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Risky decision-making in children with and without ADHD: A prospective study

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ABSTRACT

Learning from past decisions can enhance successful decision-making. It is unclear whether difficulties in learning from experience may contribute to risky decision-making, which may be altered among individuals with attention-deficit/hyperactivity disorder (ADHD). This study follows 192 children with and without ADHD aged 5 to 10 years for approximately 2.5 years and examines their risky decision-making using the Balloon Emotional Learning Task (BELT), a computerized assessment of sequential risky decision-making in which participants pump up a series of virtual balloons for points. The BELT contains three task conditions: one with a variable explosion point, one with a stable and early explosion point, and one with a stable and late explosion point. These conditions may be learned via experience on the task. Contrary to expectations, ADHD status was not found to be related to greater risk-taking on the BELT, and among younger children ADHD status is in fact associated with reduced risk-taking. In addition, the typically-developing children without ADHD showed significant learning-related gains on both stable task conditions. However, the children with ADHD demonstrated learning on the condition with a stable and early explosion point, but not on the condition with the stable and late explosion point, in which more pumps are required before learning when the balloon will explode. Learning during decision-making may be more difficult for children with ADHD. Because adapting to changing environmental demands requires the use of feedback to guide future behavior, negative outcomes associated with childhood ADHD may partially reflect difficulties in learning from experience.

ARTICLE HISTORY

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KEYWORDS

ADHD; Risk-taking; Decision-making; Learning; Prospective

Attention-deficit/hyperactivity disorder (ADHD) is characterized by developmentally aberrant levels of inattention and hyperactivity (American Psychiatric Association, 2013) with a worldwide prevalence rate of 5.3% (Polanczyk, de Lima, Horta, Biederman, & Rohde, 2007). Longitudinal studies consistently reveal that children with ADHD are frequently impaired across multiple domains (Lee, Lahey, Owens, & Hinshaw, 2008; E. B. Owens, Hinshaw, Lee, & Lahey, 2009). In fact, ADHD has been conceptualized as a disorder of disinhibition (Nigg, 2001) based partly on the prospective association between ADHD and outcomes characterized by poor inhibitory control,

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such as alcohol and substance use disorders (Charach, Yeung, Climans, & Lillie, 2011; Lee, Humphreys, Flory, Liu, & Glass, 2011), risky driving, sexual behavior, gambling, and unintentional injury (Breyer et al., 2009; Garzon, Huang, & Todd, 2008; Thompson, Molina, Pelham, & Gnagy, 2007; Wymbs et al., 2013). Such longitudinal associations following ADHD diagnoses motivate interest in understanding the neuropsychological factors that may result in increased risky behaviors among children with ADHD.

Altered decision-making among those with and without ADHD is a promising avenue for these investigations. Sonuga-Barke, Cortese, Fairchild, and Stringaris (2016) posit that deficits in decision-making found among individuals with ADHD may be due to alterations in several brain systems involved in disparate processes (i.e., executive, reinforcement, and self-referential processes). The result of such alterations is decision-making characterized as impulsive (e.g., selecting immediate smaller rewards over delayed larger rewards) and deficient (e.g., not appropriately reflective; Sonuga-Barke et al., 2016). As a result, findings of increased risk-taking among individuals with ADHD (DeVito et al., 2008; Humphreys & Lee, 2011) may not be a sign of risk proneness, but rather reflect deficiencies in decision-making (Sonuga-Barke et al., 2016). Evidence for this view comes from work indicating that adolescents with ADHD placed smaller bets than typically-developing adolescents on a modified version of the Cambridge Gambling Task—a probabilistic gambling task with explicit probabilities of contingencies—suggesting reduced risk-taking during decision-making (Kroyzer, Gross-Tsur, & Pollak, 2014).

Importantly, the Cambridge Gambling Task allows for calculated determinations of optimal behavior and does not require the learning of contingencies. Most decisions, however, are not accompanied by explicit probabilities of contingencies. Thus, there is considerable interest in studying decision-making in the context of uncertainty, given that this context is a better representation of real-life decision-making. Tasks which require individuals to make decisions based on experience have found that ADHD-related impairments may be explained, in part, by executive processing difficulties, including those related to working memory (Duarte, Woods, Rooney, Atkinson, & Grant, 2012). Learning from experience is a critical aspect of effective decision-making, given that the appropriate use of feedback can usefully guide future behavior (Barto, Sutton, & Watkins, 1990). To date, there is mixed evidence regarding reinforcement learning in ADHD, such that one study found no differences among children with and without ADHD in rates of instrumental learning (Luman, Goos, & Oosterlaan, 2015) whereas another found that adolescents with ADHD demonstrate impaired learning during decision-making compared to those without ADHD (Hauser et al., 2014).

The present study seeks to probe this question further by examining sequential risky decision-making among children with and without ADHD. The Balloon Emotional Learning Task (BELT; Humphreys, Lee, & Tottenham, 2013) was used, which is structurally similar to the Balloon Analogue Risk Task (BART; Lejuez et al., 2002, 2007), in that both tasks require participants to pump up a series of virtual balloons for points. Following each pump, participants choose to either save points (and end the trial) or continue to pump. However, no points are earned on the trial if the balloon explodes. Crucially, unlike the BART, the BELT features two stable conditions in addition to a variable balloon condition. Each stable balloon condition consists of a
fixed explosion point (i.e., a low vs. high feedback threshold), which provides the opportunity for participants to learn the explosion point, therefore guiding decision-making regarding how much to pump up subsequent balloons. The varying conditions of the BELT allow for the assessment of how task experience affects subsequent behavior (i.e., through learning) given that the feedback provided (e.g., fixed vs. variable explosion point) indicates information regarding the likelihood that subsequent balloons from the same condition will explode at a given number of pumps. Prior research suggests that both children and adults differentiated between balloon conditions and earned more points with greater task experience (Humphreys et al., 2013; Humphreys, Telzer et al., 2016).

Study Rationale and Hypotheses

This study has two aims. The first aim is to examine whether Wave 1 ADHD prospectively predicts risk-taking (i.e., pumps) as well as the outcome of that behavior (i.e., points) on the BELT, assessed at a follow-up approximately 2.5 years later (Wave 2). Given the large body of literature demonstrating the prospective association between ADHD and later risky behaviors (Babinski et al., 2011; Charach et al., 2011; Lee et al., 2011), it was hypothesized that children with ADHD would demonstrate greater risk-taking. However, it was noted that reduced risk-taking among those with ADHD might also be found (Kroyzer et al., 2014). The second aim—considering findings of a positive association between an attentional construct and learning on the BELT in young adults (Humphreys et al., 2013)—is to examine the association between ADHD and learning on the BELT. Given that two of the three BELT conditions provide stable feedback regarding the explosion threshold, learning on the task was examined as a function of ADHD. There was reason to hypothesize that the children with ADHD would demonstrate less learning than the children without ADHD (Hauser et al., 2014), but also to hypothesize that those with and without ADHD would show no differences in learning (Luman et al., 2015).

Method

Participants

At baseline (i.e., Wave 1), 230 participants aged 5 to 10 years were assessed. All families were invited back to the laboratory for a follow-up assessment (Wave 2, occurring approximately 2.5 years after the baseline evaluation). Of the initial Wave 1 sample, 192 participated in the Wave 2 follow-up assessment, comprising the sample size of the present study. The families who participated in the follow-up had a higher mean number of child ADHD symptoms than the families who did not participate in Wave 2, t(226) = −2.08, p = .04, but there are no other significant demographic differences between these two groups of families. The Wave 1 participants had a mean age of 7.85 years (SD = 1.17) and slightly more than half were diagnosed with ADHD (n = 104) than without (n = 88). The Wave 2 participants were 7 to 14 years old with a mean age of 10.31 years (SD = 1.43). The mean length of the time between Wave 1 and 2 was 2.51 years (SD = 0.74, range = 1.50 to 4.94 years). Approximately one third
of the participants (32%) regularly took psychotropic medications, though only 13% took medication on the testing day. Families were recruited from a large metropolitan area in the Western United States (US) using presentations to self-help groups for ADHD, advertisements mailed to local elementary schools, pediatric offices, clinical service providers, and some referrals from mental health clinics. Table 1 provides the demographic information based on ADHD status in Wave 1. More information about the study sample can be found in Humphreys, Aguirre, and Lee (2012) and Lee and Humphreys (2014). No prior publications using this sample have included the BELT.

### Procedure

In Wave 1, study eligibility for interested families was determined through a telephone screening. Families were invited to the laboratory for in-person assessments. After obtaining parental consent and child assent, parents completed a structured diagnostic interview of child psychopathology, children completed neuropsychological and computerized assessments, and other information not relevant to the current study was also included. Interviewers were initially unaware of the child’s diagnostic status, although this was difficult to maintain following the completion of the diagnostic interview. Procedures for the Wave 2 follow-up were highly parallel to those of Wave 1; for more information on the procedures used in Wave 2, see Tung, Brammer, Li, and Lee (2014). The UCLA institutional review board approved all study procedures.

### Measures

**The Diagnostic Interview Schedule for Children – Fourth Edition (DISC-IV).**

In Wave 1, trained graduate students administered the DISC-IV (Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000)—a computer-assisted, fully-structured diagnostic interview—with the parent in order to obtain child ADHD data based on the *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition* (DSM-IV; American Psychiatric Association, 2000). The ADHD module of the DISC-IV has good psychometric properties, including high test–retest reliability ($r = .79$ after 1 year) and internal consistency.

---

Table 1. Demographic Measures by ADHD Diagnostic Group Status.

<table>
<thead>
<tr>
<th></th>
<th>ADHD ($n = 104$)</th>
<th>No ADHD ($n = 88$)</th>
<th>$t$ or $\chi^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age in years at Wave 1, $M (SD)$</td>
<td>7.77 (1.16)</td>
<td>7.92 (1.17)</td>
<td>0.87</td>
</tr>
<tr>
<td>Age in years at Wave 2, $M (SD)$</td>
<td>10.18 (1.39)</td>
<td>10.54 (1.42)</td>
<td>1.80</td>
</tr>
<tr>
<td>Sex (% male)</td>
<td>75%</td>
<td>63%</td>
<td>3.50</td>
</tr>
<tr>
<td>Race/ethnicity</td>
<td></td>
<td></td>
<td>4.48</td>
</tr>
<tr>
<td>Caucasian</td>
<td>47%</td>
<td>51%</td>
<td></td>
</tr>
<tr>
<td>Hispanic</td>
<td>13%</td>
<td>7%</td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td>8%</td>
<td>3%</td>
<td></td>
</tr>
<tr>
<td>Asian</td>
<td>3%</td>
<td>3%</td>
<td></td>
</tr>
<tr>
<td>Mixed</td>
<td>17%</td>
<td>24%</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>3%</td>
<td>3%</td>
<td></td>
</tr>
<tr>
<td>Missing</td>
<td>10%</td>
<td>8%</td>
<td></td>
</tr>
<tr>
<td>Estimated FSIQ, $M (SD)$</td>
<td>104.71 (13.94)</td>
<td>111.04 (14.71)</td>
<td>2.99**</td>
</tr>
</tbody>
</table>

Note. **$p < .01.$
(intraclass correlation [ICC] = .84 for symptoms counts, ICC = .77 for criterion counts) among parents from a large community sample (Shaffer et al., 2000). Both the ADHD and comparison children were permitted to have met diagnostic criteria for other disorders (e.g., anxiety disorders, oppositional defiant disorder [ODD], etc.).

**The Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV)**
Three subtests from the WISC-IV (Wechsler, 2004) were administered to each child: Vocabulary, Symbol Search, and Arithmetic. A composite estimate based on the sum of these three scaled scores was used to estimate full-scale IQ (FSIQ), which has previously been found to correlate highly \( r = .91 \) with the 10-subtest estimate (Sattler & Dumont, 2004).

**The Balloon Emotional Learning Task (BELT)**
In Wave 2, participants completed the BELT (Humphreys et al., 2013), a computerized risky decision-making task with three different color balloon conditions (counterbalanced across participants), each with a different corresponding explosion point for the number of pumps (7 pumps = certain-short; either 7, 13, or 19 = variable; 19 = certain-long). There were a total of 9 trials per condition, and for each third of the task there was an equal number of trials per condition. The participants are asked to press a button to “pump up” balloons and earn points based on the number of pumps for each of the 27 balloon trials (i.e., more pumps earn more points). After the first pump, participants are allowed to press a button to “cash in” their pumps for points. If participants pump beyond a balloon’s limit then an explosion occurs, resulting in the loss of all points for that trial. Participants were not told that the balloon’s color signifies different response contingencies, but were explicitly told that not all balloons pop after the same number of pumps. The points accumulate from trial to trial, and the more points that participants earn, the more stickers they are awarded, which are traded for prizes at the end of the assessment. The BELT demonstrates concurrent validity in young adults, with moderate positive correlations between the number of pumps on the task and sensation-seeking (Humphreys et al., 2013). Additionally, the task has been used to examine risky decision-making following early life stress and across development from preschool-age children into early adulthood (Humphreys et al., 2014, Humphreys, Telzer, et al., 2016).

**Data Analysis**
Generalized estimated equations (GEEs) were employed using SPSS v20, (IBM Corp., 2011) specifying a negative binomial with log link distribution due to the nature of the data being counts (e.g., the number of pumps). GEEs account for correlated observations characteristic of repeated measures designs. Separate GEE analyses were performed for (1) the number of pumps, (2) the number of points earned, and (3) the number of explosions. For the number of pumps and points, there were nine observations nested within each individual by condition (certain-long, variable, and certain-short). Trial number was used as the within-subjects variable. A robust covariance estimation was implemented and an autoregressive structure was specified, given that trials closer together are more correlated than those further apart. The number of explosions reflects the sum across each third of the task across all conditions to create a
continuous measure of integers, specifying task third in the repeated command and an autoregressive covariance matrix. Wave 1 ADHD diagnostic status, sex, and age at testing were included as fixed effects.

In addition, measures of learning were obtained, calculated as a change in points earned across task trials (using the GEE analysis of points earned by trial). Wave 1 ADHD diagnostic status, sex, and age were once again included as fixed effects.

**Results**

**BELT Variables**

Wave 1 ADHD diagnostic status (i.e., presence or absence of ADHD diagnosis), sex, and age were examined as predictors of BELT outcomes (Table 2). There is a marginal association between ADHD status and lower points as measured across all balloon conditions. Sex is unrelated to all outcomes. Age demonstrates a significant positive association with points earned across all conditions and a marginal association with higher pumps made on the task overall. In addition, positive correlations were found between the dependent variables of interest (i.e., pumps, points, and explosions).

**Pumps**

GEEs were employed to examine the association of Wave 1 ADHD diagnosis with the number of pumps on the BELT at Wave 2 in each balloon condition separately (Figure 1). Controlling for sex and age, ADHD is not significantly associated with pumps on the certain-long, $B = -0.06$, $SE = 0.06$, $p = .34$, 95% CI $[-0.18, 0.06]$, variable, $B = -0.05$, $SE = 0.04$, $p = .20$, 95% CI $[-0.12, 0.03]$, or certain-short, $B = -0.02$, $SE = 0.02$, $p = .55$, 95% CI $[-0.06, 0.03]$, conditions. Sex is similarly not significantly related to pumps on any condition. Age is positively associated with greater pumps on the certain-short condition, $B = 0.02$, $SE = 0.01$, $p = .03$, 95% CI $[0.002, 0.050]$. Given the significant effect of age on this condition and the wide age range of the sample, a mean split was conducted and an analysis examining pumps in those younger and older than 10.35 years was run. Among the younger children, ADHD is significantly associated with fewer pumps on the certain-short condition, $B = -0.08$, $SE = 0.03$, $p = .02$.

**Table 2.** Descriptive Statistics and Correlation Matrix among ADHD, Sex, Age, and Primary BELT Outcomes.

<table>
<thead>
<tr>
<th></th>
<th>ADHD</th>
<th>Sex</th>
<th>Age</th>
<th>IQ</th>
<th>Pumps</th>
<th>Points</th>
<th>Explosions</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADHD (Wave 1)</td>
<td>1</td>
<td>.14*</td>
<td>-.13†</td>
<td>-.22**</td>
<td>-.07</td>
<td>-.12†</td>
<td>-.01</td>
</tr>
<tr>
<td>Sex (Male = 1)</td>
<td>1</td>
<td>.001</td>
<td>.11</td>
<td>.06</td>
<td>-.01</td>
<td>.09</td>
<td></td>
</tr>
<tr>
<td>Age (Wave 2)</td>
<td>1</td>
<td>-.06</td>
<td>.14†</td>
<td>.17*</td>
<td>.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Est. FSIQ</td>
<td>1</td>
<td>.08</td>
<td>.10</td>
<td>.06</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pumps</td>
<td>1</td>
<td>.75***</td>
<td>.85***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Points</td>
<td>1</td>
<td>.33***</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explosions</td>
<td>% or M (SD)</td>
<td>54%</td>
<td>69%</td>
<td>10.35 (1.41)</td>
<td>107.65 (14.60)</td>
<td>164.81 (43.18)</td>
<td>127.88 (23.69)</td>
</tr>
<tr>
<td>Range</td>
<td>0–1</td>
<td>0–1</td>
<td>7.86–14.35</td>
<td>69–144</td>
<td>55–288</td>
<td>55–209</td>
<td>0–16</td>
</tr>
</tbody>
</table>

Note. †$p < .10$; *$p < .05$; **$p < .01$; ***$p < .001$. 

Downloaded by [Kathryn Humphreys] at 10:16 19 December 2017
95% CI $[-0.14, -0.01]$, though no effect was found in older children, $B = 0.03$, $SE = 0.03$, $p = .32$, 95% CI $[-0.03, 0.10]$.

Points

Using the same analytical approach, the association between ADHD and the number of points earned on the BELT was examined (Figure 2). Controlling for sex and age, ADHD is not significantly associated with points earned on the certain-long, $B = -0.05$, $SE = 0.06$, $p = .36$, 95% CI $[-0.15, 0.05]$, variable, $B = -0.05$, $SE = 0.03$, $p = .06$, 95% CI $[-0.10, 0.001]$, or certain-short, $B = -0.02$, $SE = 0.04$, $p = .64$, 95% CI $[-0.11, 0.07]$. 

![Figure 1. Mean number of pumps by task condition and ADHD status. Note. Error bars indicate ±1 standard error.](image1)

![Figure 2. Mean number of points by task condition and ADHD status. Note. Error bars indicate ±1 standard error.](image2)
conditions. Sex is unrelated to points, and age is associated with greater points only on the variable condition, $B = 0.03$, $SE = 0.01$, $p = .02$, 95% CI [0.01, 0.05]. Again, the sample was split by age and the association between ADHD status and points on the variable condition was examined for younger and older participants. It was found that ADHD status is significantly associated with fewer points on the variable condition in the younger group, $B = −0.11$, $SE = 0.04$, $p = .01$, 95% CI [−0.18, −0.03], but no significant effect was found in the older group, $B = −0.01$, $SE = 0.04$, $p = .80$, 95% CI [−0.08, 0.06].

Explosions

For explosions, all conditions were considered together given the relatively low rate of explosions. Once again controlling for sex and age, ADHD is unrelated to the number of explosions, $B = −0.03$, $SE = 0.10$, $p = .86$, 95% CI [−0.22, 0.16] (Figure 3). Neither sex nor age is related to the number of explosions.

Learning

Individual differences in improved performance (i.e., number of points) were examined over the course of the task to estimate learning. The same GEE models that examined points on the task were used, but trial and interaction terms were added for Wave 1 ADHD diagnostic status by trial to test whether changes (e.g., improvements) in points earned across the task differ by diagnostic group, as well as for sex and age. For the certain-long condition, a significant ADHD by trial interaction was found, Wald $\chi^2 = 5.12$, $p = .02$ (Figure 4). In order to probe this interaction, the number of points earned by trial was examined separately in children with and without ADHD. Whereas the children without ADHD earned more points across the trials, $B = 0.008$, $SE = 0.002$, $p = .002$, 95% CI [0.003, 0.013], demonstrating improvements across the task, among

![Figure 3. Mean number of exploded trials by ADHD status. Note. Error bars indicate ±1 standard error.](image-url)
children with ADHD the number of points earned did not change across trials, $B = 0.001$, $SE = 0.002$, $p = .72$, 95% CI [-0.003, 0.004], suggesting no significant improvement in performance on this condition. For the variable condition, the ADHD by trials interaction is unrelated to points earned on the task, Wald $\chi^2 = 0.32$, $p = .57$, and there is no evidence of trial-related gains on this condition. For the certain-short condition, the ADHD by trial interaction is not significant, Wald $\chi^2 = 1.12$, $p = .29$, as both groups showed strong evidence of learning through improvements in performance across trial number. In the subgroup analyses split by participant age, no ADHD group by trial interactions are statistically significant.

To minimize the possibility that IQ differences might explain group differences, given that the children diagnosed with ADHD had lower average IQ scores than those without (Table 1), analyses on the certain-long condition were conducted again with IQ as a covariate. Notably, the ADHD by trial interaction is robust to the statistical control of IQ, Wald $\chi^2 = 6.07$, $p = .01$.

**Discussion**

The present study examines the prospective association of childhood ADHD diagnostic status and risky decision-making in a large and ethnically-diverse sample of children. Given that ADHD is associated with poor decision-making (Sonuga-Barke et al., 2016) and inappropriate risk-taking (Barkley, 1997), it was anticipated that children with a history of ADHD would exhibit heightened risk-taking behavior on a computerized test of sequential risky decision-making. However, the children with a history of ADHD exhibited, on average, similar levels of risk-taking on the BELT relative to the children without ADHD. In fact, among the younger children, ADHD is associated with fewer pumps on this task, suggesting reduced risk-taking in young children with ADHD. Additionally, learning on the task was explored and it was found that the children with ADHD exhibit impaired learning on one of the two stable balloon conditions. Specifically, both children with and without ADHD showed evidence of learning through improvements in task performance on the condition with a low-punishment threshold condition. However, learning on the high-punishment threshold condition was only found in children without ADHD, as no improvements in task performance were found with greater trials among the children with ADHD.
A review of 14 studies of risk-taking and ADHD found that half detected aberrant risk-taking in children with ADHD (Groen, Gaastra, Lewis-Evans, & Tucha, 2013). The authors identify variability in demographic factors, rates of comorbidity, and form of reward offered by the task as potential contributors to the observed variability in the literature. Humphreys and Lee (2011) report moderately heightened risk-taking in children with ADHD on the BART, but the largest effect is among children with comorbid ADHD and ODD. Yet, other studies have failed to find ADHD group differences with respect to the overall number of pumps on the BART, although these studies consist of adults with ADHD (Mantyla, Still, Gullberg, & Del Missier, 2012; Weafer, Milich, & Fillmore, 2011), indicating that age may be a relevant factor. In the present study, it was found that younger children with ADHD have reduced risk-taking behavior, which may represent an alternative age by ADHD association in the prediction of risk-taking. Children with ADHD have been characterized as not only cognitively immature but also emotionally immature (J. S. Owens, Goldfine, Evangelista, Hoza, & Kaiser, 2007; Whalen, 1989), which may be magnified in younger children with ADHD. The same immature emotional processes may result in hampered decision-making via overly cautious behavior. The relatively reduced risk-taking among young children with ADHD compared to their same-age counterparts without ADHD on this task is similar to the pumps obtained by developmentally younger children than those in the present study (Humphreys, Telzer, et al., 2016), and this behavior appears to result in poorer performance (i.e., fewer points) on the task. Given that decision-making can be markedly altered across development, with age being a significant predictor of affective and deliberative decision-making (Figner, Mackinlay, Wilkening, & Weber, 2009; Schiebener & Brand, 2015; Schiebener, Garcia-Arias, Garcia-Villamisar, Cabanyes-Truffino, & Brand, 2014; Van Duijvenvoorde, Jansen, Bredman, & Huizenga, 2012; Weller, Levin, & Denburg, 2011), the interaction between age and psychopathology is a fruitful area for further study.

Although impaired inhibitory control is often thought to underlie elevated risky behavior among children with ADHD (Barkley, 1997), impulsivity may be expressed in multiple forms, including excessive pumping (e.g., balloon explosion) but also prematurely cashing out when using additional pumps would have been adaptive. The observed lack of learning on the certain-long balloon condition in children with ADHD may be due to impulsive decisions to cash out early on this balloon condition, despite the potential to earn more points. This possibility is consistent with models of decision-making in ADHD (Sonuga-Barke et al., 2016) based in part on research on delay aversion among individuals with ADHD (Barkley, Edwards, Laneri, Fletcher, & Metevia, 2001; Paloyelis, Asherson, & Kuntsi, 2009; Wilson, Mitchell, Musser, Schmitt, & Nigg, 2011). If impulsivity was guiding decision-making more than deliberative cognitive processes then cashing in early on the certain-long balloon condition is a likely result and consistent with the findings in the present study.

It is also possible that the lack of learning observed on the certain-long condition is related to poor attention and general adaptive control processes used to distinguish between the balloon conditions. Adaptive control processes are thought to be influenced by error processing deficits in children with ADHD (Shiels & Hawk, 2010). Detecting errors and changing behavior in response to feedback is essential for learning, and recent psychophysiological work indicates that children with ADHD may monitor
environmental feedback less effectively (Crone, Jennings, & van der Molen, 2003; Groen, Mulder, Wijers, Minderaa, & Althaus, 2009; Luman, Oosterlaan, Hyde, van Meel, & Sergeant, 2007; Luman, Oosterlaan, Knol, & Sergeant, 2008). Theories on the etiology of ADHD, including the dynamic developmental behavioral theory (Sagvolden, Johansen, Aase, & Russell, 2005), propose that altered dopaminergic function—specifically hypofunctioning mesocortical dopamine branches—contributes to impaired learning and memory in ADHD. Stimulant medication (e.g., methylphenidate), the most commonly used treatment for ADHD, partially normalizes this dysfunction by principally targeting the dopamine transporter (Volkow et al., 1998).

It should be noted that the children with ADHD demonstrated learning on the certain-short balloon condition. Learning on this balloon condition across both children with and without ADHD is consistent with prior work on the BELT spanning ages from 3 to 26 years (Humphreys et al., 2013, 2014; Humphreys, Telzer, et al., 2016) in which learning occurs nearly universally, likely because this condition has the lowest explosion point and therefore the quickest opportunity for feedback about the limits of this balloon condition. Despite the evidence of impaired learning in the children with ADHD observed in this task and others (Chang et al., 1999), there are clearly contexts in which children with ADHD use past experience to effectively guide subsequent decision-making. Previous work with explicit gambling paradigms has shown that, compared to children without ADHD, children with ADHD do not improve their associative learning across trials. For example, Drechsler, Rizzo, and Steinhausen (2008) used the Game of Dice Task and found that adolescents with and without ADHD performed similarly on the first run, but during the same game, the adolescents without ADHD demonstrated a significant improvement in the financial outcome whereas those with ADHD had worse outcomes and made more risky decisions. Interestingly, working memory, flexibility, and planning were found to be unrelated to the performance deficits associated with ADHD, underscoring the need for future work to consider what underlies or mediates differences in task performance. Similarly, in a study of two conditional associative learning tasks in which fixed mappings of stimulus-response pairs are learned through trial and error, no differences between children with and without ADHD were found (Gitten, Winer, Festa, & Heindel, 2006). However, performance on spatial learning task revealed a group difference, as children without ADHD improved across the course of the task (e.g., made fewer errors over time) whereas children with ADHD did not improve. These findings were characterized as deficient strategic processing.

The findings of the present study should be considered in light of its limitations. First, as mentioned above and in prior work (Humphreys et al., 2013), additional trials may have elicited more learning opportunities and, potentially, diagnostic group differences in task success. Second, the BELT simultaneously presents rewards (points) and punishment (removal of points), and—relative to children without ADHD—children with ADHD have decreased activity in the ventral striatum, a brain region associated with reward processing anticipation in children (van Hulst et al., 2016). It is possible that unmeasured differences in the salience of the reward on the BELT may have been relevant to ADHD group differences. Third, ADHD is associated with a wide array of co-occurring problems, including comorbid learning disabilities (Pastor & Reuben, 2008). Thus, difficulties associated with ADHD complicate inferences of specificity. However, the inclusion of IQ strengthens the specificity of the observed patterns. Lastly, it is unclear as to whether or not medication played a role in the findings. While the majority of participants were not
taking medication on the day of the assessment, some parents elected to continue with their child’s typical medication routine. It should be noted that medication status is not controlled for in any model as it is unlikely to be a measure of “treatment effects” because it is positively correlated with psychopathology (Larzelere, Kuhn, & Johnson, 2004). Indeed, participants in the present sample who were medicated had higher ADHD symptom scores and poorer performance on a social decision-making task (Humphreys, Galan, Tottenham, & Lee, 2016).

In conclusion, there appears to be little evidence of increased risk-taking among children with ADHD on this sequential decision-making task; further, among the younger children ADHD is associated with reduced risk-taking behavior and fewer points earned. Poorer decision-making among children with ADHD is supported, given that the children with ADHD did not appear to learn across conditions in the way that the children without ADHD did. While the children with ADHD improved as expected on the low-punishment threshold condition, no learning was observed on the condition with a high-punishment threshold. Poorer classroom and academic performance found in children with ADHD (Loe & Feldman, 2007) may be partially explained by relatively impaired learning in contexts without immediate feedback. These findings may have clinical implications, as the children with ADHD had more difficulty learning in contexts without immediate feedback. Behavioral interventions for children with ADHD may, therefore, be more effective in this population if immediate feedback schedules are emphasized when learning new skills. Future work should consider how learning from feedback may be impaired in individuals with ADHD and, if replicated, how these difficulties may be treated. Further, it may be useful to try to understand how impulsivity may affect instrumental learning in those with ADHD across development.

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