Studying the relation between temporal reward discounting tasks used in populations with ADHD: A factor analysis

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Abstract

Background: This study aimed at investigating the relationship between tasks that have been used in attention deficit hyperactivity disorder (ADHD) to measure choices between smaller immediate and larger delayed rewards: real and hypothetical temporal discounting tasks, and single-choice paradigms.

Methods: Participants were 55 undergraduate psychology students. Tasks included a real and hypothetical version of a temporal discounting (TD) task with choices between a large reward (10 cents) after delays up to 60 seconds, and smaller immediate rewards (2–8 cents); two versions of a hypothetical temporal discounting task with choices between a large reward ($100) after delays up to 120 months, and smaller immediate rewards ($1–$95); a Choice Delay Task with choices between one point now and two points after 30 seconds (one point is worth five cents).

Results: Correlation analyses showed that the real and the hypothetical TD tasks with 10 cents were very strongly associated. However, the hypothetical TD tasks with $100 did not correlate with either the real or the hypothetical TD task with 10 cents. Principal component analysis extracted two components: one for small amounts and short delays, and a second one for large rewards and long delays.

Conclusions: Temporal reward discounting is not a uniform construct. Functional brain imaging research could shed more light on unique brain activation patterns associated with different forms of temporal reward discounting. *Copyright © 2010 John Wiley & Sons, Ltd.*

Introduction

Impulsivity is thought to play a key role in various psychiatric conditions such as substance abuse (Reynolds, 2006), pathological gambling (Alessi and Petry, 2003; Petry and Casarella, 1999), and attention deficit hyperactivity disorder (ADHD) (American Psychiatric Association, 2000; Sonuga-Barke, 2003). ADHD is characterized by three symptoms domains: inattention, hyperactivity, and impulsivity, with the focus of most theoretical models and recent research being on impulsivity (e.g. Barkley, 1997; Sonuga-Barke, 2002, 2003).

Specifically, theoretical models of ADHD propose that one main underlying mechanism associated with impulsivity in ADHD is delay aversion. Sonuga-Barke *et al.* (1992) was the first to propose that children with ADHD are delay averse, expressed as an unusually strong preference for smaller immediate rewards over larger delayed rewards. Earlier studies that have tested this hypothesis used single-choice paradigms such as the Choice Delay Task (CDT) (Sonuga-Barke *et al.*, 1992; Antrop *et al.*, 2006; Kuntsi *et al.*, 2001; Schweitzer and Sulzer-Azaroff, 1995; Solanto *et al.*, 2001; Tripp and Alsop, 2001) and found evidence for this notion [see Luman *et al.* (2005) for a review).

In single-choice paradigms such as the CDT, participants are presented with 20 choices between one point after two seconds and two points after 30 seconds, with one point being worth five cents. Thus, in single-choice paradigms, neither magnitude of the immediate reward nor delay preceding the large reward is varied. While these paradigms have provided useful initial data in the study of delay aversion in ADHD, they do not allow for measuring the trade-off between reward magnitude and pre-reward delays, as Temporal Discounting (TD) paradigms do. By contrast, studies of impulsivity in adult populations have employed more sophisticated paradigms in which reward magnitude and delay duration are varied in order to obtain a temporal discounting function, which shows the decrease in subjective reward value as a function of increasing pre-reward delay [e.g. Crean *et al.*, 2000; Green *et al.*, 1996; Kollins, 2003; see Green and Myerson (2004) for review]. Recently, researchers have started to take advantage of these paradigms and apply them to the study of ADHD (Barkley *et al.*, 2001; Scheres *et al.*, 2006).

Similar to most studies on impulsivity within adult populations, Barkley and colleagues used a TD task with hypothetical choices in adolescents with ADHD and healthy controls. Choices were between large rewards ($100 or $1000) delivered after delays up to one year and smaller immediate rewards. Adolescents with ADHD had stronger preferences for immediate rewards than controls in the $100 condition but not the $1000 condition. Scheres *et al.* (2006) used a TD task with real choices that was more similar to the previously used CDT in terms of reward magnitudes and delay durations. Participants chose between 10 cents delivered after delays up to 30 seconds and smaller immediate rewards. This task was administered to children and adolescents with ADHD, and healthy controls. Although clear age effects were reported for TD (shallower TD with increasing age), no effect of diagnostic group was found.

As described earlier, the tasks that have been used to study delay aversion in ADHD vary greatly across studies. Additionally, although the majority of studies with the CDT report relatively strong preferences for small immediate rewards in ADHD, less consistent findings have been obtained in studies with TD tasks. Therefore, it is possible that the extent of ADHD-related preferences for small immediate rewards depends on a number of task-specific factors that may seem subtle on the surface, but could turn out to be important factors contributing to reward preferences in ADHD. These factors include, but are not limited to real versus hypothetical choices, small versus large amounts of the delayed reward, short versus long delays, constant choices versus varying choices. Thus, various TD tasks tap into different reward-related aspects to a varying degree, and so it is an empirical question how much overlap there is between these tasks. Specifically, Navarick (2004) has suggested that when experimenters use TD tasks with hypothetical rewards, they may be studying an entirely different discounting process than when real rewards are used. Thus, it is an empirical question whether various TD tasks as used with ADHD populations measure similar or different discounting processes. Therefore, this study aims at comparing the paradigms that have been used in the field of ADHD: the CDT [Sonuga-Barke *et al.*, 1992; Solanto *et al.*, 2001; see Luman *et al.* (2005) for review], a hypothetical TD task (Barkley *et al.*, 2001), and a real TD task (Scheres *et al.*, 2006). Because studies with real TD tasks tend to use smaller rewards than studies with hypothetical rewards, differences between real and hypothetical TD tasks could be due to magnitude effects. Therefore, in order to test whether hypothetical and real tasks yield different or same results while controlling for differences in reward magnitude and delay durations, we also included a hypothetical version of the 10-cents task. We generally hypothesized that hypothetical TD tasks with large amounts and long delays would be distinguishable from TD tasks (real or hypothetical) with small amounts and short delays.

Methods

Participants

Participants were 18 and 19 year old undergraduate psychology students at the University of Arizona. Fifty-nine participants were enrolled in this study. Four were excluded from data analyses: three because of psychoactive medication use, and one due to technical problems. Therefore, we report data for 55 participants (26 male,

29 female). The mean age was 18.2 [Standard deviation (SD) = 0.4].

Tasks

Participants performed the following computerized tasks: (1) a TD task with small immediate rewards ranging from two to eight cents and large delayed rewards of 10 cents delivered after delays up to 60 seconds; (2) a hypothetical version of task 1; (3) a hypothetical TD task with small immediate rewards between $1 and $100 and large delayed rewards of $100 delivered after delays up to 10 years; on half of the task trials, the immediate option was available today, while on the other half of the task trials, the 'immediate' option was available after one year instead of today; (4) the CDT with repeated choices between one point after two seconds and two points after 30 seconds (Sonuga-Barke *et al.*, 1992; Solanto *et al.*, 2001). Tasks were administered in two blocks (1–4 and 2–3). We balanced the block order as well as the order of tasks within blocks across participants. This resulted in the following two orders: 1-4-3-2 and 2-3-4-1. Tasks 1 and 2 were never presented sequentially because we wanted to avoid that participants would generate responses in the hypothetical task that were consistent with those given in the real version of that task, and vice versa. For all tasks, standardized instructions were displayed on the screen. The left or right position of the delayed reward on the computer screen was balanced over trials, and trials were administered in the same pseudo-random order for all participants. Participants chose by pressing the key corresponding to their preferred choice (all TD tasks), or by selecting their preferred choice with a mouse click (CDT). Tasks started with five practice trials. Participants were informed of the number of trials they would play at the beginning of each task. After completion of the real TD task and the CDT, participants received the total amount of money that they won. The dependent variables used were area under the discounting curve (AUC) for all TD tasks, and proportion preference for the delayed reward for the CDT.

Temporal discounting task with small rewards – real version

Before task practice, participants were exposed to each delay, so they learned the durations of each delay and they learned that delays were not associated with uncertainty. In other words, no matter how long the delay, the reward was delivered with 100% certainty. Following that, participants were presented with five practice choice trials. Then, in the experiment, they made repeated choices between a small variable reward (two, four, six, or eight cents) that would be delivered immediately (i.e. zero seconds) and a large constant reward (10 cents) that would be delivered after a variable delay of 5, 10, 20, 30, or 60 seconds (modified from Scheres *et al.*, 2006). Each small immediate reward was paired twice with every delay for the large reward, resulting in a total of 40 choice trials. Choices were visually represented by two airplanes on a computer screen (one on each side), each carrying their corresponding quantity of money. Delays were represented by the 'height'/level at which the planes were flying; the higher the plane, the longer the delay duration (see Figure 1). Choosing the preferred plane resulted in the plane dropping its money cargo into the participant's basket on the bottom of the screen, either immediately or after the appropriate delay. After each trial, the total amount won was updated on the screen.

Temporal discounting task with small rewards – hypothetical version

Choices in this task were the same as in the real task (see earlier), except that this time, delays were not experienced and rewards were not paid. Choices were shown in white letters against a grey background. After participants selected the preferred option, the screen turned blank for 1000 milliseconds, after which the next choice was presented.

Hypothetical temporal discounting tasks with large money amounts

Participants made choices between a small variable reward ($1, 10, 20, 30, 40, 50, 60, 70, 80, 90, 95, or 100), either available today (on 50% of trials) or after one year (on 50% of trials), and a large constant reward ($100) available one month, one year, five years, or 10 years after the immediate option (Barkley *et al.*, 2001). Each small reward was paired twice with every delay for the large reward, resulting in a total of 192 trials, 96 on which the immediate option was available today, and 96 on which the 'immediate' option was available after one year. For example, participants chose between $50 now and $100 after one month, or between $75 after 12 months and $100 after 13 months. Choices were shown in white letters against a grey background. After participants selected the preferred option, the screen turned blank for 1000 milliseconds, after which the next choice was presented.

Choice Delay Task (CDT)

Participants made 20 repeated choices between one point (worth five cents) to be delivered after two seconds, and
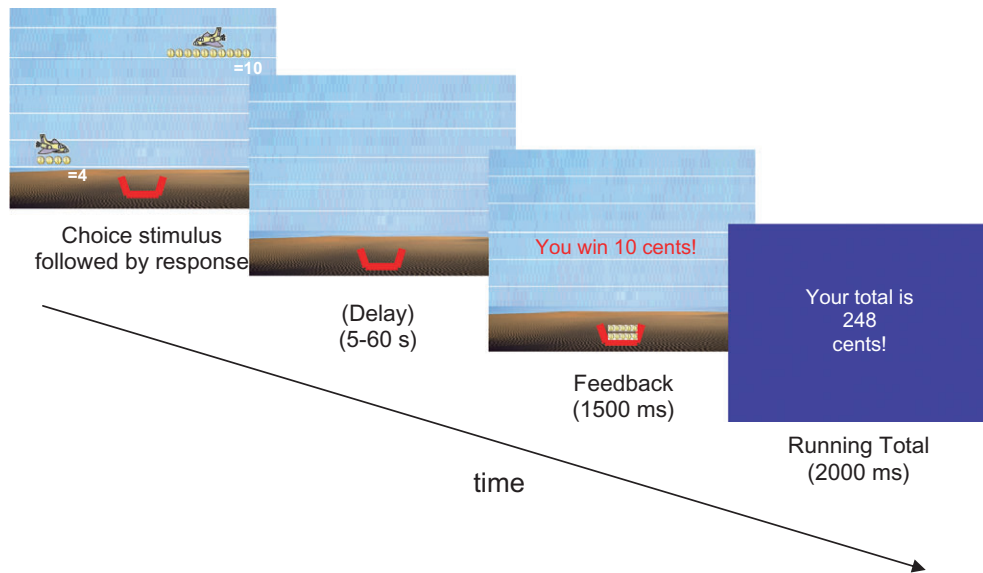
Figure 1 Example of a trial on the 10 cents temporal discounting task with real rewards and real delays. This choice is between four cents immediately and 10 cents after 30 seconds.

two points to be delivered after 30 seconds (Solanto *et al.*, 2001). Choices were visually represented by a green square labeled 'one point' and a blue square labeled 'two points'. After choosing the preferred option, the screen turned green for two seconds (immediate reward), or blue for 30 seconds (delayed reward). After the delay, the corresponding number of points was presented on the screen, accompanied by a sound effect.

Procedure

Participants were invited by e-mail. After arrival, they read and signed a consent form before performing the tasks. Participants were instructed to leave their watch and cell phone in the waiting area. The experimenter administered the tasks in one of two task orders. At the end of the CDT and at the end of the real TD task, participants were paid the monetary amount they won. At the end of the session, participants also received academic credit points for their time.

Data preprocessing

Data were preprocessed based on previously reported procedures (Myerson *et al.*, 2001; Scheres *et al.*, 2006). First, for each TD task, subjective values were calculated for the delayed reward for each delay. Subjective value was defined as the magnitude of the small immediate reward for which the participant showed indifference in a choice against the large delayed reward (Critchfield and Kollins, 2001). For example, if I prefer two cents now and four cents now over

10 cents after 30 seconds, but my preference switches to 10 cents after 30 seconds when the immediate alternative is six or eight cents, then five cents would be considered the indifference point, or the subjective value of 10 cents after 30 seconds. In order to determine the subjective values, choice preferences for each participant were ordered based on delay duration and magnitude of the immediate reward. Then, two raters (AS and ALT) independently determined subjective values. Agreement between the raters was very good (mean kappa 0.89, range 0.76–0.98), partly reflecting that participants responded in quite a stable way, despite the random order of trials. In rare cases of disagreement, a consensus on subjective value was reached by discussion. In Table 1, the determination of the subjective value is illustrated by an example of temporal discounting. The large delayed reward is preferred when the immediate reward has a low value (indicated by a 'D'). However, as the value of the immediate reward increases, preference shifts towards the immediate reward (indicated by an 'I'). In this example (Table 1), the subjective value of $100 after one month is $100, and drops to $45 after five years, and $35 after 10 years.

The second step was to calculate AUC for the temporal discounting functions [following the procedure described by Myerson *et al.* (2001), and used by Scheres *et al.* (2006)]. First, subjective values and delays were normalized. That is, subjective values were expressed as proportions of the amount of the maximum delayed reward, and delays were expressed as proportions of the maximum delay. The normalized values were used as x and y coordinates ($x =$

Table 1 Example of hypothetical temporal discounting data and the determination of the subjective value

Immediate reward in $	Delay to large reward ($100) in months							
	1		12		60		120	
	t1	t2	t1	t2	t1	t2	t1	t2
1	D	D	D	D	D	D	D	D
10	D	D	D	D	D	D	D	D
20	D	D	D	D	D	D	I	I
30	D	D	D	D	D	D	D	D
40	D	D	D	D	D	D	D	I
50	D	D	D	D	I	I	I	D
60	D	D	D	D	I	I	I	I
70	D	D	D	I	I	I	I	I
80	D	D	I	D	I	I	I	I
90	D	D	I	I	I	I	I	I
95	D	D	I	I	I	I	I	I
100	D	D	I	I	I	I	I	I
Subjective value of delayed reward	100		75		45		35	

Note: t1 = trial 1; t2 = trial 2. Preferences for the delayed reward are indicated with a 'D', and preferences for the immediate reward are indicated with an 'I'. For each delay, the subjective value of the delayed reward is located where the choice preference switches from 'D' to 'I'.

delay; y = subjective value). The data points on the y axis were connected, thus forming the discounting function. From each standardized subjective value, vertical lines were drawn to determine four separate trapezoids. The area of each trapezoid equals $(x2 - x1) \times [(y1 + y2)/2]$, where $x1$ and $x2$ are successive delays, and $y1$ and $y2$ are the subjective values associated with these delays. The standardized subjective values range between zero and one. Using this formula, the area of each trapezoid was calculated and subsequently the areas were summed, resulting in the dependent variable of interest: total AUC. In general, a smaller AUC reflects a steeper discounting function (i.e. less willingness to wait as time increases).

Missing data

After excluding four participants from data analyses (see Participants), the total number included was 55. One participant did not finish the hypothetical version of the 10 cents TD task. Thus, the total number of participants for this task was 54.

Statistical analyses

Factor analysis

In order to examine the pattern of correlations between the tasks, we performed principal component analysis. Components with eigenvalues greater than one were extracted. A Varimax rotation was then applied to obtain a final solution.

ANOVA

In order to examine whether the degree of discounting differed between the real and hypothetical 10 cents TD tasks, we performed ANOVA with task version (real versus hypothetical) as within-subject variable, and AUC as dependent variable. In order to examine whether the degree of discounting differed between trials on which the immediate reward was available today versus after one year for the hypothetical $100 task, we performed ANOVA with trial type (immediate reward available today versus after one year) as within-subject variable, and AUC as dependent variable.

Results

Factor analysis

The correlation matrix is displayed in Table 2. For the TD tasks with 10 cents, a significant correlation was found between the real and the hypothetical version. No significant correlations were found between the 10 cents and the $100 TD tasks. The CDT correlated significantly with the real and hypothetical versions of the 10 cents TD task, but not with the $100 TD tasks.

In the principal component analysis, two components were extracted: the first one had an eigenvalue of 2.2 and accounted for 45% of the variance; the second factor had an eigenvalue of 1.8 and accounted for an additional 35% of the variance. The dependent variables of the 10 cents TD tasks and the CDT loaded on the first factor, and the dependent variables of the hypothetical $100 tasks loaded on the second factor. Thus, there were two factors: one 'small amount-short delay factor' (including both real and hypothetical tasks), and one 'large amount-long delay factor'. The rotated component matrix is displayed in Table 3.

ANOVA

For TD of 10 cents, no significant effect of task version was found [$F(1,53) = 0.37$, not significant (ns), see Figure 2]. For hypothetical TD of $100, a significant effect of trial type was found [$F(1,54) = 40.0$, $p < 0.001$]. Participants

Table 2 Correlations between task variables

	1	2	3	4	5
1 CDT proportion delayed chosen	1				
2 TD real 10 cents AUC	0.40*	1	–	–	–
3 TD hypothetical 10 cents AUC	0.49*	0.68*	1	–	–
4 TD hypothetical $100 today AUC	0.03	0.11	0.09	1	–
5 TD hypothetical $100 one year AUC	0.04	0.18	0.12	0.92*	1

Note: CDT, Choice Delay Task; AUC, area under the discounting curve; TD, temporal reward discounting.
* $p < 0.01$.

TD of 10 cents
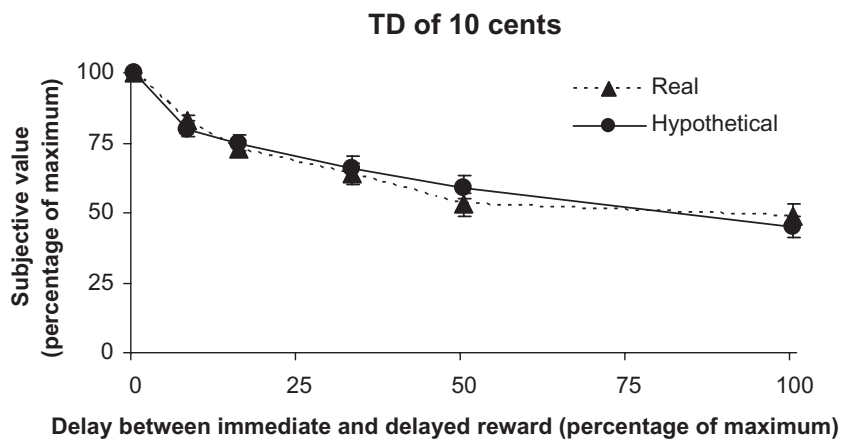
Figure 2 Temporal discounting functions for real and hypothetical tasks for small rewards (10 cents).

Table 3 Rotated component matrix

	Component	
	1	2
TD real 10 cents AUC	0.84	0.12
TD hypothetical 10 cents AUC	0.89	0.07
TD hypothetical $100 today AUC	0.03	0.98
TD hypothetical $100 one year AUC	0.07	0.98
CDT proportion delayed chosen	0.74	−0.04

discounted large delayed rewards more steeply when the immediate alternative was available today, than when it was available after one year (see Figure 3).

Discussion

This study investigated the relationship between various versions of temporal reward discounting tasks previously used in ADHD. We found no difference for real versus hypothetical TD of small monetary rewards, and a high correlation between real and hypothetical versions of tasks as long as reward amounts were the same. For hypothetical TD of large rewards, we found steeper discounting when the immediate reward was available today, compared to after one year, and high correlations between these tasks. No correlations were found between 10 cents tasks and $100 tasks, not even when both were hypothetical.

The CDT, which is the most frequently used delay aversion task in ADHD populations, loaded on the same factor as the real and hypothetical TD tasks with 10 cents. This suggests that the overlap between the CDT and the TD tasks was substantial, despite some procedural differences: fixed choices (in terms of reward magnitudes and delay durations) in the CDT versus varying choices in the TD tasks; real choices in the CDT versus hypothetical choices in the hypothetical TD task; tertiary rewards (points exchangeable for money) used in the CDT versus
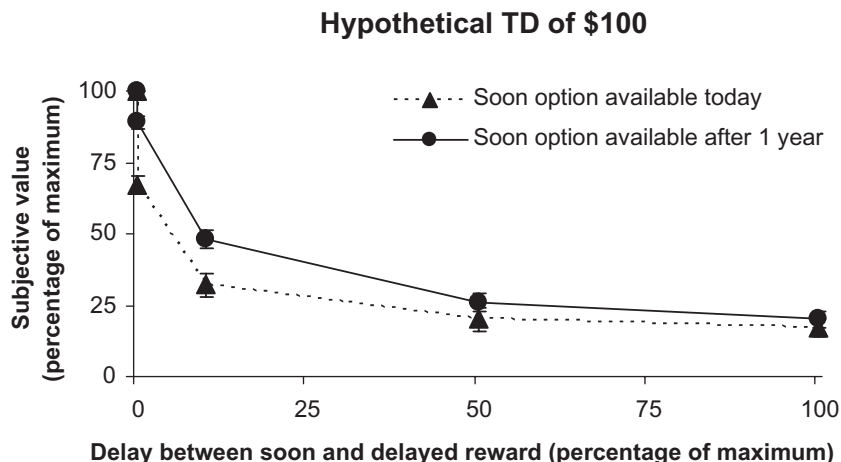
Figure 3 Temporal discounting functions for hypothetical rewards of $100, with smaller immediate rewards available today or after one year.

secondary rewards used in the real TD task. Despite these differences, the overlap between the CDT and the two TD tasks with 10 cents was substantial enough for the tasks to load on the same factor. It suggests that, as long as reward magnitudes and delay durations are comparable, delay aversion tasks measure very similar discounting processes, despite some procedural differences such as the use of hypothetical versus real choices. At the same time, it needs to be acknowledged that, likely due to the procedural differences described earlier, the overlap between the CDT and the TD tasks with 10 cents was smaller than the overlap between the two versions of the TD task with 10 cents.

The high positive correlation between real and hypothetical TD of 10 cents shows that generally, there was congruency between what participants believed they would choose, and what they actually chose. The lack of difference in AUC between these tasks suggests that hypothetical and real TD tasks measure a similar construct, as long as amounts and delay durations are constant. This finding contributes significantly to a similar finding previously reported in only six college students (Lagorio and Madden, 2005). It was previously proposed that TD tasks with hypothetical rewards may measure an entirely different discounting process than TD tasks with real rewards (e.g. Navarick, 2004). However, the current dataset suggests that as long as real and hypothetical TD tasks do not differ in terms of reward magnitudes and delay durations, they measure very similar discounting processes. Indeed, in previous reports that did find differences between real and hypothetical TD tasks, this comparison was confounded by differences in reward magnitudes and delay durations (Kirby, 1997; Lane *et al.*,

2003). Although these findings are encouraging, it remains to be seen whether hypothetical and real TD tasks correlate highly when large amounts and long delay durations are used. In this experiment, we did not use a real version of the $100 task for practical reasons. When using sufficient trials and participants, total gains easily exceed researchers' budgets. A compromise for future research could be to compare hypothetical and *potentially* real TD tasks in which participants are told that one of their choices will be selected and that they will be paid according to this one choice (Johnson and Bickel, 2002; Madden *et al.*, 2004).

The lack of correlation between the 10 cents and $100 tasks (even when both were hypothetical) suggests that the discounting of small amounts of money over short delays is a different discounting process than the discounting of large amounts of money over long delays. Thus, temporal reward discounting does not seem to be a uniform concept. This has implications for measuring delay aversion in populations with impulsivity, such as ADHD. With different tasks, we apparently measure different kinds of TD, and some TD tasks may therefore be more sensitive to ADHD-related impulsivity than others. Indeed, we found that TD of <u>real</u> rewards was the most sensitive measure to be associated with ADHD-related symptoms of impulsivity in college students (Scheres *et al.*, 2008). Researchers who study delay aversion in clinically diagnosed patients with ADHD may consider using a battery of TD tasks rather than one specific version, in order to investigate the sensitivity of various TD task versions.

Finally, it needs to be noted that the sample under study here was older and probably better-functioning

than participants with ADHD in most studies that have used TD tasks. Therefore, it remains to be demonstrated whether the factor structure of the tasks is similar in children and adolescents with and without ADHD.

Although not previously used in populations with ADHD, we added choice trials to the hypothetical $100 TD task in which the immediate option was available after one year (versus being available today). Adding these trials allows for studying preference reversals, and may be useful in future research on the relation between ADHD and TD. Preference reversals refer to situations when individuals may resist the 'immediate' reward when it is not available immediately (i.e. after one year), but choose it when it is available right away (i.e. today). For example, a significant proportion of lottery winners who chose to receive the full jackpot over 25 annual payments at the time of ticket purchase, changed their mind and instead chose to receive half of the jackpot immediately when they won the lottery (Baker *et al.*, 2003). Although there are plenty of examples of preference reversals in daily life, there is little research on this phenomenon with experimental TD tasks in the laboratory (Green *et al.*, 1994; Green *et al.*, 2005). Our data demonstrated that TD functions were steeper when the immediate reward was available today, as compared to after one year. This is consistent with the notion of preference reversals, and is in line with Green *et al.*'s (2005) finding that AUC decreased as the delay to the immediate reward was increased. As stated by Green *et al.* (2005), p. 1130, decreasing discounting rates as a function of increasing delay to the immediate reward suggests that 'adding a constant to both the delay to the sooner reward and the delay to the later reward decreased the influence of the time dimension, thereby increasing the relative influence of the monetary dimension'. We therefore suggest that future research with individuals with ADHD should study TD when the choice is between two delayed rewards, as it allows for distinguishing the relative contribution of the time dimension and the monetary dimension to steep TD.

The tasks used in this study were selected primarily because they had been used previously with ADHD populations (Barkley *et al.*, 2001; Solanto *et al.*, 2001; Sonuga-Barke *et al.*, 1992; Scheres *et al.*, 2006; Scheres *et al.*, in press). However, there are some limitations in these tasks that should be noted. First, the real TD task and the CDT did not include post-reward delays; thus, inter-choice interval was not controlled for. Therefore, choosing the smaller immediate reward resulted not only in sooner delivery of a reward, but also in shorter inter-trial intervals and shorter task duration (the number of trials was held constant). In order to distinguish the factors responsible

for discount rate, future research is needed that compares TD tasks without post-reward delays with TD tasks with post-reward delays (see Scheres *et al.*, 2006). However, it needs to be noted that tasks with post-reward delays suffer from their own limitations: For example, previous research has shown that TD tasks with post-reward delays often result in ceiling effects: subjects choose the large delayed reward on the vast majority of trials (e.g. Jackson and Hackenberg, 1996; Logue *et al.*, 1986; Scheres *et al.*, 2006). Moreover, tasks with post-reward delays have been shown to be insensitive to inter-individual differences in symptoms of ADHD (Sonuga-Barke *et al.*, 1992; Scheres *et al.*, 2006). As a result, although tasks with post-reward delays may be considered to be technically more correct measures of TD, such tasks often yield data without sufficient between-subject variance, and may therefore be insensitive to individual differences in symptoms of impulsivity (Logue *et al.*, 1986). This could be interpreted as support for the notion that impulsivity-related steep TD is mainly a result of delay aversion (Sonuga-Barke *et al.*, 1992; Sonuga-Barke, 2002, 2003).

Secondly, because of their previous use in ADHD populations (Barkley *et al.*, 2001; Scheres *et al.*, 2006; Solanto *et al.*, 2001; Sonuga-Barke *et al.*, 1992), we used conditioned reinforcers in this study (money or points), instead of primary reinforcers (such as food or juice) that could be consumed at the end of every trial. Consequently, participants experienced not only delays to the delivery of the conditioned reinforcer (points or coins presented on the computer screen) at the end of every trial, but also delays to the end of the task session when the conditioned reinforcer was exchanged for the actual reward (i.e. money) (Jackson and Hackenberg, 1996; Hyten *et al.*, 1994). The delay to the exchange may be an important determinant of subjects' choices, in addition to the delay to the conditioned reinforcer (Hyten *et al.*, 1994). In other words, as suggested by Logue and colleagues (Logue *et al.*, 1986; Logue *et al.*, 1990), humans may be sensitive to events integrated over longer time periods and thus choose to maximize their total gains, especially when task duration is constant.

Based on these limitations we suggest that there is a need for the further development and use of TD tasks that prove to be both sensitive to inter-individual differences in impulsivity, while at the same time controlling for factors such as session duration. In humans, this may prove to be a challenging task. While in animals, tasks with primary reinforcers (food/juice) and post-reward delays yield choices that alternate between impulsivity and self-control (Logue, 1988), humans typically choose to maximize their rewards when task duration is constant,

especially when money/points are used (e.g. Logue *et al.*, 1990; Scheres *et al.*, 2006; Sonuga-Barke *et al.*, 1992). Thus, such tasks yield ceiling effects and are insensitive to impulsiveness (Logue *et al.*, 1986). Even when consumable reinforcers such as video-game playing (Millar and Navarick, 1984) or picture viewing (Navarick, 1986) were used, only a minority of human subjects showed impulsive preferences. We suggest that future studies in humans use food/juice as a primary reinforcer in combination with post-reward delays (resulting in constant task duration) in a TD paradigm that varies duration preceding the large reward as well as magnitude of the immediate reward. In a study that did not manipulate these parameters, Logue and King (1991) found that choices varied from self-control to impulsivity in a paradigm with constant task duration and choices between three seconds of juice access after one second and nine seconds of juice access after 60 seconds. This suggests that TD tasks with juice as a reinforcer and post-reward delays may be both sensitive to inter-individual differences in impulsivity, while at the same time controlling for factors such as session duration. Generally, there is a need for more studies that directly manipulate various relevant task features, so that TD can be compared within one sample when using monetary rewards versus primary rewards, and post-reward delays versus no post-reward delays.

In conclusion, the current study showed that hypothetical and real experiential TD tasks previously used with ADHD populations yielded very similar TD functions, as long as reward magnitudes and delay durations were held constant. When, however, reward magnitudes and delay durations differed across TD tasks, no relation between discounting functions was found, not even when both were hypothetical. Thus, we cannot assume that all TD tasks measure one uniform construct. We propose that functional brain imaging research, including connectivity analyses, can help to clarify the brain systems involved in different kinds of temporal reward discounting in humans.

Acknowledgments

Declaration of interests statement

The authors AS, MS, and ALT reported no biomedical financial interests or potential conflicts of interest.

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