Childhood ADHD and delayed reinforcement: A direct comparison of performance on hypothetical and real-time delay tasks

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**Abstract**

Objective: Individuals with ADHD have been shown to prefer smaller sooner over larger later rewards. This has been explained in terms of abnormally steeper discounting of the value of delayed reinforcers. Evidence for this comes from different experimental paradigms. In some, participants experience delay in the laboratory (real-time delay tasks; R-TD), in others they imagine the delay to reinforcers (hypothetical delay tasks; HD). Method: We directly contrasted the performance of 7- to 12- year-old children with ADHD (n=23) and matched controls (n=23) on R-TD and HD tasks with monetary rewards. Results: Children with ADHD displayed steeper temporal discounting on the R-TD, but not the HD tasks. Conclusion: These findings suggest that the experience of waiting prior to the delivery of rewards is an important determinant of heightened temporal discounting in ADHD - a finding consistent with models that emphasize the aversive nature of delay for children.

Key words: ADHD, delay discounting, delay aversion, impulsive choice, temporal discounting

**Introduction**

Temporal discounting refers to the universal phenomenon whereby reinforcers decrease in perceived value as the delay to their delivery in the future is increased (Scheres, Water, & Mies, 2013). A number of reinforcement-based theories predict exaggerated levels of temporal discounting in ADHD (Luman, Tripp, & Scheres, 2010). Recent meta-analyses support this assertion (Patros et al., 2016; Jackson & Mackillop, 2016). When offered a series of choices between two reward alternatives differing from one another in terms of delay length and reward magnitude, individuals with ADHD are more likely than controls to trade-off a reward’s size for its immediacy. Different types of procedures have been used to assess temporal discounting in ADHD. In some of these, the choices are hypothetical and participants are asked to imagine choosing between outcomes of different sizes delivered at different times in the future – although they never experience the delay in the laboratory (Barkley, Edwards, Laneri, Fletcher, & Metevia, 2001; Demurie, Roeyers, Baeyens, & Sonuga-Barke, 2012, 2013; Dias et al., 2013; Wilson, Mitchell, Musser, Schmitt, & Nigg, 2011). In some versions participants receive their chosen rewards at some point, in others they do not (Reynolds, 2006). Other paradigms involve real-time choices in laboratory settings. In these, after making their choice individuals have to “sit through” the delay (if they chose the delayed option). Participants then typically receive the rewards they choose during the testing session (Scheres et al., 2006; Scheres, Tontsch, Thoeny, & Kaczkurkin, 2010; Schweitzer & Sulzer-Azaroff, 1995). As well as differing in the extent to which delays are experienced and rewards are received, hypothetical tasks tend to offer choices differing from one another over a much larger time-frame. For example, a typical hypothetical task would involve choosing between 10 dollars in 180 days or 1 dollar now. In a real-time task, a typical choice would be between receiving 2 cents now or 30 cents in a minute.

Sonuga-Barke, Cortese, Fairchild and Stringaris (2016) have recently highlighted the complex nature of intertemporal decision-making and the way in which disruptions in multiple distinct neuropsychological processes, and their underlying neural circuitry, may contribute to sub-optimal choices in ADHD. More specifically, they highlight the potential role of three brain systems each of which has been shown in neuroimaging studies to be altered in ADHD (Sonuga-Barke & Fairchild, 2012): ( i ) the default mode network implicated in the ability to think in abstract ways about future experiences (so called prospection); (ii) the reward circuit which codes the motivational salience and valence of the future outcomes and allows rewards to be evaluated one against another; (iii) the executive network which allows decision to be made and delay to be managed. From the point of view of understanding the precise nature of the neuropsychological deficits underpinning intertemporal decision-making in ADHD, it is important to note that performance on real-time and hypothetical temporal discounting tasks typically correlate poorly (Krishnan-Sarin et al., 2007; Melanko, Leraas, Collins, Fields, & Reynolds, 2009; Paloyelis, Asherson, Mehta, Faraone, & Kuntsi, 2010; Shiels et al., 2009; Smits, Stein, Johnson, Odum, & Madden, 2013). The reason for this lack of correlation remains to be fully explained. However, it is consistent with the idea that different task variants tap different neuropsychological systems. So for instance, tasks requiring prospection about long-term abstract outcomes are likely to require a greater degree of prospection (Benoit, Gilbert, & Burgess, 2011; Peters & Buchel, 2010). On other hand, tasks where individual receive real rather than imagined rewards are likely to activate reward network (Umemoto, Lukie, Kerns, Müller, & Holroyd, 2014). Finally, tasks where participants actually have to wait for the rewards they choose are likely to require executive functions to manage the decision outcomes (Duckworth & Kern, 2011). Performance on these latter types of tasks are also likely to vary as a function of how well individuals tolerate the frustration associated with delay during waiting – while this is not an issue in tasks where no actual delay is involved. In this regard, it is interesting that Smits and his colleagues (2013) found a significant correlation between boredom tolerance and tasks with real-time but not hypothetical delay.

Despite these obvious differences between the task paradigms, recent meta-analyses failed to take account of task type when estimating discounting differences between ADHD and controls (Patros et al., 2015; Jackson & Mackillop, 2016). Furthermore, despite the possible value of contrasting the two types of tasks for understanding ADHD pathophysiology, only two studies have directly compared different discounting paradigms in ADHD and control cases. The results were complex and inconsistent. Paloyelis et al. (2010) found that individuals with ADHD carrying a specific allele of the DAT1 gene exhibited higher discounting in hypothetical, but not real-time, paradigms. However, rewards were delivered probabilistically which may have confounded the discounting measure (Smits et al., 2013). Rosch and Mostofsky (2015), in contrast, found that ADHD girls, but not boys, discounted rewards more steeply on real-time, but not hypothetical, paradigms. However, because in this study the real-time paradigm involved choices between different amounts of a consumable reward (videogame playing) and the hypothetical one involved imagined monetary amounts, the task differences were difficult to interpret (Demurie et al., 2013). Although not focused on diagnosed cases, Scheres, Lee and Sumiya (2008) found a specific relation between ADHD symptoms and delay discounting in real-time but not hypothetical paradigms.

In the current study, we compared the performance of individuals with ADHD on two temporal discounting paradigms: one involving real-time delay (R-TD) and the other hypothetical delay (HD) discounting. Past studies have highlighted that R-TD and HD tasks are sensitive to discounting changes over very different time-frames (Scheres et al., 2010; Demurie et al., 2012, 2013; Dias et al., 2013) – a finding that in itself highlights differences in their putative underlying processes. Therefore, as has always been the case in past studies, the two tasks employed here differed in terms of the implicated time-scale – with the HD task asking about periods of time ranging over days and weeks and the R-TD task presenting delays in the range of seconds and minutes. Furthermore, the rewards involved were larger in the HD than the R-TD tasks. While in previous studies, HD tasks most often employed hypothetical rewards and R-TD tasks most often delivered real rewards, in the current study both tasks used hypothetical rewards in an attempt to rule out reward type as a possible confounding factor.

On the basis of the model of sub-optimal decision making in ADHD presented by Sonuga-Barke et al. (2016), that postulates deficits in multiple brain systems implicated in temporal discounting, we predicted that individuals with ADHD would show exaggerated temporal discounting on both HD and R-TD tasks. At the same time, we predicted that their performance on the two tasks would not be correlated suggesting that different neuro-psychological processes are implicated.

**Method**

**Participants**

Twenty-night children with ADHD (7 females; 20 ADHD-inattentive and 9 ADHD-combined type) and twenty-five controls (7 females) aged between 7 to 12 years of age participated in the current study. The ADHD participants and some controls were recruited via advertisements posted in local special education institutions and primary schools. The remaining control participants (n=19) were randomly selected by teachers working in one local primary school. Parents completed the Chinese version of Conners’ Parent Rating Scale-Revised (CPRS-R; Fan, Du, & Wang, 2005) and the Strength and Difficulties Questionnaire (SDQ; Kou, Du, & Xia, 2006; Kou, Du, Xia, & Xu, 2005). Children performed the Raven’s Standard Progressive Matrices-Chinese Revised (R’SPM-CR) to assess their intelligence (Zhang & Wang, 1989). For the participants with ADHD the inclusion criteria were: (i) having a clinical diagnosis of ADHD from a hospital psychiatrist; (ii) exceeding the T-score cut off (> 63) on the ADHD scales of CPRS-R (Paloyelis et al., 2010; Marco et al., 2009); (iii) a current impact score of more than 2 on SDQ; and (iv) no evidence of neurological disorder, psychosis, or pervasive developmental disorder; (v) medication-naïve. Controls needed to meet the following criteria: (i) having the T-score below 63 on all ADHD scales of CPRS-R; (ii) a zero impact score on the SDQ; and (iii) no evidence of neurological disorder, psychosis, or pervasive developmental disorder.

**Measures**

**HD task:** This task was based on the one used by Demurie et al. (2012). Participants chose between a smaller reward (5, 10, 20, or 25 yuan) received “now” and a larger reward with a constant reward size (30 yuan, equal to approx. 4 euros) received after variable delays (tomorrow, the day after tomorrow, one week and two weeks; see figure 1). Reward amounts were visualized on the screen as Chinese bank notes. There was a total of 40 trials with each choice pair presented twice. Choices were presented in the same pseudorandom sequence to all participants. The position (left or right) of the delayed reward option was counter-balanced across trials. Participants were instructed to press the “left” or “right” button corresponding to the position on the screen of their preferred choice. They were informed that they would neither receive actual rewards nor experience real delays. They had to imagine that they would receive these rewards after a given delay. Length of delay and amount of money, as well as the total number of trials, were described before participants began to make choices during a short interview (see supplementary information). This ensured that participants had an accurate representation of task parameters. After the task, participants were asked to describe strategies they used and the reasons for their choices.

**R-TD task:** This task was previously used by Scheres et al. (2010). Participants chose between a smaller reward (2, 4, 6, or 8 yuan cents) delivered immediately and a larger reward with a constant reward size (10 yuan cents) delivered after variable delays (5, 10, 20, 30 and 60 secs). The number of trials, the response options and the experimental design aspects (e.g. counterbalancing) were the same as in the HD task. The reward amounts and delays were visualized respectively by the number of coins a plane carried and the height of the plane: the higher the plane, the longer the delay before reward was delivered (see figure 2). After the participant made a choice, the plane disappeared, and an image corresponding to the coins carried by their chosen plane would appear in the participant’s money basket on the bottom of the computer screen for 1500 ms, immediately or after the appropriated delay. The total number of cents won by the participants was then presented – updated after each trial - for 1000 ms. Before the choice trials, participants experienced each delay to ensure that they understood the link between plane’s height and the reward delay. Participants were told that they would not receive the money they won during the task but should make choices as if they were to receive it. They were told the number of trial they would perform in the task.

**Procedure**

The study was approved by the Ethic Review Committee of the School of Psychology in Beijing Normal University. Advertisements were sent to parents with children aged from 7 to 12 through the social media network of special education institutions and primary schools in Beijing. A short screening procedure was conducted (asking about the child’s age, clinical diagnose of ADHD and physical and psychiatric conditions) and information about the study was presented. Parents who met criteria and verbally consented attended a session at the testing location. A detailed description of the study was then given. All parents and children gave written informed consent. During their visit, parents completed the CPRS-R and SDQ under the guidance of a trained clinical psychology postgraduate student. At the same time, children completed the Raven’s Standard Progressive Matrices-Chinese Revised test and digit span subscales of the WISC-III in a quiet small room with one instructor present. If children met the inclusion criteria, they undertook the two temporal discounting tasks. Children were told that they could speak during the tasks but the instructor was not permitted to reply at that time. After the completion of the two tasks, the participant received a prize (a pencil) regardless of their performance. An account of their child’s performance was provided for parents.

**Data preprocessing**

Two dependent variables were calculated for each tasks: the subjective value of the larger reward (SV) at each delay and the area under the curve (AUC). The former reflected the effect of delay at each level and the latter is a model-free estimation of the delay discounting rate and can be used to compare performances across different discounting tasks (Myerson, Green, & Warusawitharana, 2001). Smaller AUC represents a steeper rate of discounting of future rewards. Two independent raters determined the SV of delayed rewards based on the procedure reported by Scheres and her colleagues (more details please see Scheres et al., 2006). The SV was defined as the magnitude of the immediate reward at which participants showed no preference for the immediate over the delayed reward (Critchfield & Kollins, 2001; Mitchell, 1999). Inter-rater agreement was good (mean kappa 0.94, rang 0.89-0.99). In cases of disagreement, a consensus was reached through discussion. AUC was calculated following the procedure described by Myerson et al. (2001). The delay discounting curve was plotted by using normalized subjective values (SV divided by the maximum reward, 30 RMB in HD and 10 cents in R-TD) as y coordinates and normalized delay level (delays divided by the maximum delay, 14 days in HD and 60 seconds in R-TD) as x coordinates. Vertical lines were drawn from each point on the x axis, resulting in several trapezoids. Then the areas of each trapezoid were calculated and summed, resulting in the AUC.

**Statistical analyses**

First, the effects of delay and group on SV, were explored separately for the HD and R-TD tasks in two ANOVAs with group as the between-subjects variable and delay as the within-subjects variable. Secondly, a repeated measures ANOVA with AUC standardized scores (Z scores) was used to make a direct comparison between ADHD and controls on the HD and R-TD tasks. Third, Pearson product-moment correlation coefficient was employed to explore the correlations between performances (AUC) of children on HD and R-TD discounting tasks.

**Results**

Data from 23 ADHD and 23 controls were included in the final analyses. Demographic information is presented in table 1. Eight participants (2 controls and 6 ADHD) were excluded from the final analysis: (i) two controls thought there was time limitation imposed on task performance; (ii) one child with ADHD thought that choosing the small immediate outcome would give him that reward every day; (iii) one ADHD participant always pressed the “right” button in the R-TD task; (iv) three children with ADHD did not finish the R-TD task; (v) one child with ADHD failed to recognize the amount of money during the HD task.

 A significant main effect of delay on SV was observed in the HD task (F (3,132) = 19.88, p < .01, η2 = .31) suggesting that the delayed rewards were effectively discounted. Neither the main effect of group (F (1,44) = .27, p = .67, η2 = .01) nor the delay by group interaction (F (3,132) = 1.32, p = .27, η2 = .03) were significant. Post-hoc analyses (Bonferroni) indicated that subjective values became smaller with increasing delay: SV of tomorrow > SV of the day after tomorrow > SV of 1 week > SV of 2 weeks (all p < .01). These results suggested that both groups showed discounting sensitivity to changes in hypothetical delay (figure 3).

 For R-TD task, when SV was the depend variable, there was a significant main effect of delay (F (4,176) = 39.61, p < .01, η2 = .47) and a marginally significant main effect of group (F (1,44) = 3.96, p = .05, η2 = .08). The significant interaction effect between delay and group approached significance (F (4,176) = 1.96, p = .10, η2 = .04). Post-hoc analyses (Bonferroni) also showed that SV became smaller as the increasing delay (for each paired comparison: P < .01). To investigate group differences on SV at each delay level, planned contrasts were performed. These analyses revealed that there were no group differences in the SV of the monetary reward offered 5 and 10 seconds. However, children with ADHD devalued the delayed reward more sharply than controls at the delay of 20 (p = .02, η2 = .11) and 30 seconds (p = .04, η2 = .09). The subjective values of delayed rewards delivered 60 seconds was marginally lower in the ADHD group (p = .07, η2 = .08). These findings demonstrated that children with ADHD only devalued delayed reward more steeply when delays were of sufficient length (figure 3).

 The cross task analysis of standardized AUC revealed a significant group by task interaction effect (F (1,44) = 5.46, p = .02, η2 = .11), but no effect of group (F (1,44) = .69, p = .41, η2 = .02). The simple effects tests demonstrated that children with ADHD devalued delayed reward at higher rate on the R-TD task (F (1,44) = 4.51, p = .04, η2 = .09), but not the HD task (F (1,44) = .56, p = .46, η2 = .01). AUC on the two tasks was not significantly correlated either in pooled sample (r = .21, p = .15) or within ADHD/ Control children (ADHD: r = .30, p = .17; Control: r = .24, p = .27).

**Discussion**

In the current study, we explored the extent to which children with ADHD discounted delayed monetary rewards on two paradigms potentially tapping different neuropsychological processes - HD and R-TD. We hypothesized that children with ADHD would display greater discounting on both tasks although performance on the tasks will not be correlated – consistent with the theory that impulsive choice in ADHD is determined by multiple independent processes.

There were a number of findings to note. First, consistent with previous studies (Krishnan-Sarin et al., 2007; Melanko et al., 2009; Paloyelis et al., 2010; Shiels et al., 2009; Smits et al., 2013) and our hypothesis, discounting on the HD and R-TD tasks was uncorrelated. Several specific processes have been implicated in intertemporal decision-making, including prospection, reinforcement and executive control processes (Sonuga-Barke et al., 2015). In the introduction, we speculated that the HD paradigm would require a greater degree of prospection while the R-TD would tap reinforcement and executive processes differentially. Isolating the specific psychological processes implicated in the two tasks was beyond the scope of the current paper. Future studies should include tasks that tap these specific processes alongside the two temporal discounting paradigms.

Second, contrary to our hypothesis, we observed exaggerated discounting in ADHD on the R-TD paradigm only. Prior studies demonstrating heightened discounting on paradigms similar to the R-TD task include the studies by Schweitzer and Sulzer-Azaroff (1995) and Scheres et al. (2010). Paloyelis et al. (2010) and Scheres et al. (2006) failed to find any difference between ADHD and controls on this type of tasks. These null findings in the R-TD paradigm might be attributed to the relative shorter wait time for delayed reward (Yu, Sonuga-Barke, & Liu, 2015). Studies using HD tasks have also produced inconsistent results. Some have found similarly negative results as ours (Chantiluke et al., 2014; Crunelle et al., 2013; Rubia et al., 2009; Wilbertz et al., 2012, 2013; Rosch & Mostofsky, 2015). Other studies have observed higher delay discounting in ADHD (Barkley et al., 2001; Demurie et al., 2012, 2013; Dias et al., 2013; Wilson et al., 2011). It is interesting that this form of sub-optimal choices observed in the HD paradigm disappears after the controlling of IQ or inattentive (Wilson et al., 2011; Rosch & Mostofsky, 2015) suggesting that low IQ may drive ADHD effects on HD tasks.

According to the logic of our rationale, the failure to find deficits on the HD paradigm suggests that the neuropsychological processes underpinning this form of temporal discounting are intact in ADHD. For instance, thinking about future hypothetical rewards requires prospection which itself depends on introspective processes that have their neurobiological basis in the so called default model network – which incorporates medial prefrontal and precuneus/posterior cingulate hubs as well lateral regions such as the medial temporal gyrus and lateral parietal cortex (Hsu & Sonuga-Barke, 2016; Lavallee & Persinger, 2010; Spreng &Grady, 2010; Snyder & Raichle, 2012;). Interestingly, there is now considerable evidence that this network is both dysregulated in rest and over-active during task performance in ADHD (Castellanos et al., 2008; Helps et al., 2010; Liddle et al., 2011). Activity within this network has also been directly implicated in successful temporal discounting (Smallwood, Ruby, & Singer, 2013). Future studies should explore directly the role of this network in hypothetical discounting tasks.

At the same time, the results also suggest that some processes specifically underpinning RT-D paradigm performance are deficient in ADHD. Choosing the large delayed, over a small immediate reward involves a range of different neuropsychological processes and implicates different brain networks (Sonuga-Barke et al., 2016). As described in the introduction, both reinforcement and executive processes are activated during intertemporal choice processes (van den Bos, Rodriguez, Schweitzer, & McClure, 2014). Prior research has demonstrated deficits in both these processes in ADHD (Plichta & Scheres, 2014; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Along with Scheres et al. (2008), it is important to highlight that the emotional experience of time passing during delay may also be a critical factor – a view consistent with the predictions of the delay aversion hypothesis (Sonuga-Barke, Taylor, Sembi, & Smith, 1992; Sonuga-Barke, Wiersema, van der Meere, & Roeyers, 2010). This model is based on the idea that individuals with ADHD choose immediate rewards over delayed in part to avoid the negative affective states associated with delay during waiting. In the RT-D tasks, children typically have nothing to do but just wait for the reward while monitoring the totally blank computer screen during the delays. This is likely to induce delay aversion. In this way, Smits and his colleagues (2013) found that boredom was significant correlated with delay discounting in the real-time task but not in the hypothetical task. Antrop and her colleagues (2006) found that children with ADHD performed similar choice pattern when they could watch pictures during delay between trials – stimulation, which it was argued, made time pass more quickly.

The current study had a number of limitations. First, the lack of independent measures of the candidate neuropsychological processes that might underpin the discounting effects is a limitation. Second, we did not measure the subjective value of reward options. This raises the question whether the steeper discounting slope is a product of lower baseline values of rewards. Paglieri, Addessi, Sbaffi, Tasselli and Delfino (2015) have demonstrated that different delay discounting of candy versus money is attributed to their baseline values, and some studies have observed different reward sensitivity in individuals with ADHD (Kohls, Herpertz-Dahlmann, & Konrad, 2009; Demurie, Roeyers, Baeyens, & Sonuga-Barke, 2011). Finally, the sample in the current study was small and this limited the potential of the study to examine heterogeneity and the idea that just a subset of individuals with ADHD might have altered delay discounting (Dias et al., 2013; Sonuga-Barke, Bitsakou, & Thompson, 2010).

In summary, HD and R-TD task performance was uncorrelated suggesting that the two paradigms tapped different neuropsychological processes. Individuals with ADHD displayed exaggerated temporal discounting only on the R-TD task. This is consistent with a model of ADHD discounting linked to the actual experience of delay.

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Tables

Table 1 Demographic characteristics of ADHD and Controls Group

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | ControlsMean(SD) |  | ADHDMean(SD) | P |
| Gender (male: female) | 16:7 |  | 17:6 |  |
| Age (years) | 9.56(1.61) |  | 9.28(1.83) | 0.58 |
| IQ | 116.95(10.14) |  | 114.81(10.35) | 0.48 |
| PSQ subscales |  |  |  |  |
| ADHD index  | 45.73 (4.72) |  | 65.79(10.23) | 0.00 |
| Inattention | 48.19(6.19) |  | 73.89(8.31) | 0.00 |
| Hyperactivity-impulsivity | 44.84(4.24) |  | 58.16(11.33) | 0.00 |
| delay discounting (AUC) |  |  |  |  |
| HD | 0.49(0.21) |  | 0.54(0.25) | 0.46 |
| R-TD | 0.50(0.27) |  | 0.34(0.22) | 0.04 |

ADHD, attention deficit/hyperactivity-impulsivity disorder; PSQ, Chinese version of Conners’ Parent Rating Scale; HD: hypothetical delay task; R-TD: real-time delay task

Figures



Figure 1 Example of a trial the hypothetical delay task. Words in parentheses are the meanings of Chinese.



Figure 2 Example of a choice trial in the real-time delay task. This choice is between 2 cents immediately and 10 cents after 30 sec. Words in parentheses are the meanings of Chinese.

Figure 3 Delay discounting functions of children with ADHD and controls for hypothetical and real-time discounting tasks. Error bar represents the standard error.