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Dissociable Effects of Monetary, Liquid, and Social Incentives on Motivation Across the Adult Life Span

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by

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ABSTRACT OF THE THESIS

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Humans are social creatures and, as such, can be motivated by aspects of social life, like approval from others, to guide decision-making in everyday life. Indeed, a common view in the aging literature is that older adults have a stronger orientation towards socioemotional goals or incentives, relative to other incentive modalities, like money, because of changing motivational priorities in older adulthood. In prior work, however, we found that older adults actually showed greater effects of monetary relative to primary (liquid) incentives, suggesting alternative interpretations of impaired motivational integration and/or slower adaptation to incentive conditions. The current study tested these alternatives, comparing monetary to more clearly socioemotional incentives (social feedback in the form of positive, neutral or negatively valenced short video clips), while also providing greater practice under incentives to older adults. The results clearly indicate no effect of task practice on incentive effects, while also supporting an interpretation of impaired motivational integration whereby older adults show no effect of either monetary or social incentives on task performance. Moreover, in a follow-up experiment, we also demonstrate that social incentives, relative to primary incentives (liquid), show weaker motivational effects on task performance and self-reported affect and motivation ratings in

younger adults, calling into question the effectiveness of social incentives in motivating cognitive behaviors across the adult life span.

Introduction

Incentives are recognized as powerful sources of motivation that support the pursuit of goal-directed behavior. Although most of this evidence comes from studies using monetary incentives (e.g. Braver et al., 2014) recent work has begun to highlight the utility of other incentive types, such as social rewards, in motivating behavior (Tamir & Hughes, 2018). Indeed, social incentives have been shown to increase performance to the same extent as monetary rewards on a cognitive control task (Ličen, Hartmann, Repovs, & Slapničar, 2016). Further, social incentives have been demonstrated to increase attentional orienting for trials associated with positive social reward (Anderson, 2016; Hayward, Pereira, Otto, & Ristic, 2018). Taken together, this work provides initial evidence of the potential motivational value of social incentives in guiding goal-directed behavior.

An important component in understanding the mechanisms underlying social motivation lies in characterizing the subjective value ascribed to the social stimuli used to motivate behavior. Indeed, many investigators have adopted a neuroeconomic framework to study how social incentives are valued and how these value signals are represented in the brain. In both humans and non-human primates, participants have been willing to forego rewards (money-humans, juice-primates) to receive social incentives, suggesting that across species, social incentives have value (Deaner, Khera, & Platt, 2005; Jones & Rachlin, 2006). Neuroimaging investigations using fMRI have shown that the reward value of social incentives, like other forms of reward (i.e., money and food; Levy & Glimcher, 2011; Sescousse, Caldú, Segura, & Dreher, 2013), appear to be represented in a core valuation network, that includes regions such as the ventromedial prefrontal cortex (vmPFC) and ventral striatum (VS). Such findings are consistent with the hypothesis that the brain uses a "common currency" to guide behavior across a diverse set of incentives (Bhanji & Delgado, 2013).

The types of social rewards used in these studies have been somewhat variable. Multiple studies have shown that static images of faces elicit neural responses in reward regions akin to monetary rewards (Cloutier, Heatherton, Whalen, & Kelley, 2008; Spreckelmeyer et al., 2009). In addition, work using social feedback has also demonstrated activation in these same reward-related regions when participants receive positive feedback or social approval from others (Hughes, Leong, Shiv, & Zaki, 2018; Izuma, Saito, & Sadato, 2008; Korn, Prehn, Park, Walter, & Heekeren, 2012). Moreover, other work has directly compared the neural activation between social and monetary rewards and found that both incentive modalities activate the same reward-related brain regions (Izuma et al., 2008; Spreckelmeyer et al., 2009) and show similar patterns of activity modulation within these regions (i.e. striatum) to both incentive types (Wake & Izuma, 2017). Overall, this body of work suggests that social incentives may be supported by the same reward system that underlies the processing of other types of rewarding stimuli (i.e. money, food), providing a framework to understand the motivational utility of social incentives.

In order to gain a comprehensive understanding of social incentives and their impact on motivation, it will also be important to characterize the ways in which the value of these incentives may systematically change across the life span. There is already work showing the importance of social incentives in developmental time periods, such as during adolescence (e.g. Foulkes & Blakemore, 2016). Yet another area in which social incentives may be of particular importance in motivating behavior is aging. Though, there is a convergence of evidence across both behavioral and neuroimaging studies showing declines in many types of tasks related to attention, memory, and cognitive control across the adult life span (D. C. Park, 2000; Paxton, Barch, Racine, & Braver, 2008; Salthouse, 2006), a growing body of research suggests that social and emotional processes remain relatively intact as people age (Charles & Carstensen, 2010; Kensinger & Gutchess, 2016). In other words, despite age-related losses in cognitive functioning, emotional well-being remains relatively preserved in old age. Given the seemingly divergent trajectories of cognitive and socioemotional processes across the adult life span, the question arises as to how these two domains interact with motivation in older adulthood.

In accordance with age-related changes in cognitive and socioemotional domains, several theoretical frameworks suggest that as people age, they incur substantial motivational changes. One such theory contends that as people age and time horizons imposed by mortality shrink, they are motivated to place increasingly greater priority on goals related to well-being (Socioemotional Selectivity Theory; Carstensen, 2006). Consequently, social and cognitive resources are more likely to be allocated to the regulation of emotional well-being (Carstensen et al., 2011; Mather & Carstensen, 2005). Other work suggests that older adults encounter heightened motivational thresholds to engage in cognitively demanding tasks relative to younger adults (Selective Engagement Theory; Hess, 2014). These age-related motivational changes are thought to depend on the on the subjective perceptions of effort imposed by the task demands, as indexed by changes in systolic blood pressure (Hess, Smith, & Sharifian, 2016). In other words, when older adults encounter highly challenging cognitive tasks, their increased motivational threshold to engage with the task not only reflects task difficulty, but also their subjective valuation of the effort required to complete the task. Another line of work posits that older adults shift towards maintenance and loss prevention from a growth-related goal orientation utilized by many younger adults (Baltes, 1997; Ebner, Freund, & Baltes, 2006). Although these theoretical frameworks highlight a diverse set of motivational changes that may occur in older adulthood, the mechanisms underlying these motivational changes, and how they relate to the cognitive processes they modulate, remain largely unknown.

It has been increasingly appreciated that in order to understand the motivational changes that occur throughout the adult life span, the interactions between motivation and cognition need to be examined empirically (Braver et al., 2014; Ferdinand & Czernochowski, 2018). Indeed, a number of studies have begun to study motivated cognition in older adults; however, like most of the extant literature on reward, almost all of these studies have relied on monetary or points-based incentives (Samanez-Larkin & Knutson, 2015). Further, many of these findings are inconsistent with each other. For example, some studies document age-related impairments such that older adults have more difficulty learning from reward feedback and show attenuated activation in the brain regions that support reward processing (Eppinger, Hämmerer, & Li, 2011). Yet other work demonstrates there are comparable neural activation and behavioral patterns in younger and older adults during simple reward tasks (Samanez-Larkin et al., 2007). Importantly, although most of these studies use monetary incentives to motivate performance, other work (Jimura et al., 2011; Seaman et al., 2016) has identified differential effects of incentive type such that age differences in decision-making differ depending on the incentive type offered (e.g., juice, money, social, health). Consequently, it seems plausible that motivational systems may be differentially engaged across adulthood depending on the type of task or reward being offered. Indeed, the overwhelming focus on monetary reward in the current literature may be limiting our understanding of broader motivational function across the adult life span.

Given the preservation of socioemotional processing in older adulthood, a strong prediction would be that older adults perform better on cognitive tasks when the offered incentives are more clearly socioemotional rather than monetary or point-based incentives. Indeed, recent work has attempted to study the impact of social incentives on cognitive performance in older adults. Gorlick and colleagues (2013) examined performance on a rule learning task in both younger and older adults using both point-based (e.g. point gain and loss) and social feedback (e.g. happy and angry faces). Older adults showed age-related impairments in learning, however these deficits were attenuated with social feedback relative to point-based feedback. Interestingly, the benefit of social feedback differed depending on the level of cognitive load; during low cognitive load conditions, older adult performance benefitted the most for positive social feedback. However, under conditions of high cognitive load, older adult performance improved for negative social feedback relative to positive social feedback (Gorlick et al., 2013). These patterns were not found for point-based feedback in older adults, which could reflect the heightened motivational salience of social feedback in older adulthood. Other work has examined the differences between monetary and social feedback while older and younger adults underwent neuroimaging procedures (fMRI). Participants performed both the standard monetary incentive delay task (MID; Knutson, Fong, Bennett, Adams, & Hommer, 2003) and a modified version in which participants were offered social feedback (e.g. happy faces of differing levels of intensity). Behaviorally, both age groups showed higher hit rates for monetary relative social feedback (Rademacher, Salama, Gründer, & Spreckelmeyer, 2014). The neuroimaging results showed higher activity in the right nucleus accumbens for social relative to monetary feedback in older adults, whereas this pattern was the opposite in younger adults (Rademacher et al., 2014). This difference in neural activity patterns to social and monetary rewards across age group could provide support to the hypothesis that older adults have increased sensitivity to social rewards, relative to younger adults. Taken together, these findings provide initial evidence of the potential motivational salience of social rewards relative to other types of incentives (i.e. points, money) in older adulthood.

However, a critical consideration regarding the extant research on social incentives is whether the social content of stimuli being used to investigate social motivation are too simplified and decontextualized. In particular, social incentives are often operationalized in incentive paradigms, as static images of faces or sentences on a computer screen that are intended to convey social feedback. Although a few studies to date have tried to ameliorate this concern by using video clips (Zaki, Bolger, & Ochsner, 2008) or real, dyadic, social interactions (Zernig, Kummer, & Prast, 2013), overall there is a paucity of research examining social processes more realistically. Thus, there is a clear need to enhance the richness of the social stimuli used in studies of social motivation, in order to enhance our understanding of the complex processes at play when people encounter social stimuli and subsequently guide their behavior akin to situations in daily life.

A final, but currently under-studied issue related to the impact of motivational incentives on cognition, concerns incentive integration. Clearly, incentives are integrated together as we go about our daily lives and execute a variety of different decisions. For example, an individual who is considering whether or not to expend the time and effort needed to go play bingo at a nearby establishment will likely consider both the potential monetary earnings attainable from the game and the added social benefits of interacting with close friends when making a decision. However, little work has been done to examine the mechanisms underlying incentive integration in either younger or older adults, particularly in terms of the interactive effects of incentive integration on cognition. Prior work has shown that when younger adults are asked to integrate monetary and liquid incentives (e.g. juice, saltwater, neutral solution) during a highly challenging cognitive task they additively combine the two incentive types to modulate task performance (Yee, Krug, Allen, & Braver, 2015). In contrast, older adults appear to have impairments in incentive integration whereby their task performance is modulated by differing levels of monetary reward, but not by the valence of liquid feedback (Yee, Adams, Beck, & Braver, 2019). Given the proposed motivational changes that co-occur with healthy aging (i.e. greater motivational salience of socioemotional information), it's possible that the incentive integration deficits observed in older adults may reflect domain-specific motivational deficits, but not incentive integration processes, *per se*.

The current study aims to test this question by adapting the task used by Yee et al. (2015) to assess the differences in task performance in both younger and older adults when they're asked to integrate monetary and social incentives. Here, we use a novel set of dynamic social stimuli to begin to achieve this goal in better characterizing potentially more realistic, or ecologically valid, social stimuli that participants could encounter in daily life when faced with decision-making prospects. If older adults are able to additively combine both incentive types (i.e. monetary, social) to modulate task performance this would indicate the importance of incentive type in motivating behavior. However, if older adults are unable to integrate social and monetary incentives to modulate task performance then this would indicate a more general decline in the ability to additively combine incentive types during highly challenging cognitive tasks. Another interpretation is that the observed deficits in task performance for older adults shown by Yee et al., (2019) could also result from slower adaption to task conditions. We sought to test this by providing all older adult participants with an additional task-switching practice session prior to completing the incentive integration task. Together, these questions will help to further parse the mechanisms involved in the interactions between motivation and cognition in older adulthood and will contribute to our understanding of motivation, more generally, through the use of dynamic social reward stimuli.

Experiment 1

Method

Participants

Fifty-two younger adults (34 females; ages 18-39 years; *M* = 22.6, *SD* = 4.8) and thirty older adults (20 females; ages 66-82 years; *M* = 73.3, *SD* = 4.8) were recruited from the Washington University Psychology Department and Washington University School of Medicine Volunteers for Health subject pools. All participants provided written informed consent and were provided payment of $10/hour in addition to task-based earnings contingent upon fast and accurate performance, up to eight dollars. Participants were native English speakers, reported no current or previous history of neurological trauma, seizures, or mental illness, and no use of psychotropic medications. Three younger adult participants were excluded from analysis due to experimenter error during data acquisition. Two older adult participants were excluded from analysis; one older adult scored below the minimum required threshold (score ≥ 26) on the Montreal Cognitive Assessment (MoCA; Nasreddine, Phillips, & Bédirian, 2005) and one failed to understand task instructions. The final sample consisted of forty-nine younger adult participants (33 females; ages 18-39 years; *M* = 22.3, *SD* = 4.5) and twenty-eight older adult participants (19 females; ages 66-80 years; *M* = 72.8, *SD* = 4.6). The Washington University Human Research Protections Office approved all experimental procedures.

Tasks

All participants performed a computerized cued-task switching paradigm adapted from Yee and colleagues (2015). The task-switching paradigm was administered using E-Prime Version 2.0.10.242 (Psychology Software Tools, Pittsburgh, PA). Participant responses were recorded using an E-prime stimulus response box on which they were instructed to press buttons with their right index and middle fingers with response mappings counterbalanced across participants. Each trial began with a fixation cross, which was displayed for 200 ms. Next, a cue was presented for 500 ms, which indicated the categorization task to be performed on that trial. If the cue was “Attend Letter” the participant needed to categorize the letter as being either a vowel or a consonant, whereas the “Attend Number” cue indicated that the participant needed to categorize the number as being either odd or even. Above and below the “Attend Number” or the “Attend Letter” cues were monetary incentive cues ($= low reward, $$=medium reward or $$$$=high reward). The number of dollar signs varied from trial-to-trial. During incentive trials, participants were informed that the dollar signs represented the relative monetary worth of that trial (e.g. $$ trials being worth twice as much as $ trials and half as much as $$$$ trials). During practice and baseline trials, participants were told that dollar signs held no significance. Following the instructional cue, a blank screen was presented for 1850 ms, followed by the target stimulus which was presented for up to 2000 ms. The target stimulus always consisted of both a letter and a number, which required participants to update the appropriate task goal on a trial-by-trial basis. Following trial completion, the task would advance to a screen that read “Next Trial Coming Up”. During practice conditions participants received visual feedback indicating whether they were correct, incorrect, or too slow. In the incentive condition participants were presented with social feedback, described further below, in the form of a short video clip (positive, neutral, or negative valence), if they were both accurate and fast enough on that trial (see Figure 1). Each participant’s reward criterion was calculated from data collected in the mixed-trial baseline block performed prior to the incentive condition. Following the feedback, a fixation cross was presented until the start of the next trial.

Procedure: Social Feedback Session (All Participants)

The social feedback session began with three practice blocks of the cued-task switching paradigm. In the first two blocks, participants practiced only a single task, either the letter or number categorization task. One cue, either "Attend Number" or "Attend Letter", was presented for all trials of the block (12 trials per task, counterbalanced order). The third practice block consisted of both number and letter trials, intermixed (24 trials total).

After the practice blocks, participants performed three longer baseline blocks mirroring the structure of the practice blocks. During the baseline blacks, participants performed the same tasks as in the practice blocks, and counterbalanced in the same order, but received no feedback after each trial. The first two baseline blocks (either single-task letter or number) consisted of 48 trials each and the third task-switching block (intermixed number and letter trials) consisted of 96 trials. In each of the baseline runs, participants were instructed to perform as quickly and accurately as possible.

Following the baseline blocks, participants performed six incentive blocks. Participants were told that they could earn a monetary reward on each trial if they responded both accurately and faster than a certain reward criterion cutoff time. The reward criterion was calculated individually for each participant, based on the 30th percentile of their correct reaction times in the mixed baseline run performed during that session. In the incentive blocks, if the participant responded accurately and faster than their reward criterion they would be shown a short video clip (i.e. social feedback) that indicated that they received the monetary reward for that trial. Participants were told they could earn up to $8 in addition to their hourly pay.

The social feedback consisted of six blocks, in sets of two blocks of 48 trials each, performed consecutively. Each set was associated with social feedback of a different affect/motivational valence (positive, neutral, and negative), with valence order counterbalanced across participants. The social feedback was presented in the form of a short video clip, each approximately six seconds in length (Tully, Zakskorn, Skymba, Morrison, Sellers, & Rahim, 2017). Examples of social feedback presented to the participants are as follows: “People think positively of you” (positive); “You are a disappointment” (negative); “A minute is a unit of time” (neutral). Within each type of valenced stimuli (e.g. positive, negative, neutral), there were 64 unique videos, recorded using 26 different actors (13 females; ages 18-41, *M* = 25.0, *SD* = 5.2; 4 Asian, 2 Black, 19 Caucasian, 1 more than one race). For a subset of younger adult participants (N=25), there were only 30 unique videos, recorded from 10 different actors (5 females; ages 18-29, *M* = 22.6, *SD* = 3.8; 2 Asian, 1 Black, 6 Caucasian, 1 more than one race) presented throughout the task.

Following each incentive run, participants completed ratings of their current affective state, using a 5-point scale of 6 words taken from the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988). Participants were instructed to indicate “to what extent you feel this way right now” for each of the six words: Alert, Determined, Inspired, Ashamed, Irritable, Upset.

Upon completing all task blocks, all participants then completed two self-report questionnaires: the Behavioral Inhibition System and Behavioral Activation System Scale (BISBAS; Carver & White, 1994) and the Dimensional Anhedonia Rating Scale (DARS; Rizvi et al., 2015). In addition, participants completed a post-task questionnaire in which they rated how much they liked the social feedback, how intense or arousing they found the stimuli; they also rated their overall levels motivation, liking, and performance for each incentive type (e.g. $-positive social feedback, $$$$-negative social feedback) using a seven-point likert scale.

Procedure: Practice and Neuropsychological Testing Session (Older Adults Only)

Whereas younger adults only completed a single experimental session, older adults additionally took part in an initial session that included additional task-switching practice as well as neuropsychological testing. The task-switching procedures in this practice session were identical to those described above, except that participant performed 4 baseline blocks of 48 trials each. Following the baseline blocks, they performed two incentive blocks of 48 trials each, although these blocks did not involve social feedback. Instead, performance feedback was given via visual presentation of dollar signs that were identical to the monetary incentive cues presented at the beginning of each trial (i.e., $, $$, or $$$$). Except for how reward feedback was provided to participants, the instructions were similar, in that participants were informed that they could earn monetary rewards on each trial, up to $3 total, if they responded both accurately and faster than a certain cutoff time. Likewise, the reward criterion was calculated individually for each participant based on the 30th percentile of correct reaction times in the mixed baseline run performed during that session.

In this session, neuropsychological function was also assessed for all older adults using a battery of tests indexing several cognitive domains (e.g. executive function, verbal fluency, working memory, episodic memory, fluid intelligence, crystallized intelligence). General cognitive ability was assessed with the MoCA (Nasreddine et al., 2005). Measures of executive function included the Trail Making Test (TMT; Reitan, 1958), Stroop (Stroop, 1938), and verbal phonemic fluency (Borkowski, Benton, Spreen, 1967). Working memory was indexed by the Corsi Finger Tapping Task (Kessels, van Zandvoort, Postma, Kappelle, & de Haan, 2000) and WMS-III Letter-Number Sequencing (Wechsler, 1997). Episodic memory was examined using the WMS-III verbal paired associates task (Wechsler, 1997). Fluid intelligence was assessed with the Number Series task (Redick et al., 2013) and crystallized intelligence was indexed by performance on the Shipley Vocabulary scale (Shipley, 1940). In addition, older adults completed a variety of individual difference questionnaires related to physical health (Cornell Medical Index; Abramson, Terespolsky, Brook, & Kark, 1965), mental health (Geriatric Depression Scale; Yesavage et al., 1982), affect and well-being (Satisfaction with Life Scale; Diener, Emmons, Larsen, & Griffin, 1985; Future Time Perspective Scale; Carstensen & Lang, 1996; Prioritization of Positivity Scale; Catalino, Algoe, & Fredrickson, 2014), and financial assets and liabilities.

The order of neuropsychological tasks was counterbalanced across participants. A subset of the neuropsychological assessments (Corsi Finger Tapping, Letter-Number Sequencing, Stroop, Trail Making Test, and Number Series) were administered using Inquisit Lab 5 (Millisecond Software, Seattle, WA) and the Shipley vocabulary measure was presented using the web platform, REDCap. All other neuropsychological measures were collected using pen and paper administration. Individual difference questionnaires were presented and managed with a secure web-based application, Research Electronic Data Capture (REDCap), hosted at Washington University (Harris et al., 2009). These data were collected for exploratory purposes and to inform future research effort, but were not the primary focus of the current study, and consequently are not analyzed or discussed further; results from this session are presented in a supplementary results section.

Results

Task Performance

To determine if older adults showed deficits in incentive integration involving monetary and social incentives, we used reward rate (i.e., the percentage of rewarded trials in each incentive condition) to quantify each participant's subjective motivation to implement cognitive control to earn the rewards offered during the task. Both age groups performed above the expected reward rate (.3), as determined the criterion RT. According to a binomial test, all younger adults, and all but 2 older adults performed significantly higher ($p < .05$) than the expected reward rate, demonstrating that incentives can effectively enhance performance on this highly challenging cognitive task (figure 2a). Although younger adults showed a higher level of reward rate (M= .703) relative to older adults (M=.595), t(75)=3.43, p=.001, older adults were overall more accurate (M=.911) than younger adults (M=.876), t(75)=-1.97, p=.053. There was no difference in the rate of commission errors between younger (M=.031) and older adults (M=.027), p=.503 (errors are not the complement to accuracy, since non-responses are not coded as true commission errors). Likewise, when compared to younger adult baseline performance, older adults in the incentive condition, showed faster RTs (M_{YA}=833.93, M_{OA}=703.03, t(75)=2.97, p=.004), and equivalent accuracy (M_{YA}=.919, M_{OA}=.909, p=.741), demonstrating a remarkable enhancement in performance (figures 2b,c).

Further, to test whether motivational incentive integration occurred similarly in younger and older adults, we examined reward rate effects by both monetary reward and social feedback. The omnibus model showed a significant monetary reward effect, $F(2,624) = 5.746$, $p = .003$, as well as an effect of age group, $F(1,624) = 70.099$, $p < .001$, but no effect of social feedback, F(2,624)=.340, p=.712 (figure 3). To further decompose this pattern, we next examined each age group separately. In younger adults, there was a main effect of monetary reward, F(2,436)=6.658, p=.001, such that $$$$-trials had significantly higher reward rate than $-trials, p<.001, but no effect of social feedback, (F(2,436)=.586, p=.557). In older adults, neither the effect of monetary reward (F(2,184)=1.035, p=.357), nor social feedback (F(2,184)=.381, p=.684) were significant.

Affect Ratings

In contrast to the null finding of social feedback in modulating task performance for both age groups, younger adults did report differences in their current affective state following each of the social feedback blocks (i.e., positive, neutral, negative). Younger adults showed an effect of social feedback for the following PANAS terms: inspired, $F(2,144)=8.959$, $p<.001$, and upset, $F(2,144)= 6.026$, $p=.003$ (figure 4). Interestingly, for inspired, the rating was highest in the positive feedback condition (greater than neutral or negative, $p=.005$), whereas for upset, the opposite pattern was present, with the highest rating for negative (greater than neutral or negative, $p=.002$). In addition, there were trending effects of social feedback observed for alert, $F(2,144)=2.641$, $p=.0745$, and irritable, $F(2,144)=2.694$, $p=.071$, although these did not reach the threshold for statistical significance. Conversely, older adults showed no effect of social feedback for any of the affective terms, but had overall higher ratings for all of the terms conveying positive affect, relative to younger adults: alert ($M_{OA}=3.58$, $M_{YA}=2.84$, $t(208)=4.35$, $p<.001$), determined ($M_{OA}=4.08$, $M_{YA}=2.94$, $t(208)=6.47$, $p<.001$), and inspiration ($M_{OA}=3.05$, $M_{YA}=1.88$, $t(208)=4.35$, $p<.001$). In addition, older adults had overall lower ratings for the terms conveying negative affect, relative to younger adults, though the age effect was only statistically reliable for irritable ($M_{OA}=1.49$, $M_{YA}=1.84$, $t(208)=-2.64$, $p=.009$; ashamed: $M_{OA}=1.12$, $M_{YA}=1.24$, $p=.154$; upset: $M_{OA}=1.33$, $M_{YA}=1.449$, $p=.293$).

Self-reported liking and motivation ratings

Interestingly, self-reported ratings of motivation and liking did not align with task performance profiles. An omnibus model of self-reported motivation ratings showed a significant monetary reward effect, $F(2,624) = 20.535$, $p <.001$, social feedback effect, $F(2,624) = 6.466$, $p =.002$, age group effect, $F(1,624) = 49.073$, $p <.001$, and an age group × monetary reward interaction, $F(2,624)=4.375$, $p=.013$ (figure 5). To further decompose this pattern, we next examined each age group separately. In younger adults, there were main effects of monetary reward ($F(2,436)=28.224$, $p<.001$) and social feedback ($F(2,436=9.766$, $p<.001$), with the former showing motivation increasing between low ($-trials) and high reward ($$$$-trials, $p<.001$), and the latter showing higher motivation for positive compared to neutral social feedback ($p=.016$), but no difference between neutral and negative ($p=.106$). In older adults there was no effect of monetary reward, ($F(2,232)=1.943$, $p=.145$) or social feedback ($F(2,232)=.583$, $p=.559$). Younger adults self-reported higher overall motivation relative to older adults ($M_{YA}=5.37$, $M_{OA}=4.51$, $t(624)=6.75$, $p<.001$).

For the liking ratings, there was a significant monetary reward effect, $F(2,624) = 7.415$, $p <.001$, social feedback effect, $F(2,624) = 16.401$, $p <.001$, age group effect, $F(1,624) = 5.269$, $p =.022$, and an age group x monetary reward interaction, $F(2,624)=4.705$, $p=.009$. In younger adults, there was a main effect of monetary reward ($F(2,436)=11.011$, $p<.001$) and social feedback ($F(2,436)=12.423$, $p<.001$), with very similar patterns to what was observed in the motivation ratings. In older adults there was no effect of monetary reward, $F(2,232)=.656$, $p=.520$, but there was a significant effect of social feedback, $F(2,232)=4.692$, $p=.010$. In this case, both older and younger adults liked the positive social feedback, significantly more than the negative social feedback condition ($p_{YA}=.001$, $p_{OA}=.051$).

Discussion

These results provide further support to the growing body of literature highlighting the distinctive role motivation plays in modulating cognitive processes in older adulthood. Replicating the findings from Yee et al., (2019), we found that older adults were able to improve performance on a highly challenging cognitive task under incentivized conditions, relative to baseline. Indeed, as in Yee et al (2019), older adult performance under incentivized conditions older adult performance was faster and equally accurate to that observed in younger adults at baseline.

However, older adult performance exhibited reduced sensitivity to the more subtle, trial-by-trial manipulations of monetary reward present during the incentive integration paradigm, indicating that older adults may have difficulties in integrating multiple incentives together to modulate cognitive performance. Critically, this result was found even after giving older adults twice the number of practice trials used by Yee et al., (2019), providing further evidence that older adults are impaired in incentive integration.

Interestingly, younger adults also did not appear to readily integrate both monetary and social incentives—their performance was sensitive to monetary, but not social feedback. This finding lies in contrast to the work of Yee et al., (2015), which showed that younger adults are sensitive to diverse incentive types (i.e., money, liquid rewards) and are able to additively integrate them to modulate performance on the cued task-switching paradigm used in this experiment. Given these differences in incentive integration involving social incentives, it's possible that social incentives operate distinctively from other types of reward and are not easily integrated into motivational value.

We employed the use of post-block affect ratings to try to understand the role that social feedback plays in motivating behavior. In younger adults, we found that there was an effect of social feedback such that the degree to which participants rated their feelings towards words taken from PANAS, like "inspired", changed as function of the valence of the social feedback (i.e., higher for positive relative to neutral and negative). Conversely, older adults did not show an effect of social feedback for any of the six words. However, relative to younger adults, older adults had higher overall ratings for the words conveying positive affect (alert, determined, inspired) and had lower overall ratings than younger adults for negatively valenced words (ashamed, upset, irritable; though only statistically reliable for the last term). It's possible that this pattern of findings reflects motivational reprioritization in older age, akin to socioemotional selectivity theory, whereby older adults are instead focused on regulating their emotions to support positive affect rather than using the value of the incentive to modulate cognitive task performance.

Perhaps further support for this emotion regulation-like strategy in older adults comes from their self-reported ratings of motivation and liking. Older adults' motivation ratings were not sensitive to either monetary reward or social feedback and their liking ratings showed an effect for social feedback, but not monetary reward. In contrast, younger adults showed strong sensitivity in both self-reported liking and motivation to the monetary rewards. Thus, although older adults appear to like the social feedback as a function of valence, they do not show the same effects with regard to motivation, nor any clear self-reported effects of monetary rewards. Future experiments could more directly exploit the purported social and affiliative goals of older adults by providing social stimuli that are more self-relevant (i.e. close others providing social messages) or perhaps manipulating reward (i.e., monetary) to be either won for the self or a close other, like a grandchild.

Nonetheless, there still appear to be somewhat paradoxical effects of motivation on task performance, as they relate to social feedback. Even though younger adults self-reported effects of the social feedback on both motivation and liking, this did not translate to their actual performance on the task. The discrepancies between these findings and those previously documented by (Yee et al., 2015), which show that younger adults are able to integrate diverse incentives types to modulate cognitive task performance and their self-reported motivation ratings explain additional variance beyond the effects of incentive alone, suggest a possible dissociation between primary (liquid) and social incentives. To test this possibility more explicitly, we conducted a follow-up study in younger adults, in which the effects of liquid and social incentives could be directly compared through a within-subjects design.

Experiment 2

Introduction

Experiment 1 showed an effect of monetary incentive on task performance in younger, but not older adults and no effect of social feedback on task performance in either group. Although previous work has shown that younger adults are able to integrate diverse incentives (e.g. money and liquids) to modulate task performance and that individual differences in self-reported motivation predict task performance above and beyond experimental effects (Yee et al., 2015), these experiments did not include any measure to index the affective properties of the stimuli used in the experiment to be able to examine the relationships between affect, motivation, and task performance. Given the theoretical body of work that posits a potential dissociation between affective and motivational processes in modulating cognitive control processes (e.g. (Chiew & Braver, 2011), it is plausible that social stimuli elicit affective responses that operate distinctly from their motivational influences in modulating task performance.

Experiment 2 used the same task-switching paradigm and social stimuli as Experiment 1, but used a within-participants manipulation to enable direct comparisons of liquid and social feedback conditions (performed in separate sessions). Moreover, this experiment was designed to extend the prior incentive integration work completed by Yee et al., (2015) by introducing affect ratings after participants completed both the social or liquid feedback conditions. Specifically, we predicted that younger adult participants would be able to integrate liquid with monetary incentives, but not social and monetary, replicating the findings of both Yee et al., (2015) and Experiment 1. In contrast, we predicted that affect ratings corresponding to the liquid feedback would not be as strong as those for social feedback, indicating a potential dissociation between the role of affect and motivation in modulating cognitive control. Obtaining this patterns of results would provide further evidence for the distinct roles of affect and motivation in the execution of cognitive control processes and help to explain the null effects observed in Experiment 1 with regard to social feedback.

Conversely, another outcome is also possible, in which the liquid feedback condition elicits both a stronger motivational influence on performance and a stronger effect on affect ratings. Such an outcome would indicate that the affective influences of liquid feedback are greater than those for social feedback. In particular, it could be the case that it is the affective properties of liquid feedback that additively combine with the motivational influences of monetary incentives to modulate task performance. On the other hand, if the social feedback lacks strong enough affective properties to compete with the motivational manipulation (i.e. monetary reward), participants may rely solely on the monetary incentives to guide task performance. To preview, the results appear to provide the most support for the latter hypothesis.

Method

Participants

Forty-one participants (29 females; ages 18-37 years; $M = 20.71$, $SD = 3.26$) were recruited from Washington University Psychology Department and Washington University School of Medicine Volunteers for Health subject pools. Participants completed two separate sessions at Washington University in St. Louis, at least 24 hours apart. All participants provided written informed consent and were given payment of $10/hour in addition to task- based earnings contingent upon fast and accurate performance in the incentive blocks. Ten participants were excluded from analysis; four were lost to follow-up, three prematurely withdrew from the study, one failed to comply with task instructions during the first session and was not invited back to complete the second session, and two participant's data was unable to be analyzed due to experimenter error during data acquisition. The final sample consisted of thirty-one participants (21 females; ages 18-37 years $M = 20.81$, $SD = 3.41$). All participants were native English speakers, reported no current or previous history of neurological trauma, seizures, or mental illness and no use of psychotropic medications. The Washington University Human Research Protections Office approved all experimental procedures.

Task

Experiment 2 used the same task-switching paradigm as in experiment 1; however, depending on the session, participants could receive either social feedback or liquid feedback (delivered via drops of liquid to the mouth) during the incentive blocks.

Procedure

The two experimental sessions were identical in structure and only differed in the incentive condition being performed (social feedback, liquid feedback). Session order was counterbalanced across participants. The design and administration of the practice and baseline blocks were the same as described in experiment 1.

In each session, following performance of the baseline task blocks, participants performed six incentive blocks, in sets of two, grouped by affect/motivational valence. Participants were told that they could earn a monetary reward on a trial if they responded both accurately and faster than a certain cutoff time. The reward criterion was calculated individually for each participant based on the 30th percentile of correct reaction times in the mixed baseline run performed during that session.

In the incentive blocks, if the participant responded accurately and faster than their reward criterion they would either receive a squirt of liquid (liquid feedback) or be shown a short video clip (social feedback) that indicated that they received the monetary reward for that trial. Participants were told they could earn up to $16 across both visits in addition to their hourly pay.

The social feedback condition was identical to that used in experiment 1. The liquid feedback condition paralleled the social feedback condition, in that sets of two blocks were performed with three different liquids associated with a different affect/motivational valence: positive (apple juice), neutral (isotonic tasteless solution), negative (saltwater). Again paralleling the social feedback condition, liquid order was counterbalanced between participants. Liquid was dispensed (1mL per trial) using a digital infusion pump (model SP210iw, World Precision Instruments, Inc., Sarasota, FL) with Tygon tubing (US Plastics Corporation, Lima, OH) delivering liquid directly into the participant's mouth.

Following each incentive run, participants completed ratings of their current affective state, using a 5-point scale of terms taken from the PANAS (Watson et al., 1988). Participants were instructed to indicate "to what extent you feel this way right now" for each of the ten words. The terms were expanded and modified from Experiment 1, to provide broader coverage. Three coded negative affect valence (Ashamed, Irritable, Upset), three coded positive affect valence (Inspired, Content, Excited) and four coded arousal (Fatigued, Alert, Determined, Stressed).

Upon completing all task blocks, participants then completed self-report questionnaires (BISBAS, DARS). In addition, participants completed post-task questionnaires following each session in which they rated how much they liked the incentive type (e.g. social or liquid feedback), how intense or arousing they found the stimuli; they also rated their overall levels motivation, liking, and performance for each incentive type (e.g. $-positive social feedback, $$$$-saltwater) using a seven-point likert scale.

Results

Task performance

As in Experiment 1, we used reward rate to quantify each participant's subjective motivation to implement cognitive control to earn the incentives offered both in the liquid and social feedback tasks. Performance in both the liquid and social feedback conditions exceeded the expected reward rate (.3), as determined the criterion RT taken from baseline performance on each day of testing, demonstrating that incentives can modulate performance on both of these incentive-based tasks. Reward rate was higher overall for social (M= .780) relative to liquid feedback (M=.631), t(30)=5.86, p<.001 (figure 6). Accuracy was also greater for social (M=.851), as compared to liquid feedback (M=.816; t(30)=2.26, p=.031), but this pattern did not extend to error rate (social: M=.036, liquid: M=.040; p=.598). These data are broken down by session in the supplemental results section.

To follow-up from the null findings of social feedback observed in Experiment 1, we examined reward rate effects by both social and liquid feedback within individuals. We examined each feedback condition (i.e., social, liquid) separately. Replicating the results from Experiment 1, there was hint of an effect of social feedback, F(2,274)=.130, p=.878; however, in this condition, the effects of monetary reward also failed to reach statistical significance, F(2,274)=2.179, p=.115 (figure 7). In the liquid feedback condition, there were effects of both monetary reward, F(2,274)=3.748, p=.025, and liquid feedback, F(2,274)=6.473, p=.002, such that $$$$-trials had higher reward rate than $-trials (p=.042) and juice trials had higher reward rate than saltwater trials (p<.001). This suggests that participants were able to additively combine liquid and monetary rewards to modulate task performance. In contrast, the social feedback condition did not produce reliable integration effects, and further, resulted in weaker effects of monetary rewards.

Affect ratings

To be able to parse the relationship between affect and task performance, we examined the affect ratings following each incentive run across social and liquid feedback tasks, within individuals. Overall, there were no differences in affect ratings across the two experiments, $F(1,1854)=2.643$, $p=.105$; a complete description of ratings is provided in the supplemental materials. We next wanted to determine if we would see effects of feedback if we separated the terms according to their valence. In the liquid feedback condition, the feedback type × affective valence term interaction was observed, $F(2,180)=17.661$, $p<.001$ (figure 8). This was due to significantly higher ratings for the positively valenced terms in the juice condition ($M=2.753$) relative to saltwater ($M=1.849$, $t(92)=2.45$, $p<.016$). Conversely, the opposite pattern was observed for the negatively valenced terms, such that participants rated higher levels of negative affect for saltwater ($M=2.183$) relative to juice ($M=1.400$, $t(92)=2.88$, $p<.001$). In the social feedback condition, the feedback type × affective valence term was not significant, $F(2,180)=2.954$, $p=.065$). Moreover, there was no effect of social feedback type for either the positively ($p=.191$) or negatively ($p=.278$) valenced terms, even though the effects were in the same directions as observed in the liquid feedback condition. This suggests that the social feedback condition and experimental manipulation had a weaker influence on participants' self-reported affect when compared to the liquid feedback condition.

Self-reported liking and motivation ratings

Self-reported ratings of motivation and liking aligned well to task performance for the liquid condition, in that for both types of rating there were main effects of monetary reward (motivation: $F(2,270)=19.832$, $p<.001$; liking: $F(2,270)=5.864$, $p=.003$) and liquid feedback (motivation: $F(2,270)=52.311$, $p<.001$; liking: $F(2,270)=151.528$, $p<.001$; figure 9). In contrast, the social feedback condition did not align well with task-performance, in that there were main effects of monetary reward, (motivation: $F(2,270)=37.913$, $p<.001$; liking: $F(2,270)=13.653$, $p<.001$) and social feedback, (motivation: $F(2,270)=2.974$, $p=.053$; liking: $F(2,270)=3.325$, $p=.037$) on self-reported motivation and liking, even though these variables did not reliably impact task performance.

Next, we more directly tested this qualitative dissociation in the alignment between self-reported motivation and task performance across the liquid and social feedback conditions, by replicating an analysis performed by Yee et al (2016). Specifically, we examined whether self-reported motivation ratings explained additional variance in reward rate beyond the effects of the experimental factors (i.e., monetary reward or feedback). For the liquid feedback condition, when mean-centered motivation ratings for each participant were added to the model of reward rate predicted by monetary reward and feedback, additional variance was explained ($F(1,273)=45.252$, $p<.001$), i.e., above and beyond the level of monetary reward or valence of feedback. In contrast, performance on the social feedback task, as indexed by reward rate, was not better explained by self-reported motivation ratings, $F(1,273)=0.051$, $p=.822$.

Discussion

In Experiment 2, we directly compared the effects of incentive integration in a condition in which social feedback was combined with monetary rewards, relative to a condition used in prior work, in which liquid feedback was combined with monetary incentives. Replicating prior findings from Yee et al., (2015; 2019), in the liquid feedback condition we found effects of both monetary and liquid incentives on reward rate. In addition, for this condition, the post-block affect ratings showed robust effects of liquid feedback such that positively valenced words showed the highest ratings for juice relative to saltwater, whereas negatively valenced words showed the opposite pattern (saltwater>juice), indicating that the liquid feedback manipulation was having a translatable effect to the participant's current affective state. Further, post-task motivation ratings explained more variance in task performance, as indexed by reward rate, than the effects of both monetary and liquid incentives. Taken together, these results provide strong confirmation of prior work by Yee et al., (2015; 2019) in demonstrating that monetary and liquid incentives can combine to modulate cognitive task performance through changes in experimentally-induced motivational states.

Conversely, the results of Experiment 2 are consistent with the results of Experiment 1, in suggesting that social feedback does not appear to operate in this manner, or have a clear influence on cognitive task performance. Despite producing a higher reward rate overall, we found no observable effect of social feedback on reward rate and no effect of social feedback on the post-block affect ratings. Interestingly, however, there were effects of monetary and social incentives on self-reported motivation, such that participants rated positive social feedback to be more motivating than neutral, and neutral more motivating than negative social feedback, but these motivation ratings did not provide any unique variance in predicting task performance.

When considering the findings related to social feedback, it's possible that participants switched strategies for the social feedback condition, relative to liquid feedback, and selectively attended to the monetary reward cues (e.g., $$, $$$$) to guide performance, effectively ignoring the messages provided by the feedback stimuli. However, this seems unlikely, given that the monetary reward effects were also weaker in the social feedback condition than they were in the liquid feedback. Nevertheless, it is possible that with less meaningful social feedback stimuli, participants, attended less overall to the trial-by-trial changes in reward cues and feedback, which allowed them to retain a more consistent focus on the task, and as such obtain a higher overall reward rate in the social feedback condition relative to liquid.

Taken together, the results from this experiment indicate that liquid rewards are able to induce a robust induction of motivational state such that positive liquid rewards (i.e. juice) produce higher reward rate, higher positive affective state, and higher self-reported motivation ratings relative to negative liquid reward (i.e. saltwater) and should be viewed as a powerful incentive that can be used to modulate behavior. In contrast, for at least the set of social feedback stimuli used in the current experiments, these appeared to have a weaker overall influence over task performance and self-reported affect. Below, we discuss this issue more generally, in the context of current theorizing regarding social motivation, social incentives, and aging.

General Discussion

Overall, our study provides additional, preliminary evidence of the role of incentive integration and motivation across the adult life span using a diverse range of incentives. We replicated prior work demonstrating that older adults do show clear evidence of general motivation-based improvements in cognitive task performance. Relative to their baseline level of performance, older adults performed the task under incentive conditions dramatically faster with no accompanying loss in accuracy, which brought their performance to the level of, and even exceeding, younger adult performance at baseline. Conversely, older adults showed reduced evidence of being able to modulate their cognitive task performance more parametrically in response to trial-by-trial (or block-by-block) fluctuations in the motivational context, whereas younger adults demonstrate the ability to additively combine incentives to modulate task performance. This suggests a potential deficit for older adults in their ability to update and integrate changing motivational factors into trial performance, even when provided with social incentives.

Moreover, our findings provide further support that younger adults do readily integrate motivational variables into trial-by-trial performance. We found translatable effects of liquid feedback on task performance. Further, liquid valence strongly modulated both self-reported affect and motivational states, suggesting that these stimuli are able to robustly elicit motivational responses that guide behavior. Contrary to our initial predictions, social incentives appear to have a weaker influence on cognitive task performance than liquid (primary) incentives in younger adults. Across two separate samples of younger adults we did not find any social feedback effects on task performance. Taken together, these results provide compelling evidence of the dissociable of effects of reward type (i.e., liquid, social) in motivating cognitive behavior whereby liquid incentives induce strong motivational effects and social incentives have no direct impact on behavior.

One possible interpretation of these findings, is that even though the social stimuli were selected to increase ecological validity, they may have actually been ineffective in modulating motivational state. The stimuli may not have been personally meaningful, in that the feedback was presented by unfamiliar actors, rather than by individuals known or influential to the participants. For example, having the messages be spoken by known authority figures, friends, or family members could have been more effective. Indeed, recent work has shown that social closeness, as indexed by the degree to which participants rated how much they liked the person giving them social feedback, modulated activity in the ventral striatum in response to social feedback and increased their favorable impressions of that person after receiving positive social feedback (Hughes et al., 2018). Moreover, the actors in our social feedback videos were diverse in gender and ethnicity, however, this may have also limited effectiveness. Likewise, the actors in the videos were somewhat diverse with respect to age for the younger adult participants, but did not include any actors from the age range of the older adult participants. Actors that matched the participants on these factors may have been more effective in eliciting a motivational response by being increasingly similar to the participants completing the task. Further, the messages, though selected to be meaningful and motivating (in both positive and negative directions), may have seemed artificial to the participants and could have been easily ignored. Fine-tuning the messages to be more realistic and optimized for motivational salience could have increased effectiveness in motivating behavior.

On the other hand, these critiques apply to almost all of the existing laboratory studies that have examined processes related to social reward and motivation. Most of these studies use fairly impoverished stimuli, like emoticons, static facial expressions, or sentences relaying social information, which also could be construed as being artificial and would seem to be even more easily ignored. Despite these potential shortcomings, studies that use these relatively impoverished stimuli have shown robust responses in the neural regions associated with reward processing (i.e., striatum, vmPFC) using images of static faces (Cloutier et al., 2008; Spreckelmeyer et al., 2009; H. R. P. Park, Kostandyan, Boehler, & Krebs, 2018) and social feedback consisting only of numerical ratings or sentences conveying social information (Hughes et al., 2018; Izuma et al., 2008; Korn et al., 2012). This suggests that social incentives engage the same brain regions that support the processing of a diverse range of rewarding stimuli, like money and food, even if the social stimuli aren’t very life-like or particularly social in nature.

However, there does not yet exist tractable evidence connecting the neural activation patterns of social reward in value-encoding regions of the brain to behavior. Indeed, the few studies that examine both the neural and behavioral responses to social and monetary reward have somewhat contradictory findings. Park et al. (2018) found differential patterns of behavior whereby performance costs were only observed for the social stimuli and performance benefits were only observed for monetary reward on a cognitive control task despite shared activation patterns and magnitude of response across value-encoding regions of the brain to both monetary and social incentives. In addition, other work that has attempted to adapt the MID to social contexts has shown that older adults have greater activity modulation in the right nucleus accumbens to social reward (smiling faces of differing intensities) relative to monetary reward, whereas this pattern was the opposite for younger adults (Rademacher et al., 2014). Conversely, both younger and older adults showed the same behavioral patterns such that hit rate was higher for monetary relative to social incentives (Rademacher et al., 2014). These findings highlight the distinct possibility that social motivational variables are actually less effective, or at least less consistent, than other types of incentive modalities in motivating behavior. A convincing demonstration of the unique influence of social incentives in experimental paradigms still remains to be seen, especially in the context of aging where it has been hypothesized that the effects of social motivation are more salient.

Nonetheless, it's possible that there are real motivational consequences of social incentives across the adult life span that we are not currently sensitive to given our current experimental paradigms or social stimuli. Prior work has shown that older adults more steeply discount social rewards, operationalized as time spent with a designated close other, relative to younger adults (Seaman et al., 2016). Perhaps if social stimuli were designed such that they allowed for messages from close friends or family members or provided time with these individuals, we might observe motivational changes induced by the social incentives that affect behavior, with even more pronounced effects for older adults in accordance with the age-related changes described by socioemotional selectivity theory. Likewise, there is a growing body of work indicating that the positivity effect can be eliminated in the face of heightened cognitive load (Carstensen & DeLiema, 2018). Rather than testing our dynamic stimuli using a highly challenging paradigm, like the cued-tasking switching used in the current study, it could be informative to test the incentive effects of social stimuli using a simpler paradigm, like the MID (although see discussion above of Rademacher et al., 2014). Overall, the current body of work demonstrates that it is quite challenging to design ecologically valid, yet experimentally tractable social incentive stimuli. The burden of proof now falls on investigators to demonstrate the specific effectiveness of social incentives, especially in aging populations where these effects are presumed to exist.

In summary, our results do show that provided with social incentives, participants are able to improve their performance on a challenging cognitive task relative to a non-rewarded baseline condition. Further, these results provide support to the growing body of literature highlighting the distinctive role motivation plays in modulating performance in cognitive domains in older adulthood. Critically, despite popular theorizing that social incentives are potentially more motivating to older adults given potential shifts in motivational priorities across the adult life span (e.g. socioemotional selectivity theory), our findings lie in contrast to this claim whereby social incentives do not seem to show stronger influences of social motivation on performance. Future work is needed to characterize the role social incentives play in motivating cognition, which will be essential in understanding how diverse incentive types are used to guide decision-making processes in everyday life across the adult life span.

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Figure 1. Incentive integration task paradigm.

Participants were asked to perform a consonant-vowel odd-even (CVOE) switching task. Reward cues indicated the relative amount of monetary reward available on each trial given fast and accurate performance. If participants were accurate and faster than a subject criterion response time (30% of fastest response times for correct trials during the baseline block), then they received social feedback at the end of the trial. If subjects answered incorrectly, too slowly, or not at all, they neither received monetary reward or liquid.

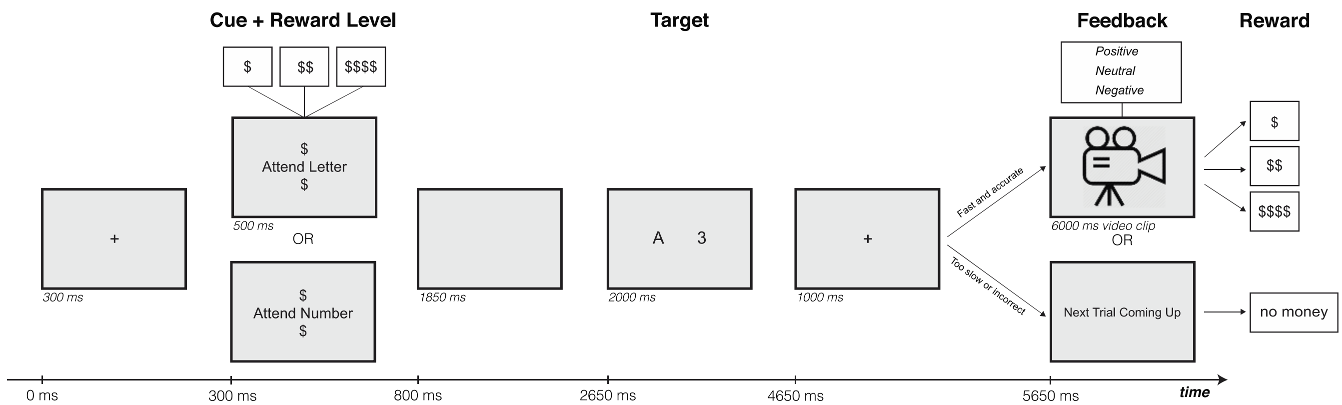


Figure 2. Reward rate by age group.

In Figure 2a, reward rate is plotted against age group. The dashed line represents the expected reward rate of 30%, assuming subjects did not improve their performance between baseline and incentive blocks. The solid lines represent 95% confidence intervals calculated by a binomial test [CI_{lower}=.20, CI_{higher}= .40]. Each dot represents a single subject's average reward rate. Figure 2b illustrates that while older adults are generally slower than younger adults, motivational incentives are associated with a significant reduction in response times (ms) between baseline and incentive blocks for both older and younger adults. Figure 2c shows accuracy between baseline and incentive blocks. Here, older adults maintained their accuracy between baseline and incentive blocks, whereas younger adults showed a significant drop in accuracy (i.e., they shifted down the speed-accuracy curve to increase reward rate). All error bars in all represent 95% confidence intervals around the mean.

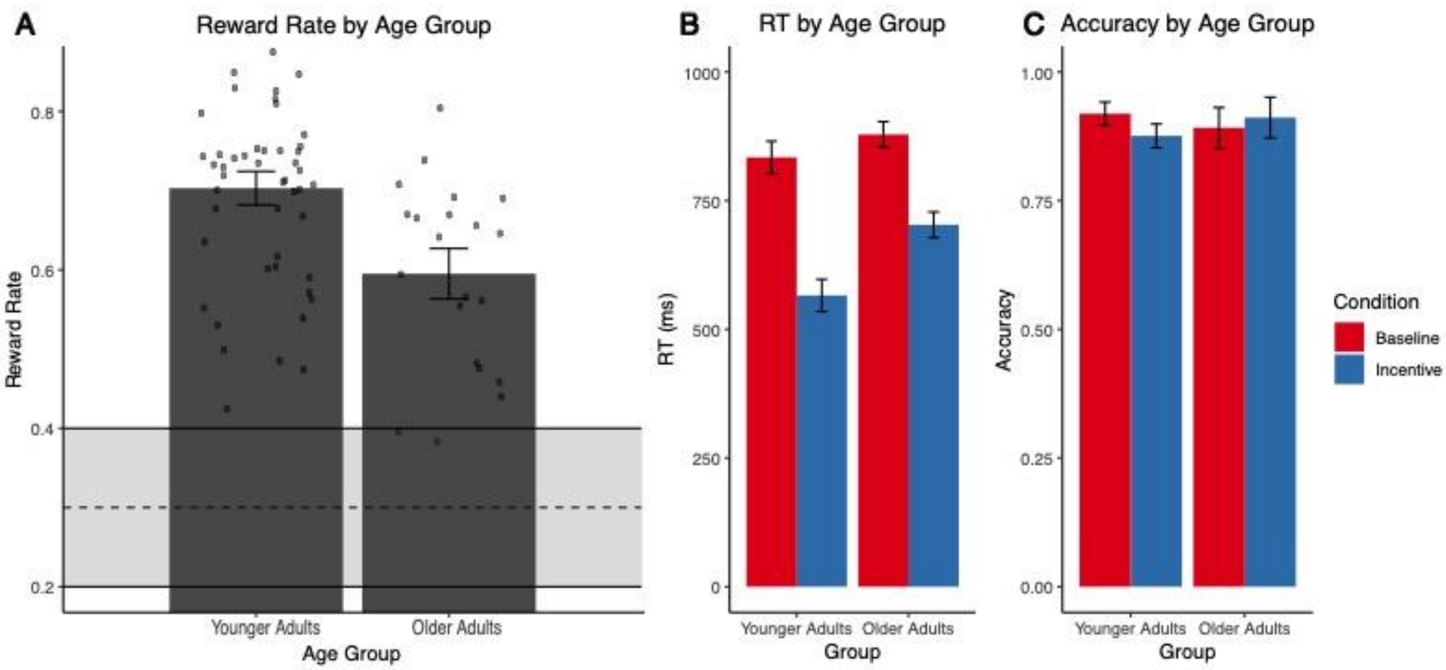


Figure 3. Incentive integration effects by age group.

Figure 3 shows reward rate by monetary reward level and social feedback type for both age groups. Younger adults showed a main effect of monetary reward, but not social feedback on task performance. Older adult task performance was not modulated by either monetary reward or social feedback. Error bars represent 95% confidence intervals around the mean.

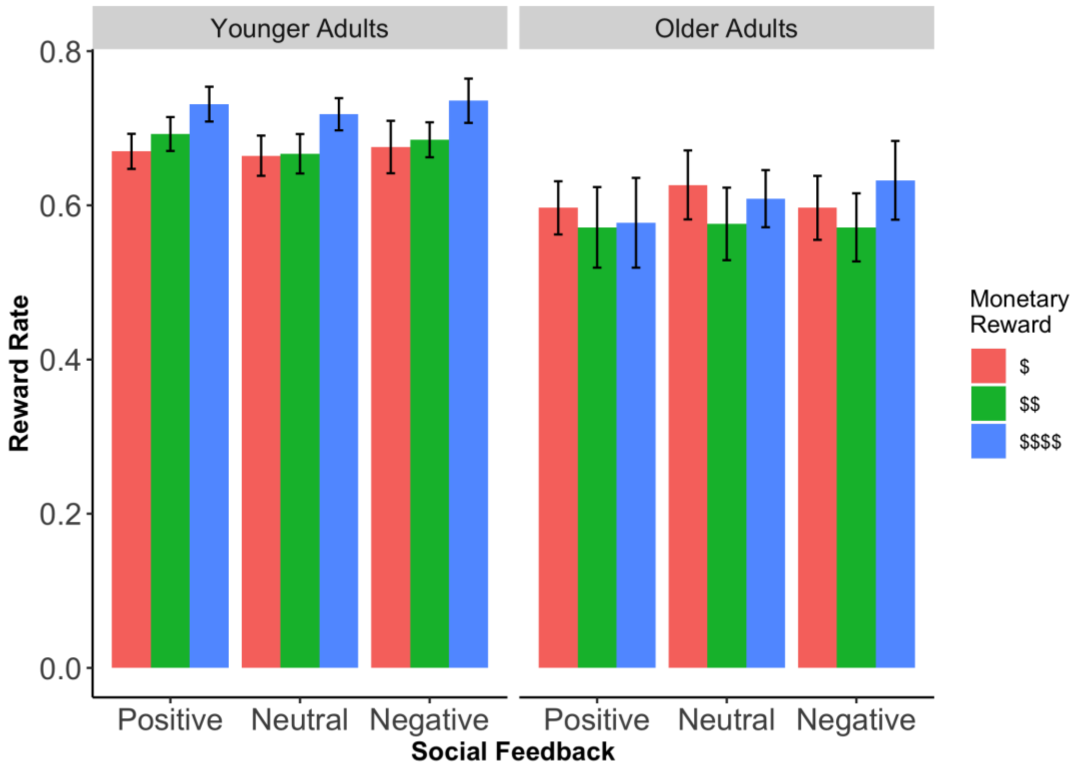


Figure 4. Affect ratings by age group.

Figure 4 illustrates the mean affect rating for each social feedback condition (i.e., positive, neutral, negative) for both age groups. Participants rated the extent to which they were feeling each of the emotion words after each block of the cued task-switching paradigm using a five-point scale (e.g. 1- not at all, 5-extremely). Error bars represent 95% confidence intervals around the mean.

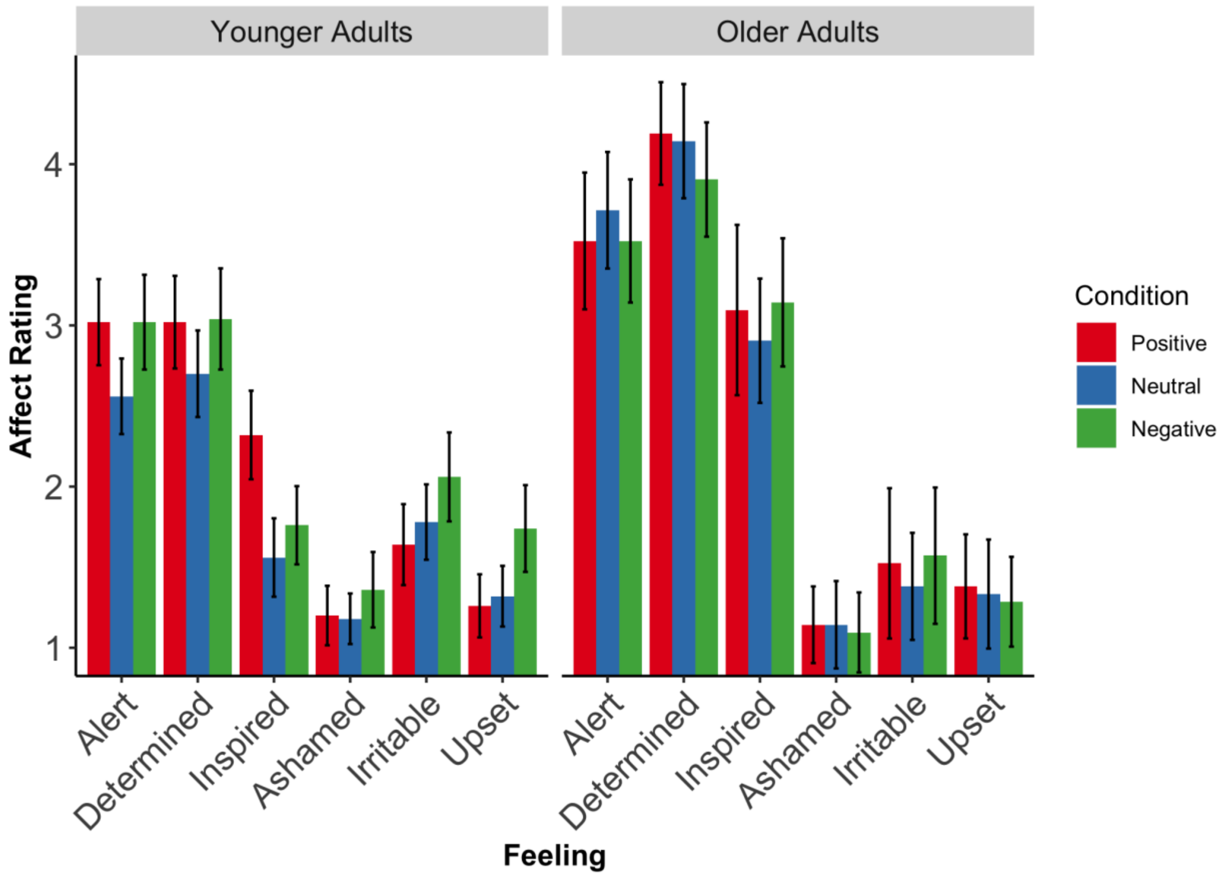


Figure 5. Self-report ratings by age group.

Figure 5 shows the motivation and liking ratings for each of the trial types (e.g., "How motivated were you on the positive-$$ trials?") for both age groups. Participants entered these ratings after task completion using a seven-point scale (e.g., 1- very unmotivated, 7-very motivated). Error bars represent 95% confidence intervals around the mean.

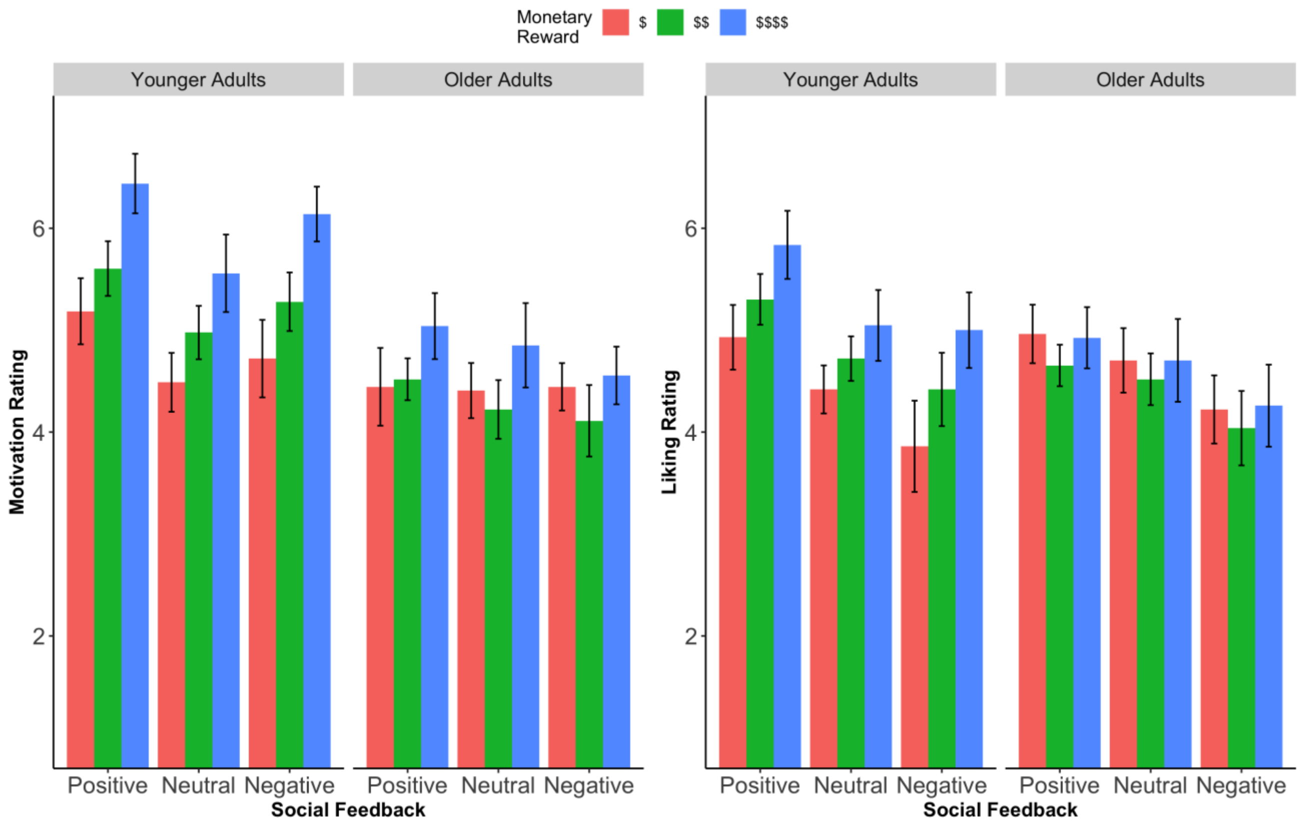


Figure 6. Reward rate by experimental manipulation.

In Figure 6, reward rate is plotted against feedback type. The solid line represents the expected reward rate of 30%, assuming subjects did not improve their performance between baseline and incentive blocks. The dashed lines represent 95% confidence intervals calculated by a binomial test [CI_{lower}=.20, CI_{higher}= .40]. Each dot represents a single subject's average reward rate. Error bars represent 95% confidence intervals around the mean.

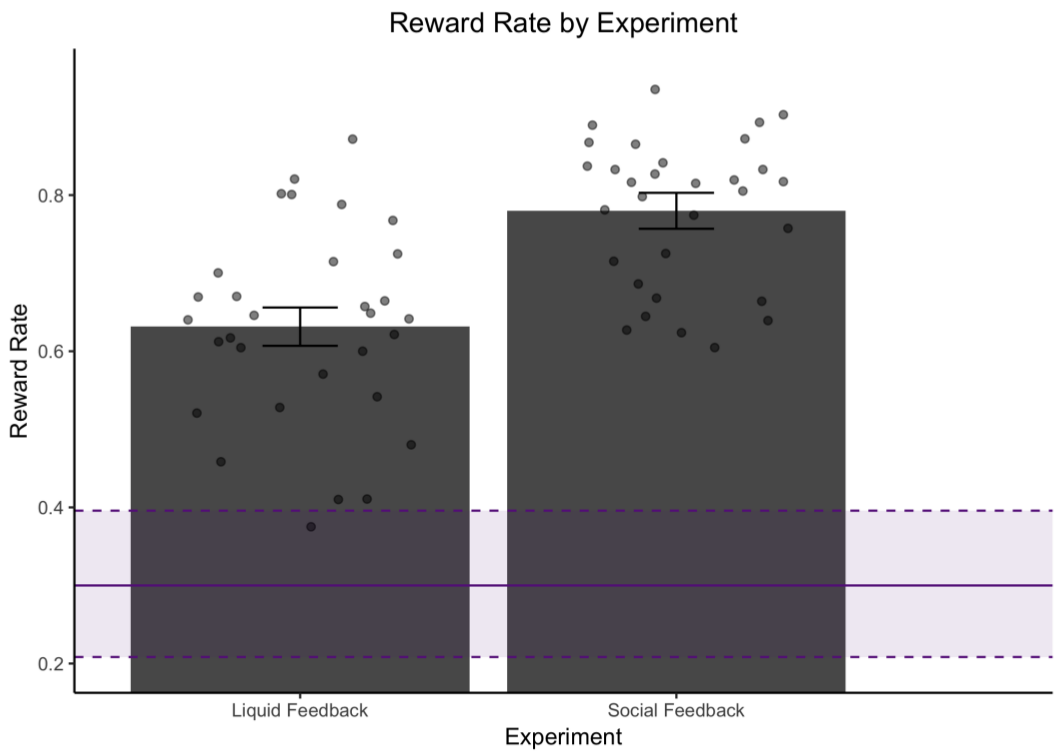


Figure 7. Incentive integration effects by experimental manipulation.

Figure 7 shows reward rate by monetary reward level and feedback (i.e., liquid, social). Participants showed a main effect of monetary reward and feedback during the liquid feedback session. However, there was no main effect of either monetary reward or feedback during the social feedback session. Error bars represent 95% confidence intervals around the mean.

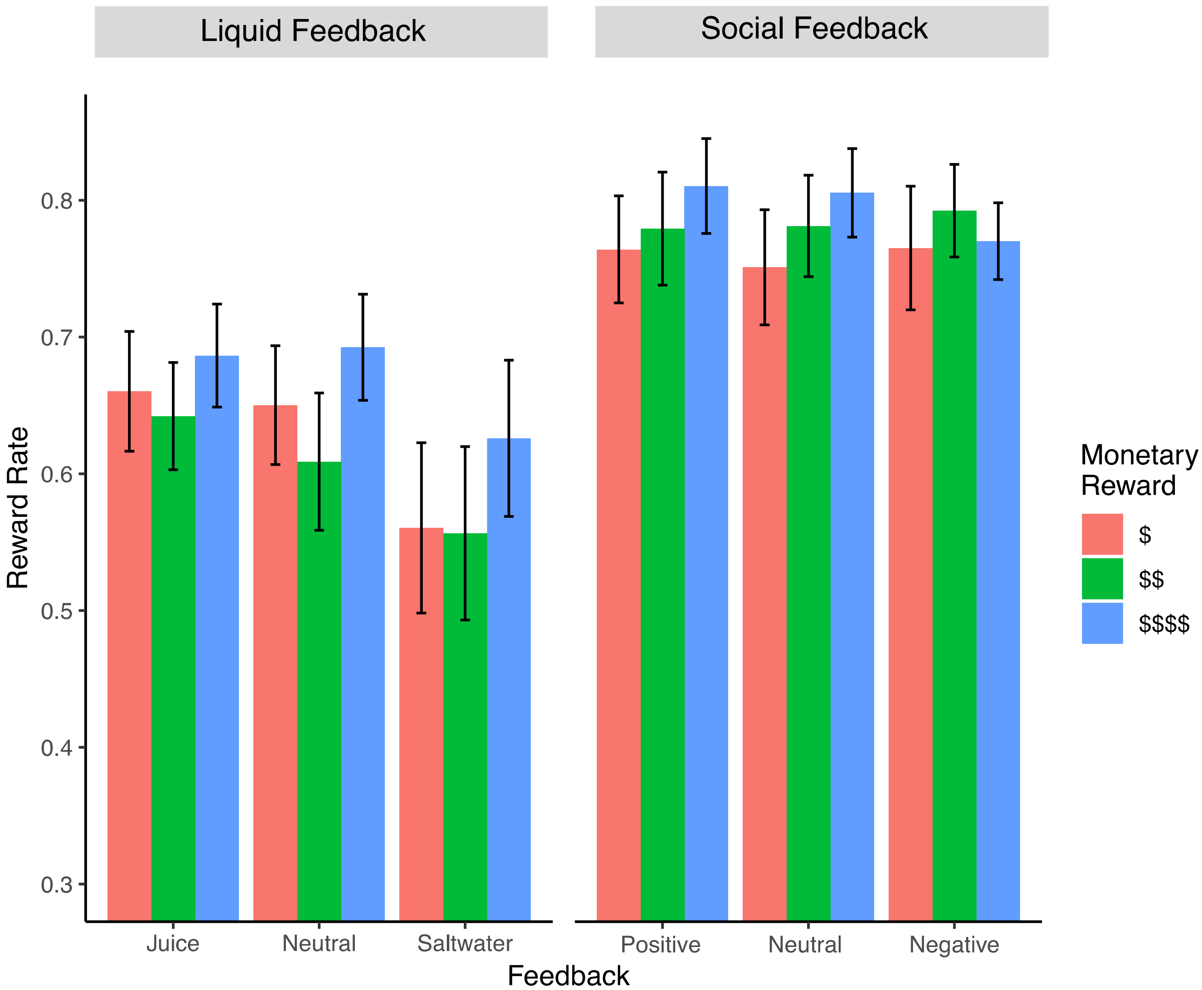


Figure 8. Affect ratings by experimental manipulation.

Figure 8 illustrates the mean affect rating for each incentive condition across both liquid and social feedback sessions. Participants rated the extent to which they were feeling each of the emotion words after each block of the cued task-switching paradigm using a five-point scale (e.g. 1- not at all, 5-extremely). Positive affect represents the average ratings across the following terms: "content", "inspired", and "excited". Negative affect represents the average ratings across the following terms: "ashamed", "irritable", and "upset". Error bars signify 95% confidence intervals around the mean.

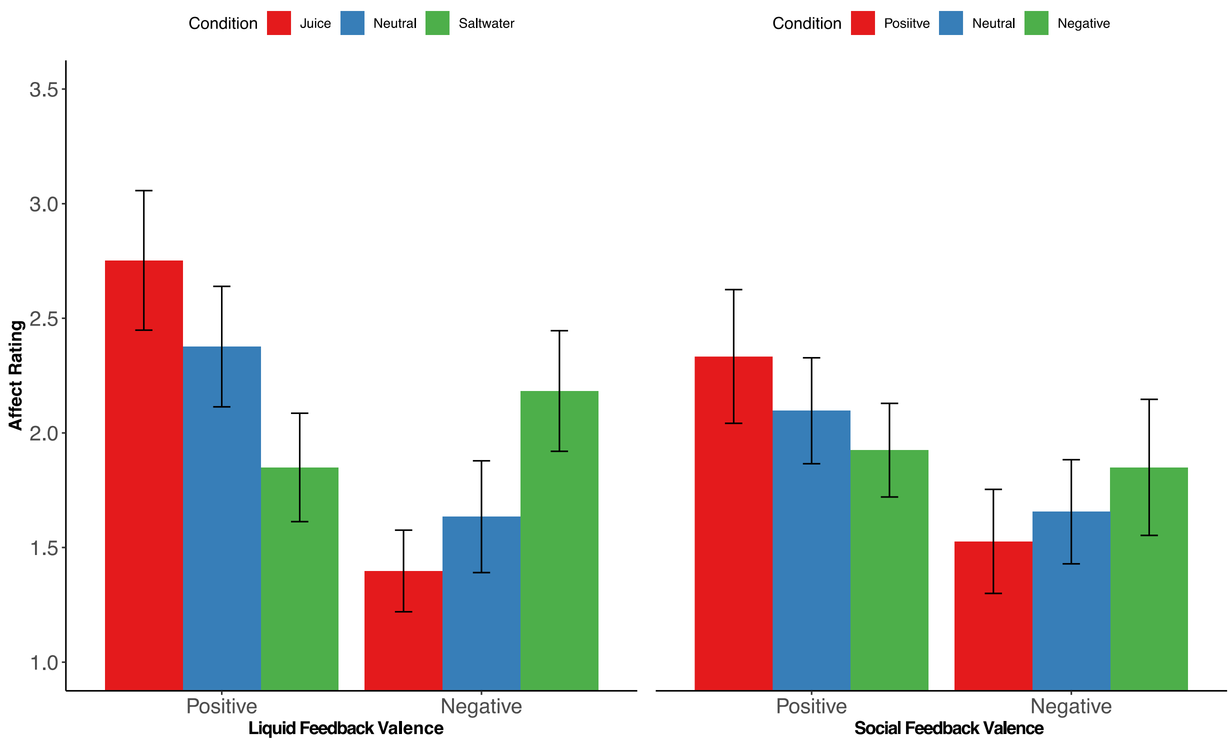
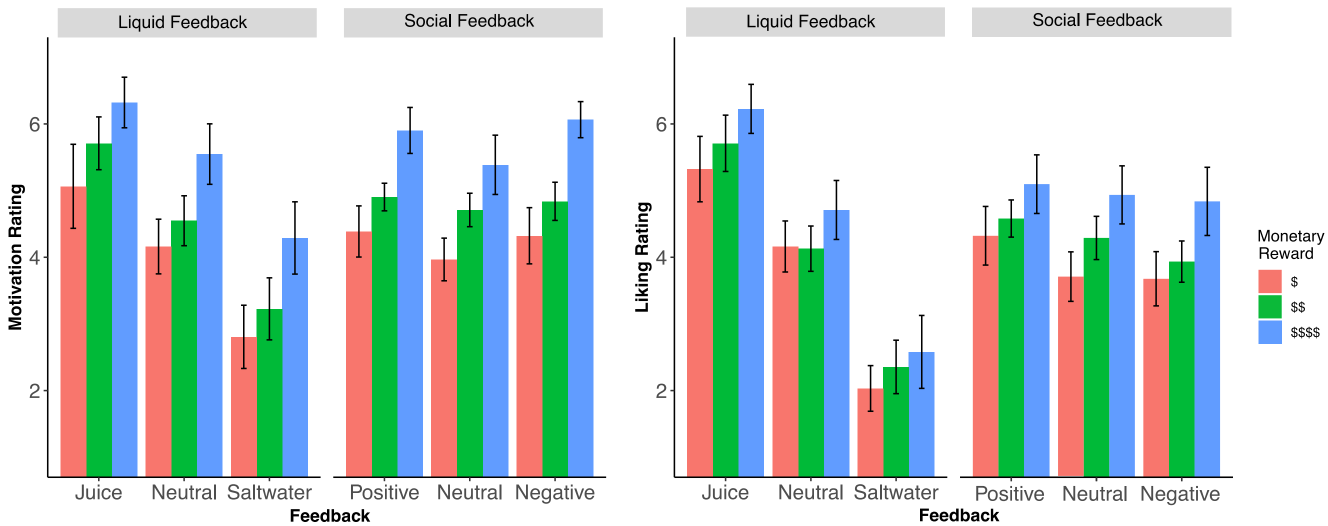


Figure 9. Self-report ratings by experimental manipulation.

Figure 9 shows the motivation and liking ratings for each of the trial types (e.g., "How motivated were you on the positive-$$ trials?") across both incentive types. Participants entered these ratings post-task using a seven-point scale (e.g., 1- very unmotivated, 7-very motivated). Error bars represent 95% confidence intervals around the mean.



Supplementary Material

Supplemental Table 1. Neuropsychological function of older adult participants.

This table provides descriptive information (mean, standrard deviation) for all instruments used in our neuropsychological battery.

Older Adult Neuropsychological Variables

Measures	Mean	SD
MoCA	27.57	1.61
Corsi Finger Tapping–Forward	7.27	1.68
Corsi Finger Tapping–Backward	7.10	1.71
Letter-Number Sequencing	8.60	2.66
Verbal Phonemic Fluency	43.77	11.18
Verbal Category Fluency	19.53	4.61
Trail Making Test–A (s)	32.78	8.54
Trail Making Test–B (s)	80.74	27.37
Stroop–Congruent (ms)	1529.91	334.89
Stroop–Incongruent (ms)	2000.43	588.83
Verbal Paired Associates I–Recall	12.23	8.66
Verbal Paired Associates II–Recall	4.17	2.72
Number Series	5.30	2.31
Shipley Vocabulary	35.50	3.10

Supplemental Table 2. BIS/BAS scale ratings across both age groups.

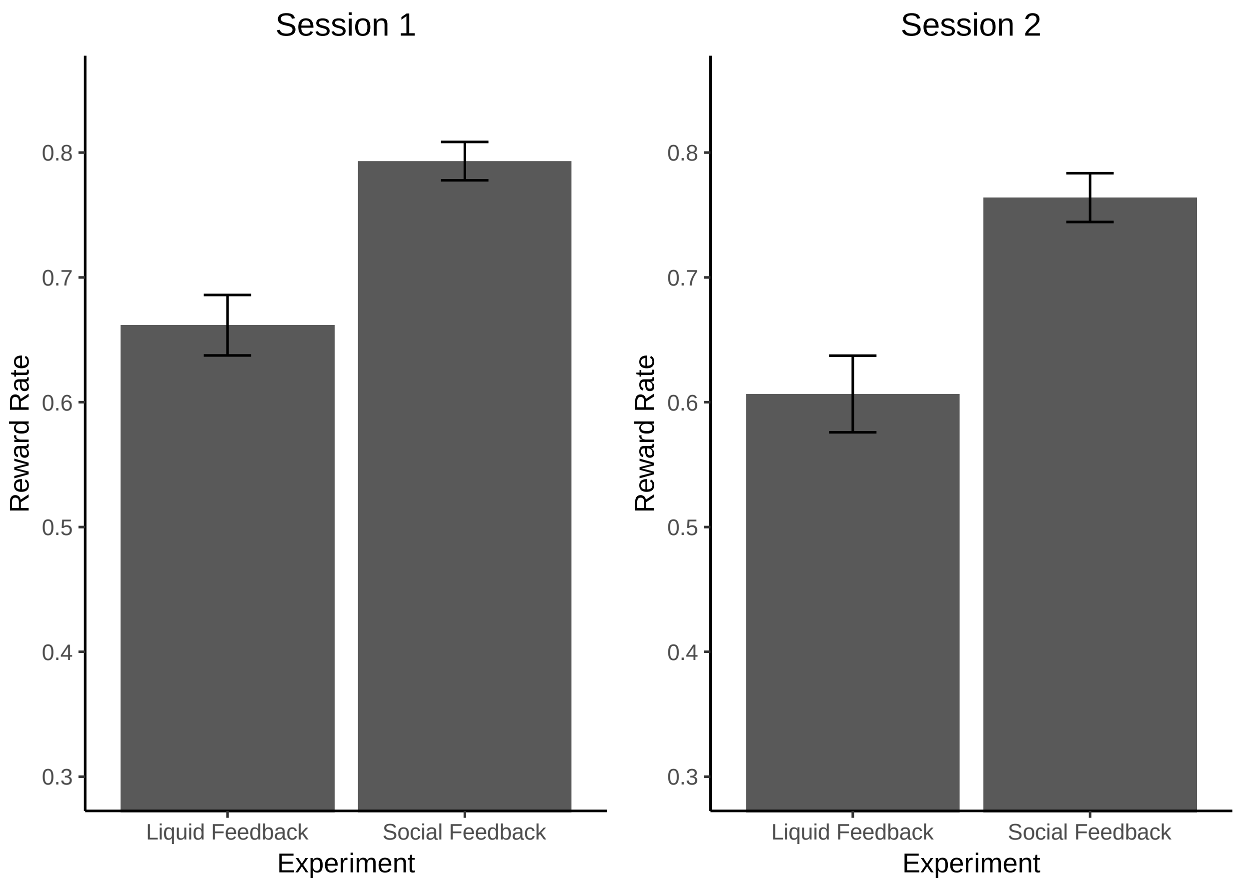
This table provides descriptive information (mean) for the BIS/BAS scale in older and younger adults. Older adults had significantly lower ratings, realtive to younger adults on the the BAS-Drive (p=.0484), BAS-Reward (p=.001), and BIS sub-scales (p=.003). Likewise, older adults also had numerically lower ratings on the BAS-fun sub-scale compared to younger adults, however, this did not reach the level of statistical significance (p=.0933).

BISBAS Scores by Age Group

Group	meanBAS_Drive	meanBAS_Fun	meanBAS_Reward	meanBIS
Older Adults	12.62	13.59	20.34	22.07
Younger Adults	14.49	15.07	22.98	26.37

Supplemental Figure 1. Incentive effects across both experimental visits (Experiment 2).

Reward rate is plotted against feedback type for each session in Experiment 2. Across both sessions, reward rate is higher for social relative to liquid feedback. Further, the mean reward rate is higher for social feedback in session 1 as compared to session 3. Likewise, reward rate is higher for liquid feedback in session 1 relative to session 2. Error bars represent 95% confidence intervals around the mean.



Supplemental Table 3. Affect ratings by experiment and term.

This table provides descriptive information (mean) for each affective term used in experiment 2, across both incentive types (social, liquid).

Feeling	Experiment	meanRating
Alert	Liquid Feedback	3.333333
Alert	Social Feedback	2.956989
Ashamed	Liquid Feedback	1.376344
Ashamed	Social Feedback	1.451613
Content	Liquid Feedback	2.731183
Content	Social Feedback	2.516129
Determined	Liquid Feedback	3.236559
Determined	Social Feedback	3.021505
Excited	Liquid Feedback	2.279570
Excited	Social Feedback	1.935484
Fatigued	Liquid Feedback	2.440860
Fatigued	Social Feedback	2.892473
Inspired	Liquid Feedback	1.967742
Inspired	Social Feedback	1.903226
Irritable	Liquid Feedback	2.053763
Irritable	Social Feedback	1.903226
Stressed	Liquid Feedback	2.021505
Stressed	Social Feedback	2.043011
Upset	Liquid Feedback	1.784946
Upset	Social Feedback	1.677419