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# Probabilistic Category Learning in Developmental Dyslexia: Evidence From Feedback and Paired-Associate Weather Prediction Tasks

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***Objective:*** Developmental dyslexia is presumed to arise from specific phonological impairments. However, an emerging theoretical framework suggests that phonological impairments may be symptoms stemming from an underlying dysfunction of procedural learning. ***Method:*** We tested procedural learning in adults with dyslexia ($n = 15$) and matched-controls ($n = 15$) using 2 versions of the weather prediction task: feedback (FB) and paired-associate (PA). In the FB-based task, participants learned associations between cues and outcomes initially by guessing and subsequently through feedback indicating the correctness of response. In the PA-based learning task, participants viewed the cue and its associated outcome simultaneously without overt response or feedback. In both versions, participants trained across 150 trials. Learning was assessed in a subsequent test without presentation of the outcome, or corrective feedback. ***Results:*** The dyslexia group exhibited impaired learning compared with the control group on both the FB and PA versions of the weather prediction task. ***Conclusions:*** The results indicate that the ability to learn by feedback is not selectively impaired in dyslexia. Rather it seems that the probabilistic nature of the task, shared by the FB and PA versions of the weather prediction task, hampers learning in those with dyslexia. Results are discussed in light of procedural learning impairments among participants with dyslexia.

*Keywords:* developmental dyslexia, probabilistic category learning, feedback, paired-associate, weather prediction task

Developmental dyslexia is a specific developmental disorder in learning to read, which is not a direct result of impairments in general intelligence, gross neurological deficits, uncorrected visual or auditory problems, emotional disturbances, or inadequate schooling (American Psychiatric Association, 2000). The usual symptoms of dyslexia are difficulties in reading, writing, and spelling, and reading-related subskills such as deficits in word identification and phonological decoding (Vellutino, Fletcher, Snowling, & Scanlon, 2004). Despite decades of intensive research, the underlying biological and cognitive causes of dyslexia remain under debate (for a review see, Démonet, Taylor, & Chaix, 2004).

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The phonological account has been one of the prominent theories guiding dyslexia research across four decades. By this account, dyslexia is presumed to arise from a deficit of direct access to, and manipulation of, phonemic language units retrieved from long-term declarative memory (Snowling, 2000). Indeed dyslexia is manifested in poor phonological awareness, impaired verbal short-term memory, and slow lexical retrieval (Vellutino et al., 2004). However, an accumulating body of research is revealing substantial nonlinguistic deficits in those with dyslexia. Dyslexia has been found to be related to deficits in nonlinguistic motor (Nicolson & Fawcett, 1994), procedural learning (Gabay, Schiff, & Vakil, 2012c; Howard, Howard, Japikse, & Eden, 2006; Stoodley, Harrison, & Stein, 2006), and attention skills (Facoetti, Paganoni, & Lorusso, 2000). These impairments are difficult to reconcile with a strictly phonological deficit and have led some to question the ability of the phonological account to serve as the sole explanatory framework of dyslexia (Nicolson & Fawcett, 2011; Stein & Walsh, 1997).

## Procedural Learning Deficit in Dyslexia

An emerging perspective in dyslexia research is that a more general deficit, not specific to phonological processing, may underlie dyslexia. The hypothesis is that a selective impairment in procedural learning may result in the difficulties in phonology, reading, writing, and spelling that characterize dyslexia (Specific

Procedural Learning Deficit, SPLD; Nicolson & Fawcett, 2007, 2010, 2011).

Behavioral studies reveal evidence consistent with procedural learning system impairments among individuals with dyslexia. Much of this work has been carried out in the domain of motor behavior. For example, individuals with dyslexia are impaired in basic motor skills while performing an additional secondary task (Nicolson & Fawcett, 1990; Yap & van der Leij, 1994). Other studies reveal that individuals with dyslexia are impaired on motor adaptation (Brookes, Nicolson, & Fawcett, 2007) and implicit motor sequential learning tasks (Bennett, Romano, Howard, & Howard, 2008; Du & Kelly, 2013; Howard et al., 2006; Stoodley et al., 2006; Stoodley, Ray, Jack, & Stein, 2008; Vicari et al., 2005). Furthermore, procedural motor learning skills of individuals with dyslexia are less stable, are more prone to interference (Gabay, Schiff, & Vakil, 2012b), and consolidate less effectively (Gabay, Schiff, & Vakil, 2012a). In contrast, recent studies suggest that declarative learning might be enhanced among individuals with dyslexia (Hedenius, Ullman, Alm, Jennische, & Persson, 2013).

These impairments are hypothesized to arise from disrupted processing in brain areas related to the procedural learning system (Nicolson & Fawcett, 2011). Evidence from neuropsychological and functional neuroimaging studies supports the distinction between task knowledge that is “declarative” (*knowing what*) and “procedural” (*knowing how*; Cohen, Poldrack, & Eichenbaum, 1997) and suggests that the declarative system is subserved in

possible card arrangements. Each arrangement was associated with one of the two weather outcomes (rainy or fine). Overall, outcomes were presented with equal frequency. Each individual card was associated with a particular outcome with a fixed, independent probability. The probability assigned to each card was counterbalanced, and the

(FB vs. PA) and with the constraint that participants were trained on a different set of cards in each condition.

## Procedure

The procedure was similar to that of Holl et al. (2012). Participants performed both the FB and PA tasks one after the other. Task order was counterbalanced across participants.

## Weather Prediction Task—FB Variant

The training phase consisted of three blocks of 50 trials. On each trial, participants saw an arrangement of cards and made a response to predict the weather (rainy/fine or hot/cold). Feedback appeared immediately after a response, with a written indication presented on the screen to convey whether the weather prediction was correct or incorrect. Participants then requested the next trial with a key press; hence, the task was self-paced. The test phase comprised a further 42 trials with the same structure. On these self-paced trials, participants predicted the weather but did not receive feedback.

## Weather Prediction Task—PA Variant

The training phase consisted of three blocks of 50 trials. On each trial, participants saw an arrangement of cards along with

terbue504g 504garran,edback
wea27 o;ea27 he27 27 self-pther.

## Task Knowledge

Participants rated how related each card was to the weather outcome using a continuous scale ranging from 0 to 100 (e.g., 0 = definitely rainy, 50 = could be either rainy or fine, and 100 = definitely fine). After participants made a vocal response, the experimenter typed the response on the keyboard.

## Self-Insight

Participants then indicated how important each card was for their weather predictions by rating its importance along a continuous scale ranging from 0 to 100, with 0 = not important at all, 50 = moderately important, 100 = very important. The experimenter typed the participant's vocal response on the keyboard.

# Results

## FB Versus PA Test Phase

We first compared the accuracy of the two groups during the test phase of the FB and PA tasks. Following prior studies using the weather prediction task, the correct answer was determined according to the most probable outcome (Gluck, Shohamy, & Myers, 2002).

Preliminary analysis revealed that the order in which the two tasks were performed did not interact with the group variable, $F < 1$. Therefore, further analyses collapsed data across order. An action was marginally significant, $F(2, 56) = 2.92$, $p = .062$, $\eta_p^2 = .08$.

We conducted a further analysis to assure that this marginally significant interaction did not suggest that the observed main effect of group arose from a fundamental difference in the baseline performance of dyslexia versus control group participants instead of a difference in learning across training. The analysis focused on performance on the first 50 training trials in the FB-version of the weather prediction task across groups. An ANOVA was conducted with the first 50 trials binned into 10-trial sets (1–5) as a within-subjects factor and group (dyslexia vs. control) as a between-subjects factor, and mean proportion correct weather predictions across the first five sets of 10 trials (1–10, 11–20, 21–40, 41–50) of the FB weather prediction task as the dependent variable. There was marginally significant main effect for the 10-trial sets, $F(4, 112) = 2.44$, $p = .0507$, $\eta_p^2 = .07$, consistent with modest improvement across these 50 trials. Of most importance, there were no interactions with group, $F(4, 112) = .444$, $p = .775$, $\eta_p^2 = .015$, and the main effect of group was nonsignificant, $F(1, 28) = .064$, $p = .801$, $\eta_p^2 = 08$. This reassures that the omnibus group main effect across the entire set of training trials was not driven by an a priori group difference instead of a difference in learning within the probabilistic category learning task.

## Analysis of Response Strategy

In order to examine if the two experimental groups used different strategies while performing the FB variant of the weather prediction task (in the PA version there was no manual response during learning phase, so strategies cannot be assessed), we followed the analysis of Gluck et al. (2002). We examined which of three possible strategies accounts best for participants' responses: (a) an optimal multicue strategy, in which participants respond to each pattern on the basis of associations of all four cues with each outcome; (b) a one-cue strategy, in which participants respond on the basis of presence or absence of a single cue, disregarding all other cues; or (c) a singleton strategy, in which participants learn only about the four patterns that have only one cue present and all others absent. A nonparametric $\chi^2$ analysis indicated no significant group differences in the number of participants optimally assigned to each strategy, $\chi^2(1) = 0$, $p = 1$; $\chi^2(1) = 1.3$, $p = .24$; $\chi^2(1) = 0$, $p = 1$ (for the multicue strategy, one-cue strategy, and singleton strategies, respectively). Thus, there were no significant differences between the groups in preferred response strategy in the FB variant of the task.

## Awareness: Task-Knowledge

Mean task knowledge difference scores were calculated across the four cards for each participant. A difference score was calculated for each card following the approach of Newell, Lagnado, and Shanks (2007). This was calculated as the actual probability of the negative outcome (.2, .4, .6, .8, for cards 1–4, respectively) subtracted from a participant's own subjective probability estimate. A positive score is indicative of probability overestimates whereas a negative score is indicative of probability underestimation. Preliminary analysis revealed no significant main effects or interactions with the order in which the task-knowledge tasks were performed across FB and PA tasks (minimum $p = .168$). Therefore, the data were collapsed across task presentation order. An ANOVA was conducted on the mean difference scores with task (FB vs. PA) as a within-subjects factor, and group (dyslexia vs. control) as a between-subjects factor. Figure 4 presents task knowledge difference scores for FB and PA tasks for each group. Overall, there was a significant main effect of group, $F(1, 27) = 8.51$, $p = .003$, $\eta_p^2$

## General Discussion

To the best of our knowledge, the present study is the first observe impairments in probabilistic category learning among participants with dyslexia. We examined two versions of the weather prediction task that shared the probabilistic association of cues and outcomes, but differed in whether learning proceeded via explicit feedback (FB version) or through observation of cues and their outcomes (PA version) among a group of adults with dyslexia and matched controls. In other domains, the FB and PA versions of the weather prediction task have served to examine the task characteristics that engage procedural learning (Knowlton et al., 1994; Knowlton, Squire et al., 1996; Shohamy et al., 2004). Both versions of the weather prediction task rely on probabilistic relationships between cues and outcomes. The key difference between the PA and FB versions of the weather prediction task is whether learning takes place via observation (PA) or corrective feedback (FB), but each task requires learning across probabilistic cue–outcome relationships. Comparison of categorization accuracy at test re367.7(Comycti[*(learh(at)]TJT*o,arhaat)]TJTcipants)-560.3

that patterns observed in the current research originated from attention impairments within the dyslexia group. However, the

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