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Domain independence and stability in young and older adults' discounting of delayed rewards

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ABSTRACT

Individual discounting rates for different types of delayed reward are typically assumed to reflect a single, underlying trait of impulsivity. Recently, we showed that discounting rates are orders of magnitude steeper for directly consumable liquid rewards than for monetary rewards (Jimura et al., 2009), raising the question of whether discounting rates for different types of reward covary at the individual level. Accordingly, the present study examined the relation between discounting of hypothetical money and real liquid rewards in young adults (Experiment 1) and older adults (Experiment 2). At the group level, young adults discounted monetary rewards more steeply than the older adults, but there was no significant age difference with respect to liquid rewards. At the individual level, the rates at which young and older participants discounted each reward type were stable over a two- to fifteen-week interval ($rs > 70$), but there was no significant correlation between the rates at which they discounted the two reward types. These results suggest that although similar decision-making processes may underlie the discounting of different types of rewards, the rates at which individuals discount money and directly consumable rewards may reflect separate, stable traits, rather than a single trait of impulsivity.

1. Introduction

Individuals often have to choose between alternatives that differ both in the amount of reward and in how soon it can be received. In such situations, the tendency for some individuals to steeply discount the value of delayed rewards has frequently been assumed to reflect an underlying trait of impulsivity (for a review, see Perry and Carroll, 2008). According to this view, individuals who steeply discount one type of reward (e.g., money) also would be expected to steeply discount rewards from other domains. Consistent with this view, substance abusers have been shown to discount both monetary and non-monetary rewards more steeply than controls (for a review, see Yi et al., 2010), consistent with the hypothesis of a unitary impulsivity trait that substance abusers possess to a greater degree than non-abusers. However, Chapman (1996) has reported that rates of discounting monetary and health rewards are uncorrelated, a finding she termed domain independence.

The present study revisits the issue of domain independence with respect to normal individuals discounting very different types of non-abused rewards. Recently, we showed that discounting rates are orders of magnitude steeper for directly consumable liquid rewards than for monetary rewards (Jimura et al., 2009), raising the question of whether discounting rates for different types of reward covary at the individual level. In the present study, we examine the correlation between individuals' discounting of delayed monetary rewards and real liquid rewards. If individuals are characterized by a unitary trait of impulsivity then the degree to which individuals discount these two types of rewards should be highly correlated. If there is domain independence, however, then discounting of the two reward types should be uncorrelated.

Correlations between different measures are difficult to interpret, however, if the reliabilities of the separate measures are not known. Therefore, in addition to assessing the degree of domain independence, the current study examines the stability (i.e., test–retest reliability) of discounting rates for these two reward types. Individual rates of discounting delayed monetary rewards have been shown to be stable over test–retest intervals of up to 6 years (Audrain-McGovern et al., 2009; Kirby, 2009); however, the stability of individual discounting rates for directly consumable rewards is not known, and the present study provides estimates of test–retest reliability for both types of reward.

The present study also addresses the issue of domain independence at the group level. If two groups are compared, and Group A discounts a particular type of reward (e.g., money) more steeply than Group B, the unitary trait hypothesis predicts that, other things being equal, Group A will also discount other types of reward more

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steeply than Group B. Young adults have been reported to discount delayed monetary rewards more steeply than older adults (Green et al., 1994), but it is not known whether this finding generalizes to other types of rewards. Therefore, we compared the discounting of monetary and liquid rewards by young adults and older adults in order to determine whether young adults are generally steeper discounters than older adults and also to examine whether, within each group, individuals who discount one type of reward more steeply than their peers also discount the other type of reward more steeply.

Two experiments are reported: one with young adults (Experiment 1) and one with older adults (Experiment 2). In each experiment, two sessions were conducted at least two weeks apart, and in each session, participants made a series of choices between immediate and delayed monetary rewards as well as a series of choices between immediate and delayed liquid rewards. For each group, individual-level analyses examined the test–retest reliability of discounting rates for each reward type separately, as well as the correlations between discounting rates for the two reward types. Finally, group-level analyses compared the rates at which young and older adults discounted the two types of reward.

2. Experiment 1

2.1. Method

2.1.1. Participants

Twenty-three undergraduate and graduate students received either course credit or $10 per h for their participation. Participants were instructed not to drink any liquid for 4 h before the two experimental sessions, and all reported that they met this criterion. One participant who chose the immediate option on all liquid reward trials in the first session was not invited to return for a second session, and another participant failed to return for the second session. Data from one participant who chose the immediate liquid reward on all test trials in the second session were discarded. The data reported are from the remaining 20 participants.

2.1.2. Procedure

Participants were tested individually in a small room. In each of two sessions, they performed three different interleaved tasks: a monetary reward discounting task, a liquid reward discounting task, and a working memory task that was used as a filler task. At the beginning of each session, the instructions for all three tasks were read aloud to the participants. In addition, they were informed that the duration of the experiment would not be affected by whether they chose the immediate or the delayed alternatives on the monetary and liquid reward discounting tasks. At the beginning of the first session, they were asked to choose a favorite drink from a list consisting of apple, orange, grape, grapefruit, and cranberry juice, lemonade, and water. This drink was then used as the liquid reward. At the beginning of the second session, participants were asked if they still preferred the previously selected liquid reward or wanted to change to a different liquid, but no participant requested a change. The two sessions were administered at least 2 weeks apart (range: 14–30 days; mean and SD: 20.7 ± 6.7 days).

Each experimental session began with two forced-choice trials for the liquid reward discounting task, one in which a 16-ml reward was presented after 20 s and another in which an 8-ml reward was presented immediately, in order to familiarize participants with the amounts and the delay procedure. Next, participants were given two practice trials on the monetary reward discounting task and four practice trials on the working memory task.

Following the practice trials, the two experimental discounting tasks and the working memory filler task were presented in blocks of five trials each: one liquid reward discounting trial, two monetary reward discounting trials, and two working memory trials. Each block began with the liquid reward trial, which was followed by two monetary reward trials and two working memory trials presented in random order. To inform participants of the type of task to be performed on the upcoming trial, a cue (i.e., "MONEY", "JUICE", or "MEMORY") was presented for 2 s before each trial. The results of a post-session questionnaire confirmed that no participant was confused about the type of task to be performed next.

Each five-trial block lasted 150 s, timed from the choice response on the first liquid reward trial to the beginning of the next liquid reward trial at the start of the following block. The time between liquid reward trials was held constant in this fashion so that participants' choices would affect only the delay until reward receipt and would not affect the rate at which the liquid rewards were obtained. The total time remaining in the block after subtracting both the time until consumption of the liquid reward ended and the duration of the remaining four trials was distributed equally among the inter-trial intervals in that block.

2.2. Discounting of real liquid rewards

On each trial of the liquid reward discounting task, two choice alternatives were presented on the computer screen: a fixed 16-ml reward available after a delay, and a smaller amount available immediately. The alternatives were presented to the left and right of a central fixation point, and their positions varied randomly from trial to trial. Participants pressed either the "1" or "2" key on the computer keyboard to indicate whether they preferred the left or right alternative, respectively.

If the smaller, immediate amount was chosen, then a message appeared on the screen: "Reward is ready, press either key to begin." If the delayed 16-ml reward was chosen, the participant had to wait for the specified delay to elapse before the "Reward is ready. . ." message appeared, indicating availability of the reward. During the delay, the number of seconds remaining until the reward would be available was indicated on the screen, below which a green horizontal bar was displayed whose length was proportional to the time remaining.

Four delay conditions (5, 15, 30, 60 s) were studied. Participants made three choices in each delay condition. The order of the delay conditions was randomized, with the constraint that participants made their first choice at each of the four delays before going on to make their second choice at each of the delays, and then finally making their third choice at each delay. On the first trial of each delay condition, the choice was between an 8-ml immediate reward and the 16-ml delayed amount. On the two subsequent trials, the amount of the immediate reward was adjusted based on the choice on the previous trial at that delay. Specifically, if the participant had chosen the smaller, immediate reward on the first trial, then the amount of the immediate reward was decreased by half to 4 ml; if the participant had chosen the larger, delayed reward previously, then the amount of the immediate reward was increased by half to 12 ml. On the third trial in a delay condition, the immediate reward was decreased or increased by 2 ml from the immediate amount presented on the second trial at that delay, depending on whether they had chosen the immediate or the delayed reward, respectively. For each delay, the subjective value of the delayed reward (i.e., the amount of immediate reward equal in value to the delayed reward) was estimated to be equal to 1 ml more than the amount of immediate reward available on the third trial if the delayed reward had been chosen on that trial, and 1 ml less than the amount of immediate reward available on the third trial if the immediate reward had been chosen on that trial.

Liquid rewards were delivered via two 60-ml plastic syringes mounted on a pump (SP210iw, World Precision Instruments, Sara-

sota, FL). Plastic tubes from the two syringes merged into one tube, which then delivered the liquid to the participant's mouth. The simultaneous use of two syringes allowed for a comfortable flow rate of 2.0 ml/s. The syringes were refilled after every six liquid reward trials, and the maximum amount of liquid that could be obtained per session was 248 ml (equal to 8.4 US fluid ounces).

Rewards were dispensed in .4-ml squirts but were experienced as a continuous flow. The amount of reward was determined by the number of squirts. Reward delivery continued as long as either key was held down; if the key was released, delivery paused and resumed when the key was pressed again. During reward delivery, the amount remaining (in squirts) was displayed below a red horizontal bar whose length corresponded to the number of squirts still available.

2.3. Discounting of hypothetical monetary rewards

On each trial of the monetary reward discounting task, two alternatives were presented on the computer screen: a fixed $80 reward available after a specified delay and a smaller amount available immediately. Participants were instructed to think of the alternatives as if they were real and to choose the alternative they preferred. The choice procedure was similar to that for liquid rewards, with the options appearing to the left and right of fixation, and participants pressing a corresponding key to indicate their choice. The position of the larger, delayed amount and the immediate, smaller amount varied randomly from trial to trial.

Six delay conditions (1 week, 1 month, 3 months, 6 months, 1 year, and 3 years) were studied. Participants made four choices in each delay condition. The order of the delay conditions was randomized, with the constraint that participants made their first choice at each of the six delays before going on to make their second choice at each delay, etc. The choice on the first trial was between an immediate $40 reward and the delayed $80 reward. The adjustment procedure across trials was similar to that for the liquid reward discounting task, with the amount of the immediate reward decreasing or increasing by half, depending on whether the delayed or the immediate alternative had been chosen previously. More specifically, on the second trial in a delay condition, the immediate reward was increased or decreased by $20, on the third trial by $10, and on the fourth by $5. For each delay, the subjective value of the delayed reward (i.e., the amount of immediate reward equal in value to the delayed reward) was estimated to be equal to $2.50 more than the amount of immediate reward available on the fourth trial if the delayed reward had been chosen on that trial, and $2.50 less than the amount of immediate reward available on the fourth trial if the immediate reward had been chosen on that trial.

2.4. Working memory filler task

At the beginning of each working memory trial, a fixation cross appeared, followed 1 s later by a list of five words that was presented for 2 s. After a 4-s delay, a test word was presented, and participants had 1.5 s to indicate whether the word was from the preceding list by pressing the "1" key if the test word was from the list or pressing the "2" key if it was not. Participants were instructed to respond as quickly and accurately as possible, and they were given feedback on each trial as to whether their response was correct, incorrect, or too slow.

2.4.1. Data analysis

The group mean subjective values of delayed rewards were plotted as a function of delay and fitted with a hyperboloid discounting function (Eq. (1)), which describes the decrease in the relative subjective value (V) of a reward (i.e., subjective value as a proportion of the actual amount) as a function of the delay until its receipt (D):

$$V = \frac{1}{(1 + kD)^s}. \quad (1)$$

In Eq. (1), k reflects how steeply the reward is discounted and s is a parameter that reflects the nonlinear scaling of amount and/or time. The hyperboloid discounting function has been shown to accurately describe choices between immediate and delayed rewards of a variety of different types including both monetary and liquid rewards like those used in the present study (Green and Myerson, 2004; Jimura et al., 2009).

In addition to describing the change in subjective value with delay by fitting Eq. (1) to the group means, the subjective values also were analyzed using repeated measures Analysis of Variance (ANOVA) to test for effects of reward type and session. Planned linear contrasts were used to assess the effect of delay on subjective value, rather than examining the main effect of delay, because the question of interest was not whether subjective values were different at different delays, but rather whether subjective values declined systematically as a function of delay.

In order to assess the stability (i.e., the test–retest reliability) of discounting at the individual level, we calculated the area under the observed subjective values for each reward using the area-under-the-curve (AuC) measure proposed by Myerson et al. (2001). The AuC represents the area under the observed subjective values, and provides a single, theoretically neutral measure of the degree of discounting. Both subjective value and delay are normalized for purposes of calculating AuC, which, as a result, ranges between .0 (maximally steep discounting) and 1.0 (no discounting). Correlations between AuCs were used to assess the degree of independence between the discounting of monetary and liquid rewards.

2.5. Results and discussion

Fig. 1 shows the relative subjective value of the real liquid (top panel) and hypothetical monetary (bottom panel) rewards, averaged across the two sessions, plotted as a function of delay. Each curve represents the hyperboloid discounting function (Eq. (1)) fit to the group mean data. As may be seen, Eq. (1) provided a very good fit to the data for both types of reward: For liquid rewards, the estimated values of the k and s parameters were .05/s and .85, respectively (R^2 = .975); for monetary rewards, the estimated values of the k and s parameters were .92/month and .42, respectively (R^2 = .998).

With regard to the discounting of the liquid rewards, a repeated measures ANOVA on the subjective values of the delayed rewards revealed no difference between sessions [$F(1,19) = .98$, $\eta_p^2 = .05$, $p = .34$], and no session × delay interaction [$F(1,19) = .00$, $\eta_p^2 = .00$, $p = .96$]. Further, planned contrasts on the subjective values revealed systematic decreases as a function of log delay in each session [Session 1: $F(1,19) = 52.3$, $\eta_p^2 = .73$, $p < .001$; Session 2: $F(1,19) = 46.0$, $\eta_p^2 = .70$, $p < .001$]. Similarly, a repeated measures ANOVA on the subjective values of the delayed monetary rewards revealed no significant difference between the two sessions [$F(1,19) = 2.00$, $\eta_p^2 = .1$, $p = .17$], and no session × delay interaction [$F(1,19) = 2.01$, $\eta_p^2 = .1$, $p = .17$]. Again, planned contrasts revealed systematic decreases as a function of log delay in each session [Session 1: $F(1,19) = 159.3$, $\eta_p^2 = .89$, $p < .001$; Session 2: $F(1,19) = 103.5$, $\eta_p^2 = .85$, $p < .001$].

In order to assess the stability of discounting, we first measured how steeply each individual discounted by calculating the AuC for each type of reward (Myerson et al., 2001). For each of the two delayed rewards, we then determined the correlation between individual AuC measures for the first and second sessions. As may

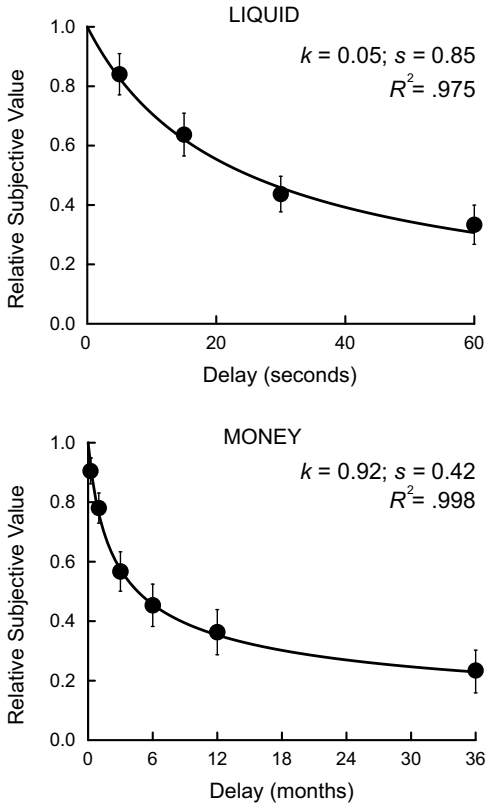

Fig. 1. Mean relative subjective value of the delayed reward for the real liquid rewards and hypothetical monetary rewards in young adults. The curves represent the best-fitting hyperboloid functions (Eq. (1)). Error bars indicate standard error of the mean. (Note that the k parameters for the liquid and monetary rewards are in different units: s^{-1} and $months^{-1}$, respectively).

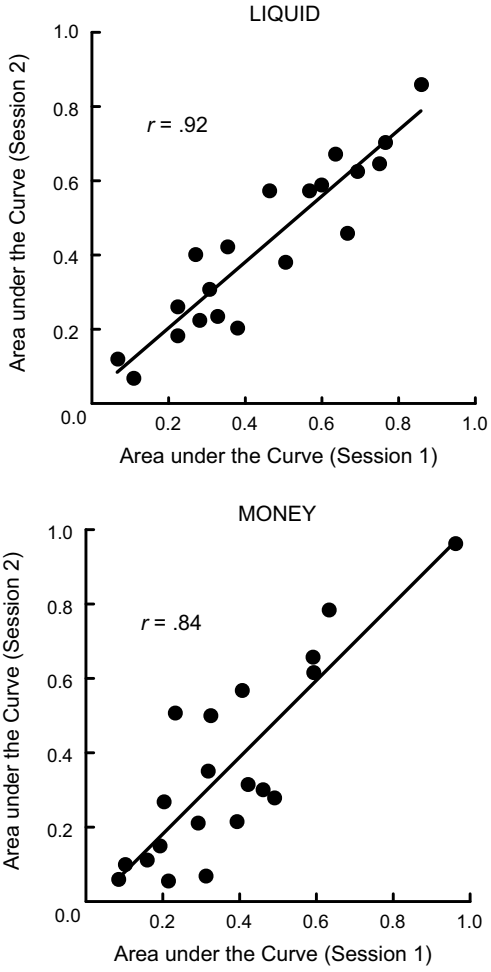

Fig. 2. Scatter plots of areas under the curve for real liquid rewards and hypothetical monetary rewards in young adults. Each data point represents the data from one participant for Sessions 1 and 2.

be seen in Fig. 2, strong correlations were observed between discounting in Sessions 1 and 2 for each of the two types of reward [liquid: $r = .92$; money: $r = .84$].

In order to assess the degree to which discounting was domain independent, we determined the correlation between individuals' discounting of the two types of delayed rewards. Fig. 3 shows the individual AuCs for the delayed monetary rewards plotted as a function of the corresponding individual AuCs for the delayed liquid rewards averaged across Sessions 1 and 2. Consistent with the hypothesis of domain independence, the correlation between discounting of monetary and liquid rewards was not significant.

These results replicate the steep discounting of real liquid rewards reported by Jimura et al. (2009) and represent a significant extension of their findings by showing that individual differences in such discounting are reliable and stable over a test–retest interval of several weeks. Individual differences in the discounting of monetary rewards also were reliable and stable, consistent with previous findings (Kirby, 2009; Simpson and Vuchinich, 2000). Notably, the correlation between discounting of liquid and monetary rewards was not significant, suggesting that these two reward domains are independent at the individual level.

3. Experiment 2

Our second experiment examined whether the results observed in Experiment 1 generalize to other populations, specifically, older adults. Examination of older adults' discounting of liquid and monetary rewards also provides an alternative approach to evaluating the domain-independence hypothesis. Because older adults discount monetary rewards more shallowly than young adults (Green et al., 1994), a failure to also observe shallower discounting of liquid rewards in this population would provide further evidence of domain specificity at the group level, whereas a replication of the same pattern observed with monetary rewards would be consistent with age differences in a domain-general impulsivity trait.

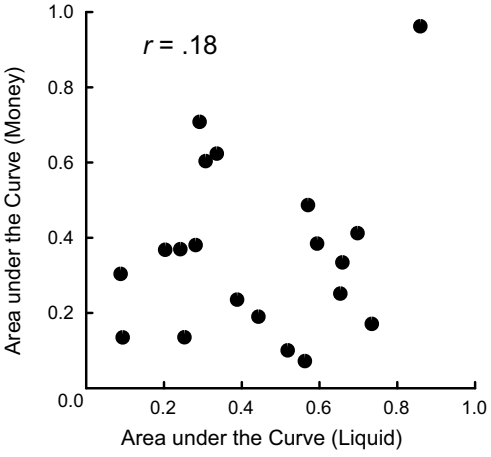

Fig. 3. Scatter plot of young adults' Areas under the curve for hypothetical monetary versus real liquid rewards.

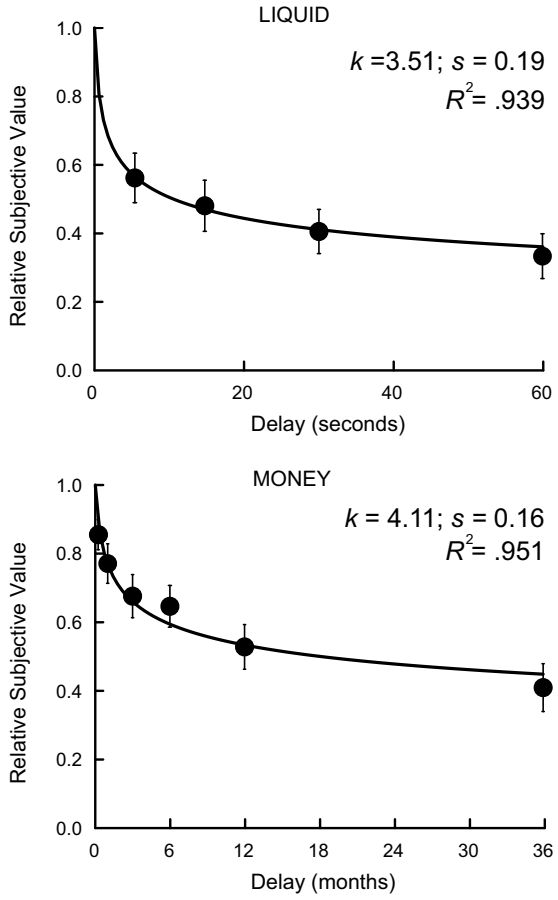

Fig. 4. Mean relative subjective value of the delayed reward for the real liquid reward and hypothetical monetary reward in older adults. The curves represent the best-fitting hyperboloid functions (Eq. (1)). Error bars indicate standard error of the mean. (Note that the k parameters for the liquid and monetary rewards are in different units: s^{-1} and $months^{-1}$, respectively).

3.1. Method

3.1.1. Participants

Twenty-seven healthy older participants (age range: 60–84 years; mean and SD: 71.0 ± 7.5 years) were recruited through phone screening from Washington University's Older Volunteer Pool to participate in the experiment for payment of $10 per h. Participants were instructed not to drink any liquid for 4 h before the two experimental sessions, and all reported that they met this criterion. Four older participants who chose the immediate option on all liquid reward trials in the first session were not invited to return for a second session, and one older participant failed to return for the second session. Data from two older participants who chose the immediate liquid reward on all test trials in the second session were discarded. The data reported are from the remaining 20 older participants. The two sessions were administered at least 2 weeks apart (range: 14–105 days; mean and SD: 34.5 ± 26.3 days).

3.1.2. Procedure and analysis

The procedure in Experiment 2 was identical to that in Experiment 1 except that for the older adults, the list of words presented in the working memory task consisted of two words whereas for the young adults, the list had consisted of five words. Discounting data were analyzed using the same methods as in Experiment 1. In addition, we conducted a planned contrast on the AuCs of individual participants to assess possible age differences in the discounting of the two types of reward.

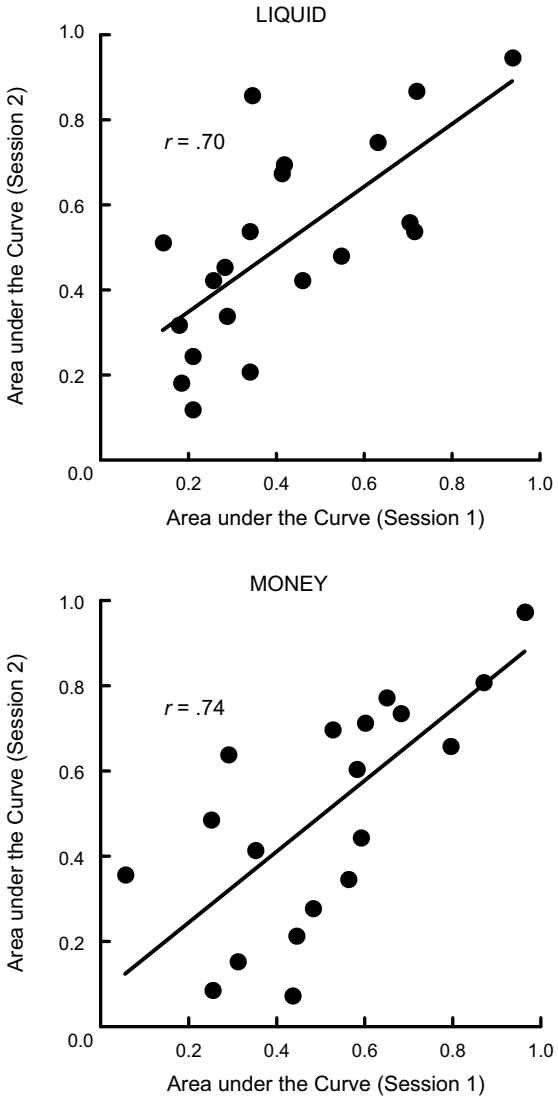

Fig. 5. Scatter plots of areas under the curve for real liquid rewards and hypothetical monetary rewards in older adults. Each data point represents the data from one participant for Sessions 1 and 2.

3.2. Results and discussion

Fig. 4 shows the relative subjective value of the real liquid and hypothetical monetary rewards, averaged across the two sessions, plotted as a function of delay. Each curve represents a hyperboloid discounting function (Eq. (1)) fit to the group mean data. As may be seen, Equation 1 provided a very good fit to the data for both types of reward: For liquid rewards, the estimated values of the k and s parameters were 3.51/s and .19, respectively (R^2 = .939); for monetary rewards, the estimated values of k and s, were 4.11/month and .16, respectively (R^2 = .951).

For liquid rewards, a repeated measures ANOVA on the subjective values revealed an effect of session [$F(1,19) = 4.68$, $\eta_p^2 = .20$, $p = .044$], but no interaction between session and delay [$F(1,19) = 1.22$, $\eta_p^2 = .06$, $p = .28$]. Planned contrasts revealed systematic decreases as a function of log delay in each session [Session 1: $F(1,19) = 4.90$, $\eta_p^2 = .21$, $p < .05$; Session 2: $F(1,19) = 12.8$, $\eta_p^2 = .40$, $p < .01$]. For monetary rewards, there was no difference between sessions [$F(1,19) = .42$, $\eta_p^2 = .02$, $p = .53$], and no session × delay interaction [$F(1,19) = .26$, $\eta_p^2 = .01$, $p = .62$]. Again, planned contrasts revealed systematic decreases in subjective value as a function

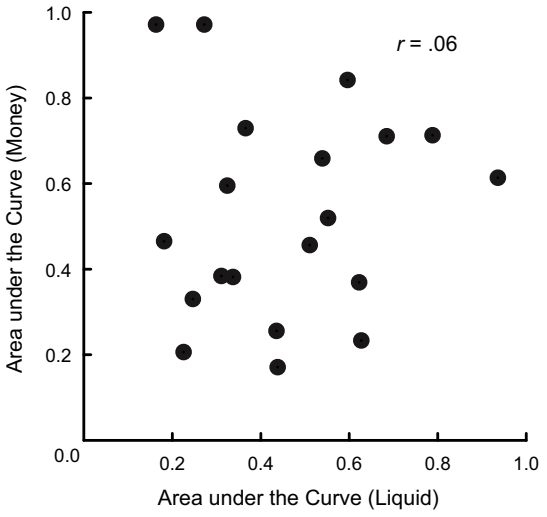

Fig. 6. Scatter plot of older adults' areas under the curve for hypothetical monetary versus real liquid rewards.

of log delay in both sessions [Session 1: $F(1,19) = 19.6$, $\eta_p^2 = .51$, $p < .001$; Session 2: $F(1,19) = 16.9$, $\eta_p^2 = .47$, $p < .001$].

As may be seen in Fig. 5, strong correlations were observed between the individual AuCs for Sessions 1 and 2 for both types of reward [liquid: $r = .70$; money: $r = .74$]. Although these correlations were not quite as strong as those observed for the young adults, nevertheless they replicate the basic findings of Experiment 1. Fig. 6 shows the individual AuCs for the delayed monetary rewards plotted as a function of the corresponding individual AuCs for the delayed liquid rewards averaged across Sessions 1 and 2: The correlation between discounting of monetary and liquid rewards was not significant, a result also consistent with the results of Experiment 1.

3.2.1. Comparisons of discounting by young and older adults

Finally, we compared the degree of discounting of both types of rewards by the older adult participants in the present experiment with that of the young adults in Experiment 1. A planned contrast on the AuCs of individual participants, averaged across both sessions, revealed an age × reward domain interaction [$F(1,38) = 5.09$, $\eta_p^2 = .12$, $p < .05$] (see Fig. 7). Post hoc tests revealed that this interaction reflected the fact that the young adults discounted the monetary rewards more steeply than older adults [$t(38) = 2.14$, $p < .05$], consistent with previous results (e.g., Green et al., 1994), whereas there was no significant difference between young and older adults with respect to the liquid rewards [$t(38) = -.80$, $p = .42$]. Taken together, the pattern of results in the two experiments is consistent with the hypothesis of domain independence at both the group and individual levels.

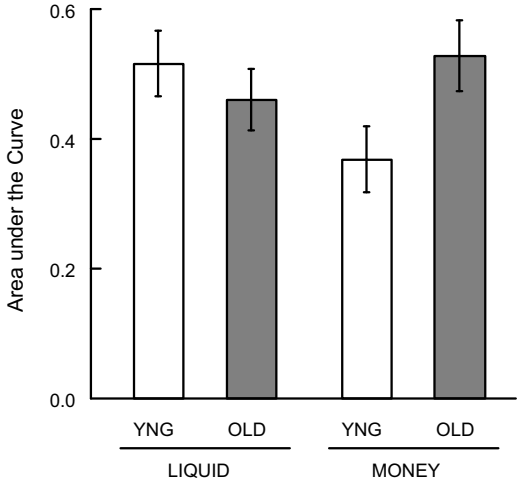

Fig. 7. Areas under the curve for young and older adults' discounting of real liquid and hypothetical monetary rewards. Error bars indicate standard error of the mean.

4. General discussion

The present study examined the discounting of delayed liquid and monetary rewards in young and older adults. Of interest was whether individual differences in discounting of these rewards were reliable and stable and whether the degree to which one type of reward is discounted predicts the degree to which the other type is discounted. For both age groups, a hyperboloid discounting function provided very good fits to the group data for both types of reward, and individual differences in discounting of both reward types were stable over several weeks. Interestingly, individuals' discounting of liquid rewards was uncorrelated with their discounting of monetary rewards, providing evidence of domain independence at the individual level. At the group level, the young adults discounted monetary rewards, but not liquid rewards, more steeply than the older adults, and the fact that this age difference was domain-specific provides further evidence of domain independence. These results suggest that although similar decision-making processes may be involved, the discounting of liquid rewards and the discounting of monetary rewards reflect separate, temporally stable individual characteristics, rather than a single trait of impulsivity.

The robust discounting of real liquid rewards observed in the present study replicates and extends the results of our previous study (Jimura et al., 2009). Moreover, the present findings, like those of Jimura et al., attest to the fact that humans discount small amounts of real consumable rewards orders of magnitude more steeply than monetary rewards: Liquid rewards tended to lose half their value when delayed for only a minute or less whereas it took a delay of several months for the monetary rewards to lose half their value.[1]

The present results demonstrate that even when discounting is as steep as that observed with real consumable rewards, substantial individual differences are present and these differences are stable for at least several weeks. Previous studies of the discounting of monetary rewards have also shown stable individual differences in discounting rates (Audrain-McGovern et al., 2009; Kirby, 2009; Simpson and Vuchinich, 2000), but the present study is the first to show stability with real consumable rewards. Such stability is important for several reasons, one of which is that it speaks to the issue of discounting states and traits (for a review, see Odum and Baumann, 2010). That is, the stability observed in the present study and others is consistent with the view that discounting tasks measure an enduring tendency on the part of individuals. This is not to say that absolute levels of discounting are stable – they are not. They change as a function of numerous variables (e.g., magnitude of reward). Rather, it is the individual differences that are stable: Those individuals, both young and older adults, who discounted

[1] Nonhuman animals also discount directly consumable rewards very steeply, and such steep discounting has sometimes been thought to reflect an important species difference (Roberts, 2002). The steepness with which humans discounted real liquid rewards in the present study raises questions as to whether there is really "a phylogenetic gap between patient humans and impulsive, present-oriented animals" (Rosati et al., 2007). Indeed, Rosati et al. recently compared delay discounting of real food rewards by humans and chimpanzees, and they reported that the humans exhibited more "impulsive" behavior.

more steeply than their peers in the first experimental session were also likely to discount more steeply in the second session.

Importantly, the present results show that individual differences in discounting are not only stable, they are also domain specific. That is, the person who discounts one type of delayed reward (e.g., money) more steeply than her peers does not necessarily discount other types of delayed reward (e.g., liquids) more steeply. The lack of correlation between the discounting of the two reward types observed in the present study is unlikely to be due to the difference in the magnitudes of the two types of reward or to the difference in how steeply they are discounted on average. In fact, the relative steepness with which rewards are discounted on average says nothing about whether those who discount one reward more steeply than their peers will discount the other reward more steeply. For example, there is a strong correlation between the discounting of rewards as different in magnitude as $200 and $40,000, even though the smaller amount is discounted much more steeply (Myerson et al., 2003). Thus, the finding that the discounting of liquid and monetary rewards is uncorrelated cannot be attributed to the fact that the liquid rewards were of a much smaller magnitude or that they were discounted much more steeply.

Nor is it likely that the domain independence observed in the present study merely reflects the difference between real and hypothetical rewards. Although the monetary rewards used in the present study were hypothetical whereas the liquid rewards were real, previous studies have shown that real and hypothetical delayed monetary rewards are discounted at equivalent rates, and that individuals' rates of discounting real and hypothetical monetary rewards are very highly correlated, with *r*s of .83 and .92 reported by Johnson and Bickel (2002) and Madden et al. (2003), respectively. In future studies, it might be of interest to compare individuals' discounting of real and hypothetical consumable rewards. Nevertheless, given the absence of a difference between the discounting of real and hypothetical monetary rewards, it would follow that the present finding of domain independence should hold for real monetary and liquid rewards.

The present findings regarding the discounting of delayed monetary and liquid rewards parallel those of Chapman (1996) who observed domain independence in her study of the discounting of delayed monetary and health outcomes, and suggest that domain independence is a general phenomenon. Interestingly, Tsukayama and Duckworth (2010) showed that domain specificity can be more subtle than a lack of correlation between the discounting of different delayed outcomes. Tsukayama and Duckworth found that even though there were significant correlations among the discounting of hypothetical candy, chips, and beer, those who reported being more tempted by candy or chips than by beer, discounted beer less steeply than they discounted candy or chips, whereas those who were more tempted by beer, showed the opposite pattern.

Thus, just because an individual discounts one type of reward very steeply, it does not necessarily follow that he or she will discount another type of reward very steeply, although in some cases this certainly will be true. The finding of domain-specific discounting calls for research directed at determining 'the natural lines of fracture' that define domains of differentially discounted rewards. It also suggests a need for caution with respect to conceptualizing choice behavior as reflecting a single, domain-general trait such as impulsivity, impatience, or an inability to delay gratification. Our findings raise the important questions of whether self-control problems are similarly domain specific, and also whether such problems are differentially modulated by age, as the dissociation of the discounting of monetary and liquid rewards would suggest. Moreover, it may well be that the seconds-level discounting of real liquid rewards better predicts behavior in some domains (e.g., dieting), whereas the discounting of monetary rewards better predicts behavior in other domains (e.g., saving for the future). If so, this would have important implications for the treatment of impulse-control problems.

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