-year-old children with SLI and peers matched for age and nonverbal IQ. The children practiced the production of the symbol for 4 consecutive days. Retention testing took place 10 days later.

Results: Children with SLI began each practice day slower than their peers but attained similar levels of performance by its end. Although they increased their performance speed within sessions more than their peers, they did not retain their learning as well between sessions. The loss in speed was largest in the 10-day retention interval. They were also less accurate, but accuracy differences decreased over time. Between-session group differences in speed could not fully be accounted for based on fine motor skills.

Conclusions: In spite of effective within-session learning, children with SLI did not retain the new skill well. The deficit may be attributed to task forgetting in the presence of delayed consolidation processes.

The incidence of specific language impairment (SLI) among kindergarten children is estimated to be 7% (Tomblin et al., 1997). Children with SLI present delayed or disordered language acquisition that is not secondary to conditions such as hearing loss, developmental delay, neurological insult, or environmental deprivation. Although language performance is, by definition, the central impairment in these children, their deficits do not appear to be limited (or specific) to language and include weaknesses in basic nonlinguistic processing skills (Archibald & Gathercole, 2006; Ullman & Pierpont, 2005; Windsor, Kohnert, Loxtercamp, & Kan, 2008). For example, there is considerable evidence that within the nonlinguistic domain, the performance of children with SLI on a variety of motor tasks is slower and is more vulnerable to the influence of cumulative experience (see, e.g., Adi-Japha, Strulovich-Schwartz, & Julius, 2011; Bishop, 2002; Estil, Whiting, Sigmundsson, & Ingvaldsen, 2003; E. Hill, 2001; Lee & Tomblin, 2012).

Studies of children with SLI have considered the extent to which their deficits are specific to linguistic processing and the extent to which they are secondary to general problems in auditory perception (P. Hill, Hogben, & Bishop, 2005; Joanisse & Seidenberg, 1998; Tallal, Merzenich, Miller, & Jenking, 1998), short-term/working memory (Archibald & Gathercole, 2006; Kail, 1994), or procedural memory (Ullman & Pierpont, 2005). Deficits in short-term/working memory (Leonard et al., 2007) as well as deficits in procedural memory (Tomlin, Mainela-Arnold, & Zhang, 2007; Ullman & Pierpont, 2005) can explain impaired skill learning. However, working memory is more strongly associated with performance while learning. On a background of unimpaired initial acquisition, deficits in working memory are less likely to explain long-term deficits in retention of skills. The current study focuses on these deficits in kindergarten children with SLI.

Procedural memory is a long-term memory system that subserves the acquisition and retention of skills (“how to” knowledge) and habits, specifically the repetition-dependent, implicit knowledge of the structure of recurring experiences (Brown & Robertson, 2007; Cohen & Squire, 1980). Motor skill learning paradigms have been used extensively to study the procedural learning system. Motor skills are typically learned slowly over multiple training sessions. Children with SLI show deficits in fine and gross motor tasks such as peg
moving, bead threading, ball rolling, tapping, and handwriting fluency (Bishop & Edmundson, 1987; Corriveau & Goswami, 2009; Dockrell, Lindsay, Connelly, & Mackie, 2007; Miller, Kail, Leonard, & Tomblin, 2001; Powell & Bishop, 1992). These skills require repeated training to be mastered and are acquired by the procedural memory system through repeated training (Robertson, Pascual-Leone, & Miall, 2004; Ullman, 2004).

Skill acquisition initially develops relatively fast across different experimental paradigms (i.e., rapid improvements measured over the course of a single training session) and later slows as further gains develop incrementally over multiple practice sessions until performance reaches nearly asymptotic levels (for a review, see Doyon & Benali, 2005). Progression from fast to slow motor skill learning is thought to depend on appropriate consolidation processes (Doyon & Benali, 2005; Robertson et al., 2004), defined as the progressive stabilization of a recently acquired memory (Dudai, 2004). It has been shown, in both adults and children, that significant training-dependent gain in performance following a training experience can appear hours after the termination of training, for example, 24 hours post-training (Dorfberger, Adi-Japha, & Karni, 2007; Savion-Lemieux, Bailey, & Penhune, 2009). This enhancement reflects memory consolidation processes for the newly acquired skill. Ullman (2004) highlighted the fact that the procedural memory system is involved in the acquisition of language skills and habits, such as our implicit knowledge of language rules, in addition to the acquisition of new motor skills. It was later shown that consolidation processes support the extraction of grammatical aspects for words (Wilhelm, Prehn-Kristensen, & Born, 2012), for example, in language learning of infants (Gomez, Bootzin, & Nadel, 2006), and therefore enhance word learning (Dumay & Gaskell, 2007; McGregor, Rohlfling, Bean, & Marschner, 2009).

Consolidation gains are not always apparent 24 hours post-training. These gains were shown to exist only after an intensive training on simple motor tasks. A shift in processing within the initial training session from steep improvement to saturation (a plateau performance), which occurs after a critical number of task iterations, was proposed as a necessary trigger for individuals’ improvement between daily sessions. Failure to reach saturated performance, which may have occurred either due to an insufficient amount of training or due to task complexity (Wilhelm, Fischer, & Born, 2008), resulted in retention of the skill level (Hauptmann, Reinhart, Brandt, & Karni, 2005). Between-session effects can also be negative in the absence of saturation and related consolidation, presumably due to forgetting processes (Adams, 1952, 1987; Dayan & Cohen, 2011). The passage of time between sessions is assumed to be essential for a maximum benefit of practice to be gained, since the time delay may allow consolidation of learning. However, a long duration of the delay may hinder retrieval due to forgetting (Savion-Lemieux & Penhune, 2005).

Several studies have shown poor procedural learning in individuals with SLI in the learning (training) phase (Lum, Conti-Ramsden, Morgan, & Ullman, 2014; Tomblin et al., 2007; but see Gabriel, Stefaniak, Maillard, Schmitz, & Meulemans, 2012). Other studies have shown additional deficits in the formation of long-term procedural memories, assessed as the level of retention of the learned skill. Deficits were reported when assessment took place 24 hours post-training (Adi-Japha et al., 2011) or a few days post-training (Hedenius et al., 2011). It was suggested that these children presented a unique deficit in forming long-term memories for newly acquired procedural skills: loss of knowledge (Hedenius et al., 2011). This is in contrast to the gain in knowledge that is expected through memory consolidation. For example, Adi-Japha et al. (2011) used a simple grapho-motor task (a dot-to-dot task compromised of three dots) with only one session of training. The study demonstrated that 5-year-old children with SLI were slower at performing the task 24 hours following the initial training, whereas their peers improved their speed of performance significantly, thus creating a significant difference between the groups. At 2 weeks post-training, however, children with SLI closed the gap as their performance speed improved relative to their 24 hours post-training, but not significantly beyond the level reached at post-training.

A complex dot-to-dot pattern production task composed of six dots was used in the present study in order to further study the deficit of children with SLI in the consolidation and retention of new skills. Participants were 5-year-old children with SLI and their peers. This task has relevance to the development of grapho-motor skills (e.g., handwriting), skills that are central in young children’s everyday life. It resembles dot-to-dot tasks used in kindergarten and is an extension of a previously used dot-to-dot task in kindergarten children (Adi-Japha et al., 2011). Invented letter writing (Longcamp, Zerbato-Poudou, & Velay, 2005), grapho-motor mirror drawing tasks (Sosnik, Hauptman, Karni, & Flash, 2004; Vicari et al., 2005), circle drawing (Vinter & Detable, 2008; Vinter & Perruchet, 2000), as well as real letter writing (Adi-Japha & Freeman, 2000, 2001; Adi-Japha et al., 2007; Balas, Nester, Giladi, & Karni, 2007; Dorfberger, Adi-Japha, & Karni, 2009; James, 2010; James & Gauthier, 2006) have been used extensively in both behavioral and brain imaging experiments (see, e.g., James, 2010; Wamain, Tallet, Zanone, & Longcamp, 2012) for studying the effect of training on letter-form recognition and grapho-motor performance.

The Current Study: Specific Hypotheses and Research Questions

The aim of the current study was to test the acquisition and retention of a new complex motor skill in preschool children with SLI. Saturated performance in complex tasks is expected to appear only after several training sessions (Yarrow, Brown, & Krakauer, 2009), and training in the current study therefore extended over 4 days. Retention was tested 10 days after the last training session. Because saturation is expected to be delayed, greater effects of between-session forgetting were expected. Two research hypotheses were put forward.

Based on previous studies (Adi-Japha et al., 2011; Hedenius et al., 2011), it was hypothesized that the children
with SLI and their peers in the comparison group would exhibit effective within-session learning. Effective learning is defined by improvement in at least one of the measures, speed or accuracy, but not at the expense of the other. Effective within-session learning sets the stage for studying between-session differences.

Based on previous studies, it was expected that significant group differences would emerge between sessions because children with SLI would show slowing of performance. Two intervals were expected to show significant group differences: between Day 1 and Day 2 (Adi-Japha et al., 2011) and between Day 4 and retention testing (Hedenius et al., 2011). In line with theories of forgetting, it was hypothesized that group differences would be larger in the 10-day interval between Day 4 and retention testing than between the daily training sessions.

Further analyses were carried out to test whether children with SLI who have low motor skills show a different pattern of learning than their group peers.

**Method**

**Participants**

Thirty-two Israeli kindergarten children participated in the current study. Sixteen children with SLI (3 girls and 13 boys) ages 60–74 months were recruited from language kindergartens. Sixteen children with typical development (3 girls and 13 boys) ages 59–73 months were recruited as a comparison group. The participants spoke Arabic as their first language and used their right hand when they drew. All of the participants were monolingual and attended Arabic-speaking kindergartens. Participating children were recruited from kindergartens in a centrally located area in Israel. According to the Central Bureau of Statistics, the participating kindergartens were from neighborhoods of low-middle socio-economic status (SES) with an average maternal education of 11–13 years. Similar levels of SES and education are reported for the area of referral to the kindergartens of the children with SLI and for the area of referral to the kindergartens of the children in the comparison group.

Children are admitted to a language kindergarten based on significant primary language impairment, normal nonverbal intelligence, and sound adaptive behavior skills. The placement committee (comprised of the special education kindergarten district supervisor, municipal kindergarten psychologist, and special education therapists) assesses 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) adapted to Arabic (Liblich, 1975). 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 clinical practice in Israel and having normal performance IQ (Friedmann & Novogrodsky, 2004).

It should be noted that language tests for Arabic speakers are translations that were not normed in Israel. However, nonverbal tests used by the Ministry of Education were normed in Israel (Liblich, 1979).

Consent forms were sent to parents of children who were identified by the teachers of the language kindergarten as having normal hearing, no additional communication disorders, no formal diagnosis or signs of attention deficit disorder, and not regularly taking any medication. Consent forms were sent to parents of children with typical development from two kindergartens in the same area. The 32 children, matched by age and raw scores on a Raven Colored Matrices test (Raven, Raven, & Court, 1991), were tested on the Preschool Language Scale—3 (PLS–3; Zimmerman, Steiner, & Pond, 1992). Children were eligible to participate in the study if they scored in the normal range of the Raven test. Children were identified as having SLI if they scored ≤ 1.25 SDs on the PLS–3.

The PLS–3 was translated into Arabic at the Hearing and Speech Clinics, Al-Ahliyya Amman University, and is used by practitioners in Jordan. This version is used in the area of the kindergartens recruited to participate in the current study. The norms of the English version were used.

**Measures**

Measures in the current study included tests of basic skills used for comparing the groups (a visual-motor integration test and two sequential short-term memory tests) and the study task.

**Tests of basic skills.** The children were further tested on the Beery–Buktenica Developmental Test of Visual-Motor Integration (Beery–VMI; Beery, Buktenica, & Beery, 2006), which was used to assess the extent to which the participants could integrate their visual and grapho-motor abilities, and on two sequential short-term memory tests: the number recall and the hand movement measures from the sequential subtests of the Kaufman Assessment Battery for Children (K–ABC: Kaufman & Kaufman, 1983). The K–ABC was adapted to Hebrew and was normalized in Israel (Phizer, Shimborzy, Walf, & Hazani, 1995). 

**Beery–VMI.** This test assesses the extent to which individuals can integrate their visual and motor abilities. The test contains a sequence of 27 geometric forms of increasing complexity, ranging from a simple vertical line to a complex three-dimensional star. The children are asked to copy each item as accurately as possible. Testing continued until the child made three consecutive errors.

**Number recall.** The experimenter read a random string of digits of varying lengths (two to seven digits) out loud. The children were asked to repeat the string in the same order. Testing continued until the child made three consecutive errors.

**Hand movement test.** The children were presented with a random sequence of movements (palm down, fist, and side) of varying lengths (two to five movements) and were requested to imitate the movements. Testing continued until the child made three consecutive errors. Table 1
provides descriptive data of the children with SLI and their peers. Groups were comparable in age and on the raw and standard score of the Raven test. Results of the Beery–VMI and of the Kaufman number recall and hand movement tests indicated superior performance of the comparison group, suggesting significant differences in visual-motor integration skills and in short-term memory span between groups. The PLS–3 scores indicated that the language scores of the comparison group were in the normal range and were significantly better than the scores of the children with SLI. Participants from the comparison group had a standardized score ≥85 on the total score of the PLS–3, whereas each of the children with SLI had a standardized score ≤82. All children scored at or above the 90th percentile on the Raven’s standardized scores (U.S. norms are available for age 5 [Raven & Summers, 1986] with no group difference, although caution should be exercised when using these norms; see Raven, 2000).

The two groups of children were of similar age. The raw scores on all measures were also compared, and group differences reported in Table 1 remained: t(30) = 3.22, p < .01; t(30) = 4.58, p < .001; t(30) = 3.64, p < .01; t(30) = 7.04, p < .001, for the raw scores of the Beery–VMI, Kaufman number recall and hand movement tests, and the PLS–3 total raw score, respectively.

The study task: A complex dot-to-dot pattern production task. The task was used to study the time-dependent course of acquisition of a complex motor task. This dot-to-dot task consists of six dots and involves four point-to-point planar movements. The task does not require memory load because the visual stimulus is available to the participants throughout the task. The current task is a complex version of a previously used invented letter task (Adi-Japha et al., 2011) that consisted of three dots and involved two movements.

In the complex dot-to-dot pattern production task, children are asked to connect six encircled dots (circle diameter = 2 mm) with lines (see Figure 1). Movement progress is from right to left (as in Arabic writing). Each experimental block was comprised of three rows of nine dot-to-dot shapes.

Coding and analyses. Each experimental block was coded for speed using a stopwatch (Adi-Japha et al., 2011). Time was computed from the first touch of the pencil tip on the page, until completion, and was coded in seconds. Accuracy was manually scored as the number of encircled dots that were correctly passed (total of 162 points per block). About 5% percent of the sample data were randomly chosen (60 blocks) and coded for accuracy by an additional rater. Cohen’s κ coefficient for independent, point-to-point, inter-rater agreement was .91 (p < .001).

Within-session performance was estimated as the gains accrued within each training day. Between-session performance refers to differences in performance between the first block of a session and the last block of the preceding session. Within- and between-session differences were analyzed using analysis of variance (ANOVA) for repeated measures. The Greenhouse–Geisser correction was used when appropriate. The Bonferroni correction was used in cases of multiple comparisons. Analyses were carried out using SPSS. It should be noted that in SPSS, the reported Bonferroni correction p-value is the actual value of the probability multiplied by the number of comparisons. Thus, if the actual (least significant difference [LSD]) result is p = .013 and there are three groups, the reported Bonferroni would be .013 × 3 = .039. The alpha level in all analyses was .05.

A power-law model was found to fit well with group averages for different learning paradigms. In an additional analysis, daily performance time data were fitted with a power-law model, and the between-session difference in performance times was tested by comparing the performance of the first block of Days 2, 3, 4 and retention testing with the performance level predicted by an extrapolation of the performance in the preceding session (Adi-Japha, Badeer, Dorfberger, & Karni, 2014; Adi-Japha, Karni, Parnes, Loewenschuss, & Vakil, 2008; Rickard, 2007). Learning curve analysis is considered more reliable for testing between-session differences (Robertson et al., 2004; Stickgold, 2005).

Procedure

The experiment was held on 4 successive days (Days 1–4), and long-term retention was tested on Day 14. Testing on all days was identical and included seven experimental blocks. The experimenter (second author) explained the task to the children on each of the five experimental days: The children were asked to look at the pattern in the

Table 1. Descriptive data of the two groups.

<table>
<thead>
<tr>
<th></th>
<th>Children with SLI</th>
<th>Comparison group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Age (months)</td>
<td>66.25</td>
<td>4.55</td>
</tr>
<tr>
<td>Raven (raw)</td>
<td>15.00</td>
<td>3.10</td>
</tr>
<tr>
<td>Raven (standard)</td>
<td>104.75</td>
<td>7.58</td>
</tr>
<tr>
<td>Beery–VMI (standard)</td>
<td>85.81</td>
<td>13.84</td>
</tr>
<tr>
<td>PLS–3 (total score, standard)</td>
<td>76.68</td>
<td>4.08</td>
</tr>
<tr>
<td>Kaufman–Number recall (standard)</td>
<td>5.30</td>
<td>2.89</td>
</tr>
<tr>
<td>Kaufman–Hand movement test (standard)</td>
<td>6.58</td>
<td>2.75</td>
</tr>
</tbody>
</table>

Note. SLI = specific language impairment; Raven = Raven Progressive Matrices; Beery–VMI = Beery–Buktenica Developmental Test of Visual-Motor Integration; PLS–3 = Preschool Language Scale–3.

**p < .01. ***p < .001.
upper line and were told that they need to connect the dots as shown in the pattern, on their own. The experimenter explained that the drawn line needs to go through all of the required dots, in one continuous movement. The children were given one practice line in a paced manner at the beginning of each experimental day. Children who did not succeed in connecting the dots of all nine patterns in that line were given an additional explanation with emphasis on accurately progressing between the dots, and they practiced another line. Following this procedure, the children were given the first block and were asked to complete the dot connection as rapidly and accurately as possible ("حاول أن تكون سريع ودقيق في الهسكة"; "Try to be as fast and as accurate as you can").

Overall, 35 blocks of the task were performed. On all testing days, the blocks were separated by 15 to 30 seconds. The experimental task was performed by the children on half of an A4 sheet of paper, using a HB pencil. After completion of each experimental block, the experimenter placed an identical sheet of paper in front of the child, for completion. No feedback was provided on any performance measure, only general encouragement:

"أنت جيد، تقدم بشكل ممتاز"

"الإجابة": "You are good and advancing excellently"

"الإجابة": "Pay attention"

"تذكر أن تكون سريع ودقيق في الهسكة": "Remember to be as fast and as accurate as you can"

A daily session took 20–25 minutes, including the initial training procedure. The children were happy to participate in the study but needed more encouragement toward the end of the session. Prizes of school supplies (e.g., markers, stickers, etc.) were handed out at the end of each session. Block performance time varied from 3–5 minutes in Block 1 to 1–2 minutes for the last experimental block. The children were tested on the selection tests and on the tests of basic skills on two separate days, before and after the experimental paradigm.

### Results

Separate analyses were conducted in order to test group differences in within-session and between-session gains in speed and accuracy. These analyses were followed by a test of possible speed–accuracy trade-offs. In an additional section, analyses were carried out to test whether children with SLI who have low motor skills show a different pattern of learning than their group peers.

#### Speed of Performance

The block time data are presented in Figure 2A. The within-session and between-session analyses refer to the performance in the five days of experiment: Days 1–4 (training) and Day 14 (retention test).

**Within-session group difference in speed.** Speed of performance was subjected to a 5 (days) × 7 (blocks per day) × 2 (groups) analysis of variance (ANOVA) for repeated measures. Participants improved their performance across the experimental period and across blocks in each day, as shown by a day main effect, F(4, 120) = 52.40, p < .001, h² = .63, and a block main effect, F(6, 180) = 57.79, p < .001, h² = .66. These main effects were modulated by a Day × Block interaction, F(24, 720) = 9.00, p < .001, h² = .23; a Day × Group interaction, F(4, 120) = 2.50, p < .05, h² = .08; and a Block × Group interaction, F(6, 180) = 9.03, p < .001, h² = .21. The Day × Block interaction indicated that improvement across blocks on Day 1 was significantly larger than on all other days for both groups. Specifically, the difference between the first and the last block on Day 1 was significantly larger than this difference in all other sessions (Bonferroni for comparing across days, p < .01 for both). It should be noted that performance speed on the last three blocks of Day 1 decreased significantly, F(2, 60) = 3.90, p < .03, with no group difference, suggesting that both groups did not reach saturation by the end of Day 1.

The Day × Group interaction suggests that the two groups improved across the 2-week period, but at different rates. Post hoc analysis of the interaction across the four intervals between days of training indicated an interaction between Days 2 and 3, F(1, 30) = 6.29, p < .02, h² = .17, where only children with SLI showed significant improvement in their averaged daily performance, t(15) = 3.56, p < .01; and between Day 4 and retention testing on Day 14, F(1, 30) = 6.07, p < .02, h² = .17, where only the comparison group showed significant improvement, t(15) = 2.80, p < .05. Importantly, only the comparison group showed no improvement across blocks on Day 14, indicating saturated performance.

The group of children with SLI improved within each day more than the comparison group. This was the source of the Block × Group interaction, F(1, 30) = 12.84, p < .001, h² = .30, for the difference in the averaged within-session gains between groups. Between pairs of subsequent blocks,
significant group differences emerged between Blocks 2 and 3, where children with SLI improved more than the comparison group, $F(1, 30) = 6.18, p < .02, \eta^2_p = .17$. These data suggest that the within-sessions group difference decreased with daily practice. Both groups rapidly improved between Blocks 1 and 2, but group differences decreased because children with SLI improved more than their peers between Blocks 2 and 3. As indicated in Figure 2, the group of children with SLI was slower than the comparison group on Block 1 on each of the experimental days, and they closed the gap by the end of the session on Block 7. An analysis of group differences in speed of performance on Block 1 and on Block 7 of each day (see Table 2) indicates that children with SLI were significantly slower than their peers on Block 1 of Days 1, 2, and 14. However, no group differences emerged on Block 7.

Between-session group difference in speed. Analysis of the between-session difference in speed of performance (the difference between the production time of Block 7 of a session and Block 1 of the subsequent session on the following day) was undertaken in order to test the notion of slowing by children with SLI between sessions. The 4 (between-session differences) × 2 (group) analysis indicated that, overall, the comparison group had a smaller between-session difference, $F(1, 30) = 12.28, p < .001, \eta^2_p = .29$; that the between-session difference had different magnitudes across days, $F(3, 90) = 4.28, p < .01, \eta^2_p = .13$; and that there was an interaction effect, $F(3, 90) = 7.66, p < .001, \eta^2_p = .20$, suggesting that the between-session difference across days differed between the groups.

A follow-up analysis on the interaction indicated two significant differences between the groups: between Day 1 and Day 2, $t(30) = 2.73, p < .02, \eta^2_t = .33$, and between Day 4 and retention testing on Day 14, $t(30) = 4.72, p < .001, \eta^2_t = .60$. These between-session differences reflected slowing of performance in children with SLI (negative enhancement on Day 2 and Day 14), $t(15) = 2.53, p < .03, \eta^2_t > .30$, but not for the control group, $p > .1$. It is interesting to note that all of the children in the SLI group (16/16) slowed their performance between Day 4 and retention testing. Pair-wise comparisons revealed that the group difference between Day 1 and Day 2 was significantly larger than between Day 2 and Day 3, $F(1, 30) = 6.44, p < .02, \eta^2_p = .18$; and that the group difference between Day 4 and retention testing was significantly larger than between Day 2 and Day 3, $F(1, 30) = 21.74, p < .001, \eta^2_p = .42$, and between Day 3 and Day 4, $F(1, 30) = 14.38, p < .001, \eta^2_p = .32$. No group differences emerged between Day 2 and Day 3 and between Day 3 and Day 4 because both groups slowed their performance in these intervals, $F(1, 30) = 11.67, p < .01, \eta^2_p = .28$; $F(1, 30) = 18.30, p < .01, .001, \eta^2_p = .38$. These findings indicate that slowing of performance in children with SLI at the onset of Day 2 and retention testing were atypical.

Learning curve analysis of the between-session difference within groups. A power law analysis was undertaken in order to test whether the between-session slowing within each group differed between days. In this analysis, a power-law function, $f(x) = ax^b$, was fitted to the group averaged data of each day and extrapolated to an additional block. The differences between actual and previous-day extrapolation data (Rickard, 2007) on Block 1 of Days 2, 3, and 4 and retention testing were compared.

The power law fit was significant for the two groups for all five sessions, $R^2 > .70, p < .05$, for all sessions of both groups, except for the two last sessions of the comparison group, which were not fitted as well, $R^2 > .50$. The data were fitted using the power-law function, $f(x) = ax^b$, with three parameters: $a$, the initial production time; $b$, the rate of change; and $x$, the number of days. The power-law function was fitted to the group averaged data of each day and extrapolated to an additional block.
were correctly passed per block) are depicted in Figure 2B.

Block 1 of Day 3 (was significantly larger in this group than the slowing on (larger than this difference on Block 1 of Day 3 and Day 4 slowing) on Block 1 of retention testing was significantly difference between actual and predicted values (relative twice as large as other between-session differences. The last day of practice and retention testing was more than of children with SLI. Slowing of performance between the within-group differences in performance) was detected in performance between Day 2 and Day 3 in interaction. When tested within groups, a marginal difference only between-session difference in which children with SLI did not show significant slowing in performance. The Block × Group interaction similarly indicated no change across blocks for the control group as opposed to improvement for the group of children with SLI. This interaction was significant only on Day 1, $F(6, 180) = 2.20$, $p < .05$, $η^2_p = .07$, with significant improvement for the group of children with SLI, $F(6, 90) = 2.25$, $p < .05$, $η^2_p = .13$. Groups accuracy was comparable only by Block 7 of Day 14 (see Table 2).

**Table 2.** Between-group differences in speed and accuracy on Blocks 1 and 7.

<table>
<thead>
<tr>
<th>Day</th>
<th>Block</th>
<th>Children with SLI</th>
<th>Comparison group</th>
<th>Speed (s)</th>
<th>Accuracy (#/162)</th>
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<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
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$p < .05$, and which had a power law coefficient that was only marginally different from 0, $t = 2.38, 2.41; p = .06, .06$; $η^2 = .28$.

Next, the power law models for the group averaged data of Days 1, 2, 3, and 4 were extrapolated to an additional block, and the differences between this extrapolation and each individual’s performance on the first block of the next session was assessed. The analyses indicated that performance in children with SLI was significantly slower than expected on Block 1 of Day 2, Day 4, and retention testing on Day 14, $t(15) = 2.31, 2.18, 4.29; p < .04, .05, .001$; $η^2 = .26, .24, .55$. No significant differences were found in the analyses of the comparison group.

Bonferroni follow-up analysis on the between-session slowing indicated significant differences only in the group of children with SLI. Slowing of performance between the last day of practice and retention testing was more than twice as large as other between-session differences. The difference between actual and predicted values (relative slowing) on Block 1 of retention testing was significantly larger than this difference on Block 1 of Day 3 and Day 4 ($p < .01$). Furthermore, the slowing on Block 1 of Day 2 was significantly larger in this group than the slowing on Block 1 of Day 3 ($p < .05$). These findings corroborate the results of the linear models presented in the last section.

**Accuracy of Performance**

The accuracy data (number of encircled dots that were correctly passed per block) are depicted in Figure 2B. The maximal possible score was 162.

**Within-session group difference in accuracy.** Accuracy data were analyzed using a $5$ (day) $\times 7$ (blocks per day) $\times 2$ (groups) ANOVA for repeated measures. The results indicated that the performance of children with SLI was less accurate than that of their peers, with an overall improvement in accuracy across blocks, as indicated by a group main effect, $F(1, 30) = 8.59, p < .01$, $η^2_p = .23$, and a block main effect, $F(6, 180) = 3.49, p < .01$, $η^2_p = .10$. These main effects were modulated by a Day $\times$ Group interaction, $F(4, 120) = 5.77, p < .001$, $η^2_p = .16$, and a Block $\times$ Group interaction, $F(6, 180) = 4.13, p < .001$, $η^2_p = .12$.

The Day $\times$ Group interaction emerged because, although children with SLI were less accurate than their peers, the difference in accuracy diminished across the experimental period. The comparison group maintained its accuracy close to the ceiling score throughout the entire period (with a mean score of 151.31/162), whereas the group of children with SLI became more accurate from Day 1 (with a mean score of 128.21/162) to Day 14, the retention testing session (with a mean score of 135.83/162), $t(15) = 2.53, p < .03$, $η^2 = .30$.

The Block $\times$ Group interaction similarly indicated no change across blocks for the control group as opposed to improvement for the group of children with SLI. This interaction was significant only on Day 1, $F(6, 180) = 2.20$, $p < .05$, $η^2_p = .07$, with significant improvement for the group of children with SLI, $F(6, 90) = 2.25$, $p < .05$, $η^2_p = .13$. Groups accuracy was comparable only by Block 7 of Day 14 (see Table 2).

**Between-session group difference in accuracy.** The accuracy of between-session differences was subjected to a $4$ (between-session differences) $\times 2$ (groups) ANOVA for repeated measures. The analysis indicated no main effects or interaction. When tested within groups, a marginal difference was detected in performance between Day 2 and Day 3 in children with SLI, $r(15) = 1.97, p < .07$, $η^2 = .21$, where children with SLI were less accurate on Block 1 of Day 3 than on Block 7 of Day 2. It should be noted that this is the only between-session difference in which children with SLI did not show significant slowing in performance.

**Speed–Accuracy Trade-Offs**

Overall, speed and accuracy were negatively correlated in children with SLI, $r(16) = .51, p < .05$, indicating that children who performed the task faster were also more accurate. No significant correlation was found in the comparison group, possibly due to a ceiling effect in accuracy. Furthermore, for children with SLI, averaged daily
improvement in speed from Block 1 to 7 was negatively correlated with the difference in accuracy between these blocks on Day 3 and Day 4, $r(16) = .51, p < .05$; $r(16) = .64$, $p < .01$, respectively, indicating improvements in both speed and accuracy. Between-session differences were studied as well. A negative correlation was found only for the group of children with SLI between Day 2 and Day 3: Becoming less accurate on Day 3 meant becoming slower in speed as well. These data suggest that the group of children with SLI did not gain in speed within-session at the expense of accuracy and that the lower accuracy reported on Block 1 of Day 3 did not emerge due to an increase in speed.

**Associations Between Task Learning, Low Motor Skills, and Language Measures**

Overall, children with SLI had lower scores on the motor tests. Six of the 16 children in the group of children with SLI had a standardized score of 1 SD or more below the mean on the Beery-VMI as well as on the Kaufman hand movement test, suggesting that these children were more impaired in motor skills than their peers. These children also had significantly lower overall accuracy (but not speed) scores, $t(14) = 3.07, p < .01$, although their averaged daily improvement from Block 1 to Block 7 in speed and in accuracy was similar to that of their peers, $p > .13$. These children did not show any slowing more than their peers between sessions, $t(14) = 1.61, p > .1$, and specifically not between Day 1 and Day 2, $t(14) = 1.92, p = .08, \eta^2 = .19$, or between Day 4 and retention testing, $t(14) = 0.56, p > .50$. These data suggest that children with SLI who had low motor skills showed lower accuracy but nevertheless improved daily in their performance.

To further strengthen the notion that between-session slowing in children with SLI could not be fully explained by the lower motor skills of some of these children, between-session group differences in speed were tested after controlling for the raw scores on the Beery-VMI as well as on the Kaufman hand movement test. Findings suggest that the overall between-session slowing presented by children with SLI was larger than that presented by their peers, $F(1, 28) = 4.29, p < .05, \eta^2 = .13$. Furthermore, the group difference of the between-session slowing between Day 4 and retention testing remained significant, $F(1, 28) = 7.54, p < .01, \eta^2 = .21$. However, the group difference on Block 1 of Day 1 and Day 2 as well as the group difference in slowing of performance between Day 1 and Day 2 were no longer significant after adding the covariates ($p > .1$ for both).

The overall between-session slowing as well as slowing of performance between Day 4 and retention testing were associated with language comprehension scores even after controlling for the motor skills, Day 4: $r_p = .72, p < .01$; retention testing: $p < .01$, $r_p = .74$, suggesting that association between language and slowing of performance in children with SLI may not be fully accounted by differences in visual-motor integration skills and sequential short-term motor memory.

**Discussion**

The aim of the current study was to test whether difficulties of children with SLI in skill acquisition are related to learning processes that occur while practicing a new skill or to the passage of time between practice and later performance. Five-year-old children with SLI and their peers practiced the production of a complex grapho-motor pattern on 4 successive days. Retention was tested 10 days later. Our results show that children with SLI improved their speed of performance within the practice sessions more than their peers. Furthermore, although these children were overall less accurate than their peers, they steadily improved their accuracy during practice, whereas the comparison group maintained its high accuracy across the experimental sessions. These data indicate effective within-session learning in children with SLI.

The performance of children with SLI was, however, characterized by loss of speed between successive sessions held on different days. Significant group differences emerged 24 hours post-initial training (on the second training day) and after the 10-day retention interval. Whereas the comparison group maintained its level of performance, children with SLI became slower. Their initial performance on the onset of the second training day and retention testing was slower than at the end of the preceding training day. Performance losses in speed of children with SLI were larger when the sessions were 10 days apart (at retention testing) than when they were 1 day apart. These data suggest that the difficulties of children with SLI in skill acquisition are related to the passage of time between practice and later performance (Adi-Japha et al., 2011; Hedenius et al., 2011) and occur because of forgetting. The lower motor skills in the group of children with SLI did not fully account for the between-session group differences in performance speed.

**Learning, Consolidation, and Retention of Skills in Children With SLI**

In the current study children with SLI improved more than their peers within sessions, a finding that indicates effective within-session learning. This result is similar to results of studies in children with SLI who had a large number of task repetitions (Lum et al., 2014). It has been suggested that speed-up in children with SLI is delayed (Adi-Japha et al., 2011; Tomblin et al., 2007), and therefore a small number of task iterations may result in a group difference. In the current study, children with SLI improved more than their peers between Blocks 2 and 3, rather than between Blocks 1 and 2, supporting the notion of a longer period of speed-up.

The complex task in the current study was not acquired within one training session, as indicated by a performance level that did not reach saturation by the end of first training day. This suggests that consolidation processes were not completed 24 hours post-training, as evidenced by the finding that enhanced performance did not evolve. Children with SLI showed atypical slowing of performance.
at the onset of the second training day, whereas their peers maintained their level of performance. Maintenance of performance level in the comparison group is in line with reports about skill acquisition in adults (Hauptmann et al., 2005) and indicates partial consolidation. The slowing of performance in children with SLI supports the notion of impaired consolidation processes in this population. The finding that no slowing occurred between the second and third day of training may suggest that consolidation processes in this group are delayed (Adi-Japha et al., 2011).

The performance in the retention test of the comparison group was saturated. Importantly, the 14th day performance maintained the level achieved by the end of the 4th training day. This suggests that the consolidation process was completed in this group shortly after the 4th training day. The loss of speed in the group of children with SLI further indicates impaired consolidation processes in this group. The loss of speed in the 10-day retention interval was larger than the loss of speed in the 24-hour interval between training days, in line with accounts of a decrease in performance due to forgetting of behavioral support structure for the skill (Adams, 1952, 1987). These data support the notion that the slowing of children with SLI reflected forgetting as a result of the passage of time between practice sessions (Anderson, Fincham, & Douglass, 1999; Dayan & Cohen, 2011; Savion-Lemieux & Pennhune, 2005). Consolidation processes stabilize the amalgamation of task-general and task-specific skills as well as the concatenation of smaller task units into a new unit (Adi-Japha et al., 2008; Sosnik et al., 2004). These processes merge the behavioral support structure for the skill with the movements required to perform the task, thereby enhancing task performance and reducing forgetting. In the absence of consolidation, forgetting facilitated the performance of children with SLI between sessions.

It has been suggested that forgetting decreases performance on a short time scale (i.e., between sessions) and consolidation processes are incremental and improve performance over a longer time scale (Newell, Mayer-Kress, Hong, & Liu, 2009; Rickard, 2007). This may explain the finding that overall children with SLI improved their performance across days as indicated by their performance at the end of sessions. By the end of retention testing children with SLI reached levels of performance similar to their peers in both speed and accuracy.

Not all studies report retention deficits in children with SLI, possibly due to task differences. In a simpler grapho-motor learning task of sequentially connecting only three dots (Adi-Japha et al., 2011, rather than six as in the current study), saturation by children with SLI and typically developing children was achieved at the end of the first training session. Children with SLI showed slowing of performance 24 hours post-training, but they closed the gap following a 2-week retention period. Furthermore, no group differences in the motor pursuit task were reported at retention testing 2 weeks post-training, possibly because this task does not involve sequence-specific information (Hsu & Bishop, 2014).

**Skill Acquisition and Motor Deficits in Children With SLI**

In the current study, participants with SLI had lower motor skills than their peers and had overall lower accuracy scores on the grapho-motor task. Impaired grapho-motor activity, whether tested by tracing figures (Estil et al., 2003), design copying (Marton, 2008), or handwriting fluency (Dockrell et al., 2007), characterizes motor difficulties in SLI. Motor skills were also associated with group differences in speed of performance at the onset of training. This suggests that low motor skills are associated with some deficits in procedural learning. However, children with SLI who had lower motor abilities showed a pattern of learning that was similar to that of their group peers. Furthermore, motor skills could not fully explain the difference between groups due to the loss of speed by children with SLI between sessions, both for differences averaged across the training days and between the end of the 4th training day and the retention test. These findings may explain why children with SLI benefited less than their peers from practice (Windsor et al., 2008). It is possible that children with SLI tend to stress accuracy over speed and may benefit from instructions that emphasize speed, in order to reduce slowing between sessions. This behavior was described in Parkinson’s disease motor dysfunction (Mazzoni, Hristova, & Krakauer, 2007) and may apply to other individuals with motor deficits.

Loss of speed between sessions in children with SLI was associated with their language comprehension score, above motor skills, supporting the notion that difficulties in skill acquisition may be related to impaired language in these children (DiDonato Brumbach & Goffman, 2014; Hedenius et al., 2011; Ullman & Pierpont, 2005). This notion is in line with findings of forgetting in verb learning of children with SLI (Rice, Oetting, Marquis, Bode, & Pae, 1994; Riches, Tomasello, & Conti-Ramsden, 2005). Future studies should combine verb learning and procedural learning in this population (see Hsu & Bishop, 2014).

**Limitations and Future Directions**

The current study is a small-scale correlational study, and other factors (e.g., attention) not studied here may have affected the results. The tests used for identifying children were not normed on the population and are only translations of the English version. Furthermore, although the children with SLI in this sample were not diagnosed as having other developmental deficits, these may be diagnosed at a later age. For example, dyslexia and attention problems are typically diagnosed in primary school. Individuals with these disorders were reported as having deficits in procedural learning (see, e.g., Adi-Japha, Fox, & Karni, 2011; Fox, Adi-Japha, & Karni, 2013; Lum, Ullman, & Conti-Ramsden, 2013). A sample of older children may have lowered the risk of unknown comorbid disorders. Future studies are needed in order to corroborate the notion of impaired skill acquisition in young children with SLI and to test additional aspects of skill learning such as the effect of time in the awake state, sleep, and stability against interference.
Clinical Implications

In terms of clinical implications, the findings suggest that, although children with SLI may learn well within (clinical) sessions, caution should be exercised with respect to the time interval between sessions. When learning a new complex skill, children with SLI may require more frequent practice sessions over a longer period of time for enhancing stabilization as well as reducing between-session forgetting. Home or school practice of specific skills between clinical sessions may be of a short duration. Furthermore, a longer “warm-up” period is required immediately before these children are tested on newly learned skills. It should be remembered that the initial performance of these children on any task is not always informative of their true knowledge.

Conclusions

Kindergarten children with SLI and their peers learned to produce a complex grapho-motor pattern on 4 successive days. Retention was tested 10 days later. Children with SLI showed effective within-session learning in terms of speed and accuracy. These children, however, did not retain the new skill well and presented performance losses in speed between-sessions. Performance losses were larger when the sessions were 10 days apart than when they were one day apart. The deficit may be attributed to task forgetting in the presence of delayed consolidation processes. These findings emphasize the importance of adjusting learning protocols to meet the needs of children with SLI.

References

Fox, O., Adi-Japha, E., & Karni, A. (2013). A skipped dose (placebo) of methylphenidate can reduce motor skill acquisition but not retention in adolescents with attention deficit hyperactivity disorder (ADHD) or normal controls. Cortex, 49, 1021–1031.


