The Psychological Record (2018) 68:239–253
https://doi.org/10.1007/s40732-018-0292-1

ORIGINAL ARTICLE

A Summary of Methods for Measuring Delay Discounting in Young Children

Johanna L. Staubitz[1] · **Blair P. Lloyd**[1] · **Derek D. Reed**[2]

Published online: 27 April 2018

Abstract

Delay discounting is a process hypothesized to underlie impulsive decision-making and is associated with a host of risky health behaviors, addictive behaviors, and psychiatric diagnoses. While delay discounting has primarily been studied in adult populations, these assessments have potential to facilitate early identification of impulsivity, particularly for children who are at risk for poor long-term outcomes. As a first step toward early identification of risk based on delay discounting, we reviewed the literature including pre-adolescent children to determine (a) for whom delay discounting has been assessed, (b) what assessment procedures have been used, and (c) how assessment parameters affect discounting estimates. Of the 21 identified studies, the majority of participants were children 7 years of age and older who were typically developing or had attention deficit/hyperactivity disorder. Hypothetical choices about money were most often used in assessments, although commodity magnitudes varied widely. Less than half of assessments included visual supports to aid comprehension of choice options. Effects of assessment parameters on delay discounting were largely unexplored. Future directions for research include identifying limits regarding for whom hypothetical money choice assessments produce interpretable and valid outcomes, as well as alternative assessment approaches or adaptations for children who may have difficulty understanding hypothetical constructs, money, delays, or some combination thereof.

Keywords Delay discounting · Temporal discounting · Impulsivity · Early identification · Children

Delay discounting is defined as the process by which commodities lose their subjective value as the delay to their receipt increases (Ainslie, 1974). Often conceptualized as an index of impulsivity, delay discounting is hypothesized to represent how people make choices that take into account the immediacy of a commodity. For example, when offered the choice between receiving \$95 right now or \$100 available after a delay of 1 month, a person may choose the smaller sooner amount (\$95 now). However, when offered the choice between receiving \$90 right now and \$100 available in 1 month, a person may instead choose to receive the larger later amount (\$100 in 1 month). The amount at which a person is indifferent between the smaller sooner amount and the larger later amount (e.g., conservatively estimating the value at \$92.50) represents the subjective value of the larger commodity at that delay (e.g., 1 month). Theoretically, the greater a person "discounts" commodity value by delay, the more "impulsive" their choices are considered. While most people discount by delay to some degree, the gradient of decrease in subjective values across successive delays varies by individual (Odum, 2011b). Due in part to its sensitivity to individual differences, delay discounting has been evaluated as a predictor for a range of outcomes.

Particularly in the last 10–15 years, delay discounting has been found to be associated with a number of person-level variables. For example, younger individuals exhibit relatively greater delay discounting, or higher impulsivity, on average. Several studies have compared delay discounting across age groups and found that adolescents (i.e., 12- to 18-year-olds) tend to discount more by delay than adults on the same measures (e.g., Green, Fry, & Myerson, 1994; Steinberg et al., 2009). Greater delay discounting also has been found to correspond with lower IQ (Dougherty et al., 2014; Shamosh & Gray, 2008), lower income levels (de Wit, Flory, Acheson, McCloskey, & Manuck, 2007), and lower educational attainment (Jaroni, Wright, Lerman, & Epstein, 2004).

✉ Johanna L. Staubitz
johanna.l.staubitz@vanderbilt.edu

[1] Department of Special Education, Vanderbilt University, Box 228, One Magnolia Circle, Nashville, TN 37203, USA

[2] Department of Applied Behavioral Science, University of Kansas, 1000 Sunnyside Avenue, Lawrence, KS 66045, USA

Additionally, behavior associated with risks to well-being correlates with delay discounting; such relations extend across myriad health concerns, leading some to conceptualize excessive delay discounting as a "transdisease" process (see Bickel, Jarmolowicz, Mueller, Koffarnus, & Gatchalian, 2012). Greater delay discounting is predictive of a variety of risky health behavior, including safety belt use, sunscreen application, and risky sexual activities (see Daugherty & Brase, 2010). Others have found that delay discounting is negatively correlated with preventive health behavior, such as dental visits, flu shot usage, mammograms, and prostate examinations (see Bradford, 2010).

Beyond risky health behavior, delay discounting is robustly related to addictive behavior, including gambling (Alessi & Petry, 2003; Canale, Vieno, Griffiths, Rubaltelli, & Santinello, 2015; Dixon, Jacobs, & Sanders, 2006), substance abuse (Kim-Spoon, McCullough, Bickel, Farley, and Longo, 2015; Kirby & Petry, 2004; Lee, Stanger, & Budney, 2015; Romer, Duckworth, Sznitman, & Park, 2010), and cigarette smoking and relapse (Sheffer et al., 2014; Yoon et al., 2007), to name a few (see also MacKillop et al., 2011). The power of delay discounting as a predictor of addiction has motivated research on whether it also predicts response to addiction treatment. Some evidence suggests that delay discounting is indeed predictive of treatment response. In other words, it may predict *resistance* to addiction treatment. For example, participants in cigarette cessation programs who discounted more steeply by delay were less likely to quit smoking and more likely to relapse than those who were less impulsive (Krishnan-Sarin et al., 2007; MacKillop & Kahler, 2009). Washio et al. (2011) demonstrated a similar relation between delay discounting and response to treatment for cocaine addiction. Taken together, results suggest that delay discounting may be a useful tool for identifying risk status for a variety of socially significant outcomes, including response to treatment.

Measuring delay discounting in young people may be particularly advantageous, given early identification of a range of risk factors allows greater opportunity to intervene and divert poor outcomes (e.g., chronic juvenile offenders [Lynam, 1996]; autism (Koegel, Koegel, Ashbaugh, & Bradshaw, 2014); mathematics difficulties (Gersten, Jordan, & Flojo, 2005). In one classroom application, Reed and Martens (2011) demonstrated that delay discounting predicted differences in the on-task behavior of typical sixth grade students between conditions in which rewards were available (a) immediately following a session and (b) after a delay. As delay discounting rates increased, differentiation in on-task behavior between conditions also increased. In other words, on-task behavior was more sensitive to the immediacy of rewards for students who were more impulsive. These findings suggest that delay discounting may be predictive of classroom behaviors that impact learning, and thus may have potential as an early indicator of risk.

The potential of delay discounting to predict classroom behavior is qualified by a lack of empirical data regarding the relative stability of delay discounting estimates from childhood to the onset of a socially significant outcome (e.g., addiction). While stable estimates have been obtained across relatively short periods of time (e.g., 3 months [Ohmura, Takahashi, Kitamura, & Wehr, 2006]; 1 year [Jimura et al., 2011; Kirby, 2009]), demonstrating adequate test-retest reliability, less is known about how early in life interpretable and stable estimates of delay discounting can be obtained.

A handful of prospective longitudinal studies have been conducted in adolescent populations. For example, Audrain-McGovern et al. (2004) measured delay discounting at three time points, in the spring of 10th grade and in the first and second years after high school graduation (i.e., between 15 and 20 years old). While delay discounting predicted the development of smoking habits, it did not change significantly over time, indicating stability at least from adolescence to the onset of smoking.

Achterberg, Peper, van Duijvenvoorde, Mandl, and Crone (2016) measured delay discounting at two time points separated by 2 years in a study that included pre-adolescent participants. Participant age ranged from 8 to 24 at the first time point, and mean participant age was 14.32 ($SD = 3.59$). Achterberg et al. found that estimates of delay discounting from each time point were significantly correlated. These results support the notion that delay discounting may be stable from pre-adolescence to the onset of an outcome of concern. However, to our knowledge, Achterberg et al. conducted the only study that has evaluated the longitudinal stability of delay discounting estimates for a sample including preadolescent children, for whom early detection of risk likely has the most impact. More research, and in particular research focused specifically on the stability of estimates of delay discounting in pre-adolescent children, will be necessary to evaluate the utility of delay discounting for early identification of risk.

To date, little delay discounting research in general has been conducted among children relative to adult, college, or even adolescent age groups. Reviews of the literature evaluating delay discounting as a predictor of addiction (Reynolds, 2006), stress (Fields, Lange, Ramos, Thamotharan, & Rassu, 2014), and IQ (Shamosh & Gray, 2008), as well as those evaluating the role of delay discounting in treatment (e.g., Ashe, Newman, & Wilson, 2015; Koffarnus, Jarmolowicz, Mueller, & Bickel, 2013), included few studies with child participants. No reviews to date have focused specifically on child populations or included a substantial number of studies focused on children.

The relative scarcity of pre-adolescent children included in delay discounting research may be related to the procedures typically used to measure delay discounting. Delay discounting assessments involve presenting a person with a series of choices between a larger amount of a commodity available after a delay and a smaller amount available immediately. Amounts are manipulated to identify the value at which a respondent is equally likely to choose either option (i.e., indifference point). Each series of choices is repeated across several delays to identify several indifference points. Figure 1 displays two sets of hypothetical delay discounting data in which indifference points are graphed across increasing delays. Indifference points across a series of delays may be analyzed to index the discounting rate or degree to which a person subjectively devalues the larger commodity as a function of delay. In Fig. 1, the dotted data path represents a steeper rate of discounting—or more impulsive choices—relative to the solid data path. Discounting analysis is typically conducted by either fitting indifference points with a quantitative model to estimate a rate of delay discounting (e.g., *k*; see Rachlin, 2006 for a discussion on fitting *k*), or calculating the area under the curve created by plotting indifference points across increasing delays (i.e., area under the curve [AUC]; see Myerson, Green, & Warusawitharana, 2001 for a discussion on AUC).

A variety of delay discounting tasks exist to estimate indices such as *k* or AUC, but most rely on hypothetical choices about money (e.g., Odum, 2011a). Choices are often hypothetical to avoid excessive cost and time requirements. For example, the Monetary Choice Questionnaire (Kirby, 1997) is a written, hypothetical-choice questionnaire that takes only a few minutes to complete and is significantly associated with a range of socially important outcomes (e.g., heroin addiction in adults [Kirby, Petry, & Bickel, 1999]; academic performance in adolescents [Duckworth & Seligman, 2005]). At least among adults, hypothetical choice assessments tend to yield similar estimates of delay discounting as those produced by assessments in which chosen rewards are experienced (e.g., Johnson & Bickel, 2002; Lagorio & Madden, 2005; Madden, Begotka, Raiff, & Kastern, 2003).

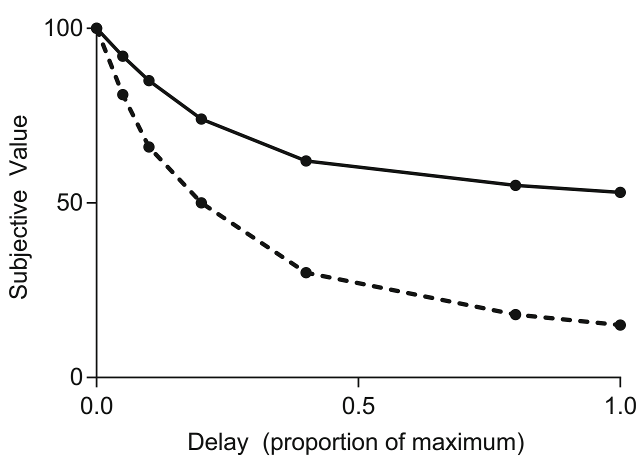

Fig. 1 Hypothetical subjective values of $100 across increasing delays for two individual respondents. Delays are represented as a proportion of a maximum hypothetical 10-year delay

However, parameters outside of choice type have been shown to influence estimates of delay discounting. Assessments that rely on hypothetical choices about consumable commodities (e.g., food, cigarettes), for example, have been shown to produce greater estimates of delay discounting than assessments with hypothetical choices about money (Estle, Green, Myerson, & Holt, 2007; Odum, Baumann, & Rimington, 2006; Odum & Rainaud, 2003). The magnitude of rewards also affects delay discounting, with smaller rewards (e.g., $100) discounted more by delay than larger rewards (e.g., $1000) among adults and adolescents (Green, Myerson, & McFadden, 1997; Kirby, 1997; Raineri & Rachlin, 1993). Applying delay discounting assessments with young children likely requires varying several of the assessment parameters, including choice type, commodity, and magnitude. We would not expect children who have limited experience with money—or those who do not understand the hypothetical choices—to respond systematically. Extending applications of delay discounting for early identification of risk will likely require an increased focus on measuring this construct in younger populations.

Purpose

Measuring delay discounting in young or particularly at-risk populations (e.g., children with disabilities) is necessary to evaluate the longitudinal stability of delay discounting and its potential for early identification of risk. The purpose of this review was to summarize methods used to measure delay discounting in young children (i.e., age 12 years old and younger) and explore how procedural variations in the delivery of these assessments might impact delay discounting estimates. We addressed the following research questions. For young children (i.e., age 12 and younger):

1. What populations have been included in delay discounting studies?
2. What assessment procedures (i.e., choice types, commodities, magnitudes of delayed monetary rewards, presentation of choice stimuli, and visual supports) have been used to measure delay discounting?
3. How do assessment parameters affect estimates of delay discounting?

Method

We searched the delay discounting literature for studies in which (a) mean participant age was 12.99 years or younger (i.e., children in grades pre-k through 6) and (b) at least one delay discounting assessment was conducted. Although our primary interest was how delay discounting has been assessed for children in elementary grades and younger, we extended the age limit to allow us to evaluate patterns across this age span as well as include children with disabilities who may be older but have developmental delays. We excluded studies that were not available in English. We defined *delay discounting assessment* as any procedure in which participants made a series of choices between a smaller reward available immediately and a larger reward available after a specified delay such that three or more indifference points could be estimated. Three or more indifference points are the minimum number required for fitting a model to estimate delay discounting rate (k) or area under the curve (AUC). These measures align with the concept of delay discounting, defined as the decrease in the subjective value of a reward as the delay to its receipt increases (Ainslie, 1974; Green, Myerson, & Ostaszewski, 1999; Odum, 2011a). While two indifference points could be fitted by a linear function, the delay discounting function is best described by hyperbolic and hyperboloid models (Green et al., 1997; McKerchar et al., 2009; Rachlin, Raineri, & Cross, 1991). Studies in which the Monetary Choice Questionnaire (MCQ; Kirby et al., 1999) was used to assess delay discounting were also included because the MCQ infers k based on a hyperbolic model.

Our definition of delay discounting excluded "delay of gratification" tasks in which both the smaller, immediately available commodity as well as the larger commodity available after a delay were held fixed (e.g., choice between one item available today versus two later at various delays) or in which the delay was not specified to the participant in advance (e.g., participants are told to wait as long as they can or until the experimenter returns). Although conceptually related to delay discounting, delay of gratification tasks do not identify indifference points that are used to estimate discounting rate. Furthermore, evidence suggests that delay of gratification and delay discounting are distinct processes (Reynolds & Schiffbauer, 2005).

Search Procedures

To identify studies that met these inclusion criteria, we searched *ProQuest*/*PsycINFO*, *PubMed Central*, and *ERIC* databases for peer-reviewed articles with abstracts containing the following terms: *delay discounting*, *temporal discounting*, or *inter-temporal choice*, in conjunction with variations on *child* or *children*, *school*, *adolescents*, and *youth*. We screened studies by first reviewing titles and abstracts to exclude articles that clearly did not meet inclusion criteria. Then, we completed full-text screenings to identify studies meeting all inclusion criteria. Finally, we conducted ancestral searches, in which we screened studies listed as references for all studies meeting inclusion criteria. We completed this search on articles published through January 1, 2016.

Coding Procedures

We developed an original coding manual to address our research questions. The full coding manual is available from the authors upon request. We coded participant characteristic variables, variables related to assessment parameters, and results of direct comparisons of delay discounting estimates derived from unique assessments within studies. When studies did not report a variable but cited previous studies or supplementary information, we located the cited source and coded the relevant information based on its reported procedures.

Participant Characteristics To describe participants, we coded mean, minimum, maximum, and standard deviation of age and IQ. In addition, we coded proportion of males and proportions of white and non-white participants included in each study. Finally, we coded target populations recruited for inclusion in each study as described by study authors, which included the following categories: typically developing children, children with ADHD (all subtypes), children with both ADHD and oppositional defiant disorder (ODD), children with autism spectrum disorder (ASD), children with comorbid ADHD and ASD, children with or at risk for obesity, and children with or at risk for substance abuse (e.g., alcohol, cigarettes).

Assessment Parameters To address assessment parameters, we first coded the number of unique delay discounting assessments administered in each study. We defined an assessment as unique when it differed from another assessment in the same study in any aspect other than time point of administration (e.g., differing magnitudes of the delayed commodity; choices involving different commodities). After coding the number of unique assessments, we coded the following variables for each unique assessment within each study.

First, we coded choice type (i.e., hypothetical or real) for each assessment. For assessments coded as hypothetical, we coded whether participants contacted the commodity prior to or following the assessment to identify whether they shared elements of 'real' choice assessments. Contacting the commodity post-assessment included participants being told prior to assessment that an experimenter- or randomly-selected choice would be delivered following the assessment, or being told that there was some probability that one of their choices would be delivered following the assessment (e.g., 25% chance on each trial of receiving a selected smaller, immediate reward or larger reward available after a delay). After coding choice type, we coded assessment commodity by recording whether choices were about money, food, other items or activities, or money equivalents of food or other items or activities. When we coded other items or activities as a commodity, we coded the specific items or activities used. We also coded the amount (i.e., magnitude) of the commodity available after a delay used in each unique assessment along with its relevant unit (e.g., dollars, candies, minutes of access to a preferred game).

Finally, to identify how choice stimuli have been presented to children within delay discounting assessments, we coded two additional variables for each unique delay discounting assessment. First, we coded assessment modality—whether assessments were computerized, delivered by the experimenter (by reading choices aloud or displaying choices one at a time), or delivered as pencil and paper questionnaires (e.g., MCQ). Second, we coded whether visual aids were used. If visual aids were used, we coded whether the visual stimuli represented commodity magnitude, duration of delays, or both. We also coded whether they were used prior to the assessment, during the assessment, or both.

Evaluations of Assessment Parameters For each study that included more than one unique delay discounting assessment, we coded two additional variables. First, we recorded which parameters differed across included assessments (i.e., choice type, commodity, magnitude). Second, we coded whether parameters were systematically manipulated (i.e., altered one at a time or otherwise controlled across comparison assessments).

Interrater Agreement A graduate student in special education (first author) coded all studies. After primary coding was complete, we randomly selected eight of the 21 included articles (38.1%) to be coded by a second graduate research assistant, trained to a criterion of coding two consecutive studies with at least 90% agreement with primary codes. When coders disagreed, we discussed the discrepancy and came to consensus on the correct code. When appropriate, primary codes were corrected to match consensus, but disagreements were retained in estimates of interrater agreement (IRA) for each variable. To assess IRA, we calculated point-by-point agreement (i.e., agreements divided by the sum of agreements and disagreements multiplied by 100; Ledford, Lane, & Gast, 2018) on studies coded by both raters. Mean point-by-point agreement at the study level was 97.1% (range, 92.3–100%). At the variable level, mean agreement was 97.0% (range, 87.5–100%).

Data Summary and Analysis

After coding study and assessment-level variables, we summarized each variable to report prevalence within the sample. We coded participant characteristic variables at the study level and calculated percentages of total studies in which each respective variable was coded. We coded all other variables (e.g., choice type, assessment modality) for each unique assessment. We then summarized each assessment parameter by calculating the percentage of total assessments in which it was coded. For quantitative variables (e.g., age, magnitude of USD), we calculated means and ranges across studies or assessments, as appropriate. We also graphed potential interactions between assessment parameter variables and reported these when patterns were evident (e.g., magnitude in USD by choice type).

Results

The initial search returned 1052 articles across databases. Figure 2 displays results at each step of the screening procedures—consistent with PRISMA guidelines (see Moher, Liberati, Tetzlaff, Altman and Prisma Group, 2009)—which included identifying records, title and abstract screening, full-text screening, and ancestral searches. Fifty-three studies included participants younger than 12.99 years of age and met

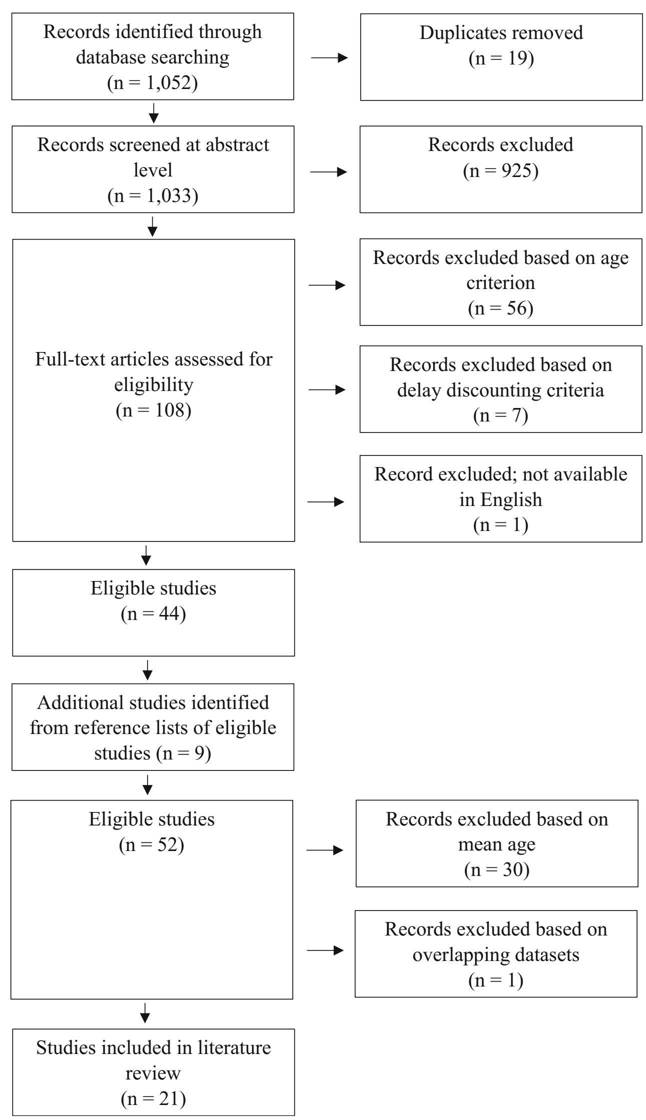

Fig. 2 Results of literature search

delay discounting assessment criteria. A graduate student in special education repeated these search procedures and identified no additional studies meeting inclusion criteria. Next, we identified the mean age of participants in each study and excluded all studies in which mean age exceeded 12.99 years (i.e., 30 studies). Of the 22 remaining studies, one pair included the same dataset (Scheres, Tontsch, & Thoeny, 2013; Scheres, Tontsch, Thoeny, & Kaczkurkin, 2010). We randomly selected one study from this pair for inclusion (i.e., Scheres et al., 2010).

The final sample included 21 studies with 2621 total participants. The number of participants per study ranged from 19 to 386. Studies were published between 2006 and 2016, across 17 journals and 16 corresponding authors. As shown in Fig. 3, the number of published studies with delay discounting measures for children aged 12.99 years and younger increased from 2006 to 2015. This pattern may reflect an overall increase in publications about delay discounting, regardless of included populations (see Odum, 2011a). All included studies are listed by citation in Table 1 in order of mean participant age (increasing).

Participant Characteristics

Figure 4 displays the number of studies including each participant population represented in this sample. Among the 21 studies we identified, most focused on either children with ADHD ($n = 10$, two of which also included participants with autism) or typically developing children ($n = 8$). The remaining three studies included children with or at risk for substance abuse disorders ($n = 2$) and those who were overweight ($n = 1$). A fairly narrow range of ages were represented within the study sample. Mean age ranged from 7.98 to 12.70 years (i.e., 2nd/3rd grade to 6th/7th grade), with the exception of one study focused on 3- to 4-year-olds (Garon, Johnson, & Steeves, 2011). Means and upper and lower limits of participant ages across studies are displayed in Fig. 5. Many of the studies we identified included participants with a mean age nearing the limit of 12.99 years. In over half of included studies, mean participant age was at least 11.41 years (i.e., 6th grade; 57.14%). Thus, despite our identification of 21 studies that included children under 13 years of age, half included children who were pre-adolescent to adolescent. Median percentage of included participants who were male was 56.8 (range, 37.3–80.0). Of the 38.1% of studies reporting ethnicity, median percentage of participants who were white was 76.4 (range, 50.0–86.8). Fifty-seven percent of studies reported IQ. Among them, median participant IQ was 105.34 (range, 96.3–114.4).

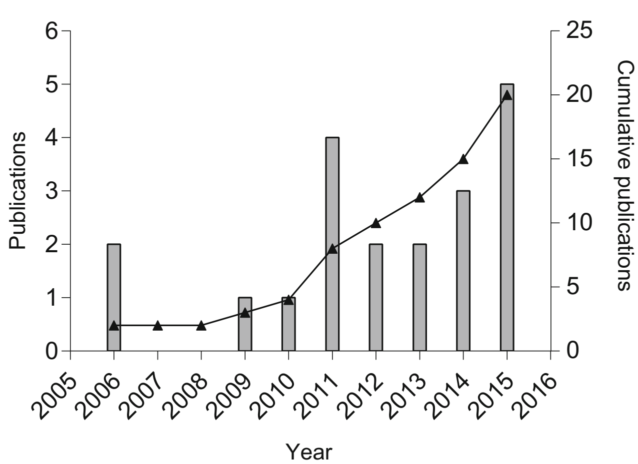

Fig. 3 Number of publications per year (left y-axis; bars) and cumulative publications (right y-axis; lines) in which delay discounting was measured in participants with a mean age 12.99 years or younger

Assessment Parameters

Table 1 includes a list of unique assessments in each included study. In total, our sample of 21 studies included 25 unique delay discounting assessments. In the majority of studies, experimenters conducted a single type of delay discounting assessment; experimenters delivered more than one unique assessment in only three studies. In three other studies, experimenters delivered the same delay discounting assessment at more than one time point to estimate test-retest reliability ($n = 2$; Reed & Martens, 2011; Shiels et al., 2009) or as part of a prospective analysis ($n = 1$; Dougherty et al., 2015). Table 1 also summarizes choice types, commodities, magnitudes of the larger later reward (LLR), visual supports, and information about delays for each unique assessment.

Choice Type . Hypothetical choices were used in over twice as many assessments as real choices (i.e., $n = 17$, $n = 8$, respectively). No hypothetical choice procedures included contact with the rewards prior to or following the assessment.

Commodity. The majority of assessments used money as the commodity (88%; $n = 22$). Of these 22 assessments, 19 used United States Dollars (USD) and three used Euros or Yen. The remaining assessments ($n = 3$) relied on other commodity types, including stickers (Garon et al., 2011), seconds of access to a preferred game (Rosch & Mostofsky, 2015), and "points" which were not reported to be exchanged for another commodity (Shimoni, Asbe, Eyal, & Berger, 2016). Of the eight assessments that used real choices, most used money ($n = 5$; Scheres et al., 2006/2010), one used stickers (Garon et al., 2011), one used points (Shimoni et al., 2016), and one used seconds of access to a game (Rosch & Mostofsky, 2015).

Magnitude. Figure 6 displays magnitudes of the LLR in real versus hypothetical choice assessments in which USD was the commodity. Magnitudes were considerably larger in hypothetical choice assessments ($n = 10$ assessments; range,

Table 1 Summary of delay discounting studies and assessment parameters

Citation	N	Mean age (min, max)	Commodity	Choice type	Magnitude of LLR	Visual supports	Number of delays	Min delay	Max delay
Garon, Johnson, and Steeves (2011)	66	4.17 (3, 4)	Stickers	R	5	M Prior	4	1 story	4 stories
Wilson, Mitchell, Musser, Schmitt, and Nigg (2011)	70	7.98 (7,9)	Money	H	$10	–	4	7 days	180 days
Shimoni, Asbe, Eyal, and Berger (2016)	87	8.54 (8, 9)	Points	R	10	–	5	2 s	40 s
Antonini, Becker, Tamm, and Epstein (2015)	130	9.05 (7, 12)	Money	H	$10	–	4	7 days	180 days
Costa Dias et al. (2013)	122	9.27 (7, 12)	Money	H	$10	–	4;5	1 day	180 days
Costa Dias et al. (2015)	105	9.28 (7, 13)	Money	H	$10	–	4;5	7 days	180 days
Best et al. (2012)	241	9.90 (7, 12)	Money	H	$25 - $85	–	23	7 days	186 days
Rosch and Mostofsky (2015)	120	9.94 (8, 12)	Money	H	$10	–	4	1 day	90 days
			Access to game	R	60 s	M, D During	3	25 s	100 s
Shiels et al. (2009)	49	10.50 (9, 12)	Money	H	$100	–	5	1 day	1 year
Dougherty et al. (2014)	386	11.41 (10, 12)	Money	H	$25 - $85	–	23	7 days	186 days
Scheres et al. (2006)	46	11.42 (6, 17)	Money	R	$0.10	M, D During	5	5 s	30 s
			Money	R	$0.10	M, D During	5	5 s	30 s
Dougherty et al. (2015)	386	11.54 (10, 12)	Money	H	$25 - $85	–	23	7 days	186 days
Demurie, Roeyers, Baeyens, and Sonuga-Barke (2013)	271	11.70 (8, 16)	Money	H	€ 30	M during	5	1 day	2 weeks
Scheres, Tontsch, Thoeny, and Kaczurkin (2010)	82	11.81 (6, 17)	Money	R	$0.10	M, D During	5	5 s	30 s
			Money	R	$0.10	M, D During	5	5 s	30 s
			Money	R	$0.05	M, D During	5	5 s	60 s
Prencipe et al. (2011)	102	11.85 (8, 16)	Money	H	$10	–	5	1 day	365 days
Lamm, Zelazo, and Lewis (2006)	33	11.87 (7, 17)	Money	H	$10	–	5	1 day	365 days
Benningfield et al. (2014)	19	12.00 (10, 14)	Money	H	$25 - $85	–	23	7 days	186 days
Demurie, Roeyers, Baeyens, and Sonuga-Barke (2012)	118	12.02 (8, 16)	Money	H	€ 30	M During	5	1 day	2 weeks
Reed and Martens (2011)	46	12.10 (11, 13)	Money	H	$100	–	8	1 day	4 years
Daniel, Said, Stanton, and Epstein (2015)	42	12.23 (9, 14)	Money	H	$50	–	6	1 day	6 months
Lu et al. (2014)	100	12.70 (12, 13)	Money	H	¥100	–	5	10 days	365 days

Note. Studies are presented in order of mean participant age (increasing). "Pre" indicates that visual supports were used pre-assessment and "during" indicates that visual supports were used during assessment administration. Age minimum and maximum rounded to nearest whole numbers

H hypothetical, *R* real, *LLR* larger later reward, *M* magnitude, *D* delay

$10–$100) than in real choice assessments ($n = 5$ assessments; range, $0.05–$0.10). Four assessments used the 27-item MCQ, which includes hypothetical choices and magnitudes of the LLR ranging from $25 to $85 across items.

Presentation of Choice Stimuli.

Assessment Modality Figure 7 presents information about how choices were presented to participants. Of the 25 assessments delivered, 18 (72%) were computerized. Experimenter-delivered assessments and written questionnaires were each used in three assessments and relied on hypothetical choices; five of six assessments used hypothetical choices. For one assessment, modality was not reported.

Visual Aids Table 1 includes information about visual representations of commodity magnitudes and delays. Relatively few assessments used visual supports to communicate

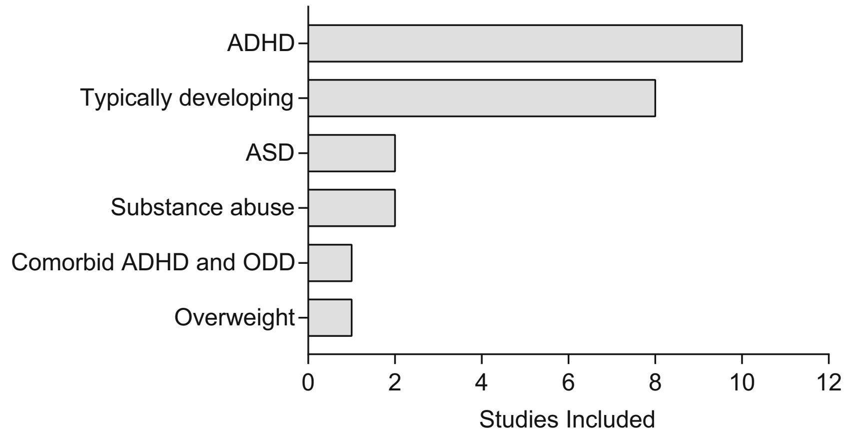

Fig. 4 Number of studies including each population group. Excludes control groups. ADHD = attention deficit/hyperactivity disorder. ODD = oppositional defiant disorder. ASD = autism spectrum disorder

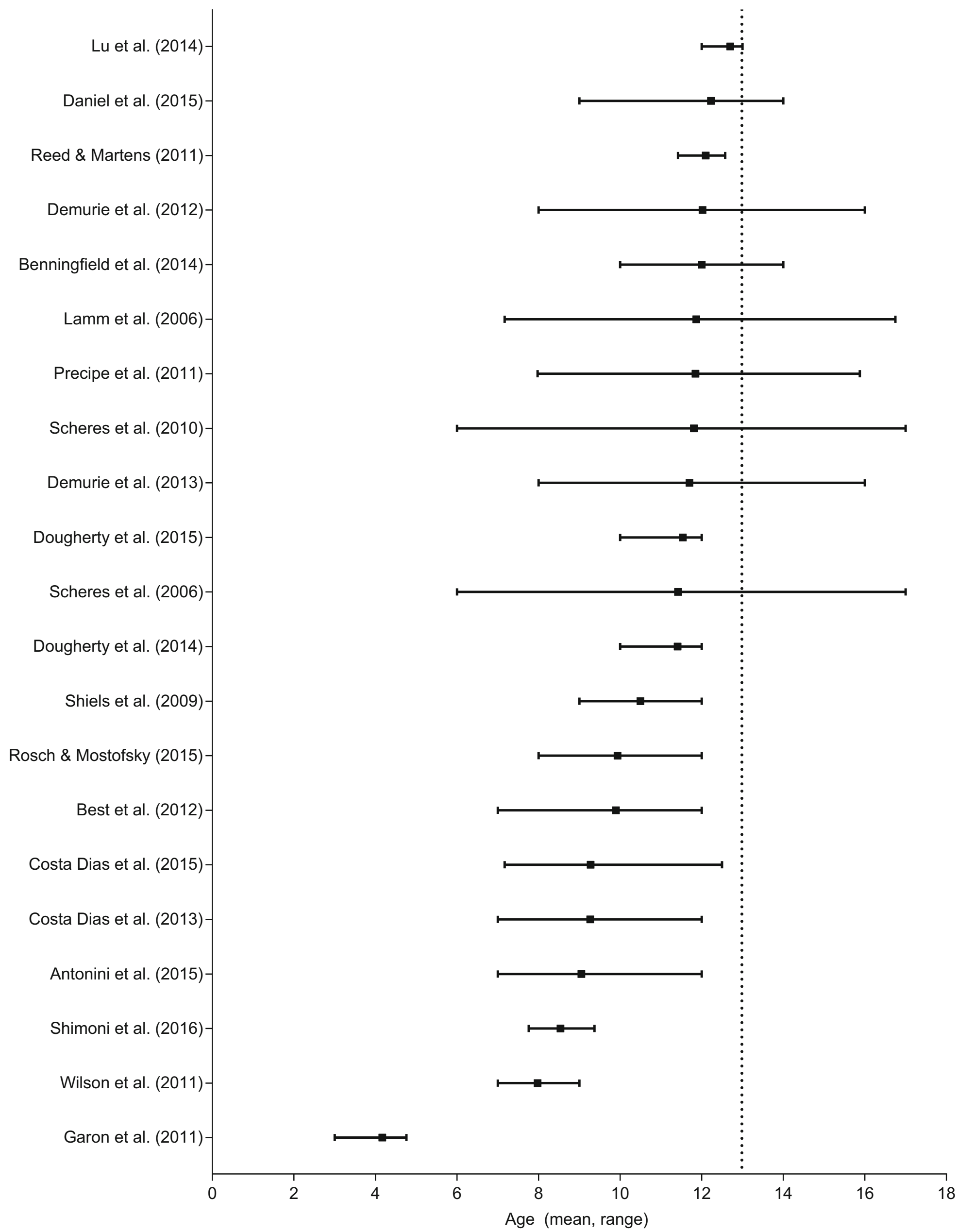

Fig. 5 Means and upper and lower age limits for all studies including participants with mean age of 12.99 years or younger. Dotted line displays mean age inclusion criterion of 12.99 years

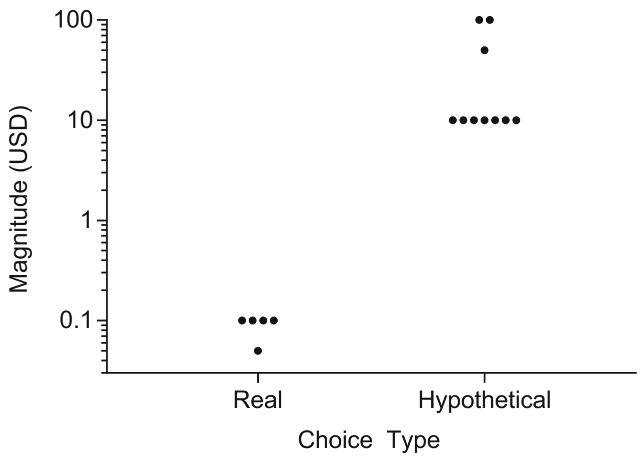

Fig. 6 Larger later reward (LLR) magnitudes by choice type. Note the *y*-axis is plotted on a $\log_{10}$ scale to depict magnitudes of difference in LLR sizes

magnitudes of smaller and larger reward options or delays ($n = 9$ assessments). Of these, five used the same visual supports. Scheres et al. (2006/2010) used a computerized, real-choice assessment in which digital airplanes dropped the amount of money chosen by participants into their digital "baskets." Airplanes flew across the screen and dropped the money at a pace that allowed the commodity to reach the basket at the last moment of the programmed delay. Garon et al. (2011), who assessed delay discounting in very young children (i.e., 3 to 4 years old), used a teddy bear to role play a trial prior to the assessment, enacting the story-based delay by reading the story to the bear. Rosch and Mostofsky (2015) used visuals in one of their two assessments, in which choices were real and the commodity was access to a preferred game.

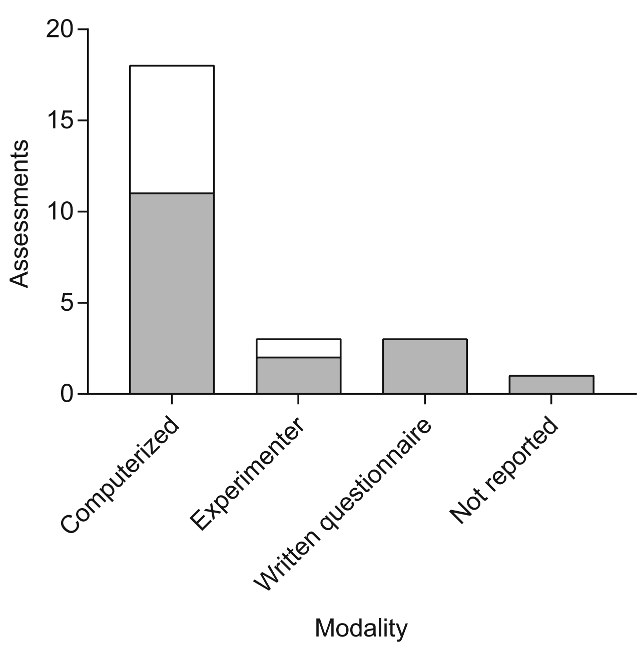

Fig. 7 Number of assessments of each modality. Hypothetical-choice assessments are represented in gray; real-choice assessments in white

They displayed bars to represent maximum delays and magnitudes. Bars were proportionally filled with stop signs and smiley faces, respectively, to match programmed values in each trial. Finally, Demurie et al. (2012/2013) displayed Euro notes corresponding to each option across trials in their hypothetical money choice assessments. Overall, visual supports were used more often in assessments with real choices (i.e., six of eight) than in assessments with hypothetical choices (i.e., two of 17).

Systematic Evaluation of Assessment Parameters

Experimenters delivered more than one unique delay discounting assessment in only three studies. Scheres et al. (2010) delivered three unique assessments, Rosch and Mostofsky (2015) delivered two, and Scheres et al. (2006) delivered two. Scheres et al. (2006) delivered assessments that differed only in their inclusion or exclusion of a post-reward delay to participants with ADHD and typically developing participants. When no post-reward delay was included, selecting the smaller sooner reward (SSR) shortened the overall task duration, whereas trial duration was equal regardless of choice of SSR or LLR in the comparison task. Scheres et al. found that estimates of delay discounting were significantly greater when no post-reward delay was enacted after choice of the SSR ($p < .001$) regardless of diagnostic status, although younger participants discounted more steeply than older participants according to both measures.

Scheres et al. (2010) delivered three unique assessments, similar to those delivered in their 2006 experiment. Assessments differed on magnitude of delayed rewards and task duration. Authors did not report whether or to what extent estimates from respective assessments differed from one another. However, estimates of delay discounting from only one of the three tasks systematically differed according to ADHD subtype. In the task with the smallest LLR magnitude ($4 versus $8 in the other two tasks), steeper discounting was observed for participants with the combined inattentive/hyperactive subtype than those with the inattentive subtype. Given evidence that adults discount smaller amounts more steeply by delay than larger amounts, it is possible that this task was more sensitive due to the relatively small magnitude of the LLR.

Finally, Rosch and Mostofsky (2015) compared estimates of delay discounting derived from assessments that used real versus hypothetical choices among girls and boys with ADHD and control groups of typically developing girls and boys. The two assessments they delivered differed from one another not only by choice type, but also by commodity (i.e., money and access to a computer game, respectively) and delay (i.e., maximum 90 days and maximum 60 s, respectively). Rosch and Mostofsky found that estimates produced by the real 'access to game' choice assessment were sensitive to diagnostic differences and gender, although estimates from the money task were not. Girls with ADHD discounted more by delay than boys with ADHD or controls on the task involving real choices.

Discussion

Results of this review confirm that relative to the hundreds of existing studies on delay discounting at large, few studies have focused on measuring delay discounting in children 12 years old and younger, with even fewer studies including children under the age of seven. Publication patterns over the last 10 years, however, suggest an increasing trend in delay discounting studies including children.

Participant Characteristics

In our small sample of studies, children with ADHD and typically developing children were relatively well represented. Perhaps unsurprisingly, children with developmental delays (e.g., autism) and children under 7 years of age were targeted in few studies. This may be due to the fact that typical delay discounting measures require participants to comprehend abstract concepts such as money and time. The younger or more developmentally impaired a participant, the less likely it may be that such verbal repertoires concerning hypothetical and abstract concepts are intact. In fact, participants in both studies including children with autism had average IQs (i.e., minimum of 80; means above 100; Demurie et al., 2012/ Demurie et al., 2013) and were closer to adolescence (mean ages 11.7 and 12, respectively). Only one study—and one of the few that adapted their measure of delay discounting—included participants with a mean age younger than seven (Garon et al., 2011).

Garon et al. (2011) created an assessment for 3- to 4-year-old children who may not understand time sufficiently to respond systematically to typical delay discounting assessment items involving hypothetical money choices over a series of delays. Although potentially more appropriate for children who may not understand monetary value or time, the adaptations they used may have introduced measurement problems. Specifically, delays were represented by the number of stories read to participants by experimenters, instead of by time alone. Some evidence in the self-control intervention literature suggests that intervening activities, or opportunities for an individual to engage in an activity while a delay to a reward elapses, decreases the likelihood of impulsive choices (Binder, Dixon, & Ghezzi, 2000; Dixon et al., 1998; Dixon & Cummings, 2001; Dixon & Holcomb, 2000; Dixon, Rehfeldt, and Randich, 2003). Thus, intervening activities may result in a systematic underestimation of impulsivity. This may not be a major problem, however, if estimates are still correlated with other variables typically associated with delay discounting, or are predictive of risk relative to other participants.

What is more problematic is that preferences for intervening activities (e.g., having stories read by an adult) can vary widely across children. For children who enjoy having stories read to them, for example, choosing the LLR would result in the delivery of an *immediate* reward in that stories begin as soon as the choice is made. This reward is not only larger given the larger number of stickers combined with several stories, but also of potentially higher quality relative to the SSR. Thus, differences in estimates of delay discounting obtained from this assessment may be confounded by differences in child preference. These difficulties, combined with the dearth of studies in which delay discounting was measured in young children, highlight the need for further evaluation. Specifically, more research is needed to identify appropriate adaptations for difficult-to-assess populations, including very young children and/or individuals with developmental delays.

Although children under 7 years old and children with developmental disabilities were largely unrepresented, assessments involving hypothetical choices about money were prevalent—likely due to their relative efficiency and low costs. Identifying characteristics (e.g., age, developmental level) of participants for whom the hypothetical assessments produce outcomes that are (a) interpretable and (b) valid (i.e., strong associations with outcome variables in expected directions) may help to narrow the pool of participants for whom new or adapted assessments are necessary. Several sets of criteria exist for determining whether outcomes are interpretable or systematic. For example, Johnson and Bickel (2008) suggested patterns of "nonsystematic" discounting be considered as a possible criterion for exclusion. They defined nonsystematic discounters as those for whom any indifference point is 20% greater than the preceding indifference point (in order of increasing delays) or if the last indifference point was not less than the first indifference point by at least 10% of the largest (immediate) reward value. Interestingly, of the 10 studies from this review that reported whether any data were excluded based on delay discounting outcomes, seven excluded participants on this basis. All seven studies used hypothetical monetary choice assessments to measure delay discounting.

Assessment Parameters

The vast majority of assessments used hypothetical choices about monetary commodities. Magnitudes varied widely, generally irrespective of age. Thus, assessments were by and large very similar to those typically used with older or more developmentally mature participants (e.g., adolescents and adults).

Fewer than half of assessments delivered to children included visual supports to enhance participant comprehension of choice options. Perhaps even more surprisingly, visual supports were more prevalent in assessments with real choices (i.e., 6 of 8) than hypothetical choices (i.e., 2 of 17), for which comprehension may be more difficult. Visual supports should be investigated for their effects on estimates of delay discounting; they may be a reasonable accommodation for increasing assessment fit provided assessments remain valid for predicting outcomes and are sufficiently sensitive.

One potential explanation for the infrequent use of visual supports is that signaling delays may increase the probability of selecting the LLR (e.g., Vollmer, Borrero, Lalli, & Daniel, 1999). Because individuals' delay discounting scores are typically interpreted in a relative, rather than absolute sense, underestimation of delay discounting may not necessarily reduce the utility of a set of scores. In other words, results may still effectively indicate risk if participant rankings are preserved despite changes in raw estimates. However, underestimation may reduce variability in scores if some scores are close to the floor or minimum value on the scale of the delay discounting index. In such a situation, it may be more difficult to detect relations between delay discounting and other outcomes. In other words, underestimation may increase the likelihood of type II errors.

Assessment modality is another aspect of choice presentation worthy of further evaluation. On the whole, computerized assessments were common (72%; $n = 18$) and may be more efficient relative to experimenter-delivered assessments. Fewer staff are needed to deliver computerized assessments, and computers are ideal for administering adaptive assessments (e.g., assessments that use titrating procedures to identify indifference points; e.g., Lamm, Zelazo, & Lewis, 2006; Lu et al., 2014). In addition to efficiency, computerized assessments offer flexibility for adaptation. For example, Scheres et al. (2006, 2010) delivered five computerized assessments across two studies. These were the assessments in which digital airplanes signaled delays by flying across the screen at a pace that matched the delay. Notwithstanding the caveats that come with signaling delays, the digital elements of these assessments illustrate the potential promise of applying "gamification"—the application of game design elements in non-game contexts (Simões, Redondo, & Vilas, 2013)—to delay discounting. Some research indicates that gamification may improve child compliance with procedures. For example, Brewer et al. (2013) found that gamification increased task completion within empirical study procedures in lab environments by a significant margin. Leveraging such visual elements on a computer screen, or using more sophisticated gamification techniques (e.g., embedding the assessment within a story; e.g., Jones, Madden, & Wengreen, 2014) may serve a dual purpose of enhancing both participant comprehension of abstract concepts and the social validity of procedures. However, as is the case for signaling delays, gamification also may result in systematic underestimation of delay discounting.

Effects of Assessment Parameters

In addition to variables related to presenting choice stimuli, the effects of choice type, commodity, and magnitude of the LLR on delay discounting estimates in children are as yet unknown. While effects of these procedural elements have been evaluated and used to inform assessment design and results for adolescents and adults (e.g., Johnson & Bickel, 2002; Estle et al., 2007; Green et al., 1997), such effects have yet to be investigated for younger children. Several studies in our review did include more than one assessment of delay discounting (Rosch & Mostofsky, 2015; Scheres et al., 2006; Scheres et al., 2010), but none explicitly posed and answered research questions about the effects of choice type, commodity, or magnitudes of the LLR on delay discounting estimates.

It should be noted that in three included studies (Best et al., 2012; Demurie et al., 2013; Shiels et al., 2009), experimenters delivered additional delay discounting assessments that did not meet our criteria for inclusion but may shed light on questions about effects of assessment parameters. Shiels et al. (2009) used assessments that varied by choice type and probability. They compared outcomes of hypothetical and real money choice assessments when children were on and off medication for ADHD (i.e., methylphenidate), although probability of the LLR varied in the real choice assessment. Shiels et al. found that methylphenidate reduced delay discounting of real rewards, although they observed no difference between tasks in the non-medication condition. Because probability discounting and delay discounting have been conceptualized and demonstrated to be two distinct mechanisms (Green et al., 1999), however, observed differences in estimates of delay discounting derived from these two assessments may be attributed to choice type, differences in LLR probability, or some combination thereof.

Demurie et al. (2013) used assessments that varied by commodity. They found participants discounted hypothetical monetary rewards less by delay than they did hypothetical activity, edible, and social rewards. This is consistent with patterns observed among adults (Odum, 2011b). However, non-monetary commodities were represented by child preference, rather than amount, and indifference points were delays at which children settled for the immediately available but less preferred toy. Discounting by preference may be different than discounting strictly by delay, yet results are consistent with patterns observed in delay discounting by adults in that children discounted consumables more steeply than money.

Finally, Best et al. (2012) used assessments that varied by a combination of parameters, including commodity and magnitude of the LLR. Hypothetical monetary delay discounting predicted weight loss in an intervention, while delay discounting of food predicted weight loss only among participants for whom the relative reinforcing value of food was low. Authors interpreted this to suggest that children who both

(a) found food highly reinforcing and (b) steeply discounted food rewards by delay showed a reduced response to treatment compared to children without this combination of factors. Commodities and magnitudes of rewards differed between tasks, but differences in what variables were predicted by each assessment indicate the promise of delay discounting measures for informing or individualizing treatment. The findings of Best et al. further indicate the potential of delay discounting measures as predictors of socially important outcomes, as well as the need for systematic evaluations of main and interactive effects of assessment parameters on estimates to inform assessment design.

Limitations

Our findings and recommendations should be considered in light of three primary limitations. First, we included only studies published in peer-reviewed journals. Our results do not account for assessment methods reported in unpublished studies that may have failed to show effects or produce interpretable delay discounting estimates, and thus could be subject to publication bias. Second, we could not parse results of delay discounting assessments for children at or under 12.99 years because study results were reported in aggregate. For this reason, we did not code delay discounting outcomes and were unable to compare outcomes among the different assessment methods and/or child populations. Finally, we excluded 30 studies in which mean participant age exceeded 12.99 years, even though they included at least some participants who were ages 12 and under. When we included those studies in a prior iteration of this review, we observed similar patterns to those reported here based on the smaller subset (i.e., heavy reliance on hypothetical money choice assessments with few adaptations). We limited the breadth of our sample so we could examine studies including a meaningful subset of young children.

Conclusion

Though 21 studies have included assessments of delay discounting in children with mean ages of 12 years and younger, more research is needed to evaluate approaches to assessing delay discounting in very young children and those for whom delay discounting may be more difficult to assess (e.g., children with delayed development). Many of the assessments delivered in these studies involved hypothetical choices about money, which may be efficient and feasible provided they produce reliable and valid estimates of delay discounting. More research is warranted in several areas, including identifying limits regarding for whom hypothetical money choice assessments are appropriate and whether visual stimuli may be used to improve interpretability and validity of outcomes for children with a variety of developmental characteristics. Identifying adapted approaches to assessing delay discounting in very young or at-risk populations may serve as a first step toward using delay discounting for early identification of risk (see similar calls and recommendations from Critchfield & Kollins, 2001 and Reed, Niileksela, & Kaplan, 2013).

Compliance with Ethical Standards

Conflict of Interest On behalf of all authors, the corresponding author states that there is no conflict of interest. This article does not contain any studies with human participants or animals performed by any of the authors.

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