The Role of Procedural Memory in Grammar and Numeracy Skills

Catherine Mimeau

Dalhousie University, Halifax, Nova Scotia, Canada

Mike Coleman and Chris Donlan

University College London, London, England

Author Note

Catherine Mimeau, Department of Psychology and Neuroscience, Dalhousie University, Life Sciences Centre, 1355 Oxford Street, Halifax, Nova Scotia, B3H 4R2, Canada. Phone: 902-494-3229. E-mail: catherine.mimeau@dal.ca; Mike Coleman, Division of Psychology and Language Sciences, University College London, Chandler House, 2 Wakefield Street, London, WC1N 1PF, England. Phone: 020-7679-4213. E-mail: m.coleman@ucl.ac.uk; Chris Donlan, Division of Psychology and Language Sciences, University College London, Chandler House, 2 Wakefield Street, London, WC1N 1PF, England. Phone: 020-7679-4243. E-mail: c.donlan@ucl.ac.uk.

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Correspondence concerning this article should be addressed to Catherine Mimeau.

Abstract

The objective of this study was to examine the contribution of procedural memory to grammar and numeracy skills, which both involve the manipulation of abstract patterns. Seventy-six typically developing children between 5 and 7 years of age were assessed on grammar with a past tense production task and a sentence comprehension task, on numeracy with a counting task and a calculation task, and on procedural memory with a serial reaction time task. Moderate correlations were found between the measures of grammar and numeracy. Moreover, four hierarchical linear regressions indicated that procedural memory was associated with calculation but not with counting or grammar skills when age and working memory were taken into account. These novel findings suggest that procedural memory may have a role to play in the development of some numeracy skills. Several possible explanations for the absence of contribution to grammar are considered.

Keywords: procedural memory, statistical learning, grammar, numeracy, typically developing children

5590 words

The Role of Procedural Memory in Grammar and Numeracy Skills

Procedural memory, also referred to as implicit memory, statistical learning, or sequential learning, is a system that allows implicit learning of motor, perceptual, and cognitive procedures, rules, and sequences (Ullman, 2004). The study of this memory system has gained in popularity in the last decades. In particular, researchers are starting to investigate its role in the development of higher-level cognitive functions such as grammar skills, which involve the manipulation of abstract patterns (e.g., the sequence subject-verb-object in English). Like grammar, numeracy relies on abstract patterns. For instance, in English, most two-digit numbers are built from the sequence *tens digit* + *-ty* + *units digit* (e.g., seventy-nine). Recent research even suggests that grammar and numeracy share a similar structural organization (Schneider, Maruyama, Dehaene, & Sigman, 2012). However, the role procedural memory plays in the development of numeracy skills has seldom been tested empirically. The objective of this study is thus to examine the contribution of procedural memory to grammar and numeracy skills in children.

Grammar and Numeracy

Research in the area of cognitive development points to the existence of an association between grammar and numeracy. For instance, some studies have shown that children with grammatical impairments have difficulty achieving a range of numerical tasks compared with typically developing children of the same age (Cowan, Donlan, Newton, & Lloyd, 2005; Donlan, Cowan, Newton, & Lloyd, 2007; Fazio, 1996). Moreover, studies of individual differences in typically developing children have shown consistent associations between measures of language that assessed grammar skills among other things and measures of numeracy skills (Cowan et al., 2011; Durand, Hulme, Larkin, & Snowling, 2005). Besides, a research team working on generalist genes found significant associations between language (including grammar) and numeracy in school-aged twins, and most importantly, high genetic correlations between the two domains, indicating that the genes that affect the learning of grammar are largely the same genes that affect the learning of numeracy (Haworth et al., 2009). This result could be explained by the involvement of common cognitive processes, such as procedural memory, in the achievement of both grammar and numeracy tasks (Plomin & Kovas, 2005).

Procedural Memory and Grammar

The relation between procedural memory and grammar has been demonstrated in several ways. Theoretically, Ullman (2004) proposed that procedural memory underpins the development of grammar, given that this component of language is largely rule-based (e.g., past tense in English is usually formed by adding *–ed* to the verb) and that it involves a meaningful sequencing of words (e.g., "The man eats the bear" versus "The bear eats the man").

In pioneering empirical studies, Saffran and her colleagues (Saffran, Aslin, & Newport, 1996; Saffran, Newport, Aslin, Tunick, & Barrueco, 1997) provided evidence for the use of procedural memory in language. They presented to babies, children, and adults a lengthy and unfamiliar stream of speech sounds within which the transitional probabilities of particular sound sequences were systematically varied. Following the presentation, participants were able to identify high-probability sequences, even though they may have been unaware that learning was taking place. A more recent study (Evans, Saffran, & Robe-Torres, 2009) used the same task to assess procedural memory in children with specific language impairment (SLI), who consistently show deficits in grammar (e.g., Leonard, Eyer, Bedore, & Grela, 1997). Procedural memory deficits were found in the children with SLI, compared to typically developing controls, suggesting that procedural memory may play a role in grammatical development.

Several studies also assessed procedural memory with variants of Nissen and Bullemer's (1987) serial reaction time (SRT) task, an entirely non-linguistic procedure based on motor responses to the presentation of visual sequences. Like Saffran's team (Evans et al., 2009), researchers using SRT tasks have observed that procedural memory of SLI children is not comparable to that of typically developing children (Hedenius et al., 2011; Lum, Conti-Ramsden, Page, & Ullman, 2012; Lum, Gelgic, & Conti-Ramsden, 2010). Some studies also revealed that procedural memory measured with SRT tasks is associated with sentence comprehension skills in typically developing children (Lum et al., 2012; Conti-Ramsden, Ullman, & Lum, 2015).

Studies using other measures of procedural memory also showed an association with grammar. For instance, Kidd and Arciuli (2016) asked children to complete a task similar to that developed by Saffran et al. (1996, 1997). However, the task consisted of non-verbal visual stimuli instead of a stream of speech sounds. The authors found that children's performance on that task was associated with their performance on a task measuring sentence comprehension skills. Other studies conducted with various verbal and non-verbal measures of procedural memory also revealed similar findings in adults (Conway, Bauernschmidt, Huang, & Pisoni, 2010; Misyak & Christiansen, 2012; Misyak, Christiansen, & Tomblin, 2010). Overall, these empirical results provide broad support for Ullman's hypothesis that procedural memory enables the development of grammar.

Procedural Memory and Numeracy

The role procedural memory plays in numeracy is far less documented than for grammar. It is generally agreed that procedural knowledge (i.e., knowledge of the procedures, rules, and sequences needed to solve numerical problems) is an essential component of numeracy development (e.g., Baroody, 1983). For instance, in order to add up 2 and 5, children may have learned to (a) put two fingers up on one hand, (b) put five fingers up on the other hand, and (c) count all the fingers up. Thevenot and her colleagues showed that both children (Thevenot, Barrouillet, Castel, & Uittenhove, 2016) and adults (Barrouillet & Thevenot, 2013; Fayol & Thevenot, 2012) solve simple addition and subtraction problems using procedures and rules (e.g.,

$x + 1$ = number after x in the count sequence) instead of retrieving the answers directly from long-term memory (although most multiplication problems are thought to be solved by retrieval).

Nonetheless, while the contribution of some memory systems, such as declarative (e.g., Ayr, Yeates, & Enrile, 2005) and working (e.g., Berg, 2008) memory, to numeracy development has been well acknowledged, the contribution of procedural memory remains largely unexplored. In other words, it remains unclear whether individual differences in procedural memory are associated with individual differences in numeracy. Only two relevant empirical studies were found in the literature. First, a single-case study showed that a man with procedural deficits had difficulty not only applying grammatical rules but also solving rule-based multiplication problems (e.g., $0 \times 9 = ?$; Macoir, Fossard, Nespoulous, Demonet, & Bachoud-Lévi, 2010). Second, an experimental study reported a significant association between performance in a SRT task, general language skills, and general mathematical skills in adults (Pretz, Totz, & Kaufman, 2010). However, no study, to our knowledge, has yet examined the association between procedural memory, as indicated by performance on an implicit learning task, and numeracy skills in children.

The Present Study

Given the sequential and rule-based nature of the grammatical and numerical systems, procedural memory is hypothesised to be involved in their development. Yet, very little empirical work including measures of procedural memory has focused on numeracy skills or compared grammar and numeracy. Furthermore, most studies to date have been conducted in adults or impaired children. Therefore, the objective of this study is to examine the contribution of procedural memory to grammar and numeracy skills in typically developing children. This work will contribute to the body of research aiming to identify the sources of individual differences in the development of higher-level cognitive functions.

Methods

Participants

Seventy-six children (36 boys and 40 girls) between 5 and 7 years of age (*M* = 6.50; *SD* = 0.58) participated in the study. They were all recruited from Year 1 and Year 2 of a primary school in the outer London area, and all had English as their first language. This age group was targeted because children entering school have advanced but still developing grammar skills in the context of emergent numeracy skills. The target age range, therefore, offered maximal variability across domains, facilitating the study of individual differences.

Materials

Grammar. Grammar skills were assessed using an adaptation of Marchman, Wulfeck, and Ellis Weismer's (1999) past tense production task, and Bishop's (2003) second version of the Test for Reception of Grammar (TROG). In the past tense production task, participants were shown and described a picture of an action (e.g., "This girl is building a sandcastle. She builds sandcastles everyday.") They were asked to find the past tense of the verb by completing the sentence "Yesterday, he/she…?" Half of the 20 trials were regular verbs, and the other half were irregular verbs. The number of correct trials was recorded. In the TROG, participants were read a sentence (e.g., "The elephant is pushed by the boy.") and shown four pictures. They were asked to show the picture corresponding to the sentence. There were 80 trials grouped in 20 blocks. A block was coded as correct if all of its four trials were correct. The number of correct blocks was recorded.

Numeracy. Numeracy skills were assessed using a counting task and a calculation task (Cowan et al., 2005). In the counting task, participants were asked to count aloud from 1 to 41, from 25 to 32, from 194 to 210, from 995 to 1010, and backwards from 25. The number of correct trials, out of five, was recorded. In the calculation task, participants were shown and read eight addition and eight subtraction problems composed of numbers and sums all smaller than 20. The first half of trials were composed of numbers and sums smaller than 10. Participants were encouraged to use the counters provided or their fingers if needed. The number of correct trials, out of 16, was recorded.

Procedural memory. Procedural memory was assessed using an adaptation of Nissen and Bullemer's (1987) SRT task, based on Lum et al. (2012). Sitting in front of a computer screen, participants were shown four squares arranged in the form of a diamond. The left square will thereafter be referred to as 1, the lower one as 2, the right one as 3, and the upper one as 4. Participants were also given a gamepad that had four buttons that matched the squares on the screen. During the task, a smiley face appeared in one of the squares and participants had to press on the corresponding button on the gamepad as fast as they could. As soon as participants pressed on the correct button, the smiley face shifted position for the next trial.

Participants completed a 10-trial practice session, followed by five blocks of 90 trials each. Unbeknown to participants, the first four blocks each consisted of nine repetitions of the 10-trial sequence 4-2-3-1-3-2-4-3-2-1. On the fifth block, the trials were presented in random order, with the following constraints: (a) the smiley face appeared in each square the same proportion of time as in the first four blocks; (b) the proportion of time the smiley face shifted to a certain position, given its initial position, was the same as in the first four blocks. After completing the fifth block, participants were told that the first four blocks' trials followed a sequence and were asked to recall it. The recall session consisted of four trials in which the smiley face appeared in one of the squares (a different one on each trial), and participants were asked to indicate the next nine positions they thought the smiley face would shift to. This task aimed to assess explicit learning of the sequence.

Reaction times across the five blocks were recorded and then transformed into *z*-scores using each participant's individual median and standard deviation for all trials. This provided control for between-subject variability in motor speed. Moreover, to ensure that distractions encountered during the task did not influence the results, all normalised reaction times equal to or greater than 3 were deleted. Mean normalised reaction times were then computed for each block. Finally, SRT learning, that is, the difference between mean normalised reaction times in Blocks 5 and 4, was calculated. It should be noted that a positive score is an indication of learning. Indeed, if participants completed the fourth block faster than the fifth one, this provides a strong indication that they learned the repeated sequence presented in the first four blocks.

Regarding recall, only consecutive correct answers were taken into account. As soon as a participant made a mistake in the sequence, the remaining answers were coded as incorrect for that trial. Since all four positions occurred more than once in the sequence, all possible sequences were considered. For example, for the recall trial starting at position 4, the two following sequences were correct: 4-2-3-1-3-2-4-3-2-1, 4-3-2-1-4-2-3-1-3-2. For each participant, the sequence providing the highest number of consecutive correct answers was retained for each of the four trials, and the average of consecutive correct answers was computed across these four sequences.

Working memory. Working memory, which has been shown to be a particularly strong predictor of language and numeracy (Alloway & Alloway, 2010), was used as a control variable. It was assessed using the Backward Digit Span subtest of the third edition of the Wechsler Intelligence Scale for Children (Wechsler, 1991). In this task, participants were presented with spoken series of two to eight digits and were asked to repeat them in reverse. Each of the 14 trials was coded as correctly or incorrectly recalled, and the total number of digits across all correct trials was recorded.

Procedure

The tasks were presented over two individual sessions of approximately 30 minutes each. The testing took place in the participants' school and the sessions were separated by about two weeks. The first session consisted of the counting task, the past tense production task, the calculation task, and the backward digit span task, respectively, for half of the participants, and it consisted of the TROG and the SRT task, respectively, for the other half.

Results

The SRT task's mean normalised reaction times across the five blocks are presented in Figure 1. A paired-samples *t*-test revealed that the mean normalised reaction time was significantly greater in Block 5 than in Block 4, $t(75) = 9.15$, $p < .001$, $d = 1.05$, indicating that as a group, participants did learn the repeated sequence. During the SRT task's recall session, participants correctly recalled an average of 2.02 ($SD = 0.64$) consecutive items out of 9 (range: 0.75–3.50; chance level: 1.17). A one-sample *t*-test revealed that this result was significantly above chance level, $t(75) = 11.68$, $p < .001$, $d = 1.34$, indicating that at least some of the SRT learning was explicit. However, it is also possible that the actual number of consecutive items correctly recalled was artificially inflated because the repeated sequence included the clockwise subsequence 4-3-2-1 and participants might have used a clockwise strategy to recall the items. Importantly, no significant correlation was found between SRT learning and recall, $r = .14$, $p = .24$.

(Insert Figure 1 here)

Descriptive statistics of and correlations between all measures are presented in Tables 1 and 2, respectively. Most correlations between the main measures of grammar and numeracy were moderate and all were significant. When controlling for age and working memory, only the correlation between TROG score and counting remained significant ($r = .26$). Regarding the procedural memory measure, the correlation with past tense production was modest and marginally significant and the one with calculation was moderate and significant. However, the correlation with TROG score and the one with counting were not significant. When controlling for age and working memory, only the correlation with calculation remained significant ($r = .25$).

(Insert Table 1 here)

(Insert Table 2 here)

To investigate the role of procedural memory in grammar and numeracy, four hierarchical linear regressions were performed with past tense production, TROG score, counting, and calculation as the dependent variables. Age was entered first in the models, followed by working memory, and then by procedural memory. The results are presented in Table 3. Procedural memory could predict calculation once age and working memory were taken into account. It explained an additional 4% of the variance in that model. The results were similar (although only marginally significant) for addition ($\beta = .19$, $p = .07$) and subtraction ($\beta = .18$, $p = .09$) problems. However, procedural memory could not predict past tense production, TROG score, or counting once age and working memory were taken into account. For past tense production, the results were similar for regular ($\beta = -.05$, $p = .69$) and irregular ($\beta = .14$, $p = .18$) verbs. Logistic regressions also indicated that the results were similar for all items in the counting task (*p*s > .23).

(Insert Table 3 here)

Discussion

The objective of this study was to examine the contribution of procedural memory to grammar and numeracy skills in typically developing children. First looking at the relation between grammar and numeracy, we found an association between the two domains that is consistent with previous literature (e.g., Cowan et al., 2011; Donlan et al., 2007). However, most of the correlations between grammar and numeracy (all but the one between TROG score and counting) became non-significant when we controlled for age and working memory, which suggests that these relations are likely indirect and mediated by cognitive factors. These findings are not surprising given the well-established associations between working memory and both grammar (e.g., Adams & Gathercole, 1995; Ellis Weismer, Evans, & Hesketh, 1999) and numeracy (Berg, 2008; Swanson & Jerman, 2006). Yet, they are challenging for modular theories of language (e.g., Chomsky, 1965) and mathematics (e.g., Butterworth, 1999) and rather support generalist views of learning (e.g., Plomin & Kovas, 2005).

Turning to procedural memory, we found that it was associated with calculation but not with counting or grammar skills. These findings are, to our knowledge, the first empirical evidence of an association between procedural memory and numeracy in children. However, whereas children's implicit memory for sequences was found to be associated with their ability to add and subtract small numbers, it was not associated with their ability to count up to large numbers, suggesting that procedural memory is relevant only to some aspects of numeracy. The reason why procedural memory was associated with calculation but not with counting might have to do with the fact that for young primary school children, counting involves rote learning to a greater extent than calculation, which rather involves a greater reliance on procedures (as illustrated, for example, by finger-counting).

Regarding grammar, it is possible that procedural memory truly has no role to play in its development. It is well established that implicit learning in adults is independent from many cognitive faculties, including general intelligence (Gebauer & Mackintosh, 2007; Siegelman & Frost, 2015). Therefore, it might be the case that procedural memory has no relevance to higher-level cognitive function such as verb and sentence processing.

Nevertheless, the failure of SRT learning to contribute to grammar in the present study conflicts with previous findings. For instance, Lum et al. (2012; see also Conti-Ramsden et al., 2015), in a sample of 51 typically developing children aged from 8 to 11 years, reported a significant correlation of *r* = .31 between procedural memory as assessed with a SRT task and grammar as assessed with a compound measure including TROG score. The measure of procedural memory used in the present study closely modelled on the implementation developed by Lum and colleagues. Moreover, unequivocal evidence of learning was found, and the function shown by Lum et al.'s sample (see Figure 1, p. 1148) was even replicated with some precision.

The difference between the ages of participants, however, was substantial. Might it be the case that implicit learning of grammatical regularities is a feature of the older age-range? This explanation seems implausible, given Thomas and Nelson's (2001) finding that pre-schoolers acquire implicit knowledge similarly to older school-aged children, age having an impact only on explicit learning.

Might the grammatical tasks selected in this study be poorly suited to the current purpose? A recent study conducted by Kidd and Arciuli (2016) is relevant to this question. The authors examined the relation between procedural memory and grammar in 6- to 8-year-old typically developing English speakers. They measured procedural memory with a non-verbal task based on transitional probabilities similar to that developed by Saffran et al. (1996, 1997), and they measured grammar skills with a task assessing comprehension of four different sentence structures. They found that procedural memory was associated with comprehension of passives and object relative clauses but not with comprehension of actives and subject relative clauses. Because the TROG evaluates sentence comprehension without distinguishing between different sentence structures, it is likely that this measure is not sensitive enough to the grammatical skills that could potentially depend on procedural memory. Interestingly, using a sentence comprehension task similar to the TROG, Spencer, Kaschak, Jones, and Lonigan (2015) also found no relation with procedural memory as measured with two tasks: one similar to that used by Saffran et al. and one similar to that used in the present study.

Other studies by Kidd and his colleagues could also explain the absence of an association between procedural memory and grammar in the present study. Kidd and Kirjavainen (2011), Lum and Kidd (2012), and Kidd (2012) all used a SRT task to measure procedural memory in 4- to 6-year-old children. Kidd and Kirjavainen and Lum and Kidd found no correlation between SRT learning and past tense production (using an elicitation task similar to that used in the present study) with Finnish and English speakers. However, Kidd, using a complex hierarchical model that accounted for individual differences in IQ and vocabulary level, found that SRT learning was significantly associated with a measure of syntactic priming in English speakers. This procedure tracks the extent to which children consistently follow an adult model and use passive sentences in picture description. This measure of syntactic priming differs substantially from the test of sentence comprehension used in the current study and by Lum et al. (2012), Conti-Ramsden et al. (2015), and Spencer et al. (2015). It also differs substantially from the past tense production tasks used in the present study (which, it should be mentioned, showed a ceiling effect for the regular verbs) and by Kidd and Kirjavainen and Lum and Kidd.

Another construct that might benefit from being evaluated differently is procedural memory itself. Different procedural memory tasks were shown not to be correlated among them, and the reliability of the SRT task has been questioned by some (Gebauer & Mackintosh, 2007; Siegelman & Frost, 2015). These findings leave open the possibility that another measure of procedural memory might have produced different results in relation with grammar skills. Still, several researchers did observe an association between performance in a SRT task and grammar skills in children (e.g., Lum et al., 2012; Conti-Ramsden et al., 2015), so the null results we obtained in the present study are unlikely due solely to our choice of procedural memory measure.

Conclusion

In this study on typically developing children, we investigated the relation between procedural memory and two higher-level cognitive functions: grammar and numeracy. Although we could not replicate previous findings associating procedural memory and grammar, we found that procedural memory could predict calculation above and beyond age and working memory. As this is, to our knowledge, the first empirical evidence of such a relation, further research should clarify the scope of the role procedural memory plays in numeracy. For instance, researchers could examine whether children who express difficulties in numeracy also show deficits in procedural memory. They could also determine whether aspects of numeracy not assessed in the present study, such as problem solving, which requires both grammatical and numerical knowledge, are associated with procedural memory. This may help better understand the function of cognitive processes in the development of numeracy in children.

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Table 1

Means and Standard Deviations for Measures of Grammar, Numeracy, Procedural Memory, and Working Memory

Measure	*M*	*SD*	Range
Grammar			
Past tense production (max = 20)	14.00	3.73	5–20
Regular verbs (max = 10)	9.00	1.33	1–10
Irregular verbs (max = 10)	5.00	3.33	0–10
TROG score (max = 20)	11.20	4.13	1–19
Numeracy			
Counting (max = 5)	2.82	1.53	0–5
1–41 (max = 1)	.86	.35	0–1
25–32 (max = 1)	.86	.35	0–1
194–210 (max = 1)	.26	.44	0–1
995–1010 (max = 1)	.32	.47	0–1
25–1 (max = 1)	.53	.50	0–1
Calculation (max = 16)	11.86	3.60	1–16
Addition problems (max = 8)	6.22	1.82	0–8
Subtraction problems (max = 8)	5.63	2.33	0–8
Procedural Memory			
SRT learning (Block 5 - Block 4)	0.21	0.20	-.30–.83
Working Memory			
Backward digit span (max = 70)	10.59	4.09	4–19

Note. TROG = Test for Reception of Grammar; SRT = serial reaction time.

Table 2

Correlations Between Measures of Grammar, Numeracy, and Procedural Memory, Controlling for Age and Working Memory

Measure	1	a	b	2	3	a	b	c	d	e	4	a	b	5
Grammar														
1. Past tense production	–	.44***	.91***	.39***	.14	-.01	.04	.17	.16	.07	.15	.16	.10	.12
a) Regular verbs	.47***	–	.04	.10	.06	-.05	-.17	.11	.11	.13	.01	.13	-.08	-.05
b) Irregular verbs	.94***	.12	–	.38***	.13	.01	.12	.14	.13	.02	.16	.11	.15	.16
2. TROG score	.53***	.18	.52***	–	.26*	-.03	.27*	.27*	.26*	.07	.01	.10	-.07	-.03
Numeracy														
3. Counting	.40***	.16	.38***	.46***	–	.52***	.62***	.66***	.69***	.69***	.39***	.22†	.39***	.07
a) 1–41	.19†	.03	.20†	.16	.61***	–	.42***	-.01	.08	.32**	.55***	.31**	.56***	.18
b) 25–32	.17	-.11	.24*	.36**	.64***	.47***	–	.14	.16	.36**	.17	-.01	.26*	.10
c) 194–210	.35**	.18	.33**	.42***	.74***	.16	.25*	–	.68***	.22†	.08	.08	.05	-.08
d) 995–1010	.39***	.19†	.36**	.44***	.79***	.28*	.28*	.75***	–	.22†	.04	.09	-.01	.01
e) 25–1	.29*	.20†	.25*	.27*	.77***	.43***	.43***	.39***	.42***	–	.43***	.24*	.44***	.03
4. Calculation	.39***	.12	.39***	.26*	.59***	.64***	.29*	.30**	.33**	.57***	–	.77***	.87***	.25*
a) Addition problems	.37***	.21†	.34**	.31**	.46***	.44***	.13	.29*	.34**	.42***	.83***	–	.35**	.22†
b) Subtraction problems	.31**	.02	.34**	.16	.55***	.65***	.34**	.24*	.24*	.56***	.90***	.50***	–	.20†
Procedural memory														
5. SRT learning	.21†	-.01	.23*	.07	.17	.23*	.15	.03	.12	.13	.31**	.28*	.25*	–
Control variables														
6. Age	.43***	.17	.42***	.38***	.50***	.40***	.21†	.34**	.46***	.34**	.51***	.42***	.45***	.12
7. Backward digit span	.42***	.15	.42***	.39***	.51***	.26*	.24*	.41***	.45***	.43***	.43***	.43***	.33**	.22†

Note. Correlations above the diagonal control for age and working memory. TROG = Test for Reception of Grammar; SRT = serial reaction time.

$^{\dagger}p < .10$. $^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

Table 3

Hierarchical Linear Regression Analyses Predicting Grammar (Past Tense Production and TROG Score) and Numeracy (Counting and Calculation) From Procedural Memory (SRT Learning)

	Past tense production		TROG score		Counting		Calculation	
Predictor	*B* (*SE*)	β	*B* (*SE*)	β	*B* (*SE*)	β	*B* (*SE*)	β
1. Age	1.96 (0.71)	.30**	1.86 (0.82)	.26*	0.91 (0.27)	.35**	2.40 (0.64)	.39***
2. Backward digit span	0.25 (0.10)	.27*	0.29 (0.12)	.29*	0.13 (0.04)	.36**	0.19 (0.09)	.22*
3. SRT learning	1.99 (1.89)	.11	-0.56 (2.17)	-.03	0.41 (0.72)	.05	3.75 (1.71)	.21*
Total R^2		.27		.21		.37		.36

Note. TROG = Test for Reception of Grammar; SRT = serial reaction time.

*p < .05. **p < .01. ***p < .001.

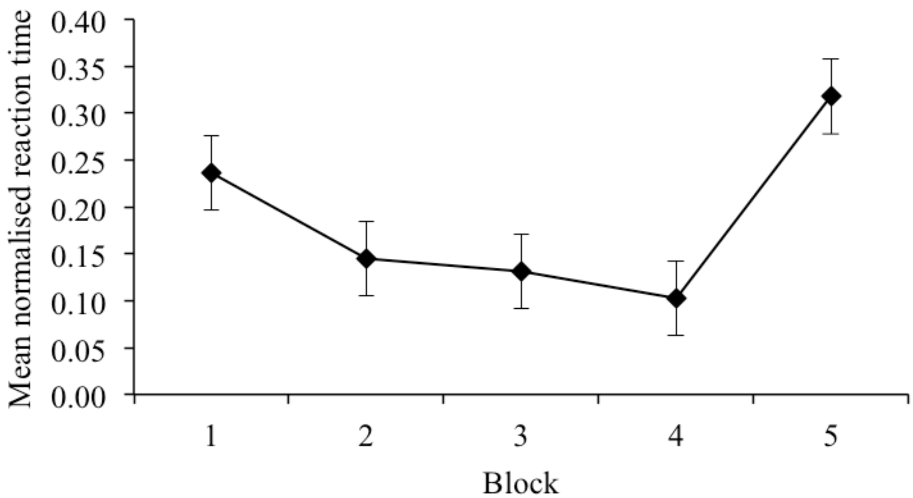

Figure 1. Serial reaction time task's mean normalised reaction times across the five blocks. Error bars show the standard error.