Sequential Learning among Individuals with Developmental Dyslexia: Evidence

from Visual and Auditory Artificial Grammar Learning Tasks

Shani Kahta

School of Education

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Abstract

The aim of this study was to explore implicit sequential learning processes among individuals with Developmental Dyslexia (DD). Sequential learning is claimed to play an important role in learning a language and linguistic skills such as reading and writing. It has been proposed that the neural basis of language may be part of a broader family of neural mechanisms that the brain recruits when extracting and integrating sequential information in any domain in order to make implicit predictions about the next element in a sequence. Indeed, several studies that explored implicit learning among adults with DD found deficits in tasks that require processing of nonlinguistic sequences, suggesting that a sequential learning deficit underlies DD. One of the most widely used paradigms that require implicit sequential learning is the Artificial Grammar Learning (AGL) task. This paradigm is at the center of the current investigation. Three main issues were at the focus of the present research, within the framework of AGL: the effect of modality on performance, the mechanisms underlying performance, and the ability to generalize abstract information using the transfer paradigm. Five experiments were conducted in order to address these issues.

The aim of Experiment 1 was to investigate implicit learning processes among adults with DD using visual stimuli based on Knowlton and Squire's grammar. Twenty-nine native Hebrew-speaking university students took part in the experiment. Of these, 14 were typically developed (TD) students (controls) with no history of speech, hearing or language impairments, nor learning difficulties, and 15 were students with DD. The DD diagnosis was verified by a

set of reading tests. All participants were first exposed to 20 visual training strings, after which they were asked to classify the test strings for their grammaticality. The results indicated that while learning occurred in both groups, a significant group and grammaticality interaction was found such that individuals with DD identified fewer grammatical strings than TD readers. The results were interpreted as indicating that when classification can be based on a single cue letter, as were the non-grammatical strings in the first experiment, adults with DD can perform as well as TD readers. However, when no such cues are available and the entire sequence needs to be processed, a deficit in sequential learning occurs among persons with DD.

Experiment 2 focused on sequential learning in the auditory modality using a classic AGL task. Twenty four participants were tested: 14 TD controls and 10 individuals with DD. The stimuli were created by mapping each letter in the original grammar to a pure tone and creating tone strings that were identical in their structure to the visual ones. The procedure was identical to the first experiment and contained training and test phases. The results revealed that unlike their performance in visual AGL, individuals with DD failed to exceed chance level when auditory strings were processed. TD readers, on the other hand, performed as well as during the visual task, and were able to classify the strings at above chance level. This result pointed to a-modal implicit learning among TD readers, i.e. no effect of modality on performance, and to modality differences in sequential learning among adults with DD.

Experiments 3 and 4 were designed to investigate the characteristics of the sequential deficit found among individuals with DD in order to elucidate the

underlying mechanisms recruited during the AGL task in both modalities. Since the literature pointed to two main mechanisms: abstractive rule-based processes and similarity-based theories; the stimuli in experiments 3 and 4 were presented in a similarity-balanced design in which the participants were asked to classify grammatical and non-grammatical strings divided into high- and low-similarity strings. This design enables examination of the involvement of each mechanism separately.

Experiment 3 addressed this question using visual stimuli. Thirty-four participants were tested: 16 TD controls and 18 individuals with DD. The procedure was similar to the one in the previous experiments. The results again supported the assumption of a deficit in sequnetial learning, since individuals with DD were less successful in classifying strings than TD readers, although both groups exceeded chance level. The results also revealed dominance of the similarity-based mechanism in classification during AGL for both groups. However, while evidence for also using rule-based processes was found for the TD group, no such evidence was found among the DD group.

Experiment 4 replicated experiment 3 but included auditory rather than visual stimuli. Eleven TD controls and 13 individuals with DD participated in experiment 4. Contrary to the results of the visual experiment, a similarity effect in the auditory task was found only among TD readers but not among the DD group. These results demonstrated the inability of individuals with DD to apply similarity-based processes due to their deficit in sequential learning. The classification rates in the DD group thus did not exceed chance level, while TD readers performed above chance level. It can be concluded, from experiments 3

and 4, that the deficit among adults with DD exists in both modalities, although it is more distinct in the auditory task. The difference between TD readers and individuals with DD was also apparent in the employment of the underlying mechanisms. Thus, even though the results pointed to a dominance of similarity-based processes during the AGL task, TD readers also employed abstractive rule-based processes, while no evidence for the employment of rule-based processes was found in the DD group.

The last issue at the focus of this research was exploration of transfer ability and the flexible nature of implicit sequential learning among adults with DD. The results of the visual tasks (Experiments 1 and 3) indicated that although deficient, individuals with DD were able to learn regularities during AGL Nevertheless, the flexibility of this knowledge, i.e. whether it is input-dependent or can also be used in a different vocabulary, was still unclear. The aim of the fifth experiment was to explore this issue by using the transfer paradigm, in which participants are exposed to a training set in one vocabulary, and are asked to classify strings in another. Since learning occurred among individuals with DD only for visual stimuli, the transfer task was also conducted using visual strings. Thirty participants (half TD controls and half with DD), took part in the transfer experiment. The participants were exposed to 20 training items and 40 test items in a procedure identical to experiment 1, after which they were asked to perform another test in which the set of letters was changed (new vocabulary). The results of the non-transfer condition supported the results of experiments 1 and 3, indicating that participants with DD can indeed exceed chance level in visual AGL, although less efficiently than TD readers. In the transfer test, however, their

performance did not exceed chance level, but rather reached borderline results. This indicated that while TD participants exhibited generalized and flexible sequential learning that can transfer knowledge to new set of items, individuals with DD appeared to use surface-dependent sequential learning.

In conclusion, the results of all five experiments support the hypothesis of a deficit in sequential learning among individuals with DD that might reflect temporal and attentional deficits. Furthermore, the deficiency in implicit sequential learning found among adults with DD highlights the importance of further examination of cognitive aspects of DD which, in turn, may be useful for developing effective assessment and remediation tools for individuals with DD.