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Insensitivity to Response-contingent Feedback in Adolescents with Developmental Language Disorder (DLD)

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Abstract

The aim of the study was to investigate the efficiency of the use of response-contingent feedback in adolescents with and without developmental language disorder (DLD) by using the balloon analogue risk task (BART). The BIS/BAS scales were also used to evaluate a participant's responses to reward- or punishment-related events in everyday situations. The results showed that adolescents with DLD performed on the BART at a suboptimal level due to inefficient use of response-contingent feedback. Findings of the BIS/BAS scales also generate a possible hypothesis of reduced motivational salience for larger monetary outcomes in DLD. Given that dopamine plays an important role in modulating BART responding through the corticostriatal pathways, these behavioral findings implicate an association between dopamine and individual differences in language, including DLD. Future studies are needed to directly test whether people with DLD have reduced level of dopamine in striatal neural synapses, leading to dopamine-dependent learning difficulty.

Keywords

developmental language disorder; the dopaminergic system; feedback processing; motivational salience; risky decision making

1. Introduction

Developmental language disorder (DLD)¹ is a neurodevelopmental disorder, with an early onset and persistent language difficulty in adolescence and adulthood (Tomblin, 2008). While there is no clear biomedical etiology and diagnosis of DLD, the general consensus is that DLD is a complex multi-factorial disorder, wherein a collection of risk factors (e.g.,

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¹There is no agreed terminology for describing childhood language problems with unknown etiology yet. Some commonly used terms include *specific language impairment* (SLI) or *developmental language impairment* (DLI). In the current study, the term *developmental language disorder* (DLD) is used as suggested in Bishop et al. (2017). It refers to a profile of language difficulties that yields a barrier to effective functional communication (Reilly, Bishop, & Tomblin, 2014). In addition, I also use this term to represent the lower end of a continuous distribution with regard to language abilities, instead of a qualitatively distinct clinical group (Dollaghan, 2011; Leonard, 2009).

genetic, neurobiological, or environmental) acts together, increasing the susceptibility of a disrupted language development (Bishop, 2008).

Findings from behavioral and neuroimaging research have suggested an association between DLD and abnormality of the corticostriatal pathways (see Krishnan et al., 2016, for a review). The corticostriatal pathways are a complex neural network, wherein the basal ganglia receive input from the cortex and then decide what information is (or is not) returned to the cortex (Alexander, DeLong, & Strick, 1986). This neural network involves a variety of human behaviors, including acquisition of habits, learning of sequence and categorization, working memory function, and reinforcement learning (Koziol & Budding, 2009). Previous studies showed that individuals with DLD have difficulty with different types of procedural learning as well as reinforcement learning (Lee & Tomblin, 2012, 2015; Lum & Conti-Ramsden, 2013; Ullman & Pierpont, 2005), which is consistent with brain imaging findings showing structural and functional alterations in the corticostriatal pathways of DLD (Badcock et al., 2012; Jernigan et al., 1991; Lee, Nopoulos, & Tomblin, 2013; Soriano-Mas et al., 2009).

Dopamine neurotransmission is one of the key modulators of these corticostriatal activities, affecting a wide range of motor and cognitive learning behaviors (Aarts, van Holstein, & Cools, 2011; Calabresi et al., 2007; Reynolds & Wickens, 2002). Growing evidence has shown an association between the dopaminergic system and individual differences in language learning (Eicher et al., 2013; Lee, Mueller, & Tomblin, 2016; Tettamanti et al., 2005; Wong et al., 2013). While the exact mechanisms underlying this association remain unclear, it is likely that the dopaminergic system modulates several fundamental learning behaviors that are also critical for language learning and processing (e.g., prediction error-based learning; Schultz & Dickinson, 2000). It is also possible that the relationship between dopamine and language is indeed mediated via the corticostriatal pathways.

One of the higher-level cognitive processes known to involve the dopaminergic system is risky decision making (Simon et al., 2011), a form of behavior entailing striking a balance between options with different probabilities of reward and punishment. During risky decision making, dopamine acts as a learning signal in the brain, constantly shaping behaviors to maximize rewards and to avoid punishments based on previous experiences (Calabresi et al., 2007; Surmeier et al., 2010). When an action is followed by increased dopamine activities, the corticostriatal pathway will be altered to make the same action easier to evoke when similar situations occur in the future. In contrast, when an action is followed by decreased dopamine activities, the corticostriatal pathway will be altered so that this action is more likely to be suppressed in the future. Thus, studying behaviors in the face of risky decision making can be a key to unravel how the brain processes reward-based and punishment-based feedback, as well as examining dopaminergic function at the behavioral level.

1.1. Balloon Analogue Risk Task

In the current study, I used the balloon analogue risk task (BART; Lejuez et al., 2002) to examine sensitivity to response-contingent feedback in a risk-taking situation in adolescents with and without DLD. The BART has been widely used to study the brain mechanisms of

risky decision making (Mata et al., 2012; Rao et al., 2008). During the task, participants are able to accumulate money by pressing a key that inflates a simulated balloon. Each balloon has an explosion point unbeknownst to participants. Too many pumps will explode a balloon, resulting in the loss of money for that balloon trial (i.e., punishment). In contrast, participants can decide to stop inflating a balloon and collect the money earned so far for that balloon trial (i.e., reward). In other words, participants need to balance the potential gain of accruing more money against the potential risk of losing all money accrued for a balloon. It has been shown that BART responding was a good predictor of adolescent real-world risk taking behaviors (Lejuez et al., 2002, 2003a, 2003b).

The dopaminergic system plays an important role in modulating the performance on the BART through the corticostriatal pathways (Kohn et al., 2015; Lancaster et al., 2012; MacDonald et al., 2016; Mata et al., 2012). While BART responding has been often used to reflect the propensity for real-world risk taking behavior, I am more interested in the ongoing process underlying risky decision making in the BART. Thus, in the current study, I examined how individuals with and without DLD utilized response-contingent feedback to deal with risky situations.

1.2. Behavioral Inhibition System/Behavioral Activation System (BIS/BAS) Scales

The BART looks at risky decision making within a laboratory setting. In contrast, the BIS/BAS scales, a self-report questionnaire, evaluate a participant's responses to reward-related or punishment-related events in daily situations. Carver and White (1994) developed the BIS/BAS scales based on the Reinforcement Sensitivity Theory (RST; see Corr, 2004, for a review). According to the RST, two systems are proposed for regulating human behavior. The behavioral activation system (BAS), on the one hand, is responsible for responses to rewarding stimuli, which is facilitated by the dopaminergic pathways. High sensitivity in the BAS results in appetitive behavior in the presence of cues that predict reward. On the other hand, the behavioral inhibition system (BIS) regulates responses to aversive stimuli, which is supported by the amygdala and the septo-hippocampal system. High sensitivity to the BIS is reflected in inhibitory behaviors and avoidant responses to stimuli associated with non-reward/punishment. The BIS/BAS scales have been widely used as a neuropsychological measure for understanding how neurobiological mechanisms for behavioral regulation relate to personality traits, and moreover, to a broad range of psychopathology (Johnson, Turner, & Iwata, 2003).

1.3. The Current Study

The aim of the current study was to examine the efficiency of the use of response-contingent feedback in adolescents with and without DLD. I hypothesized that compared with those without DLD, adolescents with DLD would be insensitive to response-contingent feedback, resulting in abnormal risk taking behavior on the BART. While there is no prior work on response-contingent feedback in DLD, this hypothesis is generated from previous studies showing poor feedback-based learning as well as structural abnormality of the nucleus accumbens in DLD (Kemeny & Lukacs, 2010; Lee & Tomblin, 2012; Lee et al., 2013). As an ancillary analysis, the BIS/BAS scales were used to evaluate a person's response to

reward-related or punishment-related events in daily situations. I expected to see group difference on the BIS/BAS scales, but no direction was predicted.

2. Methods

2.1. Participants

Two groups of adolescents, one with DLD ($n=26$) and the other without ($n=36$), were recruited from several high schools and colleges in Eastern Iowa. The diagnosis was made based on five language tests and two nonverbal IQ subtests of the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999). The five language tests include: 1) Peabody Picture Vocabulary Test, Fourth Edition (PPVT-4; Dunn & Dunn, 2007) to assess receptive vocabulary, 2) Expressive Vocabulary Test, Second Edition (EVT-2; Williams, 1997) to assess expressive vocabulary, 3) Recalling Sentences in Clinical Evaluation of Language Fundamentals, Fourth Edition (CELF-4; Semel et al., 2003) to assess the ability to recall and reproduce sentences of syntactic complexity, 4) Understanding Spoken Paragraphs in CELF-4 to assess passage comprehension, and 5) Word Derivations in the Test of Adolescent and Adult Language, Fourth Edition (TOAL-4; Hammill, Brown, Larsen, & Wiederholt, 2007) to assess knowledge of derivational morphology. Language composite scores were calculated for each participant by averaging the five language test scores. Table 1 summarizes the demographic information and test scores of the two groups. Theoretical reasons for not requiring participants with DLD to have nonverbal IQ levels above 85 have been discussed in other publications, so will not be repeated here (Lee & Tomblin, 2012; see also Earle et al., 2015).

2.2. Materials

2.2.1. Balloon Analogue Risk Task (BART)—The BART is a computerized task widely used to measure risk taking behavior (Lejuez et al., 2002). During the task, the examiner told participants that there was a chance to earn extra money. Then, a simulated balloon was presented on the computer screen (see Figure 1). Participants were instructed to inflate the balloon as large as possible by pressing the V key. Each key press relates to an increase in points, and points can be exchanged for real money at the end of the task (i.e., .01 dollar for each pump). If participants choose to stop pumping before the balloon explodes, they can press the N key. However, if the balloon explodes, the points for that trial will be lost. There was one practice trial, followed by 30 consecutive trials in the task (i.e., 30 balloons presented to the participants one at a time), and participants were not informed about the balloon breakpoints. Following the original method of previous work, the probability that a balloon would explode was fixed at 1/128 for the first pump. If the balloon did not explode after the first pump, the probability that the balloon would explode was 1/127 on the second pump, 1/126 on the third pump, and so on, until the 128th pump at which point the probability of an explosion was 1/1 (i.e., 100%). Based on this algorithm, the average explosion point was 64 pumps for each balloon.

2.2.2. Behavioral Inhibition and Activation (BIS/BAS) Scales—The BIS/BAS scales are a self-report questionnaire used to assess a participant's sensitivity to punishment and to reward in daily situations (Carver & White, 1994). There are twenty-four items using

a 4-point scale (from 1, *disagree strongly*, to 4, *agree strongly*). These items provide information about a person's behavioral inhibition system (i.e., BIS; e.g., "*Criticism or scolding hurts me quite a bit*") and three dimensions of the behavioral activation system (BAS), including persistence to obtain goals (BAS-Drive; e.g., "*If I see a chance to get something I want I move on it right away*"), the willingness to seek out and spontaneously approach potentially rewarding experiences (BAS-Fun Seeking; e.g., "*I'm always willing to try something new if I think it will be fun*"), and the anticipation of and positive response towards reward (BAS-Reward; e.g., "*when I get something I want, I feel excited and energized*").

3. Procedure

The task order was randomly varied across participants. The BART and the BIS/BAS scales were part of a large task protocol, and therefore participants had to complete other language and cognitive tasks in addition to the BART and the BIS/BAS scales. The time span between the BART and the BIS/BAS scales was no longer than an hour. During the BART, an examiner read the instruction to the participant in order to ensure task understanding. When participants filled out the BIS/BAS scales, an examiner was available to provide assistance if needed (e.g., clarifying word/phrase meanings, reading items for those who did not feel comfortable reading himself/herself). It takes 15–20 minutes to complete the BART and 3–5 minutes to fill out the BIS/BAS scales.

4. Data Analysis

With regard to the BART, I analyzed the adjusted number of pumps across balloons as the dependent measure. The adjusted value is defined as the average number of pumps on trials where the balloon did NOT explode. This adjustment was suggested in the literature because the total number of pumps is restricted by the exploded balloons, which limits between-subject variability in the absolute averages (Lejuez et al., 2002). Other potential dependent measures (e.g., total earned points, total earned money) were analyzed and elicited similar findings, and therefore were not reported in the Results to avoid redundancy. Given that there were significant correlations between nonverbal IQ and the adjusted number of pumps, $r=.37$, $p=.003$, analysis of covariance (ANCOVA) was carried out to compare the adjusted number of pumps between the DLD and the comparison group, with nonverbal IQ as the covariate. In addition, considering language ability also as a continuous variable, a partial correlation was performed to examine the relationship between the adjusted number of pumps and individual differences in language, with nonverbal IQ as the covariate.

To assess sensitivity to punishment (i.e., making fewer pumps due to prior balloon explosion), for each balloon that exploded, I subtracted the number of pumps made on the trial preceding the exploded balloon from the number of pumps made on the balloon trial immediately following the exploded balloon. Negative values mean fewer pumps following a balloon explosion, indicating that the role of punishment comes into play. To assess sensitivity to reward (i.e., making more pumps after a trial of an unexploded balloon), I subtracted the number of pumps made on an unexploded balloon trial (i.e., a successful collection of money) from the number of pumps made on the balloon trial immediately

following the unexploded balloon trial. Positive values mean more pumps following an unexploded balloon trial, indicating that the role of reward comes into play (see Humphreys & Lee, 2011; Poon & Ho, 2016, for a similar method). Independent-samples *t*-tests were performed to compare the difference of sensitivity to punishment and sensitivity to reward between the DLD and the comparison group.

In terms of the BIS/BAS scales, the dependent variables include: 1) the BIS score, 2) the BAS-Drive score, 3) the BAS-Fun Seeking score, and 4) the BAS-Reward score. Independent-samples *t*-tests were performed to compare the difference of the behavioral inhibition system and the behavioral activation system between the DLD and the comparison group. Given that this is an exploratory analysis, no corrections were made for multiple testing.

5. Results

5.1. BART

The ANCOVA showed a significant difference in the adjusted number of pumps between the two groups with nonverbal IQ as the covariate, $F(1,61) = 9.61$, $p = .003$, such that the DLD group made fewer pumps than the comparison group, leading to lower monetary rewards. The balloon explosion rate was lower in the DLD group relative to the comparison group, $t(60) = 3.06$, $p = .003$, partial $\eta^2 = .14$, indicating that adolescents with DLD preferred safe/conservative actions. Table 2 summarizes performance on the BART of the two groups.

Sensitivity to punishment and reward were assessed respectively. The results showed that when compared with the comparison group, the DLD group was less sensitive to reward, $t(60) = 2.85$, $p = .006$, and also less sensitive to punishment, $t(60) = 2.25$, $p = .03$. The effect size (Cohen's *d*) for the sensitivity to reward was .74, larger than that for the sensitivity to punishment, $d = .60$.

Language ability can be represented on a continuum instead of a dichotomy (i.e., without DLD vs. with DLD). Therefore, a partial correlation was carried out to examine the role of individual differences in language in the BART. The result showed a significant correlation between language composite scores and the adjusted number of pumps in the BART, $r = .38$, $p = .002$, with nonverbal IQ controlled as a covariate (see Figure 2). This finding suggests an association between individual differences in language and risky decision making.

5.2. BIS/BAS Scales

Table 2 illustrated the descriptive statistics of the BIS/BAS scores. The DLD group was significantly different from the comparison group only in the BAS-Reward subscale, $t(60) = 2.22$, $p = .031$, $d = .56$, but not in the BIS scale or other BAS subscales ($p > .15$). This finding indicates that in general, reward-related information in the environment is not a strong motivation to guide behaviors of adolescents with DLD. Examples of items showing the BAS-Reward subsystem are illustrated below: “*When I’m doing well at something I love to keep at it*”, “*When I get something I want, I feel excited and energized*”, or “*When I see an opportunity for something I like I get excited right away*”. In contrast, the DLD and the comparison group had relatively equivalent responses to punishment-related information.

6. Discussion

The aim of the study was to investigate the efficiency of the use of response-contingent feedback in adolescents with and without DLD. The findings implicate the dopaminergic modulation of corticostriatal function as possible neurobiological mechanisms underlying individual differences in language, including DLD.

6.1. Summary of Findings

To summarize the results, participants with DLD performed the BART at a suboptimal level, making fewer pumps per balloon trial than the comparison participants. Further analyses suggested that the abnormal tendency to engage in safe over risky decisions was, at least partially, due to their reduced sensitivity to response-contingent feedback. In other words, individuals with DLD did not adjust their actions following an exploded and a rewarded balloon trial as effectively as the comparison participants. Given that the BART requires risky decision making over a time window (i.e., participants have to withhold their actions until larger rewards are presented if they want to earn more money), the current findings suggest that adolescents with DLD cannot efficiently utilize response-contingent information to guide long-term decision-making. The results are consistent with my prior work on reinforcement learning in young adults with DLD, who could not effectively use positive/negative feedback to learn nonverbal categories (Lee & Tomblin, 2012).

Previous studies showed that scores on the BART are positively correlated with self-reported engagement in real-world risk taking behaviors (e.g., smoking, delinquency, or safety-related behaviors), but are negatively correlated with long-term alcohol use and levels of anxiety (Campbell, Samartgis, & Crowe, 2013; Lejuez et al., 2002, 2003a, 2003b; Maner et al., 2007). On the one hand, individuals with DLD are reported to have social withdrawal (e.g., isolation or shyness) as well as emotional problems, anxiety and depression in particular (Conti-Ramsden et al., 2013; St Clair et al., 2011). These social and emotional difficulties, which have been associated with corticostriatal functioning (Baez-Mendoza & Schultz, 2013; Marchand, 2010), are consistent with the less optimal performance on the BART in the DLD group. Risk taking behaviors in DLD, on the other hand, have not been widely examined in the literature. Beitchman et al. (1999) found a high proportion of substance use in individuals with DLD. These findings appear to contradict those of Conti-Ramsden et al. (2013) showing the strength of pro-social behaviors in DLD, given that pro-social behaviors have been shown to reduce substance use in adolescents and young adults (Carlo et al., 2011). Future studies are needed to examine real-world risk taking behaviors in individuals with DLD.

In addition to the BART, I also used the BIS/BAS scales as an ancillary analysis to explore how adolescents with and without DLD respond to reward-related or punishment-related events in everyday situations. The results showed that in general, adolescents with and without DLD had equivalent reactions in response to aversive stimuli (e.g., both groups showed equivalent levels of worry when doing poorly at something important, or equivalent levels of anger and anxiety when something unpleasant is going to happen). However, the DLD group showed a lower level of motivated behaviors than the comparison group in the presence of cues that predicts reward/positive reinforcers (e.g., the DLD group showed less

excitement or satisfaction when being praised for doing something good than the comparison group). These data provide a possible explanation to the conservative behavior of the DLD group in the BART, suggesting that adolescents with DLD may have reduced motivational salience, and thus during the BART, they were not as motivated as those without DLD to adjust the number of pumps in order to maximize the overall reward (i.e., total points in exchange of money).

These two possibilities to explain the suboptimal performance of the DLD group on the BART (i.e., reduced sensitivity to reward-based and punished-based feedback and reduced motivational salience) are not mutually exclusive. Indeed, both possibilities, along with other cognitive (e.g., poor executive functioning or poor memory) and environmental factors (e.g., vicious circle of educational failure), could all contribute to their conservative behavior in risky decision making. These task-extrinsic factors are worth being studied in the future.

6.2. The Dopaminergic System: A Possible Mechanism Underlying Individual Differences in Language

The dopaminergic system modulates performance on the BART through the corticostriatal pathways (Kohn et al., 2015; Lancaster et al., 2012; MacDonald et al., 2016; Mata et al., 2012). Excessive or suboptimal responses, which indicate a high or a conservative risk taking behavior respectively, have been interpreted to suggest alterations in the dopaminergic system, although it remains unclear how exactly the underlying mechanisms operate.

While there is a paucity of research on the association between the dopaminergic system and DLD (Lee et al., 2016; Mueller, 2012), more and more studies have shown structural and functional alterations in the corticostriatal pathways of DLD (Badcock et al., 2012; Jernigan et al., 1991; Lee et al., 2013; Soriano-Mas et al., 2009). The current behavioral findings are consistent with these brain imaging data, suggesting that the suboptimal performance of the DLD group on the BART may be attributed to their altered corticostriatal pathways. In addition, based on the BART literature, the findings may also implicate a possible role of the dopaminergic system in DLD. I hypothesize that adolescents with DLD have an altered dopaminergic system, which causes inefficient feedback processing as well as reduced motivation for monetary rewards when performing on the BART. Dopamine levels change in response to environmental factors (e.g., Propper et al., 2008; Segovia et al., 2008), and thus it is important to investigate how the system involves in the language acquisition/learning process, which will shed light on language education and intervention (Shakouri, 2014).

6.2.1. Dopamine and feedback processing—Corticostriatal synapses are modified based on dopaminergic signals from the basal ganglia and the ventral tegmental area, which carry feedback-related information (Cepeda et al., 1993; Reynolds et al., 2000). These feedback-related signals are important, allowing people to modulate the behavior to maximize reward and minimize punishment. This can explain why people with Parkinson's disease, who have profound loss of striatal dopamine neurons, have impaired performance on tasks involving trial-by-trial feedback (Shohamy et al., 2004). The close association between dopamine and feedback processing can also explain why adolescents tend to engage

in reward-seeking behavior—previous studies showed increased dopamine levels in the striatum during adolescence, and thus when stimulated (by rewards, for instance), adolescents will have “greater dopamine release, subsequently contributing to a reinforcing feedback cycle that motivates additional reward-seeking behavior” (Galvan, 2010, p.2).

In the current study, adolescents with DLD showed reduced sensitivity to response-contingent feedback, and thus had suboptimal performance on the BART. It is possible that these language-impaired adolescents did not follow the same pattern of striatal dopamine development as their peers, which place them at a disadvantaged position with regard to feedback-based learning.

6.2.2. Dopamine and Motivational Salience—In addition to its role in feedback processing, the dopaminergic system is also associated with motivational salience (Wise, 2004). Treadway et al. (2012) used positron emission tomography (PET) to show that healthy research subjects who are willing to work hard for rewards tend to have higher release of dopamine in the striatum and the ventromedial cortex. In addition, Rutledge et al. (2015) found that high levels of dopamine boosted by levodopa administration made potential rewards more appealing to healthy research subjects in a gambling task. Their findings are consistent with the literature on risk seeking behavior in teenagers, given that increased level of dopamine in neural synapses during adolescence may make the potential reward more irresistible (Galvan, 2010; Wahlstrom et al., 2010).

Based on the prior work, it is possible that people with DLD have reduced levels of dopamine than their peers, and thus the monetary reward in the BART was not strongly appealing to them to make behavioral adaptation. In other words, instead of expending more effort on the task to choose the “best” (i.e., higher monetary rewards), they seem to prefer to settle for options that are simply good enough, and they feel satisfied with the choice. This hypothesis is mainly generated from the findings of the BIS/BAS scales, and thus requires to be further explored in the DLD population. It should be noted that the lack of general motivation could not explain the current finding, because the DLD group showed equivalent scores on other BAS subscales (i.e., BAS-Fun Seeking and BAS-Drive) with the comparison group.

In Section 6.2, I discussed about the findings concerning a possible relationship between the dopaminergic system and DLD. However, data should be interpreted with caution due to the complexity of the mechanisms underlying DLD, as well as the complexity of dopaminergic modulation of the corticostriatal pathways. While growing evidence has pointed to the corticostriatal contribution to DLD (see Krishnan et al., 2016, for a review), it requires further studies to examine how the corticostriatal pathways interact with other brain systems to characterize the profile of DLD, and how dopamine modulations of synaptic plasticity in the corticostriatal pathways plays a role in memory and learning in the DLD group. Although BART responding implicates a role of the dopaminergic system in DLD, it does not exclude the possibility of other mechanisms involving in the relationship between suboptimal performance on the BART and DLD.

In addition, the mechanisms underlying dopaminergic modulations of the corticostriatal pathways are complex and developmentally vulnerable to a group of related neurodevelopmental disorders, including DLD, Attention Deficit Hyperactivity Disorder (ADHD), Tourette's syndrome, autism, and schizophrenia (see Bradshaw, 2001, for a review). The manifestation of each disorder may depend on how the corticostriatal pathways happen to be compromised, as a consequence of inherited genetic predispositions and environmental contingency. Studying the commonalities and differences in these disorders will broaden our knowledge of the corticostriatal pathways at the behavioral and cognitive levels, which, in turn, will lead to a better understanding of the mechanisms underlying DLD.

6.3. Role of Response-contingent Feedback Processing in Individual Differences in Language

Decision making is a complex process, involving weighing reward and punishment against their probabilities in order to determine the values of the candidate actions (Simon et al., 2011). While discussion over the complexity of the decision making process is beyond the scope of the manuscript, the current findings suggest that dopaminergic modulation of risky decision making via the corticostriatal pathways may also underlie language acquisition and learning (Shakouri, 2014). I am particularly interested in the role of feedback processing, an integral component of the decision making process, in individuals with DLD because it may inform effective intervention strategies for people with developmental language disorders.

Reward-based and punishment-based feedback is a potent modulator of human and animal behavior (Brand, 2008). For example, humans learn stimulus-response associations based on trial-by-trial feedback after each response (Pavlov, 1927; Skinner, 1938). Learning can also occur by using the difference between expected outcomes and actual outcomes (i.e., prediction error) through trial-by-trial feedback to incrementally update internal representations of state-action values (Sutton & Barto, 1998). The current study showed that adolescents with DLD did not make the most use of the response-contingent feedback (i.e., reward or punishment after a response) to optimize their decisions along the task process. Therefore, it is likely that people with DLD will show language learning difficulty when updating of information based on reward- and punishment-based feedback is required (but see Krishnan et al., 2016).

Concerns may be raised regarding whether feedback is a critical component contributing to individual differences in language. After all, parents generally do not give children feedback on their language errors, but children can still acquire language well (Marcus et al., 1992; Pinker, 1984; Taatgen & Anderson, 2002). I agree that explicit/corrective feedback on language production errors is not a necessity to acquire language. However, I suggest that we should move beyond the traditional types of behavioral paradigms that limit the discussion of feedback on the role of explicit reward (e.g., food or praise) or explicit punishment (e.g., electronic shock, or direct correction) in behavioral adaptation and learning. Feedback can be internal as well. Indeed, our brain constantly sends out signals that indicate the similarity/difference between the expected outcome and the actual outcome, and this comparison can even occur under observation (Doya, 2007; Schultz & Dickinson,

2000). These signals in the brain serve as internal feedback to either positively or negatively reinforce our learning behaviors. For example, an infant learning to produce his first word needs to try out various ways of producing it. Some strategies work—he is “rewarded” (e.g., parent’s excitement, or a signal in the brain showing the perfect match between the sound he recently heard from a parent and the sound he just produced), and thus the effective strategies are more likely to stay in use. Other strategies may fail—he is “punished” (e.g., parents not getting what he wants, or a prediction error signal in the brain showing the mismatch between the sound he produced and the sound he recently heard), and thus the failed strategies are less likely to be used again. In other words, efficiency of feedback processing may be one of the important factors contributing to individual differences in language.

7. Conclusion

Multiple biological and environmental factors interact to account for individual differences in language (see Figure 3). In the current study, I examined the role of feedback processing in individuals varied with language ability. The results suggest that adolescents with DLD perform on a gambling task at a suboptimal level due to their inefficient use of response-contingent feedback. It is also possible that these adolescents have relatively reduced motivational salience for larger monetary outcomes. The behavioral findings implicate a possible role of the dopaminergic system in individual differences in language, including DLD, although no specific dopaminergic circuits could be implicated. Future studies are needed to directly test the hypothesis that people with DLD have reduced level of dopamine in the mesocorticolimbic dopaminergic system, leading to dopamine-dependent learning difficulty.

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Highlights

- Conservative actions preferred by adolescents with DLD during risky decision making
- Suboptimal performance in DLD due to inefficient use of response-contingent feedback
- Reduced motivational salience in DLD as a possible hypothesis awaiting testing
- Findings implicating a role of the dopaminergic system in DLD

Figure 1.

An example of one trial in the balloon analogue risk task (BART).

Figure 2.

A plot illustrating the partial correlation between language composite scores and the adjusted number of pumps.

Figure 3.
An illustration of multiple interactive systems contributing to individual differences in language.

Table 1
Age, sex, language scores, and nonverbal IQ scores for the two groups of participants.

	DLD group (n = 26)		Comparison group (n = 36)		p
	M	(SD)	M	(SD)	
Age (year)	16.69	1.43	16.90	1.47	0.57
Sex (Female:male)	17:9		21:15		0.57
Language composite scores	77.88	6.00	108.45	6.78	<0.001
<i>PPVT-4</i>	77.69	12.83	115.00	10.41	<0.001
<i>EVT-2</i>	78.04	9.97	113.72	9.96	<0.001
<i>Word derivations</i>	78.85	9.52	107.22	9.60	<0.001
<i>Recalling sentences</i>	76.54	16.48	102.86	9.57	<0.001
<i>USP</i>	78.27	10.95	102.57	11.72	<0.001
Nonverbal IQ	81.65	10.03	106.97	14.71	<0.001

Note. Test scores were reported in standard scores with a mean of 100 and SD of 15. Language composite scores were calculated by averaging the five language scores. *PPVT-4*: Peabody Picture Vocabulary Test, Fourth Edition; *EVT-2*: Expressive Vocabulary Test, Second Edition; *USP*: Understanding Spoken Paragraphs.

Table 2

Summary of performance on the BART and scores on the BIS/BAS scales.

	DLD Group (n=26)		Comparison Group (n=36)			
	M	(SD)	M	(SD)	<i>p</i>	<i>d</i>
BART						
<i>Number of Pumps</i>	26.32	11.76	40.60	12.63	<.001**	1.17
<i>Number of Popped Balloons</i>	7.65	3.48	10.47	3.65	.003**	.79
<i>Sensitivity to Punishment</i>	-30.35	26.64	-51.11	41.32	.03*	.60
<i>Sensitivity to Reward</i>	33.39	34.43	59.97	37.45	.006**	.74
BIS/BAS Scale						
<i>BIS</i>	20.50	4.50	21.61	3.98	.31	.26
<i>BAS-Drive</i>	10.81	2.55	10.69	2.57	.86	.05
<i>BAS-Fun Seeking</i>	11.92	1.60	12.50	1.88	.21	.33
<i>BAS-Reward</i>	16.46	2.90	17.97	2.46	.03*	.56

Note. *P*-values were generated based on independent-samples *t*-tests. A single asterisk indicates significance at *p*<.05, and two asterisks indicate significance at *p*<.01. *d*: Effect size based on Cohen's *d*.
BART: Balloon analogue risk task; BIS: Behavioral inhibition system; BAS: Behavioral activation system.