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Age-related effects in delay discounting for food☆

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ABSTRACT

Developmental influences of growth, such as hormones and metabolic factors, increase food intake and weight across the lifespan. Delay discounting (DD), a choice procedure that characterizes preferences for immediate rewards, such as food, over larger, more delayed ones may be useful in understanding developmental and metabolic changes in decision making processes related to food intake. The present study examined the relation between age and food DD in a cross-sectional design. Other variables, such as pubertal stage, were examined also as these may influence discounting. Participants (N = 114; 28 children and 86 adult) from a community sample completed measures of food and money delay discounting to determine if age-related variation in discounting tendencies is food-specific or more general. Both measures yield an omnibus discounting value and three additional values for small, medium, and large magnitudes. Analyses first revealed magnitude effects– smaller magnitudes of both food and money were discounted more steeply than larger magnitudes. Hierarchical regressions indicated subjective hunger predicted steeper food discounting. When subjective hunger was controlled, age, but not puberty, significantly predicted food discounting for omnibus, medium, and large magnitudes of food. In children, food discounting decreased from early childhood to late adolescence. In adults, food discounting increased from early to late adulthood. Neither age, puberty, nor obesity status predicted any measure of monetary discounting. Food discounting, then, appears to change across the lifespan, and therefore, may be appropriate to examine psychological processes that accompany developmental and metabolic changes across the lifespan.

1. Introduction

Developmental changes in food intake and energy regulation are somewhat predictable across the lifespan. For example, food intake increases dramatically from childhood to adolescence as growth spurts accompany a changing and growing body (Trumbo, Schlicker, Yates, & Poos, 2002). In older age, appetite and food intake decline (see Pilgrim, Robinson, Sayer, & Roberts, 2015, for review). Total energy expenditure, resting metabolic rate, and activity energy expenditure seem to also follow this same pattern—these variables increase during childhood and into adolescence, asymptote in the early-adult and middle-adult years, then begin declining in later adulthood (Black, Coward, Cole, & Prentice, 1996; Elia, Ritz, & Stubbs, 2000; Manini, 2010). Changes in sensory sensitivities to food, especially those related to palatability, also changes across the lifespan, with peak sensitivity in children and lowest sensitivity in aging adults (Boesveldt et al., 2018).

While physiological changes contribute to developmental changes in food intake, environmental variables such as diet can also play a role. Recent estimates from the National Health and Nutrition Examination Survey estimate that about 18.5% of American children and 39.6% of adults are obese (Hales, Fryar, Carroll, Freedman, & Ogden, 2018), a prevalence that is higher than two to three decades ago, in which 10% of children and 28.8% of adults were obese (CDC, 2015; Ng et al., 2014). The growing prevalence of obesity in industrialized countries is associated with poor health outcomes. Individual who are overweight or obese are more likely to suffer from chronic illnesses, such as heart disease, stroke, and type-2 diabetes (Popkin, 2006). For example, in a 10-year longitudinal study, Field et al. (2001) found participants whose BMI was 35 or greater were about 20 times more likely to develop diabetes, two times more likely to develop heart disease or stroke, 2.5 times more likely to develop hypertension, and three times more likely to develop gallstones.

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Research also shows that pediatric and adolescent obesity predicts obesity and metabolic syndrome in adulthood (Biro & Wien, 2010; Deshmukh-Takar et al., 2006), along with increased odds of health problems and poor psychosocial functioning (Halfon, Larson, & Slusser, 2013). One explanation for this relation may be that adolescents experience less parental oversight and exert more control over their own food choices. Unhealthy eating habits, such as consuming high fat and sugar foods and fewer fruits and vegetables can be established in childhood and adolescence, which may contribute chronically to adult obesity. Indeed, the immediate appeal and convenience of unhealthy food may weigh more heavily on food consumption than long-term personal health. Neumark-Sztainer, Story, Peer, and Casey (1999) found various factors reported to influence adolescents' food choices, including appeal of food, convenience, situation-specific factors, mood, and media. The study also found that adolescents attributed their higher consumption of high-fat/high-sugar food relative to fruits and vegetables to taste preferences and lack of urgency about personal health. Therefore, adolescence may be a time in which the immediacy of rewarding properties of food are especially valued.

1.1. *Delay discounting as a trans-disease process related to health*

While research has been conducted on the metabolic, physiological, and environmental factors that lead to body mass change and obesity across the lifespan, little has been researched on age-related changes in decision making processes that also may accompany these changes. One behavioral process that may underlie the establishment of these patterns is delay discounting (DD), a facet of impulsivity in which behavior is especially sensitive to immediate outcomes (Ainslie, 1975; Kirby, Petry, & Bickel, 1999). Individuals who strongly discount the value of delayed outcomes show preferences for smaller, sooner outcomes over those that are delayed. For example, if presented with a series of choices between a smaller, sooner outcome (e.g., $7 of now) vs. a larger, later outcome (e.g., $10 in 5 days), a pattern of choosing the smaller, more immediate outcome would be described as more impulsive. Behavioral patterns that show a preference for the larger, delayed reward are described as self-controlled. Delay discounting has been referred to as a *trans*-disease process (Bickel, Jarmolowicz, Mueller, Koffarnus, & Gatchalian, 2012) because high discounting of delayed rewards is a process often observed in those with substance abuse in adults (e.g., Bickel & Marsch, 2001; Bickel, Odum, & Madden, 1999; Heil, Johnson, Higgins, & Bickel, 2006; Madden, Bickel, & Jacobs, 1999) and in adolesents (e.g., Audrain-McGovern et al., 2009; Fernie et al., 2013), gambling disorders (e.g., Dixon, Marley, & Jacobs, 2003; Petry, 2001; Petry & Casarella, 1999), obesity (e.g., Appelhans et al., 2011; Hendrickson & Rasmussen, 2013; Hendrickson, Rasmussen, & Lawyer, 2015; Jarmolowicz et al., 2014; Lawyer, Boomhower, & Rasmussen, 2015; Rasmussen, Lawyer, & Reilly, 2010; Schlam, Wilson, Shoda, Mischel, & Ayduk, 2013; Weller, Cook, Avsar, & Cox, 2008), as well as those who struggle with food insecurity (Rodriguez, Rasmussen, Kyne-Rucker, Wong, & Martin, 2021).

Delay discounting for money has been identified as a process that is related to age. A number of studies suggest that age is inversely related to monetary discounting, i.e., as age increases, discounting decreases (Green, Fry, & Myerson, 1994; Green, Myerson, Litchman, Rosen, & Fry, 1996; Green, Myerson, & Ostaszewski, 1999; Steinberg et al., 2009). For instance, Green et al. (1994) compared discounting rates in 36 subjects from three age groups: 6th graders (M_{age} = 12.1 years), college students (M_{age} = 20.3 years), and older adults (M_{age} = 67.9 years). Sixth graders were found to discount larger, later rewards at a steeper rate than young adults, who had steeper discounting rates than the older adults. Another study by Read and Read (2004), however, shows that monetary discounting is more U-shaped with the greatest impulsivity in childhood and older age. Monetary DD then seems to change with age.

One theory posited for this age-related change in monetary discounting is the maturation process of the prefrontal cortex (PFC) of the brain. This brain region plays a strong role in executive control and decision making related to self-control. Studies have documented continuing development and maturation of this brain region into adulthood (Casey, Tottenham, Liston, & Durston, 2005; Diamond, 2002) in contrast to the relatively early maturation of the reward system, such as ventral tegmental area, nucleus accumbens, and striatum (Giedd, 2008; Sowell et al., 2002), all of which are involved in immediate reward sensitivity and in place during early childhood. The theory posits that an intact and hyperactive impulsive reward system in early childhood overpowers the less developed executive system which in turn leads the individual to prioritize immediate consequences and rewards. With the executive system continuing to develop well into the 20's, adolescents may be at greater risk for problem behaviors that involve the consumption of immediate rewards, such as binge drinking, binge eating, physical aggression, and substance abuse.

Studies on age-related discounting have predominately used hypothetical monetary outcomes and have populations that are typical, i.e., those without health problems. The current study was conducted to characterize age-related effects with food DD. Few, if any, studies to date have examined how food discounting changes across the lifespan, despite research that shows food consumption and obesity rates in humans increase with age (Flegal, Carroll, Ogden, & Johnson, 2002; Shomaker et al., 2010). Knowing the extent to which preferences for immediate food reward occurs across the lifespan also has implications for understanding food intake patterns related to obesity.

Only two studies to date have compared discounting across age groups with food outcomes (Hendrickson & Rasmussen, 2017; Robertson & Rasmussen, 2017). Hendrickson and Rasmussen (2017) reported on adolescents (7th and 8th graders) vs. young adults who discounted for food and money. While the adolescents showed steeper discounting for money than adults, there were no age-related differences between the two groups for food discounting. Robertson and Rasmussen (2017) found similar results with rats. No age-related effects were found between adolescent versus adult rats' discounting patterns for real food. This raises the possibility, then, that food discounting remains stable from adolescence to adulthood. Conversely, it may be the case that discounting for food changes from childhood to adolescence and stabilizes in adulthood. It is unclear, though, what happens in middle and later adulthood years.

The current study tested two specific hypotheses. First, we tested the extent to which age-related differences would be revealed with food-related discounting. We also examined the extent to which pubertal status and obesity status were related to food discounting. We hypothesized that food discounting would increase in adolescence, then level off in middle adulthood, and possibly decline in older age; similarly, we hypothesized that those in mid-puberty will display the most impulsivity for food than those in pre- and post-pubertal stages. We also hypothesized those with obesity would discount delayed food rewards more strongly than those who are not obese. Second, we also attempted to replicate age-related DD with money to determine if age-related changes in money discounting were independent of those related to food discounting (domain-dependent) or parallel, which would implicate a more general age-dependent change in impulsivity that would reflect developmental changes in the brain. We hypothesized also that age would be inversely related to money discounting and that individuals with overweight/obesity status would exhibit steeper discounting for money than healthy-weight individuals.

2. Method

2.1. *Participants*

A power analysis was conducted to determine appropriate sample size for a linear multiple regression, assuming three tested predictor variables, an alpha level of 0.05, target power at 0.80, and an effect size of 0.10 (Hendrickson & Rasmussen, 2017). The recommended total sample size was 112 participants. A total of 114 participants (n = 66 females) participated in the study, which included 28 children and adolescents (n = 8 females; M_{age} = 11.21, SD = 0.44, age range = 9–16 years) and 86 adults (n = 58 females; M_{age} = 43.03, SD = 2.12, age range = 18–86 years). Fig. 1 shows the frequency distributions of age and pubertal status of all participants.

Participants were recruited through the university, social media, and advertisements during local community events (e.g., lunch for seniors at the community center). Child and adolescent participants were recruited from local school districts, social media, and advertisement flyers in community areas. The inclusion criteria for the study were: assenting minors and consenting adults, at least 9 years of age, and non-endorsement of pregnancy. Participants were excluded if they endorsed a past/current eating disorder or a substance use disorder. Due to the collection of blood glucose samples, they were also excluded if they had a diagnosis of HIV, AIDS, or hemophilia. All participants were asked not to eat or drink at least 2 h before each session to control for prior caloric consumption as hungry participants discount food more steeply than those who are sated (e.g., Kirk & Logue, 1997), and this was confirmed by blood glucose tests.

2.2. Materials

Discounting measures. For food delay discounting, participants completed the Food Choice Questionnaire (FCQ), a modified version of the MCQ using food-related outcomes, which has been validated as a measure of food discounting (Hendrickson et al., 2015; Hendrickson & Rasmussen, 2017). Each participant was presented with a 5/8-in cube that represents a standard bite and asked to imagine the cube as a bite of their favorite food. Participants make 27 choices between smaller, sooner vs larger, delayed food outcomes (e.g., “Would you prefer 15 bites now or 35 bites in 6 h?”). Similar to the MCQ, the FCQ presented nine questions for three different outcome magnitudes: small (8–13), medium (25–35), and large (40–50) bites of food. For monetary delay discounting, participants completed the Monetary Choice Questionnaire (MCQ; Kirby & Marakovic, 1996; Kirby et al., 1999) where they were asked to make choices between smaller, sooner monetary outcomes vs larger, delayed outcomes (e.g., “Would you prefer $54 now or $55 in 177 days?”). There were 27 items. The measure presents small ($25–35), medium ($50–60), and large ($75–85) magnitudes of monetary outcomes assessed through nine questions each, so magnitude can be used as an independent variable.

Health measures. All participants were measured for blood glucose level at the start of the session, as well as height, weight, body fat percentage, and waist circumference. Blood glucose levels were checked via CONTOUR®NEXT EZ blood glucose meter. Weight and percent body fat was measured by a Tanita Body Fat Scale, which uses bioelectrical impedance analysis to determine percent body fay. Body mass indexes were calculated by dividing the participant's weight in kilograms by height in meters squared (kg/m^2).

Puberty stage. The Tanner Stages of Puberty classification system is a scale of physical development based on external primary and secondary sex characteristics, such as size of breasts and genitals, and development of pubic hair (Marshall & Tanner, 1969, 1970). There are five progressive stages for each gender. A board-certified physician met with the child/adolescent participant, parent/legal guardian, and a female research assistant to determine his/her placement on the Tanner Stages. The child/adolescent participant's pubertal status was determined as: pre-pubertal (stage 1), mid-pubertal (stages 2–4), or post-pubertal (stage 5). Self-reports of developmental status were also collected through a questionnaire version of the Tanner Stages from all participants under the age of 18, in the event that a participant or parent refused physician exam.

Demographics. Participants completed a demographics measure that queried general background information, such as the participant's

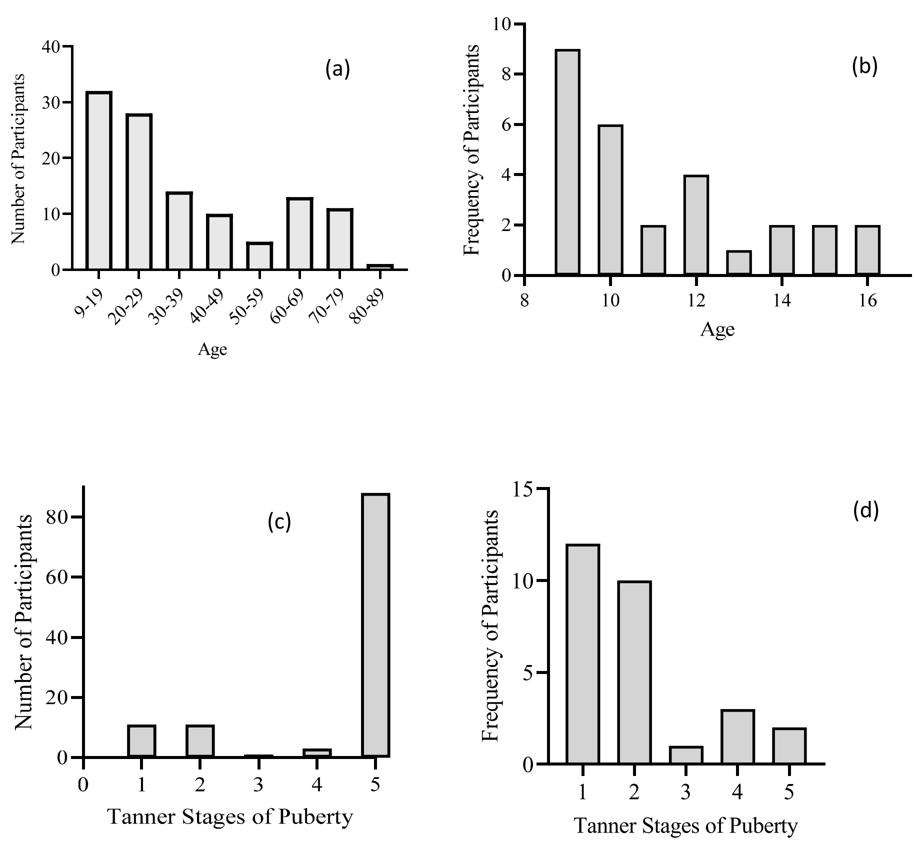

Fig. 1. Frequency distributions of age and Tanner pubertal stage.

race, age, sex, and lifestyle health behaviors, such as food and exercise practices.

Fagerstrom Test for Nicotine Dependence. (FTND; Heatherton, Kozlowski, Frecker, & Fagerstrom, 1991). The FTND is a six-item measure that evaluates the quantity of cigarette consumption, the compulsion to use, and dependence (Heatherton et al., 1991). With a range of 0–10, higher total scores on these questions suggest greater physical dependence on nicotine. This measure was included to control for smoking, a variable that is associated with steeper discounting (Baker, Johnson, & Bickel, 2004; Bickel et al., 1999; Johnson, Bickel, & Baker, 2007).

Slosson Intelligence Test Revised – 3rd Edition. (SIT-R3; Slosson, Nicholson, & Hibpshman, 1990). The SIT-R3 is an 187-item individually administered instrument that assesses participants' crystallized verbal intelligence in 10–20 min. As prior studies suggest an inverse association between intelligence and DD (e.g., de Wit, Flory, Acheson, McCloskey, & Manuck, 2007; Olson, Hooper, Collins, & Luciana, 2007; Shamosh & Gray, 2008), the SIT-R3 was administered to control for this variable. The SIT-R3 is appropriate for individuals between the ages of 4 and 65 and measures performance in vocabulary, general information, similarities and differences, comprehension, quantitative ability, and auditory memory.

Subjective Hunger Questionnaire (SHQ). The SHQ is a 3-item questionnaire that asks participants to report the amount of time since their last snack and meal. Participants are also asked to rate their hunger from 0 to 100.

Mini International Neurospychiatric Interview KIDS 6.0 (MINI and MINI KIDS 6.0). The Alcohol Use Disorder and Substance Use Disorder modules were utilized from the M.I.N.I. KIDS 6.0 and M.I.N.I. 6.0 (Sheehan et al., 1998) to assess participants' engagement in substance and alcohol use in the past 12 months. The measure is a short, structured diagnostic interview that is compatible with diagnostic criteria of psychological disorders according to the International Classification of Disease – 10th Revision (ICD-10; Sheehan et al., 1998, 1997) as well as the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.; *DSM-IV*; American Psychiatric Association, 1994). Symptom count was measured through the summation of items; the range for adults is 0–13 and for children 0–12 with higher values indicating greater likelihood of meeting criteria for a disorder.

2.3. Procedure

After participants arrived at the Health Decision-Making laboratory on Idaho State University's campus, assent and consent forms were presented to child/adolescent and adult participants and their parent or legal guardian, respectively. After assent/consent, individuals verbally reported the last time they had something to eat and drink, and a blood glucose test was completed to ensure compliance with the 2-hr fasting.

Participants then completed the demographic measure, FTND, SHQ, and discounting tasks (MCQ and FCQ) on the computer. The discounting tasks were counterbalanced to reduce order effects. Participants <18 completed a self-report measure for pubertal status and met with the physician for a physical examination with their parent/legal guardian and a female research assistant. Height, weight, percent body fat, and waist circumference were measured for all participants. Lastly, the M.I.N.I. 6.0 or M.I.N.I. KIDS 6.0 and SIT-R3 were conducted interviews by the research assistant. All participants received $30 of monetary compensation for their time and were debriefed.

2.4. Data analysis

2.4.1. Discounting scoring

To measure delay discounting, k values were derived for all participants for each magnitude (small, medium, large) of the MCQ and FCQ (see Kirby & Marakovic, 1996 and Hendrickson et al., 2015 for further information regarding scoring). A higher k value represented greater impulsivity. Consistent with the practice within the discounting field (see e.g., Kirby & Marakovic, 1996), all k values were $\log_{10}$-transformed due to positively skewed distributions. In addition to the k values for each magnitude, an omnibus or mean $\log_{10}$-transformed k values ($\log_{10}[k]$) was calculated by averaging $\log_{10}(k)$ across the small, medium, and large magnitudes for money and food outcomes, respectively.

2.4.2. Statistical analysis

Data were analyzed using IBM® SPSS 26.0©. All responders were incorporated into the analyses unless otherwise noted.

First, discounting was characterized with repeated measures ANOVAs across magnitude (small, medium, large as between-subjects variable) with $\log_{10}(k)$ for money and food as the dependent variables. Second, Pearson product-moment correlations between discounting and demographic variables were conducted. Next, we statistically analyzed age-related differences in small, medium, large, and omnibus discounting for food and money using hierarchical linear regression analyses. We analyzed models incorporating predictor variables such as age, BMI or PBF, puberty status, and the product interaction term of age and obesity, along with other significantly associated variables noted in the Results section (based on correlations with discounting). The response variables were $\log_{10}(k)$ food and $\log_{10}(k)$ money. We also applied the same analyses to a subset of the data with children only (age 20 or less) to more closely examine age and puberty-related associations with food and money discounting in that subsection of the sample.

3. Results

3.1. Demographics

Of the total 114 participants, 28 were children and 86 were adults. Table 1 provides a summary of participants' demographic characteristics, including age, gender, race/ethnicity, income, substance use, cognitive functioning, BMI, PBF, and other health variables grouped by total sample, children, and adults. Child and adolescent household income was not reported due to a large proportion of reportedly unknown, and potentially inaccurate, data.

There were several significant differences in demographic and biometric variables between children/adolescents and adults. First, adults had significantly higher BMI, $t(112) = -6.55$, $p < 0.0001$, PBF, $t(112) = -4.54$, $p < 0.001$, and waist circumference, $t(112) = -5.90$, $p < 0.001$, compared with children and adolescents. In addition, based on BMI percentile, 32.14% of children and adolescents ($n = 9$) were overweight or obese, and for adults, 65.11% ($n = 56$) were overweight or obese. Adults also reported higher number of hours since last meal, $t(111) = -3.00$, $p = 0.003$, and endorsed more symptoms related to Substance Use Disorder (SUD) on the M.I.N.I. 6.0, $t(110) = -2.32$, $p = 0.02$, though none met diagnostic criteria for an SUD.

Fig. 1 shows frequency distributions of participant ages and pubertal status. Fig. 1a shows of all participants, adolescents and young adults (ages 9–29) made up a larger proportion of the total sample population with less representation from older adults (60–89). Fig. 1b shows the age distribution of only participants under age 18; more children in the ages of 9–10 participated in the study than older children. Fig. 1c shows the frequency distribution of participants according to Tanner stage of pubertal development for all participants. Because of the large number of adult participants relative to children, there were more participants with Tanner Stage 5 pubertal status. However, when just children 19 and under were examined, most of the participants were in the lower stages (1–2).

Fig. 1 shows frequency distributions for age of all participants (a), age of participants <18 (b), Tanner pubertal stage for all participants (c), and for participants age <18 (d).

Table 1
Summary of Demographic Data in Means (SEM) for Variables across Age Groups for All Participants.

	All participants (n = 114)	Children (n = 28)	Adults (n = 86)	p-value
Age	35.22 (2.05)	11.21 (0.44)	43.03 (2.12)	<0.001**
Sex [a]	–	–	–	<0.001**
Male	48 (42.1%)	20 (71.4%)	28 (32.6%)	
Female	66 (57.9%)	8 (28.6%)	58 (67.4%)	
Annual household income	–	–	–	–
< $10,000	–	–	8 (9.3%)	
$10,000 - $20,000	–	–	15 (17.4%)	
$20,000 - $30,000	–	–	12 (14.0%)	
$30,000 - $40,000	–	–	8 (9.3%)	
$40,000 - $50,000	–	–	6 (7.0%)	
$50,000 - $60,000	–	–	11 (12.8%)	
$60,000 - $70,000	–	–	11 (12.8%)	
$70,000 or more	–	–	15 (17.4%)	
Race/ethnicity [a]	–	–	–	0.55
White/ Caucasian	104 (91.2%)	25 (89.3%)	79 (91.9%)	
Black/African American	1 (0.9%)	0 (0%)	1 (1.2%)	
Hispanic/Latino	7 (6.1%)	2 (7.1%)	5 (5.8%)	
Asian	1 (0.9%)	1 (3.6%)	0 (0%)	
Other	1 (0.9%)	0 (0%)	1 (1.2%)	
Body mass	26.23 (0.63)	20.00 (0.90)	28.24 (0.66)	<0.001**
Percent body fat	30.52 (1.03)	22.94 (1.61)	32.99 (1.15)	<0.001**
Waist circumference (cm)	86.96 (1.94)	69.39 (2.43)	92.69 (2.10)	<0.001**
Subjective hunger (0–100)	38.89 (2.72)	31.37 (6.02)	41.34 (3.00)	0.12
Glucose level	95.93 (1.47)	96.74 (2.83)	95.72 (1.71)	0.78
Hours since last meal	7.56 (0.55)	4.80 (0.76)	8.46 (0.65)	<0.05*
Hours since last snack	5.14 (0.40)	4.27 (0.67)	5.43 (0.48)	0.21
Full scale IQ	103.72 (1.43)	100.20 (3.64)	104.74 (1.51)	0.19
Fagerström nicotine score	0.07 (0.05)	0 (0)	0.09 (0.06)	0.45
Total AUD symptoms[b]	0.21 (0.10)	0 (0)	0.28 (0.13)	0.24
Total SUD symptoms[b]	0.43 (0.10)	0 (0)	0.56 (0.13)	<0.05*
Reported eating disorder[a]	0 (0%)	0 (0%)	0 (0%)	–
Reported ADHD[a]	4 (3.5%)	2 (8.0%)	2 (2.3%)	0.17

Note. BMI = body mass index; PBF = percent body fat; AUD = alcohol use disorder; SUD = substance use disorder; ADHD = attention-deficit/hyperactivity disorder; *$p < 0.05$, **$p < 0.001$.

[a] Frequency, with percentages in parentheses.

[b] From the M.I.N.I. 6.0 for adults and M.I.N.I. KIDS 6.0 for child and adolescents.

3.2. Discounting and magnitude

Discounting for food and money are first characterized in this sample. Fig. 2 shows discounting for all participants as a function of magnitude for food discounting (top) and monetary discounting (bottom). Omnibus values are also shown to the right of the magnitude data as descriptive of the sample, though are not included in the present analyses. Repeated measures ANOVAs with a Greenhouse-Geisser correction showed main effects of magnitude on food discounting (top), $F(1.56,175.68) = 4.79$, $p < 0.05$. Post hoc tests using the Bonferroni correction revealed that food discounting significantly differed between small and large magnitudes ($p < 0.05$) but did not statistically differ between small and medium ($p = 0.14$) and medium and large ($p = 0.96$) magnitudes. There was also an effect of magnitude on money discounting, $F(1.95,220.62) = 60.42$, $p < 0.001$ (see Fig. 2, bottom panel). Post hoc tests using the Bonferroni correction revealed that monetary discounting significantly differed between small and medium, small and large, and medium and large magnitudes (p's < 0.001). Given that there were significant magnitude differences for both food and money discounting, each of the three magnitudes for each outcome type was analyzed separately for age and obesity effects.

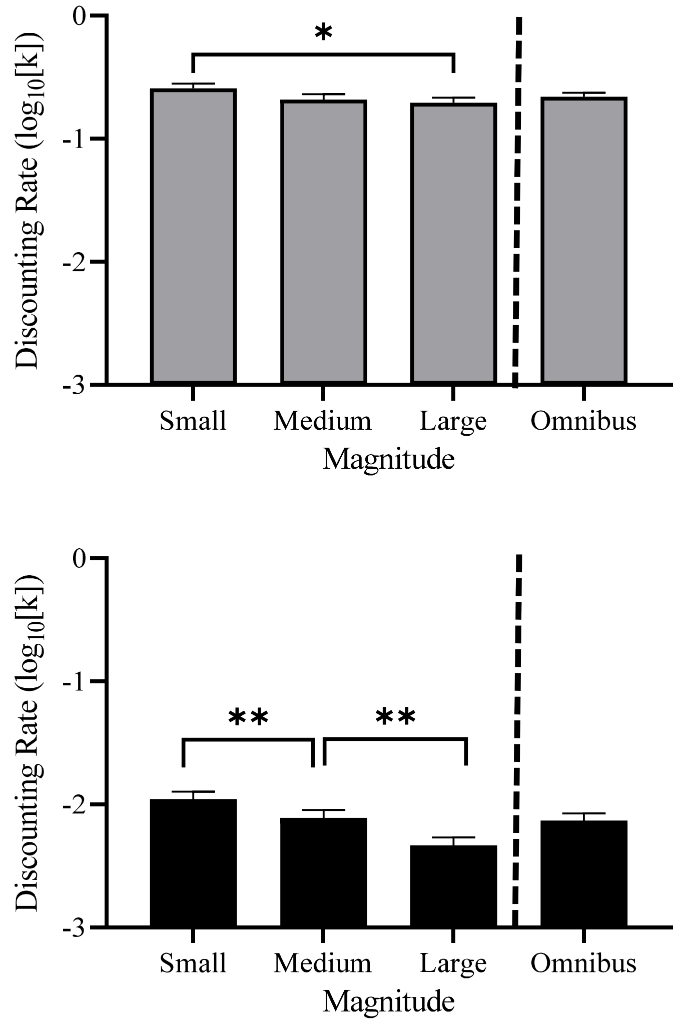

Fig. 2. Log10 Transformed Mean (± SEM) Food (top) and Money (bottom) Delay Discounting by Magnitude.

Figure shows delay discounting values (log transformed) for food (top) and money (bottom) by magnitude (N = 114). Omnibus are also shown on the right for comparative purposes. Error bars = I SEM Note. *p < 0.05, **p < 0.001.

3.3. Correlations

To determine values that were related to delay discounting and therefore needed to be controlled statistically, Pearson product-moment correlations were conducted. Table 2 shows the correlations between

Table 2
Pearson Product-moment Correlations Between Discounting, Health, and Demographic Variables Across All Participants.

	1	2	3	4	5	6	7	8	9	10	11
1. Mean FCQ $\log_{10}(k)$[a]	–										
2. Mean MCQ $\log_{10}(k)$[a]	0.20*	–									
3. Age	0.19*	0.10	–								
4. Body mass index	−0.10	0.12	0.40**	–							
5. Percent body fat	−0.05	0.09	0.41**	0.82**	–						
6. Waist circumference	−0.11	0.09	0.30**	0.86**	0.69**	–					
7. Puberty Status	−0.01	−0.05	0.58**	0.55**	0.40**	0.49**	–				
8. Subjective hunger	0.22*	−0.15	−0.04	0.07	−0.01	0.08	0.21*	–			
9. Time since last meal	0.17	0.10	0.30**	0.12	0.13	0.14	0.30**	0.08	–		
10. Time since last snack	0.08	−0.03	0.14	0.15	0.17	0.14	0.18	0.15	0.57**	–	
11. Full Scale IQ	−0.06	−0.08	0.02	0.11	0.05	0.23*	0.05	−0.14	−0.05	−0.05	–

*$p < 0.05$.
**$p < 0.01$.
[a] The mean discounting value for money and food, respectively, was calculated by averaging discounting values across the three magnitudes.

omnibus delay discounting values and health and demographic variables across all participants. Omnibus delay discounting values for money and food were positively correlated, indicating that individuals who displayed immediate preferences for money also displayed immediate preferences for food.

Age and obesity-related indicators were also associated. Age was positively correlated with food discounting, suggesting that older individuals were more impulsive for food outcomes than younger individuals. PBF was positively correlated with age, BMI, waist circumference, puberty status, and time since last meal. Similarly, BMI was positively correlated with age, waist circumference, and puberty status, suggesting that those with greater BMI and PBF tended to be older, completed puberty, and had greater waist circumference. Waist circumference significantly correlated with puberty status and full-scale IQ, but not discounting rates for money or food.

Subjective hunger was positively correlated with food discounting and pubertal status, suggesting that those who reported greater hunger levels were more impulsive for food and were also in the later stages of puberty. Time since last meal positively correlated with time since last snack and puberty status. In other words, individuals who reported longer times since last meal were also more likely to reported longer times since last snack and be in the later stages of puberty.

3.4. Food discounting, age, and obesity

3.4.1.Omnibus food discounting values

Because food discounting values were positively correlated with age and subjective hunger (Table 2), and age was correlated with measures of obesity, a hierarchical linear regression was conducted with all of the participants to examine the degree to which age (as a continuous variable) and BMI (as a continuous variable) predicted omnibus food discounting values. Subjective hunger was entered in the first step. Age and BMI were entered in the second step. The first step of the model with subjective hunger significantly predicted omnibus food discounting values ($p = 0.02$). When age and BMI were added to the models as Step 2, significantly more variation in food discounting was accounted for ($p = 0.03$). The effect size for this analysis ($f^2 = 0.07$) was found to meet Cohen's (1988) convention for a small effect ($f^2 = 0.02$–0.15). When subjective hunger was controlled, age was a significant predictor of food discounting ($p = 0.01$), but BMI, though close to significance, was not ($p = 0.054$). Table 3 shows the analysis summary. When PBF was substituted for BMI in the analysis as the obesity predictor variable, it was not a significant predictor.

3.4.2Children only and adults only

To better characterize age-related discounting patterns of children and adolescents vs. adults, Fig. 3 shows scatterplots of omnibus food discounting with children only (top) and adults only (bottom). Linear functions were the best fit for both scatterplots. For children, food discounting was negatively related to age ($r = -0.39$, $r^2 = 0.15$, $p = 0.025$). For adults (bottom), food discounting was positively associated with age ($r = 0.24$, $r^2 = 0.06$, $p = 0.04$). There were no effects of puberty for either group.

Table 3
Hierarchical Regression Analysis Summary Predicting Mean Omnibus Food Discounting ($\log_{10}$[k]) from Age and Body Mass Index (BMI), Controlling for Subjective Hunger.

Variable	b (SE)	β	t	R^2	Δ R^2	p-value
Step 1				0.05	0.05	0.02
Constant	−0.73 (0.05)		−14.05			<0.001
Subjective Hunger	0.00 (0.00)	0.22	2.29			0.02
Step 2				0.11	0.06	0.03
Constant	−0.63 (0.13)		−5.03			<0.001
Subjective Hunger	0.00 (0.00)	0.24	2.60			0.01
Age	0.00 (0.00)	0.25	2.51			0.01
BMI	−0.01 (0.01)	−0.20	−1.95			0.054

3.4.3. Magnitude and food discounting

Because magnitude affected food discounting, additional analyses were conducted with each magnitude of the FCQ. For medium and large magnitude food discounting values, subjective hunger was predicting of food discounting and therefore entered in the first step (see Tables 4 and 5, respectively). Age and BMI were entered in the second step (see Table 4 5, top, respectively). When age and BMI were added to the models as Step 2, significantly more variation in food discounting was accounted for both medium ($p = 0.002$) and large ($p = 0.02$) magnitudes. The effect size for medium ($f^2 = 0.12$) and large magnitudes ($f^2 = 0.08$) were found to exceed Cohen's (1988) convention for a small effect ($f^2 = 0.02$).

BMI was a significant predictor for medium magnitude ($p = 0.01$, see Table 4, top), but not large magnitude (see Table 5, top). When PBF was substituted for BMI as a measure of obesity, at Step 2, significantly more variation in food discounting was shown ($\Delta R^2 = 0.06$–0.08, $p = 0.01$–0.02) with BMI ($b = -0.02$, SE $= 0.01$) as a negative predictor for medium magnitude. The effect size for medium ($f^2 = 0.08$) and large magnitudes ($f^2 = 0.07$) were found to exceed Cohen's (1988) convention for a small effect ($f^2 = 0.02$). With both magnitudes, age was a significant predictor ($p = 0.003$–0.01), but PBF was not (see Table 5, bottom, and 6, bottom, respectively).

For the small magnitude, subjective hunger was not significant in predicting food discounting, and therefore was not included in the model. For small magnitude discounting, when age and PBF were

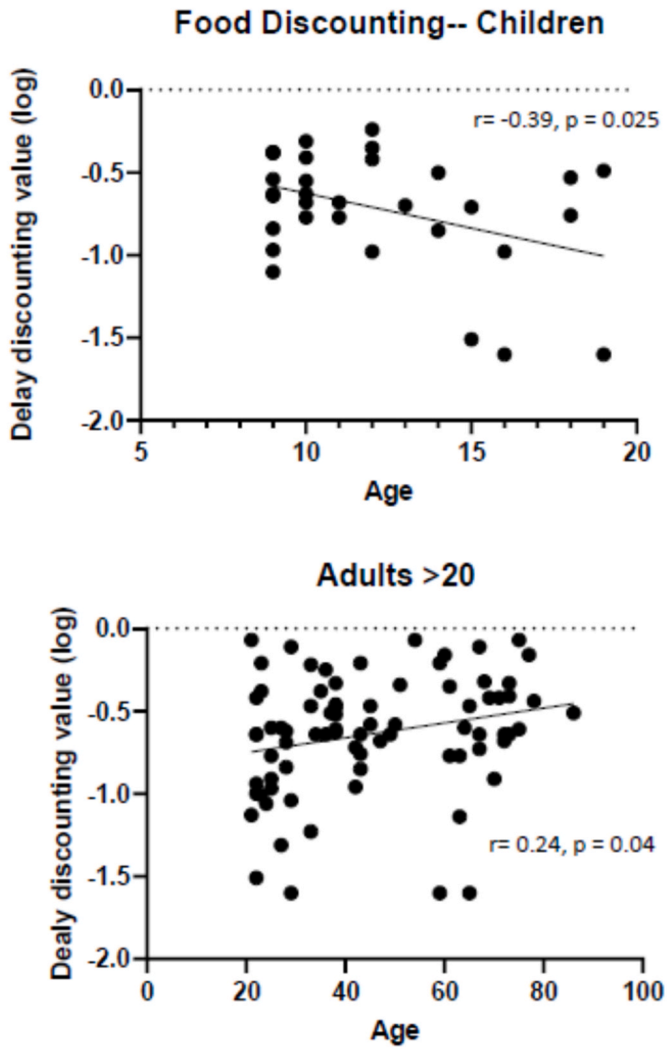

Fig. 3. Discounting for food as a function on age for children only (top) and adults only (bottom).

entered, the model to predict to food $\log_{10}(k)$ was not statistically significant. When the same model was run with BMI in place of PBF, the model remained non-significant.

The models were also run with an interaction term (age x obesity status [PBF or BMI]), but this term was not significant with any analyses. In addition, when including all participants in analyses, puberty status did not predict food discounting. Given that there were a much larger proportion of adults compared to children, we wanted to more effectively examine the role of puberty status on discounting, Therefore, the same models as above were conducted only using participants aged 20 and younger. Puberty status was simultaneously entered with age and obesity status (PBF or BMI) at step 2 but none of the factors was significant with any analysis.

3.5. Monetary discounting, age, and obesity

To control for other variables that influence monetary discounting rates, hierarchical linear regressions were conducted with all participants to examine the degree to which age (continuous variable) and PBF (continuous variable) uniquely predicted omnibus monetary delay discounting values. Variables that historically have correlated with monetary discounting– income, alcohol use, substance use, and cognitive functioning– were not significantly correlated with omnibus delay discounting for money in the present sample, so were not included in the

Table 4
Hierarchical Regression Analysis Summary Predicting Medium Food Discounting ($\log_{10}$[k]) from Age and Body Mass Index (BMI [top]) and from Age and Percent Body Fat (PBF [bottom]), Controlling for Subjective Hunger.

BMI						
Variable	*b* (SE)	*β*	*t*	R^2	Δ R^2	*p*-value
Step 1				0.06	0.06	0.01
Constant	−0.79 (0.07)		−11.68			<0.001
Subjective Hunger	0.00 (0.00)	0.23	2.50			0.01
Variable	*b* (SE)	*β*	*t*	R^2	Δ R^2	*p*-value
Step 2				0.16	0.11	0.002
Constant	−0.64 (0.16)		−4.02			<0.001
Subjective Hunger	0.00 (0.00)	0.27	2.97			0.004
Age	0.01 (0.00)	0.34	3.49			0.001
BMI	−0.02 (0.01)	−0.25	−2.54			0.01
PBF						
Variable	*b* (SE)	*Β*	*t*	R^2	Δ R^2	*p*-value
Step 1				0.06	0.06	0.01
Constant	−0.79 (0.07)		−11.68			<0.001
Subjective Hunger	0.00 (0.00)	0.23	2.50			0.01
Step 2				0.13	0.08	0.01
Constant	−0.82 (0.13)		−6.37			<0.001
Subjective Hunger	0.00 (0.00)	.25	2.71			0.01
Age	0.01 (0.00)	.31	3.09			0.003
PBF	−0.01 (0.00)	-.17	−1.68			0.10

Table 5
Hierarchical Regression Analysis Summary Predicting Large Food Discounting ($\log_{10}$[k]) from Age and Body Mass Index (BMI [top]) and from Age and Percent Body Fat (PB [bottom]), Controlling for Subjective Hunger.

BMI						
Variable	*b* (SE)	*β*	*T*	R^2	Δ R^2	*p*-value
Step 1				0.06	0.06	0.01
Constant	−0.83 (0.07)		−12.02			<0.001
Subjective Hunger	0.00 (0.00)	0.24	2.56			0.01
Step 2				0.13	0.07	0.02
Constant	−0.80 (0.16)		−4.91			<0.001
Subjective Hunger	0.00 (0.00)	0.26	2.87			0.01
Age	0.01 (0.00)	0.30	2.96			0.004
BMI	−0.01 (0.01)	−0.15	−1.46			0.15
PBF						
Variable	*b* (SE)	*β*	*t*	R^2	Δ R^2	*p*-value
Step 1				0.06	0.06	0.01
Constant	−0.83 (0.07)		−12.02			<0.001
Subjective Hunger	0.00 (0.00)	0.24	2.56			0.01
Step 2				0.12	0.06	0.02
Constant	−0.90 (0.13)		−6.90			<0.001
Subjective Hunger	0.00 (0.00)	0.25	2.74			0.01
Age	0.01 (0.00)	0.28	2.78			0.01
PBF	0.00 (0.00)	−0.11	−1.05			0.30

models. For omnibus monetary discounting, when age and PBF were entered, the model was not significant. When BMI was entered instead of PBF for obesity status, the model was not significant.

The same models were used for small, medium, and large magnitude monetary discounting values, and the outcomes were similar. The models were not significant regardless of whether PBF or BMI was used as the obesity predictor variable. The above models were also run with an interaction term (age x obesity status [PBF or BMI]) but was not significant with any analyses. Using participants aged 20 and younger, the same models were run to assess for predictive effects of puberty status, but none were found to be significant.

4. Discussion

4.1. Food discounting and age

Generally, and across all participants, the regression analyses suggest food impulsivity increases with age; that is, older individuals display more impulsivity for food than younger individuals. When isolating children and adolescent data from the adults, however, correlation analyses reveal more intricate findings. Specifically, children and adolescents under the age of 18 appear to display less impulsivity for food as they age; that is, the youngest of children are more impulsive for food and adolescents are less impulsive for food. That is, it is greater in younger children, declines in adolescence, and then increases in adulthood with age. Given the smaller sample size of children when data were analyzed separately, findings should be interpreted with some caution, as these analyses may be underpowered.

With food as an outcome, subjective hunger was positively related to omnibus food discounting values. Other studies (e.g., Hendrickson & Rasmussen, 2013; 2017) have shown that subjective hunger, though not self-reported hours since last meal or snack, predicts steeper food discounting. Therefore, we replicated this effect. When subjective hunger was controlled using a hierarchical regression analysis, age still predicted food discounting for omnibus food discounting values. Importantly, this effect was replicated also when examining medium and large magnitude food discounting, but not with small magnitude food discounting values.

Puberty, whether using all participants or just participants under 20, did not predict differences in food discounting. Therefore, there does not seem to be a significant relation between pubertal development and impulsivity for food. Although no research to date has investigated the relation between food discounting and puberty, this lack of finding is consistent with the limited existing literature on monetary delay discounting; there appears to be no relation of puberty with monetary discounting that is beyond age-related effects (Olson et al., 2007).

4.2. Obesity, age, and food discounting

Across the sample, age significantly correlated with body mass index, percent body fat, and waist circumference. This is consistent with previous studies identifying the robust relation between age and obesity (Hales et al., 2018; Masters et al., 2013; Wang & Beydoun, 2007). These findings should be interpreted in two manners, however. First, as children and adolescents get older, they also gain weight and size as they grow. In participants 18 years and younger, age was significantly correlated with body mass index and waist circumference, but not percent body fat. Second, with the adult population, age was significantly correlated to percent body fat, but not body mass index and waist circumference.

For obesity-related findings, when subjective hunger was controlled, there were no strong relations between BMI (or PBF) and food discounting for small, large, and omnibus magnitudes. This is inconsistent with the literature, as some research shows a positive relation between BMI and food discounting and other research shows a positive relation between PBF and food discounting (e.g., Hendrickson et al., 2015; Hendrickson & Rasmussen, 2013; Rasmussen et al., 2010; Schiff et al., 2016). Some of the differences in the study designs may account for the different findings regarding obesity and food discounting. Amlung, Petker, Jackson, Balodis, and MacKillop (2016), for example, in a meta-analysis identified several study factors that moderate the discounting effect, including sampling adults as opposed to children or adolescents and viewing obesity as a continuous rather than a categorical group, which are associated with smaller differences in discounting rates between non-obese and obese individuals.

In addition to the null findings between obesity and food discounting for small, large, and omnibus values, the current study found a negative relation between BMI and medium magnitude food discounting only, suggesting individuals with higher BMI display lower impulsive medium food choices. Given that this relation was not seen with any other magnitude in this study, including omnibus discounting, this effect appears as less robust. Moreover, when examining the distribution of BMIs in this sample, the distribution skewed more toward a lower BMI compared to other studies that have examined obesity effects with food discounting (e.g., Rasmussen et al., 2010; Rodriguez et al., 2021). Relatively few participants in this study compared to others met the criteria for obesity, due to the higher number of children and teenagers. This likely resulted in a restriction of range in which a positive relation between BMI and discounting was less detectable. This study, then, found age to be a more predictive variable of food discounting with obesity status more challenging to interpret. Future studies that examine age and discounting effects should try to recruit participants with a wider range of BMIs, especially in children and adolescents.

4.3. Money discounting and age

Despite prior research suggesting an age-associated effect on discounting, in which where older individuals display less impulsivity for money (e.g., Green et al., 1996; Whelan & McHugh, 2009), the current study did not find the same effect. Importantly, the current study differed from prior studies in a number of manners. First, our study had a larger number of participants from a wide range of ages and was analyzed age as a continuous variable. Other studies have used a small number of participants and analyzed age as a categorical variable (e.g., 6th graders, college students, and older adults from Green et al., 1994), or analyzed age as a continuous variable, but used a smaller range of ages (e.g., 10–30 years; Steinberg et al., 2009) or did not include participants under the age of 18 (e.g., 19–89 years; Read & Read, 2004).

The monetary rewards and delays in the discounting task in the current study also differed from previous studies. For instance, Green et al. (1999) analyzed individual choices between immediate monetary amounts ranging from $1 to $1000 versus the fixed amount of $1000 across eight delays ranging from a week to 25 years. Steinberg et al. (2009) used a discounting measure that had the same delayed reward held constant at $1000, but the delay ranged from 1 to 365 days and immediate monetary amounts ranged from $200 to $1000. Read and Read (2004) utilized a delay that ranged from 1 to 10 years and repeated the time range twice with a fixed smaller-sooner value of £600 (roughly $825.84) and a fixed larger-later amount of £1200 (roughly $1651.68). In contrast, the current study utilized smaller amounts of money on the MCQ: $25–85 (depending on magnitude) across a delay of 0–186 days. These differences in study design and use of discounting measures may account for some of the inconsistent findings across studies. It further highlights the challenges in the discounting field as three recent meta-analyses (e.g., Amlung et al., 2016; McClelland et al., 2016; Tang, Chrzanowski-Smith, Hutchinson, Kee, & Hunger, 2018) discuss; each of these studies has identified study heterogeneity as a concern in aggregating results across studies. There was also no relation between money discounting and puberty which is consistent with previous studies (Olson et al., 2007).

Obesity status, whether measured by PBF or BMI, also did not have significant relations with monetary discounting. This is consistent with some studies (Rasmussen et al., 2010; Hendrickson & Rasmussen, 2013, 2017) and inconsistent with others (Davis, Patte, Curtis, & Reid, 2010; Jarmolowicz et al., 2014; Weller et al., 2008). The lack of significant findings between obesity status and monetary discounting highlights the possible explanation of outcome-specific discounting where individuals display steeper discounting with their "outcome of choice." In this case, food, rather than money, would be the outcome that may more closely relates to an individual's obesity status. This is consistent with other studies that have examined both monetary and food discounting with overweight/obese samples (e.g., Hendrickson & Rasmussen, 2013; Rasmussen et al., 2010). When using PBF for obesity status, individuals with greater PBF displayed steeper discounting for food, but not money.

4.4. Magnitude effects

Consistent with prior studies utilizing the MCQ (Amlung & MacKillop, 2011; Kirby, 1997; Kirby & Marakovic, 1996) and FCQ (Hendrickson et al., 2015; Rodriguez, Hendrickson, & Rasmussen, 2018), the current study replicated significant magnitude effects for both monetary and food outcomes. Specifically, individuals displayed more impulsive choice patterns with smaller magnitude choices compared to those of larger amounts with both food and money. The results suggest the magnitude used in the delay discounting choice questions may be important and using a range of magnitudes may help characterize variance contributed by certain variables. For example, age effects appear to be robust in relation to all but the small magnitude of food. If only smaller amounts of outcomes are used is a discounting task, age or obesity-related effects may not be detected.

4.5. Discounting as a trait

Omnibus discounting for food and money were significantly related to one another, suggesting that those who are impulsive for one commodity (e.g., food) will likely be impulsive for the other (e.g., money). This is consistent with the literature (e.g., Hendrickson & Rasmussen, 2013; see also review by; Odum et al., 2020). In a recent review, Odum et al. (2020) discussed that discounting can be viewed as a trait in which the degree of discounting for nonmonetary outcomes (e.g., drugs, alcohol, food) is positively correlated with discounting for money. In other words, individuals who tended to discount one outcome steeply also discount other outcomes steeply. While discounting is generally viewed as a trait, a number of variables can influence it, such as mindfulness, episodic future thinking, and priming (Dixon, Dixon, & O'Brien, 2003; Hendrickson & Rasmussen, 2013; 2017; see also Rung & Madden, 2018, for review). Generally, these variables have significant, though smaller effect sizes, compared to the variance accounted for by trait-based discounting. In the present study, age and obesity, though, significant, contributed smaller effect sizes. Therefore, the present study would support a trait-based interpretation of discounting, but also recognizes that age and obesity status also contribute independently to the variance in discounting across the lifespan. Future studies could verify this, however, by using longitudinal designs in which participants are followed across the lifespan and within-subject variation could be held constant.

4.6. General discussion

Food delay discounting, then, was significantly predicted by age. In contrast, there were no age-related findings for monetary delay discounting. One possible explanation for the commodity-specific findings is the domain effect where certain outcomes, typically primary reinforcers, are more strongly discounted than more secondary or generalizable reinforcers (see e.g., Charlton & Fantino, 2008; Holt, Glodowski, Smits-Seemann, & Tiry, 2016). A number of studies have consistently found that food is discounted much more steeply than monetary outcomes and some of the reasons may be due to properties of food, such as non-fungibility, perishability, and immediacy to consumption (e.g., Holt, Newquist, Smits, & Tiry, 2014; Odum & Rainaud, 2003).

Other studies have shown domain effects with examining variables that shift discounting. Hendrickson and Rasmussen (2013; 2017) found that mindful eating decreased impulsivity for food outcomes, but not for monetary outcomes. One interpretation of this effect is that mindful eating did not reduce general levels of impulsivity, but rather only the behavioral pattern associated with food. In light of the current findings with age predicting food discounting and no strong relation to money discounting, it may the case that food discounting is a unique and separate mechanism from general impulsivity.

4.7. Strengths, limitations and future directions

The present study had a number of strengths. First, the delay discounting tasks allowed for replication as omnibus scores and within-session discounting across magnitudes was characterized and replicated. In addition, discounting for money and food were part of the design, such that general impulsivity vs. domain-specific effects of food and money related to age could be characterized. The cross-sectional design of the study also allowed for investigation of age-specific effects, including those of pubertal stage.

Second, more objective measures were taken to ensure self-reports were accurate. For example, though there were no puberty effects, the study had a board-certified physician who completed the puberty examinations, consistent with the gold-standard assessment in acquiring accurate puberty status. This was important to the alternative of relying on self-reported pubertal stage. A recent review by Dorn and Biro (2011) indicates many studies assess puberty via self-report, which may lead to inaccurate reports. In addition, blood glucose levels were taken to ensure compliance with the deprivation from food and liquid requirement. This also ensures that individuals are self-reporting their deprivation levels accurately. Individuals also completed biometric measures of obesity status, such as body mass index and percent body fat, instead of self-reporting these measures.

There were also some limitations to the study. One difficulty was recruitment of participants with sample representativeness. The study was conducted in a rural community in Southeastern Idaho, limiting access to a larger more diverse sample. For example, our study sample, though representative of Southeastern Idaho, was primarily Caucasian; therefore, our findings may nor may not generalize to other racial and ethnic groups. In addition, there were differences in the sex distribution between younger and older participants; however, statistical analyses did not find sex as a significant predictor for food (controlling for subjective hunger) and monetary discounting when examined. It would also be important to verify age related effects by examining how discounting changes across the lifespan using longitudinal designs.

Despite these limitations, the current findings support age-related effects in food delay discounting—namely that food discounting increase with age. This novel finding may be informative in a number of areas. First, for those who study age- and potential obesity-related related shifts in the endocrine system or in metabolism (e.g., sex hormones, insulin, leptin) may wish to determine the extent to which food-related decision making is impacted with these changes. Second, age-related decision making can be considered when using preventative strategies and interventions for behaviors that tend to have a delay of gratification component, such as overeating or binge eating. Specifically, at-risk groups, such as children or older adults, e.g., those with obesity, can be targeted for evidence-based preventative and treatment-focused programs. Of note, mindful eating (Hendrickson & Rasmussen, 2013), a prospective imagery intervention (Daniel, Stanton, & Epstein, 2013), and a reasoning task (Neveu et al., 2014) have all been linked to reduced discounting rates. Given the evidence pointing towards steep discounting as a trait and a *trans*-disease process (Bickel et al., 2007; Bickel et al., 2012), where individuals at risk for one problematic health behavior are at risk for others, identifying and implementing public health policies that decrease steep discounting may be crucial in reducing health concerns in society.

Ethics statement

This study was approved by and conducted under the auspices of the Idaho State University Institutional Review Board (RB-FY2017-283). All adult participants gave informed consent before participating and all children gave informed assent before participating.

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Appendix A. Supplementary data

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