



Published in final edited form as:

*Child Neuropsychol.* 2018 February ; 24(2): 261–276. doi:10.1080/09297049.2016.1264578.

## Risky Decision-making in Children with and without ADHD: A Prospective Study

Kathryn L. Humphreys<sup>1</sup>, Nim Tottenham<sup>2</sup>, and Steve S. Lee<sup>3</sup>

<sup>1</sup>Stanford University

<sup>2</sup>Columbia University

<sup>3</sup>University of California, Los Angeles

### 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). We followed 192 children with and without ADHD at ages 5–10 for approximately 2.5 years, and examined 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 related to greater risk-taking on the BELT, and among younger children ADHD status was associated with reduced risk-taking. In addition, comparison children without ADHD showed significant learning-related gains on both stable task conditions. However, children with ADHD demonstrated learning on the condition with a stable and early explosion point, but not 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.

### 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, 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 neuropsychological factors that may result in the 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, & Stringaris, 2016). These authors 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 (e.g., 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 comparison adolescents on a modified 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 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 working memory (Duarte et al., 2012). Learning from experience is a critical aspect of effect decision-making, given that 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 demonstrated impaired learning during decision-making compared to those without ADHD (Hauser et al., 2014).

The present study sought to probe this question further by examining sequential risky decision-making among children with and without ADHD. We used the Balloon Emotional Learning Task [BELT]; Humphreys et al., 2013), which is structurally similar to the Balloon Analogue Risk Task (BART; Lejuez et al., 2002, 2007), in that both tasks require participants to pump 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., 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, Telzer, et al., 2015; Humphreys et al., 2013).

## Study Rationale and Hypotheses

We had two aims in the present study. First, we sought to examine whether Wave 1 ADHD prospectively predicted 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 (e.g., Babinski et al., 2011; Charach et al., 2011; Lee et al., 2011), we hypothesized that children with ADHD would demonstrate greater risk-taking. However, we note that reduced risk-taking among those with ADHD may also be found (Kroyzer et al., 2014). Second, considering findings of a positive association between an attentional construct and learning on the BELT in young adults (Humphreys et al., 2013), we sought to examine the association between ADHD and learning on the BELT. Given two of the three BELT conditions provide stable feedback regarding the explosion threshold, we examined learning on the task as a function of ADHD. There is reason to hypothesize that children with ADHD would demonstrate less learning than comparison children without ADHD (Hauser et al., 2014), or to hypothesize that those with and without ADHD would show no differences in learning (Luman et al., 2015).

## Methods

### Participants

At baseline (i.e., Wave 1), 230 participants aged 5–10 years old 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. Families who participated in the follow-up had a higher mean number of child ADHD symptoms than families who did not participate in Wave 2 ( $t(226) = -2.08, p = .04$ ), but there were no other significant demographic differences between these two groups of families. At Wave 1, included participants were a mean age of 7.85 years ( $SD = 1.17$ ), and slightly more than half were diagnosed with ADHD ( $n = 104$ ) than without an ADHD diagnosis ( $n = 88$ ). At Wave 2, participants were 7–14 years old ( $M = 10.31, SD = 1.43$ ). The mean length of the time between Wave 1 and 2 was 2.51 years ( $SD = 0.74$ ; ranging from

1.50–4.94 years). Approximately one third of the sample (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 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 demographic information based on ADHD status at Wave 1. More information about the study sample can be found elsewhere (Humphreys, Aguirre, & Lee, 2012; Lee & Humphreys, 2014). No prior publications using this sample has included the BELT.

## Procedures

At Wave 1, study eligibility for interested families was determined through a telephone screening. Families were invited to our 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 to 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, and for more information on Wave 2, see Tung, Brammer, Li, and Lee (2014). The institutional review board approved all study procedures.

## Measures

**Diagnostic Interview Schedule for Children, Version IV**—(DISC-IV; Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000). At Wave 1, trained graduate students administered the DISC-IV, a computer-assisted, fully structured diagnostic interview with the parent, to obtain child ADHD data based on the Diagnostic and Statistical Manual, 4<sup>th</sup> 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 one year) and internal consistency (intraclass correlation [ICC] = .84 for symptoms counts, ICC = .77 for criterion counts) among parents from a large community sample (see 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).

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

**Balloon Emotional Learning Task**—(BELT; Humphreys et al., 2013). At Wave 2, participants completed a computerized risky decision-making task with three different color balloon conditions (counterbalanced across participants), each with a different corresponding explosion point (7 = 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. Participants were asked to press a button to “pump up”



## Pumps

We employed GEE 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 was 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  $[-0.12, 0.03]$ ), and certain-short conditions ( $B = -0.02$ ,  $SE = 0.02$ ,  $p = .55$ , 95% CI  $[-0.06, 0.03]$ ). Sex was similarly not significantly related to pumps on any condition. Age was positively associated with greater pumps on the certain-short condition ( $B = 0.02$ ,  $SE = 0.01$ ,  $p = .03$ , 95% CI  $[0.002, 0.05]$ ). Given the significant age effect on this condition and wide age range of the sample we conducted a mean split and reran the analysis examining pumps with those younger and older than 10.35 years. Among younger children, ADHD was significantly associated with fewer pumps on the certain-short condition ( $B = -0.08$ ,  $SE = 0.03$ ,  $p = .02$ , 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, we examined the association between ADHD and the number of points earned on the BELT (Figure 2). Controlling for sex and age, ADHD was 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  $[-0.10, 0.001]$ ), and certain-short conditions ( $B = -0.02$ ,  $SE = 0.04$ ,  $p = .64$ , 95% CI  $[-0.11, 0.07]$ ). Sex was unrelated to points, and age was associated with greater points only on the variable condition ( $B = 0.03$ ,  $SE = 0.01$ ,  $p = .02$ , 95% CI  $[0.01, 0.05]$ ). Again, we then split the sample by age and examined the association between ADHD status and points on the variable condition within younger and older study participants. We found that ADHD status was significantly associated with fewer points on the variable condition among the younger group ( $B = -0.11$ ,  $SE = 0.04$ ,  $p = .01$ , 95% CI  $[-0.18, -0.03]$ ), but no significant effect of ADHD status was found among older children ( $B = -0.01$ ,  $SE = 0.04$ ,  $p = .80$ , 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 was 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 was related to number of explosions.

## Learning

We examined individual differences in improved performance (i.e., number of points) over the course of the task to estimate learning. The same GEE models that examined points on the task were used, but we added trial and interaction terms for Wave 1 ADHD diagnostic status by trial to test whether changes (e.g., improvements) in points earned across the task differed by diagnostic group, as well as for sex and age. For the certain-long condition, a significant ADHD by trial interaction was found (Wald  $\chi^2 = 5.12$ ,  $p = .02$ ) (see Figure 4). In order to probe this interaction, we examined the number of points earned by trial separately

in children with and without ADHD. Whereas comparison children without ADHD earned more points across the trials ( $B = 0.01$ ,  $SE = 0.002$ ,  $p = .002$ , 95% CI [0.003, 0.01]), demonstrating improvements across the task, among children with ADHD, the number of points earned did not change across trial number ( $B = 0.01$ ,  $SE = 0.002$ ,  $p < .001$ , 95% CI [0.003, 0.01]), suggesting no significant improvement in performance on this condition. For the variable condition, the ADHD by trials interaction was unrelated to points earned on the task (Wald  $\chi^2 = 0.32$ ,  $p = .57$ ), and there was no evidence of trial related gains on this condition. For the certain-short condition, the ADHD by trial interaction was 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 were statistically significant.

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

## Discussion

The present study examined 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), we anticipated that children with a history of ADHD would exhibit heightened risk-taking behavior on a computerized test of sequential risky decision-making. However, children with a history of ADHD exhibited, on average, similar levels of risk-taking on the BELT relative to comparison children without ADHD. In fact, among younger children, ADHD was associated with fewer pumps on this task, suggesting reduced risk-taking in young children with ADHD. Additionally, we explored learning on the task and found that children with ADHD exhibited 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 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 identified 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. We previously reported (Humphreys & Lee, 2011) moderately heightened risk-taking in children with ADHD on the BART, but the largest effect was among children with comorbid ADHD and ODD. Yet, other work failed to find ADHD group differences with respect to the overall number of pumps on the BART, although these studies consisted of ADHD in adults (Mäntylä, Still, Gullberg, & Del Missier, 2012; Weafer, Milich, & Fillmore, 2011), indicating that age may be a relevant factor. In the present study, we found that younger

children with ADHD had 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 same age counterparts without ADHD on this task is similar to pumps obtained by developmentally younger children than those in the present study (Humphreys, Telzer, et al., 2015), and this behavior appeared 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, García-Arias, García-Villamizar, Cabanyes-Truffino, & Brand, 2014; Van Duijvenvoorde, Jansen, Bredman, & Huizenga, 2012; Weller, Levin, & Denburg, 2011), the interactions 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 excess pumping (e.g., balloon explosion) but also prematurely cashing out when 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 (e.g., 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, 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 may be related to poor attention and general adaptive control processes used to distinguish 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, contribute 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 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 3 to 26 years (Humphreys et al., 2014, 2013; Humphreys, Telzer, et al., 2015) 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 evidence of exhibited impaired learning in ADHD observed in this task and other (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 suggest that, compared to children without ADHD, children with ADHD did 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, children without ADHD demonstrated significant improvement in the financial outcome whereas children with ADHD had worse outcomes and made more risky decisions. Interestingly, working memory, flexibility, or planning was 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 ADHD and comparison children 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.

Findings from the present study should be considered in light of 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, those with ADHD symptoms 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 in 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, our inclusion of IQ strengthened the specificity of the observed patterns. Lastly, it is unclear to whether medication may play 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 we did not control for medication status in any model, as it is unlikely to be a measure "treatment effects" because it is positively correlated with psychopathology (Larzelere, Kuhn, & Johnson, 2004). Indeed, participants in our sample who were medicated had higher ADHD symptom scores and poorer performance on a social decision-making task (Humphreys, Galan, Tottenham, & Lee, 2015).

In conclusion, there appeared to be little evidence of increased risk-taking among children with ADHD on this sequential decision-making task; further, among young children ADHD was associated with reduced risk-taking behavior and fewer points earned. Poorer decision-making among children with ADHD was supported given that children with ADHD did not appear to learn across conditions as comparison children did. While 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 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 in 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.

### Acknowledgements:

We thank the families for participation in the study and the research staff for their help with data collection and management. This work was partially supported by the Consortium for Neuropsychiatric Phenomics (NIH Roadmap for Medical Research grant UL1-DE019580, RL1DA024853) and NIH grant 1R03AA020186-01 to Steve S. Lee.

### References

- American Psychiatric Association. (2013). Diagnostic and Statistical Manual of Mental Disorders, 5th Edition (DSM-5). Diagnostic and Statistical Manual of Mental Disorders 4th edition TR. Arlington, VA: American Psychiatric Publishing.
- Babinski DE, Pelham WE, Molina BSG, Gnagy EM, Waschbusch DA, Yu J, ... Karch KM (2011). Late adolescent and young adult outcomes of girls diagnosed with ADHD in childhood: an exploratory investigation. *Journal of Attention Disorders*, 15(3), 204–14. 10.1177/1087054710361586 [PubMed: 20562386]
- Barkley RA (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin*, 121(1), 65–94. 10.1037/0033-2909.121.1.65 [PubMed: 9000892]
- Barkley RA, Edwards G, Laneri M, Fletcher K, & Metevia L (2001). Executive functioning, temporal discounting, and sense of time in adolescents with attention deficit hyperactivity disorder (ADHD) and oppositional defiant disorder (ODD). *Journal of Abnormal Child Psychology*, 29(6), 541–556. 10.1023/a:1012233310098 [PubMed: 11761287]
- Barto AG, Sutton RS, & Watkins CJCH (1990). Learning and sequential decision making In Gabriel M & Moore JW (Eds.), *Learning and Computational Neuroscience* (pp. 539–602). Cambridge, MA: MIT Press.
- Breyer JL, Botzet AM, Winters KC, Stinchfield RD, August G, & Realmuto G (2009). Young adult gambling behaviors and their relationship with the persistence of ADHD. *Journal of Gambling Studies*, 25(2), 227–238. 10.1007/s10899-009-9126-z [PubMed: 19283457]
- Chang HT, Klorman R, Shaywitz SE, Fletcher JM, Marchione KE, Holahan JM, ... Shaywitz BA (1999). Paired-associate learning in attention-deficit/hyperactivity disorder as a function of hyperactivity-impulsivity and oppositional defiant disorder. *Journal of Abnormal Child Psychology*, 27(3), 237–245. 10.1023/A:1021956507983 [PubMed: 10438189]

- Charach A, Yeung E, Climans T, & Lillie E (2011). Childhood attention-deficit/hyperactivity disorder and future substance use disorders: Comparative meta-analyses. *Journal of the American Academy of Child and Adolescent Psychiatry*, 50, 9–21. 10.1016/j.jaac.2010.09.019 [PubMed: 21156266]
- Crone EA, Jennings JR, & van der Molen MW (2003). Sensitivity to interference and response contingencies in attention-deficit/hyperactivity disorder. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, 44, 214–226. 10.1111/1469-7610.00115 [PubMed: 12587858]
- DeVito EE, Blackwell AD, Kent L, Ersche KD, Clark L, Salmond CH, ... Sahakian BJ (2008). The effects of methylphenidate on decision making in attention-deficit/hyperactivity disorder. *Biological Psychiatry*, 64, 636–639. 10.1016/j.biopsych.2008.04.017 [PubMed: 18504036]
- Drechsler R, Rizzo P, & Steinhausen H-C (2008). Decision-making on an explicit risk-taking task in preadolescents with attention-deficit/hyperactivity disorder. *Journal of Neural Transmission*, 115(2), 201–209. 10.1007/s00702-007-0814-5 [PubMed: 17885724]
- Duarte NA, Woods SP, Rooney A, Atkinson JH, Grant I, & Translational Methamphetamine AIDS Research Center Group. (2012). Working memory deficits affect risky decision-making in methamphetamine users with attention-deficit/hyperactivity disorder. *Journal of Psychiatric Research*, 46(4), 492–9. 10.1016/j.jpsychires.2012.01.006
- Figner B, Mackinlay RJ, Wilkening F, & Weber EU (2009). Affective and deliberative processes in risky choice: age differences in risk taking in the Columbia Card Task. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, 35(3), 709–30. 10.1037/a0014983
- Frances A, & DSM-IV APATF on. (2000). *Diagnostic and statistical manual of mental disorders, DSM-IV-TR Text (Vol. 4th, text)*. Washington, DC: Author.
- Garzon DL, Huang H, & Todd RD (2008). Do attention deficit/hyperactivity disorder and oppositional defiant disorder influence preschool unintentional injury risk? *Archives of Psychiatric Nursing*, 22, 288–296. 10.1016/j.apnu.2007.12.006 [PubMed: 18809121]
- Gitten JC, Winer JL, Festa EK, & Heindel WC (2006). Conditional associative learning of spatial and object information in children with attention deficit/hyperactivity disorder. *Child Neuropsychology*, 12(1), 39–56. 10.1080/09297040500205579 [PubMed: 16484101]
- Groen Y, Gaastra GF, Lewis-Evans B, & Tucha O (2013). Risky behavior in gambling tasks in individuals with ADHD - A systematic literature review. *PloS One*, 8(9), e74909 10.1371/journal.pone.0074909 [PubMed: 24058638]
- Groen Y, Mulder LJM, Wijers AA, Minderaa RB, & Althaus M (2009). Methylphenidate improves diminished error and feedback sensitivity in ADHD: An evoked heart rate analysis. *Biological Psychology*, 82(1), 45–53. 10.1016/j.biopsycho.2009.05.004 [PubMed: 19464338]
- Hauser TU, Iannaccone R, Ball J, Mathys C, Brandeis D, Walitza S, & Brem S (2014). Role of the medial prefrontal cortex in impaired decision making in juvenile attention-deficit/hyperactivity disorder. *JAMA Psychiatry*, 71(10), 1165–73. 10.1001/jamapsychiatry.2014.1093 [PubMed: 25142296]
- Humphreys KL, Aguirre VP, & Lee SS (2012). Association of anxiety and ODD/CD in children with and without ADHD. *Journal of Clinical Child and Adolescent Psychology*, 41(3), 370–377. *JOUR.* 10.1080/15374416.2012.656557 [PubMed: 22420771]
- Humphreys KL, Galan CA, Tottenham N, & Lee SS (2015). Impaired social decision-making mediates the association between ADHD and social problems. *Journal of Abnormal Child Psychology*. 10.1007/s10802-015-0095-7
- Humphreys KL, & Lee SS (2011). Risk taking and sensitivity to punishment in children with ADHD, ODD, ADHD+ODD, and Controls. *Journal of Psychopathology and Behavioral Assessment*, 33(3), 299–307. *JOUR.* 10.1007/s10862-011-9237-6
- Humphreys KL, Lee SS, Telzer EH, Gabard-Durnam LJ, Goff B, Flannery J, & Tottenham N (2014). Exploration–exploitation strategy is dependent on early experience. *Developmental Psychobiology*, 57(3), 313–321. 10.1002/dev.21293
- Humphreys KL, Lee SS, & Tottenham N (2013). Not all risk taking behavior is bad: Associative sensitivity predicts learning during risk taking among high sensation seekers. *Personality and Individual Differences*, 54, 709–715. 10.1016/j.paid.2012.11.031 [PubMed: 23935235]

- Humphreys KL, Telzer EH, Flannery J, Goff B, Gabard-Durnam LJ, Lee SS, & Tottenham N (2015). Risky decision-making from childhood through adulthood: Contributions of learning and sensitivity to punishment. *Emotion*.
- Kroyzer N, Gross-Tsur V, & Pollak Y (2014). Risk taking in adolescents with attention deficit hyperactivity disorder on a probabilistic choice task. *The Journal of Nervous and Mental Disease*, 202, 247–52. 10.1097/NMD.000000000000100 [PubMed: 24566511]
- Larzelere RE, Kuhn BR, & Johnson B (2004). The intervention selection bias: An underrecognized confound in intervention research. *Psychological Bulletin*, 130(2), 289–303. 10.1037/0033-2909.130.2.289 [PubMed: 14979773]
- Lee SS, & Humphreys KL (2014). Interactive association of dopamine receptor (DRD4) genotype and ADHD on alcohol expectancies in children. *Experimental and Clinical Psychopharmacology*, 22(2), 100–109. 10.1037/a0035338 [PubMed: 24611835]
- Lee SS, Humphreys KL, Flory K, Liu R, & Glass K (2011). Prospective association of childhood attention-deficit/hyperactivity disorder (ADHD) and substance use and abuse/dependence: A meta-analytic review. *Clinical Psychology Review*, 31, 328–341. 10.1016/j.cpr.2011.01.006 [PubMed: 21382538]
- Lee SS, Lahey BB, Owens EB, & Hinshaw SP (2008). Few preschool boys and girls with ADHD are well-adjusted during adolescence. *Journal of Abnormal Child Psychology*, 36, 373–383. 10.1007/s10802-007-9184-6 [PubMed: 17914666]
- Lejuez CW, Aklin W, Daughters S, Zvolensky M, Kahler C, & Gwadz M (2007). Reliability and validity of the youth version of the Balloon Analogue Risk Task (BART-Y) in the assessment of risk-taking behavior among inner-city adolescents. *Journal of Clinical Child and Adolescent Psychology*, 36, 106–111. 10.1080/15374410709336573 [PubMed: 17206886]
- Lejuez CW, Read JP, Kahler CW, Richards JB, Ramsey SE, Stuart GL, ... Brown RA (2002). Evaluation of a behavioral measure of risk taking: the Balloon Analogue Risk Task (BART). *Journal of Experimental Psychology: Applied*, 8, 75–84. 10.1037/1076-898X.8.2.75 [PubMed: 12075692]
- Loe IM, & Feldman HM (2007). Academic and educational outcomes of children with ADHD. *Journal of Pediatric Psychology*. 10.1093/jpepsy/jsl054
- Luman M, Goos V, & Oosterlaan J (2015). Instrumental learning in ADHD in a context of reward: Intact learning curves and performance improvement with methylphenidate. *Journal of Abnormal Child Psychology*, 43(4), 681–91. 10.1007/s10802-014-9934-1 [PubMed: 25212229]
- Luman M, Oosterlaan J, Hyde C, van Meel CS, & Sergeant J. a. (2007). Heart rate and reinforcement sensitivity in ADHD. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, 48(9), 890–8. 10.1111/j.1469-7610.2007.01769.x [PubMed: 17714374]
- Luman M, Oosterlaan J, Knol DL, & Sergeant J. a. (2008). Decision-making in ADHD: Sensitive to frequency but blind to the magnitude of penalty? *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, 49(7), 712–22. 10.1111/j.1469-7610.2008.01910.x [PubMed: 18422549]
- Mäntylä T, Still J, Gullberg S, & Del Missier F (2012). Decision making in adults with ADHD. *Journal of Attention Disorders*, 16, 164–73. 10.1177/1087054709360494 [PubMed: 20410321]
- Nigg JT (2001). Is ADHD a disinhibitory disorder? *Psychological Bulletin*, 127, 571–598. 10.1037/0033-2909.127.5.571 [PubMed: 11548968]
- Owens EB, Hinshaw SP, Lee SS, & Lahey BB (2009). Few girls with childhood attention-deficit/hyperactivity disorder show positive adjustment during adolescence. *Journal of Clinical Child and Adolescent Psychology*, 38, 132–143. 10.1080/15374410802575313 [PubMed: 19130363]
- Owens JS, Goldfine ME, Evangelista NM, Hoza B, & Kaiser NM (2007). A critical review of self-perceptions and the positive illusory bias in children with ADHD. *Clinical Child and Family Psychology Review*, 10(4), 335–351. 10.1007/s10567-007-0027-3 [PubMed: 17902055]
- Paloyelis Y, Asherson P, & Kuntsi J (2009). Are ADHD symptoms associated with delay aversion or choice impulsivity? A general population study. *Journal of the American Academy of Child and Adolescent Psychiatry*, 48, 837–846. 10.1097/CHI.0b013e3181ab8c97 [PubMed: 19564796]
- Pastor PN, & Reuben CA (2008). Diagnosed attention deficit hyperactivity disorder and learning disability: United States, 2004–2006. *Vital and Health Statistics. Series 10, Data from the National Health Survey*, 1–14.

- Polanczyk G, de Lima MS, Horta BL, Biederman J, & Rohde LA (2007). The worldwide prevalence of ADHD: A systematic review and meta-regression analysis. *The American Journal of Psychiatry*, 164(6), 942–948. 10.1176/appi.ajp.164.6.942 [PubMed: 17541055]
- Sagvolden T, Johansen EB, Aase H, & Russell VA (2005). A dynamic developmental theory of attention-deficit/hyperactivity disorder (ADHD) predominantly hyperactive/impulsive and combined subtypes. *The Behavioral and Brain Sciences*, 28(3), 397–419–68. 10.1017/S0140525X05000075 [PubMed: 16209748]
- Sattler JM, & Dumont R (2004). *Assessment of children: WISC-IV and WPPSI-III supplement*. San Diego: Jerome M. Sattler, Publisher, Inc.
- Schiebener J, & Brand M (2015). Decision making under objective risk conditions: A review of cognitive and emotional correlates, strategies, feedback processing, and external influences. *Neuropsychology Review*, 25(2), 171–198. 10.1007/s11065-015-9285-x [PubMed: 25894847]
- Schiebener J, García-Arias M, García-Villamizar D, Cabanyes-Truffino J, & Brand M (2014). Developmental changes in decision making under risk: The role of executive functions and reasoning abilities in 8- to 19-year-old decision makers. *Child Neuropsychology*, 7049(July), 1–20. 10.1080/09297049.2014.934216
- Shaffer D, Fisher P, Lucas CP, Dulcan MK, & Schwab-Stone ME (2000). NIMH Diagnostic Interview Schedule for Children Version IV (NIMH DISC-IV): Description, differences from previous versions, and reliability of some common diagnoses. *Journal of the American Academy of Child and Adolescent Psychiatry*, 39, 28–38. 10.1097/00004583-200001000-00014 [PubMed: 10638065]
- Shiels K, & Hawk LW (2010). Self-regulation in ADHD: The role of error processing. *Clinical Psychology Review*. 10.1016/j.cpr.2010.06.010
- Sonuga-Barke EJS, Cortese S, Fairchild G, & Stringaris A (2016). Annual Research Review: Transdiagnostic neuroscience of child and adolescent mental disorders - Differentiating decision making in attention-deficit/hyperactivity disorder, conduct disorder, depression, and anxiety. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, 57(3), 321–349. 10.1111/jcpp.12496
- Thompson AL, Molina BSG, Pelham W, & Gnagy EM (2007). Risky driving in adolescents and young adults with childhood ADHD. *Journal of Pediatric Psychology*, 32, 745–759. 10.1093/jpepsy/jsm002 [PubMed: 17442694]
- Tung I, Brammer WA, Li JJ, & Lee SS (2014). Parenting behavior mediates the intergenerational association of parent and child offspring ADHD symptoms. *Journal of Clinical Child and Adolescent Psychology*. 10.1080/15374416.2014.913250
- Van Duijvenvoorde ACK, Jansen BRJ, Bredman JC, & Huizenga HM (2012). Age-related changes in decision making: comparing informed and noninformed situations. *Developmental Psychology*, 48(1), 192–203. 10.1037/a0025601 [PubMed: 21967563]
- van Hulst BM, de Zeeuw P, Bos DJ, Rijks Y, Neggers SFW, & Durston S (2016). Children with ADHD symptoms show decreased activity in ventral striatum during the anticipation of reward, irrespective of ADHD diagnosis. *Journal of Child Psychology and Psychiatry*. 10.1111/jcpp.12643
- Volkow ND, Wang GJ, Fowler JS, Gatley SJ, Logan J, Ding YS, ... Pappas N (1998). Dopamine transporter occupancies in the human brain induced by therapeutic doses of oral methylphenidate. *The American Journal of Psychiatry*, 155, 1325–1331. [PubMed: 9766762]
- Weafer J, Milich R, & Fillmore MT (2011). Behavioral components of impulsivity predict alcohol consumption in adults with ADHD and healthy controls. *Drug and Alcohol Dependence*, 113, 139–146. 10.1016/j.drugalcdep.2010.07.027 [PubMed: 20863628]
- Wechsler D (2004). *The Wechsler intelligence scale for children—fourth edition* The Wechsler intelligence scale for children—fourth edition. San Antonio, TX: The Psychological Corporation.
- Weller JA, Levin IP, & Denburg NL (2011). Trajectory of risky decision making for potential gains and losses from ages 5 to 85. *Journal of Behavioral Decision Making*, 24(4), 331–344. 10.1002/bdm.690
- Whalen CK (1989). Attention Deficit and Hyperactivity Disorders In *Handbook of Child Psychopathology* (pp. 131–169). Boston, MA: Springer US 10.1007/978-1-4757-1162-2\_7

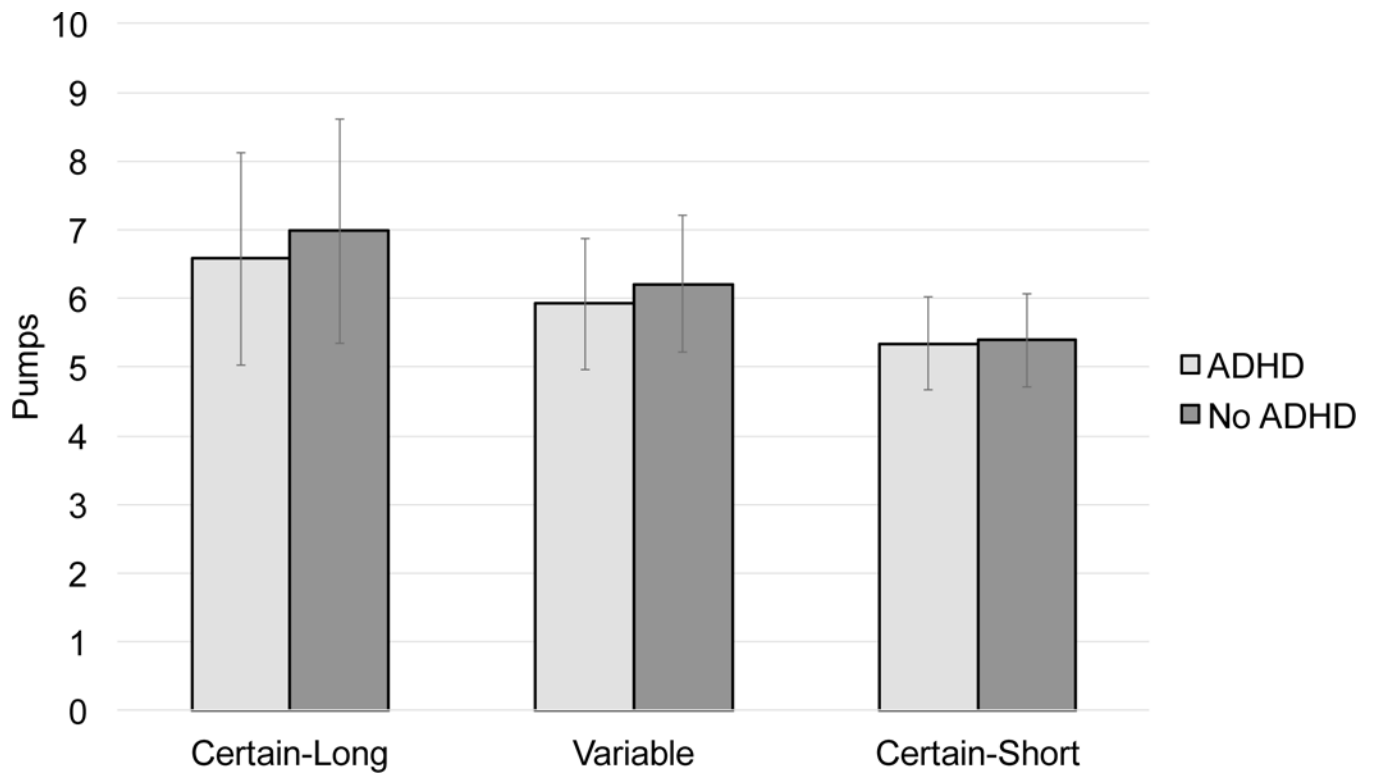
- Wilson VB, Mitchell SH, Musser ED, Schmitt CF, & Nigg JT (2011). Delay discounting of reward in ADHD: Application in young children. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, 52, 256–264. 10.1111/j.1469-7610.2010.02347.x [PubMed: 21083561]
- Wymbs BT, Molina BSG, Belendiuk KA, Pedersen SL, Walther CAP, Cheong JW, ... Pelham WE (2013). Motorsports involvement among adolescents and young adults with childhood ADHD. *Journal of Clinical Child and Adolescent Psychology*, 42, 220–31. 10.1080/15374416.2012.759227 [PubMed: 23347139]

Author Manuscript

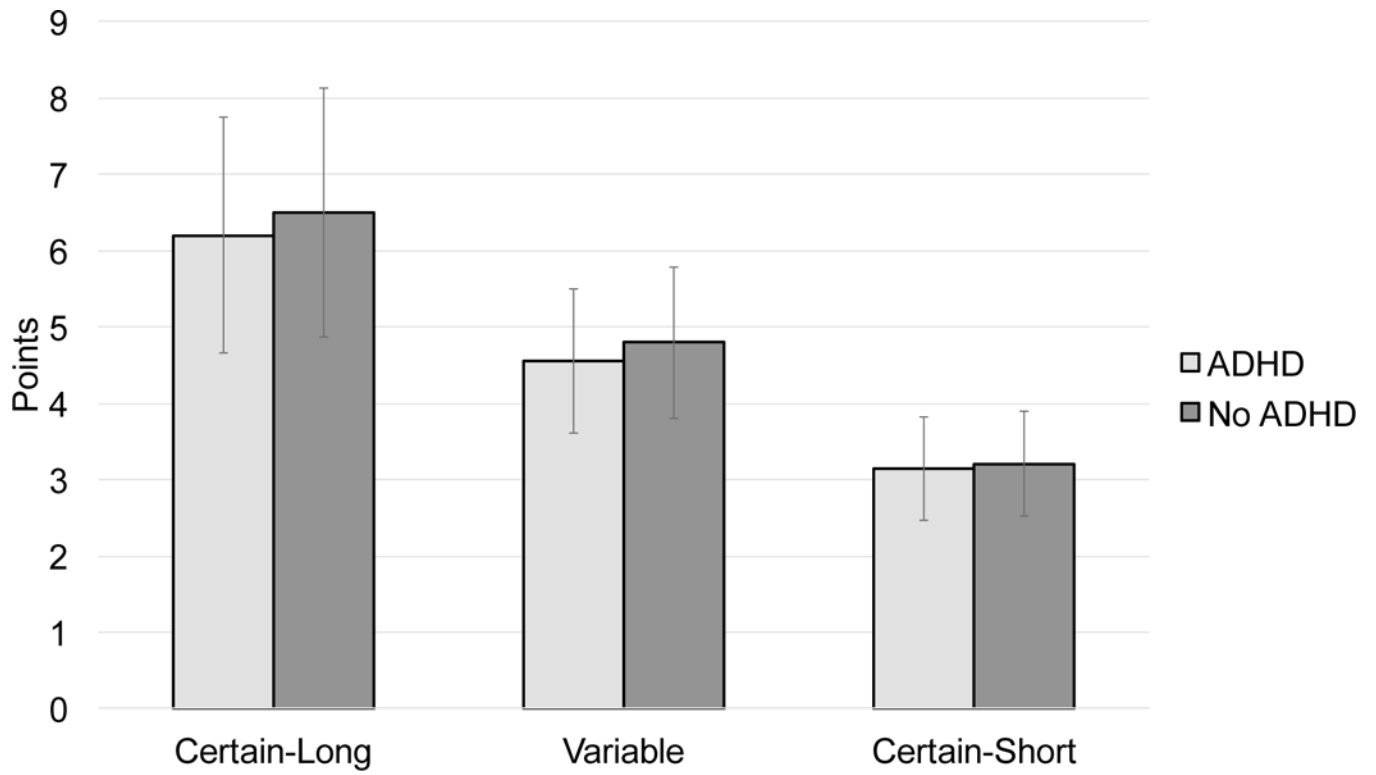
Author Manuscript

Author Manuscript

Author Manuscript

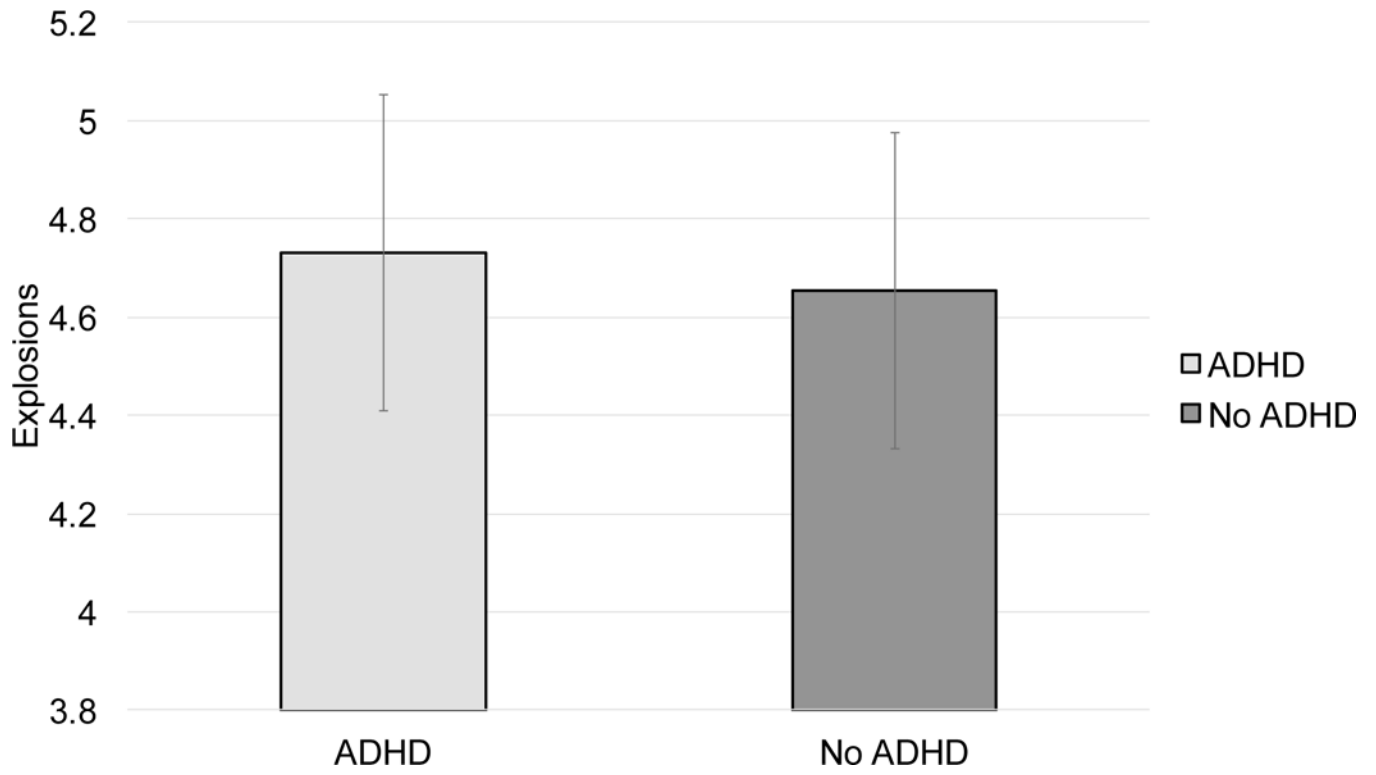


**Figure 1.** Mean number of pumps by task condition and ADHD status. *Note.* ADHD = attention deficit hyperactivity disorder. *Note.* Error bars indicate  $\pm 1$  standard error.

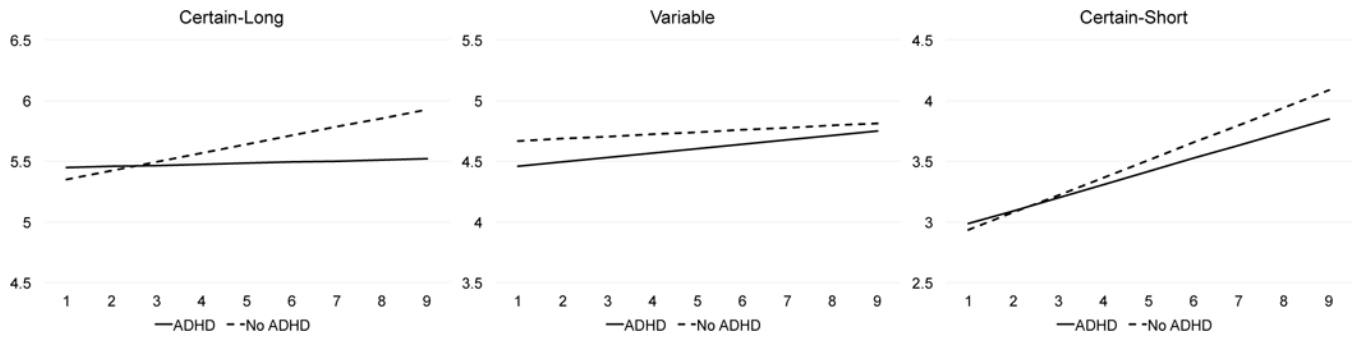


**Figure 2.** Mean number of points by task condition and ADHD status. *Note.* ADHD = attention deficit hyperactivity disorder. *Note.* Error bars indicate  $\pm 1$  standard error.





**Figure 3.** Mean number of exploded trials by ADHD status. *Note.* ADHD = attention deficit hyperactivity disorder. *Note.* Error bars indicate  $\pm 1$  standard error.



**Figure 4.** Learning on the certain-long, variable, and certain-short balloon condition by Wave 1 ADHD status. *Note.* ADHD = attention deficit hyperactivity disorder.

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

**Table 1.**

Demographic measures by ADHD diagnostic group status.

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

*Note.* Mean (SD). ADHD = attention deficit hyperactivity disorder.

\*\*  
p < .01.

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

**Table 2.**

Descriptive statistics and correlation matrix among ADHD, sex, age, and primary BELT outcomes.

	ADHD 1	Sex	Age	IQ	Pumps	Points	Explosions
ADHD (Wave 1)	1	.14*	-.13 <sup>†</sup>	-.22**	-.07	-.12 <sup>†</sup>	-.01
Sex (Male = 1)		1	-.001	.11	.06	-.01	.09
Age (Wave 2)			1	-.06	.14t	.17*	.07
Estimated IQ				1	.08	.10	.06
Pumps					1	.75***	.85***
Points						1	.33***
Explosions							1
% or	54%	69	10.35	107.65	164.81	127.88	4.69
Mean (SD)		%	(1.41)	(14.60)	(43.18)	(23.69)	(3.16)
Range	0–1	0–1	7.86–14.35	69–144	55–288	55–209	0–16

Note. ADHD = attention-deficit/hyperactivity disorder.

<sup>†</sup>  
 $p < .10$ .\*  
 $p < .05$ .\*\*  
 $p < .01$ .\*\*\*  
 $p < .001$ .