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Can poor readers be good learners?

Non-adjacent dependency learning in adults with dyslexia

Annemarie Kerkhoff, Elise de Bree and Frank Wijnen

This study aimed to test whether adults with dyslexia are impaired at non-adjacent dependency learning, and whether potential learning difficulties are domain-specific or not. Participants were familiarised with one of two languages containing dependencies between the first and third element of a string of non-sense words, e.g. “tep wadim lut”. Dyslexic adults were equally good at learning the dependencies, although a trend towards a group difference was found when test sentences contained novel middle words, requiring generalisation of the pattern. The groups did not differ on learning dependencies between unfamiliar shapes in a visual experiment. These results provide tentative support for a domain-specific learning deficit for adults with dyslexia, suggesting that they may be poorer at generalizing from language input.

Keywords: dyslexia, non-adjacent dependency learning, artificial language learning, procedural deficit hypothesis, domain-general

1. Introduction

In the vast literature on dyslexia and related language-based disorders, it has been suggested that poor readers may be poor learners: a domain-general procedural learning deficit has been argued to underlie disorders such as dyslexia and Specific Language Impairment (SLI) (e.g., Nicolson & Fawcett, 2007; Ullman & Pierpont, 2005). Dyslexia is typically associated with severe and persistent problems with reading and/or writing, and phonological problems are widely assumed to underlie these difficulties (Ramus et al., 2003; Snowling, 2000). In addition to the classic impairments in phonological awareness, verbal short term memory and lexical retrieval (rapid automatic naming), children and adults with dyslexia may also show deficits in motor control and rapid (visual and auditory) processing (for a review

see Vellutino, Fletcher, Snowling & Scanlon, 2004). Furthermore, there is substantial overlap between dyslexia and (specific) language impairment (e.g. McArthur, Hogben, Edwards, Heath & Mengler, 2000), and children with dyslexia may have problems with (morpho)-syntax (e.g. Rispens & Been, 2007; Robertson & Joanisse, 2010). Grammatical impairments have also been observed in 18- and 24-month old children at family risk of dyslexia (i.e. children with a dyslexic parent), who were less sensitive to natural language dependencies (Wilsenach & Wijnen, 2004). Such grammatical problems could at least in part be attributed to poor verbal working memory. However, there is also high co-morbidity between dyslexia and developmental disorders that have core deficits in non-linguistic domains, such as attention deficit hyperactivity disorder (ADHD), and developmental coordination disorder (DCD), see Snowling (2000).

Another prominent theory proposes that a general learning deficit affecting implicit or procedural learning is an underlying cause of language-related disorders such as dyslexia and SLI, while also accounting for the overlap with other developmental disorders (Nicolson & Fawcett, 2007; Ullman & Pierpont, 2005, Wijnen, 2013). Under this view, (sensori)motor and language-related tasks depend on the same brain regions as the procedural memory system, which can be dissociated from the declarative memory system (Ullman, 2004). A procedural learning deficit is expected to affect both motor control and the rule-based ('automatised') aspects of language, while the lexicon is 'relatively spared' (Ullman & Pierpont, 2005). The procedural deficit hypothesis has received some support in the literature, as studies have shown that children or adolescents with (a history of) language impairment have difficulties with classic (visuo-motor) procedural learning tasks such as the Serial Reaction Time (SRT) task (Nissen & Bullemer, 1987). Other studies have employed statistical learning experiments, in which transitional probabilities or predictive dependencies between elements (e.g. syllables in a speech stream) are manipulated (Saffran et al., 1997). Impairments in such implicit learning tasks have been attested in adults and adolescents with language impairment (Grunow, Spaulding, Gómez, & Plante, 2006; Hsu & Bishop, 2010; 2014; Hsu, Tomblin, & Christiansen, 2014; Plante, Gómez, & Gerken, 2002; Tomblin, Mainela-Arnold, & Zhang, 2007) and children with SLI (e.g. Evans, Saffran, & Robe-Torres, 2009), see Lum, Conti-Ramsden, Morgan, & Ullman (2014) for a meta-analysis.

In a study that closely resembles the current study, Grunow et al. (2006) tested adults with language-based learning disabilities on a non-adjacent dependency learning (NADL) task, which can be regarded as a form of implicit sequential learning. Grunow et al. exposed participants to strings of three non-words with a dependency between the first and the third word (e.g. *pel wadim jic* or *vot kicey rud*), based on experiments by Gómez (2002) and Gómez and Maye (2005). In NADL experiments, learners are exposed to one of two training languages, which

have reversed dependencies (e.g. language 1: aXc, bXd, language 2: aXd, bXc). In both languages, the monosyllabic elements (e.g. *pel* and *jic*, *vot* and *rud*) always co-occur, whereas the bisyllabic middle X-element (e.g. *wadim*, *kicey*) is variable. After training with one of the languages, the subsequent test phase contains sentences from both languages, which can only be distinguished on the basis of relationship between the dependent elements (as the two languages share the same set of X-elements). Grunow et al. show that adults could learn these dependencies (i.e. decide between grammatical *pel wadim jic* vs. ungrammatical *pel wadim rud*) and even generalise the structure to strings with novel middle elements, but only when variability of the middle elements was high (24) rather than low (12). Adults with a history of language and/or learning problems could not learn the dependencies even when variability was high. Similarly, adolescents with SLI aged 13–15 were unable to learn non-adjacent dependencies (Hsu et al., 2014).

Children and adults with dyslexia have also been tested on SRT and statistical learning tasks, with more variable findings. Poor implicit learning has been observed in SRT tasks (see Lum, Ullman, & Conti-Ramsden, 2013 for a meta-analysis) and artificial grammar learning (AGL) experiments (Pavlidou, Kelly, & Williams, 2010). In a study by Kerkhoff, de Bree, de Klerk and Wijnen (2013), 18-month-old infants at family risk of dyslexia (i.e. infants with a dyslexic parent, who are at greater risk of developing reading problems) were not able to distinguish between grammatical (trained) and ungrammatical (untrained) strings in a non-adjacent dependency learning task (using the head turn preference procedure). Only infants without a family risk of dyslexia looked longer towards ungrammatical strings (i.e. sentences with reversed dependencies), suggesting that at-risk infants may lag behind their typically developing peers in tracking long-distance dependencies.

The current study aimed at testing whether adults with dyslexia show poor implicit learning of long distance dependencies, in line with the proposed procedural learning deficit. Although previous studies have investigated procedural learning in adults with reading impairment, non-adjacent dependency learning has not been tested in this population. The first experiment (Experiment 1a), comprised a classic NADL task, replicating earlier studies by Gómez (2002) and Gómez and Maye (2005), using test items that are repeated from the training sentences. In a second experiment (Experiment 1b), we aimed at testing whether any group differences would be enhanced when participants were required to generalise to novel test items, using novel middle elements (X-elements) for the test phase. Generalization to novel instances should be a more stringent test of learning, and might be especially problematic for individuals with language learning difficulties. Indeed, Grunow et al. (2006) found poorer performance for sentences with novel middle items in the test phase than for sentences containing the same middle items as presented during training. As argued by Hsu and Bishop (2010, p. 275), NADL tasks

with novel test words might indicate to what extent statistical learning rather than working memory is deficient. The second aim was to investigate whether such a learning deficit is specific to language, as it has been argued that statistical learning derives from a domain-general learning mechanism (Saffran, 2002; Ullman & Pierpont, 2005). To test NADL in the visual domain, strings of non-words were replaced with strings of unfamiliar shapes (Experiment 2).

2. Experiment 1a: Non-adjacent dependency learning with repeated test items

2.1 Methods

2.1.1 Participants

A group of 25 adults without reading impairments (18 female, mean age 22.5, $SD = 2.7$, range 19–30) and 18 adults with dyslexia (13 female, mean age 22.5, $SD = 2.9$, range 19–29) participated in the study. Participants were recruited using a database compiled by the UiL-OTS and asking staff and (participating) students whether they knew (former) university students with dyslexia. Participants did not have a history of overt language problems or hearing difficulty and were all educated at university level. To assess the current reading level of the participants, two technical reading tasks and a verbal competence task were administered. The first reading task was the Eén-Minuut-Test (EMT), a standardised single-word reading task (Brus & Voeten, 1973). The second reading task was the Klepel, a standardised pseudo-word reading task (Van den Bos, Iutje Spelberg, Scheepstra, & de Vries, 1994). The verbal competence task was the *Overeenkomsten* (Analogies) task from the Dutch version of the Wechsler Adult Intelligence Scale (WAIS) (Uterwijk, 2000). In order to be included in the dyslexic group, a participant's performance was required to be below or equal to the 20th percentile on both the EMT and the Klepel or below or equal to the 10th percentile on either the EMT or Klepel. Alternatively, the discrepancy between the participant's percentile score on the EMT and Klepel on the one hand and the percentile score on the WAIS on the other hand had to be at least 60 (based on Kuijpers, van der Leij, Been, van Leeuwen, ter Keurs, Schreuder, & van den Bos, 2003). An additional group of 8 participants (7 males) with self-declared dyslexia were excluded for not meeting the criteria (i.e. their reading scores were too high), even though all of them had an official dyslexia statement. The participants' scores on the two reading tests are shown in Table 1.

Table 1. Mean percentile scores (SD) by group for Experiment 1a

Test	Control	Dyslexic	<i>t</i> -test
EMT	83.8 (18.6)	20.6 (16.8)	11.2***
Klepel	87.2 (15.1)	26.8 (23.5)	10.2***

*** $p < .001$

2.2 Stimuli

Participants were exposed to one of two artificial languages, both consisting of three-word sentences (based on Gómez, 2002). Language 1 contained the dependencies aXb, cXd and eXf, while Language 2 contained the dependencies aXd, cXf and eXb, where a, b, c, d, e, f were “tep”, “lut”, “sot”, “jik”, “rak” and “toef”, respectively. The 18 middle words (X’s) were “wadim”, “kasi”, “poemer”, “kengel”, “domo”, “loga”, “gopum”, “naspoe”, “hifam”, “dita”, “vami”, “snigger”, “rogges”, “densim”, “fidang”, “rajee”, “seta”, and “noeba”. Examples of sentences in Language 1 are: “tep wadim lut”, “sot wadim jik”, and “rak wadim toef”, vs. “tep wadim jik”, “sot wadim toef”, and “rak wadim lut” in Language 2. Note that if participants focus on adjacent dependencies only (e.g. “tep wadim” or “wadim lut”), they should not be able to distinguish between the two languages. There was a 250-ms interval between the words in a sentence and a 750-ms interval between the sentences (and appropriate end-of-sentence prosody at word 3), such that the speech stream was clearly divided into three-word sentences (e.g. “tep wadim lut”), stressing the dependent elements¹. The sentences were approximately 2 seconds in duration. Combining the 3 non-adjacent dependencies and the 18 X-elements resulted in a total of 54 training sentences per language. For the test phase, the middle words (X-elements) “wadim” and “kasi” were used, resulting in 12 test sentences (e.g. “tep wadim jik”, “tep wadim lut”), which were grammatical or ungrammatical according to the training language.

2.3 Procedure

The experiment consisted of two phases, a training phase and a test phase. Both phases were run in immediate succession in the same sound-attenuated booth. Sound was played through two speakers on the right and left of the participant, who

1. The stimuli were the same as those used for infants in Kerkhoff et al., (2013) and were recorded by a female speaker who used a lively, child-friendly intonation. They closely resembled the stimuli used by Rebecca Gómez (which she kindly shared with us), and were only adapted to conform to Dutch phonotactics.

was seated in front of a computer. Before the training phase started, the participants were given written instructions explaining that they were going to listen to an ‘extraterrestrial’ language while colouring a mandala. The instructions emphasised that participants were supposed to focus on the colouring and were not allowed to write anything down. The colouring task was added to promote implicit learning (i.e. preventing students from actively listening to the language and trying to find a pattern). During the training phase, the 54 unique training sentences (3 dependencies with 18 different middle words) were each presented 6 times, resulting in a total of 324 strings. The sentences were presented in a randomised order. In each group, half of the subjects heard Language 1 and half of the subjects heard Language 2, to counterbalance any effect of training language. On the computer screen a counter was shown, counting down from 324 to 0, to indicate how much longer the listening would last. The training phase lasted approximately 15 minutes. Afterwards, the participant was told that the language they had heard was constructed according to certain rules involving word order and that they would be tested on what they had learnt about the language. They were also told that they would hear 12 new sentences, 6 of which complied with the rules of the language and 6 of which did not. During the test phase, the participant was asked to respond “yes” or “no” to the question “Is this sentence correct in the language you have just learnt?” Half of the 12 test sentences contained the same non-adjacent dependencies as the language the participant had heard during the training phase and were thus grammatical. The other half contained the dependencies from the other language and were therefore ungrammatical.

After the test phase, the participants were asked debriefing questions about the experiment to determine whether learning had been implicit (e.g. they were asked whether they had noticed anything about the language).

2.4 Results

In case of successful learning, the number of endorsements (i.e. ‘yes’ answers) should be higher for grammatical sentences (‘hits’) than for ungrammatical sentences (‘false alarms’), as only the grammatical sentences corresponded to the training language. The mean number of endorsements for both types of sentences is reported in Table 2.

Table 2. Mean percentage of ‘yes’ answers by sentence type (SD) for Experiment 1a

Sentence type	Control	Dyslexic
Grammatical	76.7 (19.8)	70.2 (22.1)
Ungrammatical	54.7 (25.2)	61.8 (26.9)

A repeated measures ANOVA on the percentage yes answer was conducted with group (control, dyslexic) as between subject factor and sentence type (grammatical, ungrammatical) as the within subject factor. A main effect of sentence type was found ($F(1, 41) = 7.51, p = .009, \eta_p^2 = .16$), with participants responding “yes” more often to the grammatical sentences ($M = 72.9\%, SE = 3.2$) than to the ungrammatical sentences ($M = 58.4\%, SE = 4.0$). There was no significant interaction between sentence type and group ($p = .16$) and no effect of group ($p > .9$), indicating that both groups were successful at learning non-adjacent dependencies after a 15 minute exposure to an artificial grammar.

Three participants from the control group reported awareness of the aXb pattern (i.e. suggesting explicit knowledge), with two of them achieving a maximal difference score of 100 (i.e. 100% yes answers for grammatical items minus 0% yes answers for ungrammatical items) and one achieving a difference score of 67. In the control group, 10/25 participants (40%) were low performers, with difference scores of zero ($N = 6$) or lower ($N = 4$). In the dyslexic group, 12/18 participants (67%) were low performers, with difference scores of zero ($N = 8$) or lower ($N = 4$). The difference between the number of low performers per group was marginally significant on a Chi Square test (one-tailed $p = .078$). Finally, difference scores were positively correlated with pseudoword (Klepel) reading scores ($r(42) = .316, p = .041$), but not word (EMT) reading scores ($p > .6$).

In the current experiment, all the test sentences had been heard before. To test whether dyslexic participants are poorer at *generalising* the non-adjacent dependencies to novel instances, a second experiment was devised, using novel middle elements in the test phase. For such novel strings to be correctly accepted as grammatical, participants should rely on the relationship between the dependent elements, rather than memorisation of the entire three-word strings.

3. Experiment 1b: Non-adjacent dependency learning with novel test items

3.1 Methods

3.1.1 Participants

A group of 24 adults without reading impairments (16 female, mean age 23.0, $SD = 1.6$, range 21–27) and 13 adults with dyslexia (9 female, mean age 24.0, $SD = 3.6$, range 19–32) were included in the study, recruited in the same way as described for Experiment 1a. None of the students had participated in Experiment 1a. Two additional control participants were excluded on the basis of the discrepancy criterion (i.e. reading scores were too low), and two additional dyslexic participants

were excluded, one due to uncertainty about reading status (i.e. reading scores were too high), and one due to technical problems. The participants' scores on the reading tests are shown in Table 3.

Table 3. Mean percentile scores (SD) by group for Experiment 1b

Test	Control	Dyslexic	<i>t</i> -test
EMT	76.0 (26.8)	11.3 (4.3)	8.26***
Klepel	82.9 (14.9)	20.0 (13.8)	12.2***

*** $p < .001$

3.2 Stimuli

The participants were exposed to one of two artificial languages, as described for Experiment 1a. In contrast to the earlier studies conducted by Gómez (2002) and Gómez and Maye (2005) and the previous experiment (Experiment 1a), the middle words (X-elements) during the test phase were novel words that the participants had not heard during the training phase (i.e. “movig” and “wiffel”). Combining the two new X-elements and the three non-adjacent dependencies resulted in 12 test sentences.

3.3 Procedure

The procedure was the same as in experiment 1, except for the change in items in the test phase. Also, just before the test phase, it was pointed out to participants that they would be asked about the word order of the language they had just heard, which was also added to the instruction (“If you think that the word-order of a sentence is the same as what you just heard, then click on the “Yes” button”).

3.4 Results

The results are reported in Table 4.

Table 4. Mean percentage of ‘yes’ answers by sentence type (SD) for Experiment 1b

Sentence type	Control	Dyslexic
Grammatical	81.3 (25.2)	69.2 (20.2)
Ungrammatical	52.1 (38.8)	57.7 (23.2)

A repeated measures ANOVA was performed, as described for Exp. 1a. A main effect of sentence type (grammaticality) was found, $F(1, 35) = 8.58$, $p = .006$, $\eta_p^2 = .197$, with participants responding “yes” more often to the grammatical sentences ($M = 75.2\%$, $SE = 4.1$) than to the ungrammatical sentences ($M = 54.9\%$, $SE = 5.9$). There was no main effect of group ($p > .7$), and no interaction between sentence type and group ($p = .21$), indicating that the dyslexic group did not differ in their ability to distinguish between grammatical and ungrammatical sentences. However, given that the difference score was considerably lower for the dyslexic group, the results were analysed in separate paired t-tests per group. Here, only the control group showed effects of learning, as they responded “yes” more often to the grammatical sentences than to the ungrammatical sentences ($t(23) = 3.04$, $p = .006$, $d = 1.27$). In contrast, the difference did not reach significance for the dyslexic group ($t(12) = 1.81$, $p = .095$, $d = 1.05$).

Four participants from the control group reported awareness of the aXb pattern, all achieving a maximal difference score of 100. In the control group, 10/24 participants (42%) were low performers, with difference scores of zero ($N = 6$) or lower ($N = 4$). In the dyslexic group, 8/13 participants (62%) were low performers, with difference scores of zero ($N = 6$) or lower ($N = 2$). The number of low performers did not differ between the groups (one-tailed $p = .209$). There was no correlation between performance on the NADL task (i.e. difference scores) and reading scores, either for pseudoword reading ($p > .2$) or word reading ($p > .6$).

3.5 Discussion

The current study was aimed at testing whether adults with dyslexia are impaired at implicit learning of non-adjacent dependencies. In a classic NADL task (Experiment 1a), the performance of adults with dyslexia did not differ from that of normal readers, although the dyslexic group contained more low performers. Also, pseudoword reading scores were found to correlate with performance. When novel test elements were used (Experiment 1b), there was an indication of poorer performance by the dyslexic group. While these results are as yet inconclusive due to the lack of an interaction effect (i.e. between grammaticality and group), they warrant further research with more dyslexic participants. If replicated, this finding would suggest that adults with dyslexia have difficulties extracting non-adjacent dependencies, but only when generalising structure to new instances.

To investigate non-adjacent dependency learning in the visual domain, a second experiment was devised using unfamiliar shapes rather than pseudowords.

4. Experiment 2: Visual non-adjacent dependency learning

4.1 Methods

4.1.1 Participants

Forty-two undergraduate students of the University of Utrecht (35 female, mean age 22.6, *SD* = 4.2, range 19–45) without reading problems and 14 students with dyslexia (9 female, mean age 22.4, *SD* = 3.1, range 19–30) were asked to take part in the experiment. One dyslexic subject reported a diagnosis of ADHD, but was not excluded on this basis. One additional subject was tested but excluded from analysis due to a technical error. The same reading tests were administered as in Experiment 1. Five participants with self-reported dyslexia had reading scores that were too high to meet the criteria and were excluded. Participants’ scores on the two reading tests are shown in Table 5.

Table 5. Mean percentile scores (*SD*) by group for Experiment 2

Test	Control	Dyslexic	<i>t</i> -test
EMT	84.8 (20.4)	20.8 (13.8)	10.6***
Klepel	89.3 (16.7)	36.5 (26.9)	8.52***

*** *p* < .001

4.2 Stimuli

During training, participants were exposed to strings of three visual elements, which consisted of two shapes overlapping each other, see Figure 1. These unfamiliar shapes did not conform to known shapes or objects and were difficult to label linguistically, to ensure that the task was visual rather than linguistic.² The first and third element of the string were always ‘closed’ shapes, the X-element in the middle was a more ‘open’ figure. This was done to make the experiment as similar as possible to the NADL task employed in the language domain, where the middle element consisted of a bi-syllabic word (e.g. “wadim”) and the first and last element were mono-syllabic words (“tep” and “jik”).

2. The stimuli for the visual experiment were designed by the first two authors and Marlies Stoimenovski.

Figure 1. Experimental stimuli for Experiment 2: NADL in the visual domain

The participants were trained on one of two visual “languages”, see Figure 1. Language 1 consisted of strings with the elements ‘a X b’ and ‘c X d’, language 2 consisted of strings with the elements ‘a X d’ and ‘c X b’, presented sequentially. There were 24 middle items. Note that the design is different from Experiment 1, in which three dependencies per language were presented (instead of 2) and 18 middle items were used (rather than 24). These changes were made after a pilot experiment using a set size of $X = 18$ showed that 13/20 students scored at chance level at this task. All the pictures had the same height and width. There were 250-ms pauses between pictures and 750-ms between strings, so that pictures were distinguishable in strings and strings were distinguishable from one another.

4.3 Procedure

The experiment took place in a sound-proof booth in the UIL OTS labs at Utrecht University. All participants were tested individually. The experiment was run using the experimental program FEP (Flexible Experimental Program, Veenker 1998). During training, subjects were exposed to 2 iterations of 64 (2 dependencies $\times$ 24 X-elements) training strings, consisting of 3 stimuli with non-adjacent dependencies, shown sequentially (one at a time) in the middle of the screen. Training lasted approximately 8 minutes. Subjects were told to look at the pictures for a subsequent test, while listening to (classical) music through headphones. Music was added to ensure that differences between experiments 1 and 2 were not due to the presence of a concurrent (colouring) task in Experiment 1. Participants were instructed to view all the pictures and hit a button as quickly as possible (the middle button on a button box) when a black pause screen appeared. This was done to ensure that participants always attended to the screen. Before the test phase, participants were told that they would now see more strings, again sequentially presented on the screen, after which a question would follow. The question at each string was: ‘Did you see

these pictures in this order?’ (‘Heb je deze plaatjes in deze volgorde gezien?’), and they had to push a ‘yes’ or ‘no’ button. Half of the 12 strings presented would follow the same order as the training strings, and half would violate the order (i.e. strings of the other language).

4.4 Results

The results for Experiment 2 are shown in Table 6.

Table 6. Mean percentage of ‘yes’ answers by string type (SD) for Experiment 2

String type	Control	Dyslexic
Grammatical	78.6 (21.6)	77.4 (23.2)
Ungrammatical	38.1 (32.2)	29.8 (28.6)

A repeated measures ANOVA was conducted, as described for Experiment 1. There was a main effect of sentence type ($F(1, 54) = 40.83, p < .001, \eta_p^2 = .43$), indicating that participants endorsed grammatical strings more often than ungrammatical strings. There was no main effect of group ($p > .3$), and no interaction between string type and group ($p > .6$), indicating that both groups were able to learn the dependencies between the first and third shape in a visually presented string.

Six participants from the control group reached a perfect (difference) score of 100, although it was not recorded whether they had been aware of the pattern. In the control group, 16/42 participants (38%) were low performers, with difference scores of zero ($N = 11$) or lower ($N = 5$). In the dyslexic group, 4/14 participants (29%) were low performers, with difference scores of zero ($N = 3$) or lower ($N = 1$). The number of low performers did not differ between the groups (one-tailed $p = .38$). Finally, there was no correlation between the difference score and participants’ reading scores ($p > .5$).

4.5 Discussion

These results demonstrate that both groups of participants were successful at learning non-adjacent dependencies in a non-linguistic domain, with a larger effect size than the language experiments (Experiments 1a and 1b). However, the current experiment may have been easier, as the language experiments consisted of 3 dependencies with 18 X-elements, against 2 dependencies with 24 X-elements for the visual experiment. Furthermore, participants were instructed before the training phase that ‘the order of the pictures was important’, as piloting showed that subjects

tended to focus on the visual details of the shapes rather than their order. While no such explicit instruction was present in the language experiment, language is inherently more sequential in nature, and an emphasis on word order was deemed unnecessary or even unwanted, as it might have led to more explicit learning.

5. General discussion

The current study set out to investigate whether adults with dyslexia are impaired at learning non-adjacent dependencies, a form of implicit learning that can be regarded as crucial for grammatical development. To investigate whether such a deficit may be domain-general, participants were tested on their ability to learn dependencies between nonsense words in two auditory experiments and between unfamiliar shapes in a visual experiment.

Taken together, the results do not provide support for a general procedural or implicit sequential learning deficit in adults with dyslexia,³ as they performed as well as normal readers in both the language domain (Experiment 1a) and the visual domain (Experiment 2). However, in the classic NADL task, there were more low performers in the dyslexic group, and performance was found to correlate with reading scores. Furthermore, a group difference surfaced in the second language experiment, in which novel middle elements were used. This result forms a first indication that generalisation of a pattern to novel instances might be problematic for dyslexic individuals. This result differs from previous findings by Grunow et al. (2006), who showed that adults with language-based learning difficulties could not learn non-adjacent dependencies even when the middle element was repeated. Participants in Grunow et al.'s study were university students with a 'self-reported history of therapy and/or services for language impairment, dyslexia, and/or learning disabilities' (p. 161), subsequently tested with standardised language tests. Grunow et al. used the same number of dependencies and an even larger variability than the current experiments (i.e. set size of 24 middle items rather than 18), which should have made their experiment easier than the current one. In the original

3. Attempts to test school-aged children's ability to learn non-adjacent dependencies have so far remained unsuccessful. Unpublished data from our lab show that 5- and 8-year-old children with and without dyslexia were not able to perform above chance levels, using a language with two dependencies and a set size of $X = 18$, either when using the paradigm employed in the current study (i.e. children were asked to respond 'yes' or 'no' to a test sentence) or when asked to choose between two test sentences (data available on request). Results were the same when children were tested simultaneously in class sessions or individual testing sessions, with explicit instructions beforehand that order of the words in the nonsense ('extra-terrestrial') language was important, and when using fun animated cartoon protagonists who spoke one language or the other.

study by Gómez (2002), psychology students who were exposed to a set size of 24 performed at ceiling for the grammatical items (100% endorsements with a standard deviation of zero), which makes the poor performance of Grunow et al.'s language impaired students particularly striking. However, these students likely had more severe impairments than the dyslexic students in the current study, extending to oral language. In a study by Hsu et al. (2014), typically developing adolescents (aged 13–15) performed similarly to the normal readers in the current study, with a hit rate of 79% and a false positive rate of 49% (on a task with 3 dependencies and a set size of 24). In contrast, adolescents with SLI performed poorly, accepting grammatical items in 60% of cases and ungrammatical ones in 61% of cases. Apparently, young adults with literacy problems outperform adults and adolescents with broader language difficulties on non-adjacent dependency learning, which may be related to the latter's more severe (procedural) learning and / or working memory deficits.

A related question that can be raised is whether university students with dyslexia are representative of the general population of people with dyslexia. Other studies with adult dyslexics following higher education have also observed intact implicit learning on the SRT task (Kelly, Griffiths, & Frith, 2002). Kelly et al. argue that implicit learning is unaffected by differences in IQ, which would mean that the current results can be extended to dyslexic adults with lower educational levels. However, Gómez (2002) tested students attending an Ivy League University and found higher scores on the standard NADL task than Grunow et al. (2006), whose sample included typically developing students attending a state university.

In sum, the current findings indicate that adults with dyslexia may be good at tracking non-adjacent dependencies, especially of stimuli they have been presented with before, and when tested in the visual domain. These results contrast with earlier findings that adults with dyslexia are impaired at visuo-motor learning tasks (Lum et al., 2013) and artificial grammar learning (Pavlidou, Kelly & Williams, 2010), and that infants at familial risk of dyslexia are delayed at learning non-adjacent dependencies (Kerkhoff et al., 2013). However, performance on the non-adjacent dependency learning task was related to reading performance, in line with earlier results by Arciuli & Simpson (2012) for healthy adults and children. Moreover, the current results suggest that adults with dyslexia may be relatively poor at generalising structure across novel instances, which is an indication of a statistical or procedural learning impairment (Hsu & Bishop, 2010).

The procedural deficit hypothesis in its current form does not satisfactorily account for the differences between developmental disorders (such as SLI and dyslexia) or the conflicting findings from different implicit learning experiments across different ages and domains (see also Frost, Armstrong, Siegelman, & Christiansen (2015) on modality and stimulus specificity in statistical learning).

Future (longitudinal) studies should aim at relating statistical learning directly to language and reading skills (e.g. Arciuli & Simpson, 2012), taking into account related cognitive skills such as verbal working memory (e.g. Misyak & Christiansen, 2012). There is currently no evidence that statistical learning has clinical or diagnostic relevance, as (subtle) differences only arise in group comparisons. Nonetheless, future research should aim at devising tests of statistical learning that could be used in a clinical or educational setting. A multifactorial approach taking into account relative strengths and weaknesses in underlying cognitive skills and developmental trajectories might be better able to account for the observation that poor readers may sometimes be good learners.

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References

- Arciuli, J., & Simpson, I. (2012). Statistical learning is related to reading ability in children and adults. *Cognitive Science*, 36, 286–304. doi:10.1111/j.1551-6709.2011.01200.x
- Brus, B., & Voeten, M. (1973). *Eén-Minuut-Test, Versie A* [One-Minute-Test, Version A]. Nijmegen: Berkhout.
- Evans, J. L., Saffran, J. R., & Robe-Torres, K. (2009). Statistical learning in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*, 52, 321–335. doi:10.1044/1092-4388(2009/07-0189)
- Frost, R., Armstrong, B. C., Siegelman, N., & Christiansen, M. H. (2015). Domain generality versus modality specificity: the paradox of statistical learning. *Trends in Cognitive Sciences*, 19, 117–125. doi:10.1016/j.tics.2014.12.010
- Gómez, R. L. (2002). Variability and detection of invariant structure. *Psychological Science*, 13, 431–436. doi:10.1111/1467-9280.00476
- Gómez, R. L., & Maye, J. (2005). The developmental trajectory of nonadjacent dependency learning. *Infancy*, 7, 183–206. doi:10.1207/s15327078in0702_4
- Grunow, H., Spaulding, T. J., Gómez, R. L., & Plante, E. (2006). The effects of variation on learning word order rules by adults with and without language-based learning disabilities. *Journal of Communication Disorders*, 39, 158–170. doi:10.1016/j.jcomdis.2005.11.004
- Hsu, H. J., & Bishop, D. V. (2010). Grammatical difficulties in children with specific language impairment: Is learning deficient? *Human Development*, 53, 264–277. doi:10.1159/000321289
- Hsu, H. J., & Bishop, D. V. (2014). Sequence-specific procedural learning deficits in children with specific language impairment. *Developmental Science*, 17, 352–365. doi:10.1111/desc.12125

- Hsu, H. J., Tomblin, B. J., & Christiansen, M. H. (2014). Impaired statistical learning of non-adjacent dependencies in adolescents with specific language impairment. *Frontiers in Psychology*, 5, 1–10. doi:10.3389/fpsyg.2014.00175
- Kelly, S. W., Griffiths, S., & Frith, U. (2002). Evidence for implicit sequence learning in dyslexia. *Dyslexia*, 8, 43–52. doi:10.1002/dys.208
- Kerkhoff, A., de Bree, E., de Klerk, M., & Wijnen, F. N. K. (2013). Non-adjacent dependency learning in infants at familial risk of dyslexia. *Journal of Child Language*, 40, 11–28. doi:10.1017/S0305000912000098
- Kuijpers, C., van der Leij, A., Been, P., van Leeuwen, Y., ter Keurs, M., Schreuder, R., & Van den Bos, K. P. (2003). Leesproblemen in het voortgezet onderwijs en de volwassenheid. *Pedagogische Studiën*, 80, 272–287.
- Lum, J. A., Conti-Ramsden, G., Morgan, A. T., & Ullman, M. T. (2014). Procedural learning deficits in specific language impairment (SLI): A meta-analysis of serial reaction time task performance. *Cortex*, 51, 1–10. doi:10.1016/j.cortex.2013.10.011
- Lum, J. A., Ullman, M. T., & Conti-Ramsden, G. (2013). Procedural learning is impaired in dyslexia, evidence from a meta-analysis of serial reaction time studies. *Research in Developmental Disabilities*, 34, 3460–3476. doi:10.1016/j.ridd.2013.07.017
- McArthur, G. M., Hogben, J. H., Edwards, V. T., Heath, S. M., & Mengler, E. D. (2000). On the 'specifics' of specific reading disability and specific language impairment. *Journal of Child Psychology and Psychiatry*, 41, 869–874. doi:10.1111/1469-7610.00674
- Misyak, J. B., & Christiansen, M. H. (2012). Statistical learning and language: An individual differences study. *Language Learning*, 62, 302–331. doi:10.1111/j.1467-9922.2010.00626.x
- Nicolson, R., & Fawcett, A. (2007). Procedural learning difficulties: Reuniting the developmental disorders? *Trends in Neurosciences*, 30, 135–141. doi:10.1016/j.tins.2007.02.003
- Nissen, M. J., & Bullemer, P. (1987). Attentional requirements of learning: Evidence from performance measures. *Cognitive Psychology*, 19, 1–32. doi:10.1016/0010-0285(87)90002-8
- Pavlidou, E. V., Kelly, M. L., & Williams, J. M. (2010). Do children with developmental dyslexia have impairments in implicit learning? *Dyslexia*, 16, 143–161. doi:10.1002/dys.400
- Plante, E., Gómez, R., & Gerken, L. (2002). Sensitivity to word order cues by normal and language/learning disabled adults. *Journal of Communication Disorders*, 35, 453–462. doi:10.1016/S0021-9924(02)00094-1
- Ramus, F., Rosen, S., Dakin, S. C., Day, B. L., Castellote, J. M., White, S., & Frith, U. (2003). Theories of developmental dyslexia: Insights from a multiple case study of dyslexic adults. *Brain*, 126, 841–865. doi:10.1093/brain/awg076
- Rispens, J., & Been, P. (2007). Subject-verb agreement and phonological processing in developmental dyslexia and SLI: A closer look. *International Journal of Communication Disorders*, 42, 293–305. doi:10.1080/13682820600988777
- Robertson, E., & Joannis, M. (2010). Spoken sentence comprehension in children with dyslexia and language impairment: The roles of syntax and working memory. *Applied Psycholinguistics*, 31, 141–165. doi:10.1017/S0142176409990208
- Saffran, J. R., Newport, E. L., Aslin, R. N., Tunick, R. A., & Barrueco, S. (1997). Incidental language learning: Listening (and learning) out of the corner of your ear. *Psychological science*, 8, 101–105. doi:10.1111/j.1467-9280.1997.tb00690.x
- Saffran, J. R. (2002). Constraints on statistical language learning. *Journal of Memory and Language*, 47, 172–196. doi:10.1006/jmla.2001.2839

- Santelmann, L. M., & Jusczyk, P. W. (1998). Sensitivity to discontinuous dependencies in language learners: evidence for limitations in processing space. *Cognition*, 69, 105–134. doi:10.1016/S0010-0277(98)00060-2
- Snowling, M. J. (2000). *Dyslexia*. Oxford, England: Blackwell Publishers Ltd.
- Ullman, M. (2004). Contributions of memory circuits to language: The declarative/procedural model. *Cognition*, 92, 231–270. doi:10.1016/j.cognition.2003.10.008
- Ullman, M. T., & Pierpont, E. I. (2005). Specific language impairment is not specific to language: The procedural deficit hypothesis. *Cortex*, 41, 399–433. doi:10.1016/S0010-9452(08)70276-4
- Uterwijk, J. (2000). *WAIS-III Nederlandstalige bewerking. Technische handleiding [WAIS-III Dutch version. Technical manual]*. Lisse: Swets & Zeitlinger.
- Van den Bos, K., Iutje Spelberg, H., Scheepstra, A., & de Vries, J. (1994). *De Klepel, Vorm A en B. Een test voor de leesvaardigheid van pseudoworden [De Klepel, Form A and B. A test for the readability of pseudo words]*. Nijmegen: Berkhout.
- Veenker, T. (1998). FEP. Experimental script for UiL-OTS Labs. Ms.
- Vellutino, F. R., Fletcher, J. M., Snowling, M. J., & Scanlon, D. M. (2004). Specific reading disability (dyslexia): What have we learned in the past four decades? *Journal of Child Psychology and Psychiatry*, 45, 2–40. doi:10.1046/j.0021-9630.2003.00305.x
- Wilsenach, C., & Wijnen, F. (2004). Perceptual sensitivity to morphosyntactic agreement in language learners. Evidence from Dutch children at risk for developing dyslexia. Proceedings of 28th BU Conference on Language Development (pp. 645–656). Somerville (Mass): Cascadia Press.
- Wijnen, F. N. K. (2013). Acquisition of linguistic categories: Cross-domain convergences. In J. Bolhuis & M. Everaert (Eds.), *Birdsong, speech and language: Converging mechanisms* (pp. 157–178). Cambridge, MA: MIT press.

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