# **Examining the Relationships between Delay Discounting, Working Memory, and Fluid Intelligence**

by

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A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Masters of Science

Auburn, Alabama
May 7, 2012

Keywords: delay discounting, working memory, intelligence, attention



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## Abstract

Previous research has suggested a link between working memory, general fluid intelligence, and delay discounting by utilizing traditional behavioral measures. Because both working memory and general fluid intelligence rely on the ability to allocate attention effectively, the current study incorporates eye-tracking methodology to provide a more direct investigation of the relationship that each of these constructs shares with delay discounting. Participants in the current experiment first completed measures of working memory and general fluid intelligence. Next, participants were invited back to the lab to complete the delay discounting task during which time eye tracking was used to assess attentional processing. The current study was the first to measure attentional processing, which has been purported to account for differences in both of these executive processes. However, results from the current study do not provide support that working memory or general fluid intelligence are the mechanisms underlying differences in delay discounting.

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## Examining the Relationships between Delay Discounting, Working Memory, and Intelligence

People are presented every day with many choices. Some choices involve comparisons between options that may result in immediate gratification in contrast to options that require a certain amount of time to elapse before reaping the rewards. For instance, choosing to spend money on a new pool may be immediately gratifying whereas investing the money into a retirement saving account will require many years to yield the desired benefits. People who tend to wait for delayed rewards are considered to engage in delayed gratification (e.g., Mischel, Shoda, & Rodriguez, 1989) whereas those who tend to choose the immediate reward are often considered to be more impulsive (e.g., Kirby & Herrnstein, 1995). Individuals with real-world impulsive behaviors such as substance-abuse addiction (e.g., Kirby, Petry, & Bickel, 1999) and pathological gambling (Dixon, Marley, & Jacobs, 2003; Petry, 2001) exhibit a tendency to choose the immediate rewards more often than non-addicted individuals. The problem of addiction is paramount for an estimated 22.5 million Americans age 12 and older suffer from substance abuse or dependence (Substance Abuse and Mental Health Services Administration: SAMHSA, 2004) and approximately 5.5 million Americans suffer from gambling addictions (National Opinion Research Center at the University of Chicago; NORC, Gemini Research, The Lewin Group, & Christiansen/Cumming Associates; CCA, 1999). Given the magnitude of individuals with substance and/or gambling problems in the United States, it is important to determine which factors may contribute to decisions pertaining to immediate and delayed gratification. Researchers have contended that executive functioning, which generally develops as individuals progress through childhood into adulthood concurrent with prefrontal cortex development, may be related to the ability to delay immediate gratification of smaller rewards in order to obtain a larger reward in the future (Mischel et al., 1989). Working memory and general fluid intelligence (*g*F) are also considered to reflect executive functioning, however, it is unclear whether differences in working memory and *g*F can explain immediate versus delayed decision making processes (Franco-Watkins, Rickard, & Pashler, 2010; Hinson, Jameson, & Whitney, 2003; Shamosh et al., 2008). The proposed study aims to further investigate whether a relationship exists between working memory, *g*F, and decision making by utilizing a delay discounting task which is often used to assess how a person values immediate and delayed rewards. In the next section, the delay discounting task is discussed in detail followed by a brief overview delineating the associations between working memory, *g*F, and delay discounting before presenting the experiment conducted to investigate the relationship between the three constructs.

**Measuring the Ability to Delay Gratification.**

The delay discounting task is a common method to assess immediate and delayed preferences in both animals and humans (Green & Myerson, 2004). The task consists of presenting smaller rewards that are available immediately alongside with larger rewards that are delayed in a certain amount of time, and the person must choose between a smaller immediate reward and a larger delayed reward. Although all individuals eventually switch their preference from the larger delayed reward to the smaller immediate reward, individual differences exist as to when this preference reversal occurs.

This task is often used as an index of one's ability to delay gratification (Rachlin, Raineri, & Cross, 1991). Because placing a value on rewards is subjective, individual differences exist pertaining to the rate with which an individual discounts the delayed rewards. One way to measure individual differences in delay discounting is to examine the proportion of times an individual selects the immediate option relative to the delayed option. Another way to calculate individual differences in delay discounting is by examining an individual's choice preferences using the following hyperbolic function:

$$V = A/(1+kD)$$

Where V indicates the individual's subjective value of the chosen reward, A represents the actual monetary amount, D is the time delay associated with the reward, and k is a free parameter indicating the individual's level of discounting (e.g., Kirby & Maraković, 1995). Although there are several methods to assess discounting (e.g., Green & Myerson, 2004), the hyperbolic function is most widely used with laboratory participants and clinical populations. The standard method used in the delay discounting task is to present immediate rewards incrementally in ascending and/or descending order until a preference reversal occurs for a given delay reward at different time intervals (Rachlin et al., 1991). However, other studies have utilized the psychophysical method of constant stimuli in which the reward options are presented in a random order rather than a sequential presentation (Franco-Watkins et al., 2010; Hinson et al., 2003; Mitchell, 1999). One can argue that the sequential presentation, as opposed to random presentation, requires fewer mental resources (e.g., executive functioning or working memory) because it is easier to maintain mental representations of previous choices in mind, than when they are presented in random presentation. For example, in the current task, sequential presentation may involve presenting immediate rewards of 10 dollars along with a delayed reward of 200 dollars that is available after a given delay (e.g. 1 month). On the next trial, participants would be presented with an immediate reward of 30 dollars with the same 200 dollar reward available after the same delay (i.e., 1 month). The subsequent trials would include immediate values of 50 dollars through 190 dollars in increments of twenty dollars paired with the same delayed reward of 200 dollars at a delay of 1 month. Next, the immediate rewards would begin a new cycle paired with the 200 delayed reward coupled with the next delay (e.g., 6 months). Therefore, the participant only has to attend to the immediate reward and then to the delay only on trials that involve the delay changing. In contrast, a random presentation of reward options is likely to place demands on working memory by eliminating the predictability of the reward and delay presentation. Thus, understanding whether working memory is a factor in delay discounting decisions can help reveal whether less optimal decision making occurs when additional demands are placed on executive functions or working memory.

**Working Memory.**

Working memory was originally construed as a multi-component system capable of processing and storing information and often requires higher-order cognitive processes such as reasoning, learning and comprehension (Baddeley, 2003). Baddeley and Hitch's (1974) conceptualization of the working memory system distinguished working memory from short-term memory. More specifically, short-term memory only accounts for storage capacities associated with information presented and maintained for a brief amount of time, but does not account for the ability to manipulate information simultaneously while storing information. Engle, Tuholski, Laughlin, and Conway (1999) demonstrated that short-term memory was distinguishable from working memory because only the residual variance of working memory tasks correlated with measures of other cognitive constructs (i.e., *g*F) that involve executive functions. The authors contend that the underlying mechanism responsible for the relationship between working memory and *g*F was the ability to control attention. However, there is some disagreement regarding the strength of the relationship between working memory and *g*F (e.g., Ackerman, Beier, & Boyle, 2005; Kane, Hambrick, & Conway, 2005). Ackerman et al. (2005), as well as Kane et al. (2005) reject the contention that working memory and general reasoning ability or *g*F are isomorphic as implied by (Engle, 2002). However, Kane et al. (2004) report that confirmatory factor analysis revealed that working memory tasks reflect a domain-general ability capable of predicting scores on measures of *g*F. Nevertheless, several studies have demonstrated individual differences in the ability to control attention in studies involving both constructs. Some of the studies investigating individual differences in working memory and *g*F as they relate to the ability to control attention will be discussed below. I will begin by describing some of the findings related to individual differences in working memory and then discuss similar studies examining *g*F.

**Individual differences in working memory.** Several working memory studies have demonstrated individual differences in the ability to control attention. For example, the ability to control attention can involve inhibiting irrelevant information and selectively attending to task-relevant information (Conway, Cowan, & Bunting, 2001). Conway et al. had participants engage in a dichotic listening task where different auditory information is presented in each ear. Their results revealed that individuals with higher working memory (HWM) were able to selectively attend to auditory information in one ear (task-relevant information) while inhibiting auditory information presented in the other ear (task-irrelevant information) more effectively than individuals with lower working memory (LWM). Turner and Engle (1989) demonstrated that working memory is also related to maintaining goal-relevant information in memory while completing a secondary task. Individual differences in working memory also predict susceptibility to proactive interference (Kane & Engle, 2000; Rosen & Engle, 1998). Kane and Engle presented participants with a series of words from the same category (e.g., animals) to induce proactive interference and a secondary task to prevent rehearsal (i.e., finger tapping) and found that HWM individuals were able to accurately recall more words relative to individuals with LWM. Furthermore, individuals with HWM are better able to avoid interference during the Stroop Task relative to individuals with LWM (Kane & Engle, 2003). In essence, individuals who are deemed to have HWM, as measured by complex span tasks such as Reading Span Task and Operation Span Task, are able to control attention better than individuals with relatively LWM.

Individuals with HWM also exhibit better reading, listening, language comprehension, following directions and learning vocabulary, taking notes, writing and reasoning more proficiently than individuals with relatively LWM (Engle, 2002). Evidence from both cognitive and neuropsychological examinations concur that the ability to control attention provides the basis for investigating individual differences observed on complex span tasks (McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010). The central role of attention on measurements of executive functioning necessitates methods for measuring attention allocation during investigations of constructs such as working memory and *g*F. Contemporary researchers have utilized eye-tracking technology to investigate attentional processing (Rayner, 1998).

**Attention and eye movements.** There is ample evidence that eye movements are related to attentional processing. For example, Deubel and Schneider (1966) posited that shifts in attention are directly coupled with eye movements. Similarly, Hoffman and Subramaniam (1995) required individuals to make a saccade to a one of four possible locations on a computer screen and assessed whether the individuals could detect a string of letters presented immediately before the saccade. Accuracy for detecting the letter strings was higher when presentation of the letters coincided with the location of the saccade. Hoffman and Subramaniam interpreted their results as evidence that individuals are incapable of moving their eyes to one location and attending to another location on a computer screen. Eye-tracking technology also provides researchers with the capabilities to measure mental effort by examining pupil dilation for memory load (e.g. Kahneman & Beatty, 1966; Karatekin, Couperus, & Marcus, 2004). Kahneman and Beatty (1966) reported that pupil dilation corresponded to task difficulty during a short-term memory task, with larger changes in pupil dilation corresponding to more difficulty in the task. Similarly, Karatekin et al. (2004) reported that pupil dilation increased linearly as the length of a to-be-remembered digit span was increased, as well as when a second task was added to increase the amount of mental effort required for efficiently completing the task. Heitz, Schrock, Payne, and Engle (2008) administered a complex span task and pupil dilation indicated that LWM individuals actually exert more effort than HWM individuals during the task although performance is better for the HWM individuals. These findings would suggest that working memory is related to the amount of effort required to complete a task and that HWM individuals potentially allocate their attention more efficiently than LWM individuals, allowing HWM individuals to exert less mental effort yet perform more efficiently. Additionally, pupils tend to dilate more when individuals view items that are deemed pleasant (e.g. mothers and babies) relative to images that may be deemed less pleasant (i.e. landscape: Hess & Polt, 1960). Therefore, eye-tracking methodology provides an avenue for examining the amount of attention to potentially pleasant stimuli (e.g., monetary rewards) as well as individual differences in working memory in the delay discounting task.

**General Fluid Intelligence and Attention**.

As previously mentioned, a related construct to working memory is *g*F, defined as reasoning ability that allows some individuals to solve novel problems and reflects an ability that is generally non-verbal and free from cultural bias (Horn and Cattell, 1967). Previous research indicates some inconsistencies regarding the relationship between *g*F and attentional processing. Kahneman, Ben-Ishai, & Lotan (1973) reported that ability to engage in selective attention in the dichotic listening task was not related to *g*F. However, other researchers have utilized the same methods and reported a relationship between selective attention and *g*F (Arthur, Barrett, & Doverspike, 1990). Similarly, some researchers have suggested that there is no relationship between *g*F and the ability to avoid interference on the Stroop task (Wolitzky, Hofer, & Shapiro, 1972), although other researchers contend that a relationship does exist between performance on the Stroop task and *g*F (Silverstein & Franken, 1965). Furthermore, Blanco & Alvarez (1994) found no relationship between *g*F and the ability to focus attention to a target stimulus while ignoring a distractor stimulus presented simultaneously. However, the ability to focus attention on a speeded classification task requiring individuals to sort cards on one dimension while ignoring another dimension has been suggested to be related to *g*F (Smith & Baron, 1981). Research has demonstrated a relationship between both working memory and *g*F with the ability to control attention (Engle et al., 1999). Blanco and Alvarez suggest that the lack of consistent results regarding the relationship between *g*F and attention may suggest that only a moderate correlation exists. Therefore, it is important to investigate the relationship between working memory, *g*F, and attention using methods that provide a more direct assessment of attentional processing.

**The Relationship Between Working Memory and General Fluid Intelligence with Delay Discounting**

Previous investigations of brain functioning may suggest that each of these constructs also shares a relationship with impulsive decision making. More specifically, frontal lobe functioning is critical for working memory (Duncan, 1995; Pennington, 1994), as well as gF (Duncan, Burgess, and Emslie, 1995) and there is evidence suggesting that individuals with damage to the ventromedial prefrontal cortex (Bechara, Damasio, Damasio, & Anderson, 1994) demonstrate impulsive decision making. Using normal individuals (i.e., without brain damage and without substance-abuse addictions), some researchers found support that working memory (e.g., Hinson et al., 2003) and gF (Shamosh et al., 2008) are related to more impulsive decision making on the delay discounting task. However, other researchers do not find support for this relationship (Franco-Watkins et al., 2010).

**Evidence supporting relationship.** In support of a relationship between working memory and delay discounting, Hinson et al. (2003) reported that performing a secondary task in addition to the delay discounting task produced a noticeable decrement in performance relative to control conditions (in absence of a secondary task). Participants in their study were presented with a string of five randomly generated numbers (e.g., 36251) before each delay discounting trial and then they were prompted to recall one of the numbers after each trial (e.g., recall the number to the right of 2). Hinson et al. hypothesized that the secondary task (digit memory load) would directly interfere with working memory by consuming attentional resources (i.e. taxing working memory) that would otherwise be allocated to the delay discounting task. Their findings revealed that the rate of discounting (as measured by *k* values) was higher when the secondary task was completed with the delay discounting task relative to when the delay discounting task was completed alone. They interpreted their findings as evidence that working memory may be related to the ability to delay gratification because adding the secondary task presumably taxed the limited capacity of working memory and resulted in more impulsive choices.

Researchers have extended the investigation between working memory and delay discounting to include the potential relation to *g*F. Shamosh and Gray (2008) conducted a meta-analysis and reported that higher *g*F was associated with lower levels of delay discounting across 26 studies. Furthermore, in another study, Shamosh et al. (2008) conducted a study examining measures of working memory, *g*F, and delay discounting. The results indicate that only the relationship between *g*F remained significant when delay discounting was regressed simultaneously on working memory (assessed using a n-back task: Shamosh et al., 2008). Furthermore, working memory did not contribute any unique variance to delay discounting although *g*F shared 35% of the variance with working memory. These results support the contention that although working memory and *g*F are related constructs, they are not isomorphic (Conway, Kane, & Engle, 2003) and may be differentially related to observable differences on the delay discounting task.

**Evidence not supporting relationship.** Other researchers found evidence that contradicts the interpretation provided by Hinson et al. (Franco-Watkins, Pashler, & Rickard, 2006; Franco-Watkins et al., 2010). Specifically, after correcting for a response bias found in the stimuli used by Hinson et al., Franco-Watkins et al. (2006) provided support against the interpretation that taxing working memory leads to more impulsive decision making. In a reanalysis of the data, it was evident that the majority of participants chose the delayed option under single-task conditions (when the delay discounting task was presented alone). Therefore, random responding under dual-task conditions (when a secondary task was presented with the delay discounting task) would appear to be more impulsive as participants' responses regressed towards equally choosing each option (Franco-Watkins et al., 2006). Furthermore, this interpretation was supported in a study that taxed working memory with a demanding secondary task which resulted in more random responses and not more impulsive decision making on the delay discounting task (Franco-Watkins et al., 2010).

**Rationale for Current Study**

Performance on the delay discounting task has been reported to be related to both working memory and *g*F (Shamosh et al., 2008) when utilizing sequential presentation methods, in which participants only have to attend to a maximum of four items on this decision task. Previous research has demonstrated that working memory has a capacity of approximately four items (Cowan, 2001). Because the sequential method does not exceed the demands of working memory, a random presentation of reward options (e.g., Franco-Watkins et al., 2010) may be more likely to result in proactive interference and demonstrate a stronger relationship with working memory and *g*F by placing more demands on attentional resources. Therefore, a stronger relationship should be found when using random versus sequential presentation methods. Unlike sequential presentation of reward options, random presentation should require that individuals allocate attention to previous decisions to maintain consistent choices. The current experiment includes both presentation methods to determine whether presenting the rewards in random fashion demands more cognitive resources than sequential presentation. If so, the relationship between working memory and *g*F with delay discounting should be augmented when items are presented randomly.

More importantly, although previous experiments have reported a relationship between working memory, *g*F and delay discounting (Hinson et al., 2003; Shamosh et al., 2008), *attention*, which is the central mechanism postulated to underlie observed differences in working memory (Engle, 2002), has yet to be adequately examined in understanding the relationship between working memory, *g*F, and delay discounting. The current experiment was the first study to incorporate eye-tracking methodology as a means of directly investigating the potential role of attentional processing on the delay discounting task. Utilizing eye-tracking technology provides valuable insight concerning the mechanisms responsible for producing different patterns of discounting between individuals who display various levels of cognitive abilities as measured by traditional working memory and *g*F tasks. The current experiment recorded eye movements and pupillometic data to determine whether individual differences in working memory and *g*F regarding predict attentional processing and responses in the delay discounting task.

**Hypotheses**

**Hypothesis 1***:* Working memory and *g*F are related constructs, and this relationship will predict immediate choices and the rate of discounting in the delay discounting task. Individuals with lower working memory and lower *g*F should demonstrate more discounting of delayed rewards relative to individuals with higher working memory and *g*F.

Previous research has also demonstrated that working memory is related to the number of inconsistent (intransitive) responses (e.g. Franco-Watkins et al., 2010). An intransitive response can be defined as a response that is inconsistent with a previous choice made by that individual. For example, suppose that a participant chooses an immediate reward of 10 dollars that was paired with a 200 dollar reward available after a delay of 1 month. However, on another trial, the participant choses the delayed reward of 200 dollars available after the same delay of 1 month instead of a larger immediate reward of 30 dollars. This type of response would be considered intransitive because the participant is inconsistent and violates the assumption of coherence.

**Hypothesis 2**: Because working memory and *g*F are considered to be related constructs, both constructs should be related to the number of intransitive responses such that LWM and *g*F individuals should produce more intransitive responses than HWM and *g*F individuals. Furthermore, because random presentation of rewards should require more attentional resources, there should be more intransitive responses with the random presentation method than the sequential presentation method.

Additionally, because working memory has a limited capacity and random presentation requires individuals to hold more information in working memory than sequential presentation, individuals should take longer to make choices (longer response latencies) in the random presentation method compared to sequential presentation method.

**Hypothesis 3**: Response latencies (henceforth called reaction times) on the delay discounting task will be longer during random presentation of reward options than during sequential presentation because random presentation will place more demand on working memory.

Working memory and *g*F also share a relationship with attentional processing. Therefore, individuals who demonstrate a stronger preference for immediate gratification should allocate more attention to the reward options associated with immediate gratification (as measured by placing eye on cells associated with immediate reward). Specifically, individuals with a preference for immediate gratification (i.e. LWM) should display more fixations and shorter fixation durations to the immediate options relative to individuals postulated not to exhibit as much impulsive responding (i.e., HWM). Individuals with HWM and gF should display longer, yet fewer fixations, because these individuals are typically encode new information more efficiently.

**Hypothesis 4**: Individuals with LWM and *g*F should display more fixations and spend less time attending to the immediate reward option relative to individuals with higher working memory and *g*F.

Searching between reward options would indicate that the individual is considering both options equally before making their decision. However, individuals with LWM and *g*F should demonstrate a preference for immediate gratification and should not consider the delayed options as often as individuals who do not display a preference for immediate gratification. As a result, LWM and *g*F individuals should demonstrate a tendency to search more within the immediate option relative to HWM and *g*F individuals.

**Hypothesis 5**: Individuals with LWM and *g*F should exhibit search patterns indicative of more searching within reward options than between reward options relative to individuals with HWM and *g*F.

Finally, because pupil dilation typically increases when individuals view an item that they deem pleasant, individuals with a preference for immediate gratification (i.e., individuals with LWM and gF) should also display increased dilation when viewing immediate rewards relative to delayed rewards that they would consider less appealing. Difference scores for the average pupil dilation when viewing the immediate reward versus delayed rewards will be used as the dependent variables to determine whether differences exist between individuals with HWM and *g*F with LWM and *g*F.

**Hypothesis 6:** Because individuals with LWM and *g*F are predicted to select immediate options more often than individuals with HWM and *g*F, individuals with LWM and *g*F can be assumed to deem the immediate reward as more pleasant than the delayed reward. HWM and *g*F individuals, however, should not deem the reward as pleasant given that they are not predicted to choose the immediate option as often as LWM and *g*F individuals. Therefore, individuals with LWM and *g*F should demonstrate increased pupil dilation when viewing immediate rewards versus delayed rewards relative to individuals with HWM and *g*F.

## Method

### Participants

Fifty-eight Auburn University undergraduate students participated in the experiment[1]. Each participant was awarded extra credit for their participation to be applied towards a psychology course.

### Design

The current experiment employed a 2 (delayed reward amount) x 2 (random versus sequential presentation) within-subjects design. Whether participants received random versus sequential presentation methods first was counterbalanced across participants. There were 29 participants who received the random condition first and 29 participants who received the sequential condition first. Additionally, measures of working memory (OSPAN) and *g*F (Raven's Advanced Progressive Matrices) were collected per participant.

### Materials

**Automated Operational Span Task**. Participants completed an automated version of the operational span (OSPAN) task as a measure of their working memory (Unsworth, Heitz, Schrock, and Engle, 2005). In the OSPAN, participants indicated whether a math equation (e.g., (8/2) – 1 = 3?) was true or false and then a letter was displayed.  . Participants completed a total of 75 math plus letter trials, with 3-7 math plus letter trials in a set. After a set was completed, the participant was prompted to recall all the letters in the exact serial position. Scoring on the

[1] Initially, more participants were recruited for the experiment. However, participants were excluded who did not meet the accuracy criteria on the O-span task and/or did not attend to the screen for the decision task (n = 27).

task reflects correct letter recall while maintaining at least 85% accuracy on the math portion of the task. Individual differences in working memory were calculated by summing the total number of letters correctly recalled on trials in which participants correctly recalled all of the letters in serial order.

**Ravens Progressive Matrices**. Participants completed a short version of the Raven's Advanced Progressive Matrices (APM; Arthur & Day, 1994). The APM consists of 12 matrix problems that increase in difficulty as the task progresses. The task took approximately 15 minutes to complete. Scores for the APM were calculated by summing the total number of correct responses across matrix problems.

**Delay Discounting Task**. The delay discounting task consisted of two options on a computer screen. The first option is always a smaller reward that is available now and the second option is a larger reward that is delayed in time. Option 1 was always displayed on the left of the screen and Option 2 was always displayed on the right of the screen and participants pressed the "1" key on the keypad for Option 1 or the "2" key on the keypad for Option 2 to indicate their choice. The task consisted of six blocks of trials. However, only four blocks of trials were used in the analyses because performance in the ascending conditions did not produce enough eye-tracking data to allow computation of summary data that could then be analyzed. Therefore, the results from the current study are based on two blocks of descending trials ($200 descending and $40,000 descending), as well as two blocks of random trials ($200 random and $40,000 random). There was a $200 delayed reward condition in which participants were presented with immediate rewards ranging from $10 to $190 in $20 increments (10 total immediate reward amounts) and a $40,000 delayed reward condition with immediate rewards ranging from $2,000 to $38,000 in increments of $4,000 (10 total amounts). The delayed rewards for each condition were presented at seven delays: 1 month, 6 months, 1 year, 2 years, 3 years, 5 years, and 8 years (7 total temporal delays).

**Apparatus**. Eye-tracking variables were recorded for each participant during the delay discounting task. The current experiment incorporated a Tobii 1750 eye tracker with E-prime extensions for Tobii software. The eye tracker had a 17" monitor with 1024 x 768 voxels.The eye-tracker had a sampling rate of 50Hz, spatial resolution of 0.5° and calibration accuracy of 0.5°. Variables of interest to the current study that were collected include eye position, pupil size and validity scores recorded every 20 milliseconds. The ratio of invalid recordings to total rows of data collected was used to determine if the participants' eye-tracking data could be used for analyses. Participants with 30% or more invalid trials were excluded from the study[2].

**Eye-tracking variables computations**. The current experiment calculated fixations based on when the participants' eyes were fixated on a predefined area of interest (rewards and delays), and the average time that the individual fixated on a given area of interest. Areas of interest were four total areas with one area surrounding each of the rewards and each of the delays. The size of these areas of interest was approximately 256 voxels by 138 voxels. Fixations were calculated by averaging the duration from the onset of when participants' eyes entered a given area of interest and the time at which their pupils left that particular area of interest.

The current study utilized a similar method used by Payne, Bettman, and Johnson (1988) to determine search patterns for each individual during the discounting task (referred to in the current experiment as PBJ index). Payne, Bettman, and Johnson (1988) used the following equation to calculate search indices:

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[2] The majority of participants produced invalid eye-tracking data for the ascending reward presentation condition. Therefore, the descending condition was the only condition used for all analyses related to sequential presentation of rewards.

$$\frac{\text{Number of between option searches} - \text{number of within option searches}}{\text{Number of between option searches} + \text{number of within option searches}}$$

Essentially, scores range from -1 to 1 and calculation of the search index is produced by subtracting the number of searches within a given option from searches between options and dividing that number by the sum of searches within and between option 1 and option 2. Negative search index values indicate search strategies within (e.g., immediate reward and time) whereas positive search index values indicate search strategies between options (between immediate and delayed options).

**Procedure**

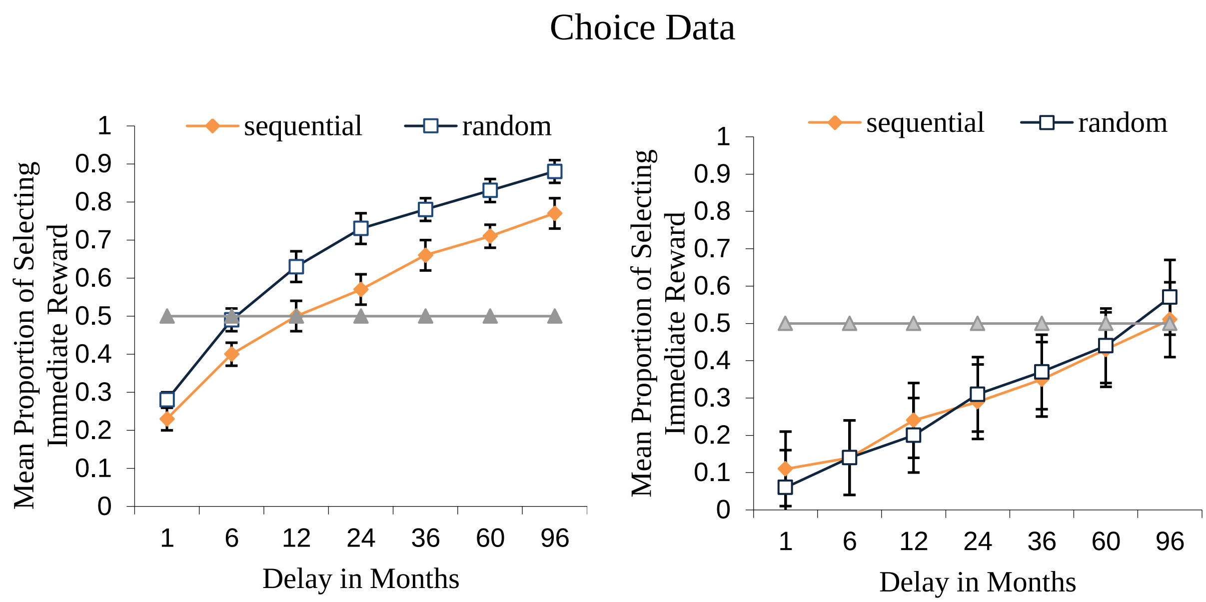
Participants completed the experiment in two separate sessions. During the first session, participants completed the OSPAN and APM to obtain scores for working memory and *g*F, respectively. Participants were then invited to complete the second session at a later date. During the second session, participants were randomly assigned to one of the counterbalanced conditions where they completed either the random presentation method of the delay discounting task first followed by the sequential method second or the sequential presentation method of the delay discounting task first followed by the random presentation method. The experimenter then briefly described the task. Participants were informed that they would be presented with a series of choices and that there were no right or wrong answers, and they should simply indicate their preference. Participants were also informed that there eye movements were being recorded during the task. Before the task began, we calibrated each participant's eye movements to the eye tracker. Participants were then administered a PowerPoint presentation that included detailed instructions for completing the task and instructed to ask the experimenter for clarification if any instruction were unclear. Participants then began the task by completing three practice trials, during which time they were encouraged to ask the experimenter for clarification if the task instructions were not clear.

## Results and Discussion

In order to ensure that presentation order (random first or sequential first) did not affect choices, First, a 2(random presentation vs. sequential presentation) x 2 (counterbalanced condition: random first vs. sequential first) ANOVA with the proportion of selecting the immediate option as the dependent variable for the $200 and $40,000 delay amounts was conducted. The results revealed that there was no effect of presentation order for either the $200, $F$ (1, 56) = .00, $p$ > .05, $\eta_p^2$ = .00, or $40,000, $F$ (1, 56) = 2.92, $p$ > .05, $\eta_p^2$ = .02, delay amounts. In addition to the proportion of immediate reward option selections, levels of discounting can also be calculated with the hyperbolic function discussed in Green and Myerson (2004) to produce (*k*) values as the dependent variable. A 2(random presentation vs. sequential presentation) x 2 (counterbalanced condition: random first vs. sequential first) ANOVA was also conducted with (*k*) as the dependent variable to ensure there were no order effects for the $200 and $40,000 delay amounts. The results again revealed that there was no effect of presentation order for either the $200, $F$ (1, 56) = .27, $p$ > .05, $\eta_p^2$ = .00, or $40,000, $F$ (1, 56) = .19, $p$ > .05, $\eta_p^2$ = .00, delay amounts. Therefore, subsequent analyses will be collapsed across the two presentation orders.

As an additional analysis, Figure 1 displays the mean proportion of selecting the immediate option for the $200 and $40,000 delay amounts at each of the 7 delays for random and sequential presentation methods. As depicted in the graphs, repeated measures ANOVAs with presentation method, delay amount, and temporal delay as repeated variables revealed that individuals discount the delayed rewards at a higher rate for the $200 delay amount relative to the \$40,000 delay amount, $F$ (1, 57) = 224.50, $p < .01$, $\eta_p^2 = .80$, which is consistent with the finding that lower amounts of money are discounted at a greater rate than larger amounts (e.g., Green, Myerson, & Ostaszewski, 1999). Delay amounts were also discounted more in the random presentation method, $F$ (1, 57) = 10.24, $p < .01$, $\eta_p^2 = .15$, compared to delay amounts in the sequential presentation method. Additionally, delay amounts were discounted more at longer delays than shorter delays, $F$ (6, 342) = 186.53, $p < .01$, $\eta_p^2 = .77$. There was also a significant interaction between the temporal delay and the delay amount, $F$ (6, 342) = 10.00, $p < .01$, $\eta_p^2 = .15$, with individuals showing larger differences in discounting beginning at a delay of 6 months for the \$200 delay amount relative to similar responding for the \$40,000 delay amount, which only differed significantly at the final delay of 8 years. A significant interaction was also observed between random and sequential presentation methods and the temporal delay, F (6, 342) = 3.29, $p < .01$, $\eta_p^2 = .05$. Participants in the random presentation method began discounting the rewards greater at early delays, but after approximately 24 months the slopes for the random and sequential presentation methods began to converge. Lastly, an interaction was observed between random and sequential presentation methods and delayed delay amount (\$200 versus \$40,000), $F$ (1, 57) = 20.55, $p < .01$, $\eta_p^2 = .26$. A paired t-tests revealed that the proportion of selecting the immediate option for the two presentation methods pertaining to the \$40,000 delay amount were very similar, $t(57) = 0.18$, $p > .05$, $d = 0.00$, whereas the \$200 delay amounts were significantly different overall, $t(57) = -4.78$, $p < .01$, $d = -0.45$.

*Figure 1*. Mean proportion of selecting the immediate reward in the $200 (left panel) and $40,000 (right panel) delay amounts for each of the seven temporal delays.




**Working memory and *g*F**

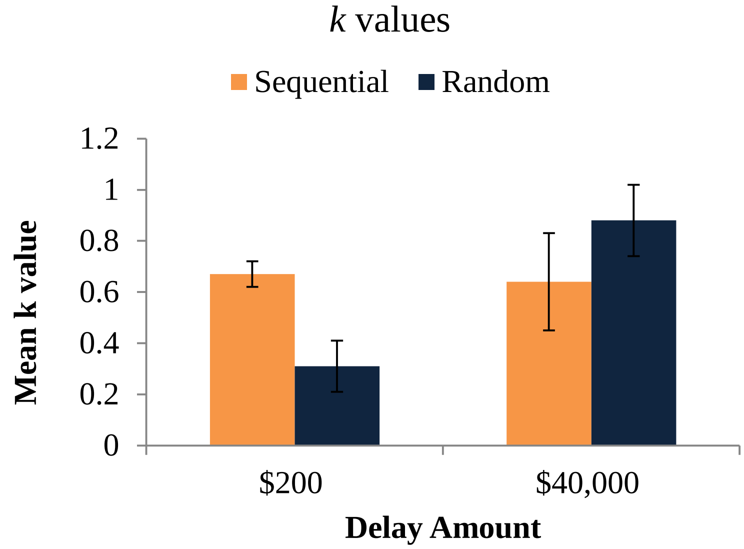
Hypothesis 1 stated that based on previous research that has suggested working memory and *g*F are highly related constructs and that both working memory and *g*F should share a relationship with differences in delay discounting. In the current experiment, there was no relationship observed between the OSPAN and APM, $r$ = .10, $p$ =.44. This lack of relationship between individual differences in the OSPAN and APM could be interpreted as evidence that questions previously reported high correlations between working memory and *g*F. At a minimum, the current results regarding the relationship between working memory and *g*F suggest that results regarding the relationship may simply be an artifact of the sample and measures used the current experiment as well as in previous experiments.

**Choice data**. Results related to choice data (i.e. the proportion of immediate rewards selected) will be presented, followed by results using $k$ values for each reward condition as they relate to scores on the OSPAN and APM. Next, results related to the mean number of intransitives for each of the conditions are presented. Lastly, the results pertaining to reaction times in each of the delay amounts are presented.

***Immediate options***. Individuals with LWM and *g*F have reportedly demonstrated more discounting of delayed rewards relative to individuals with HWM and *g*F. Multivariate multiple regression analyses with OSPAN and APM as predictor variables and proportion of immediate options selected for each of the four conditions ($200 sequential, $200 random, $40,000 sequential and $40,000 random) as the dependent variables did not support a relationship between working memory and gF with delay discounting for the $200 delay amount, $R^2 = .01$, $F(2, 57) = 0.41$, $p. > .05$, or the $40,000 delay amount during the sequential presentation method, $R^2 = .04$, $F(2, 59) = 1.32$, $p. > .05$. The random presentation method yielded similar results for the $200 delay amount, $R^2 = .01$, $F(2, 57) = 0.15$, $p. > .05$, and $40,000 delay amount, $R^2 = .05$, $F(2, 57) = 1.49$, $p. > .05$, suggesting that working memory and *g*F did not account for differences in the proportion of immediate rewards selected in the current experiment. These results are not consistent with previously reported associations between working memory and *g*F (e.g. Shamosh et al., 2008).

***k values***. In addition to the mean proportion of immediate rewards selected, previous studies have also postulated that working memory is related the levels of discounting as indicated by *k* values. Hypothesis 1 predicted that *k* values would be higher for LWM and *g*F individuals relative to HWM and *g*F individuals. Again, the current experiment did not find support for either of the measures used to indicate differences in discounting as predicted. A multivariate regression with OSPAN  and APM as predictor variables and k values for each of the four conditions  as dependent variables was conducted. The results revealed that neither working memory or *g*F predicted *k* values for the $200 delay amount, $R^2 = .00$, $F(2, 57) = 0.14$, $p. > .05$, or the $40,000 delay amount in the sequential presentation method, $R^2$ = .02 $F$(2, 57) = 0.49, $p$. > .05, as well as the $200 delay amount, $R^2$ = .04, $F$(2, 57) = 1.29, $p$. > .05, or $40,000 delay amount in the random presentation method, $R^2$ = .01, $F$(2, 57) = 0.74, $p$. > .05. Figure 2 displays the average *k* values for the $200 and $40,000 delay amounts. Although there was no relationship to working memory or *g*F, a 2 (delay amount: $200 vs. $40,000) x 2 (presentation method: random vs. sequential) repeated measures ANOVA revealed a main effect of delayed amount, $F$ (1, 57) = 5.26, p = .03, $\eta_p^2$ = .08, as well as an interaction between delay amount and presentation method, $F$ (1, 57) = 20.62, p < .01, $\eta_p^2$ = 27. Surprisingly, paired t-test revealed that individuals had larger k values in the $200 sequential presentation method relative to the random presentation method, $t$(57) = 3.94, $p$ < .01, $d$ = 64. The opposite pattern was true for the $40,000 delay amount, $t$(57) = -2.83, $p$ < .01, $d$ = -.19. These results are likely due to three participants in the sequential presentation method. Because calculating k values is based on minimizing the least squared values of the residuals, the individuals who produced extreme *k* values drastically changes the best fitting curve for the sample. Overall, hypothesis 1 was not supported in the current experiment. More specifically, neither working memory nor *g*F were related to choice behavior or *k* values. However, presentation methods do appear to affect choice behavior on the delay discounting task. The theoretical implications of these results suggest that neither working memory nor *g*F are the mechanisms responsible for observable differences regarding choices made on the delay discounting task. However, other potential interpretations for discrepancies between the current study and previous studies regarding a relationship between working memory and *g*F with delay discounting will be explored in the discussion section.

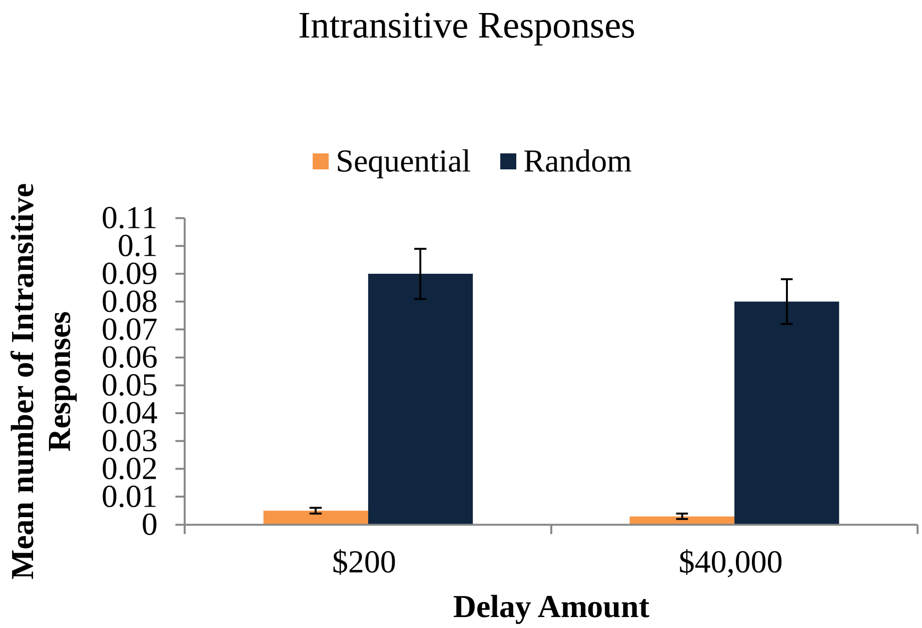
*Figure 2*. Mean *k* values for random and sequential presentation methods per delay amount.




***Intransitive responses***. Previous research has also reported that working memory may be related to the amount of intransitive responding. Hypothesis 2 predicted that there would be more intransitive responses in the random presentation method, which is supported in the present experiment. A multivariate regression with OPSPAN and APM as predictor variables and proportion of intransitive responses for each of the four conditions revealed that neither WM or *g*F were predictive of the number of intransitive responses for either the $200 delay amount, $R^2$ = .00, *F*(2, 57) = .07, *p*. > .05, or $40,000 delay amount in the sequential presentation method, $R^2$ = .01, *F*(2, 57) = .40, *p*. > .05. Similar results were found for the $200 delay amount, $R^2$ = .05, *F*(2, 57) = 1.37, *p*. > .05, and $40,000 delay amount for the random presentation method, $R^2$ = .04, *F*(2, 57) = 1.14, *p*. > .05. The results displayed in figures 3 displays the mean aggregated number of intransitive responses for random and sequential presentation of the $200 and $40,000 delay amounts. Consistent with hypothesis 2, a 2 (delay amount: $200 vs. $40,000) x 2 (presentation method: random vs. sequential) repeated measures ANOVA with mean number of intransitive responses as the dependent variable indicate a main effect of presentation method, *F* (1, 57) =

83.45, $p < .01$, $\eta_p^2 = .59$, with more intransitive responses occurring in the random presentation method. Although delay discounting was not related to working memory or *g*F, this effect appears consistent with the reaction time findings. The predictability of rewards in the sequential presentation method does not produce as many intransitive responses. Although some intransitive responses did occur in the sequential presentation method, it can be speculated that these intransitive responses were likely the result of indifference between the two reward options on behalf of the participant. More specifically, the participant may simply not have had a clear preference for either the immediate reward option or the delayed reward option on some of the trials. Consequently, participants may have not chosen consistently for those rewards for which they had no clear preference. The results also revealed that the number of intransitive responses were also higher for the $200 delay amount than the $40,000 delayed delay amount, $F$ (1, 57) = 3.85, $p = .05$, $\eta_p^2 = .06$, which is also consistent with the interpretation that individuals may not have had a clear preference for some of the $200 delay amounts. A potential reason that participants did not have clear preferences for the $200 delay amount is that the sample involved college students and the $200 delay amount involves more realistic choices for a sample of college students relative to the extreme values that were used for the $40,000 delay amount.

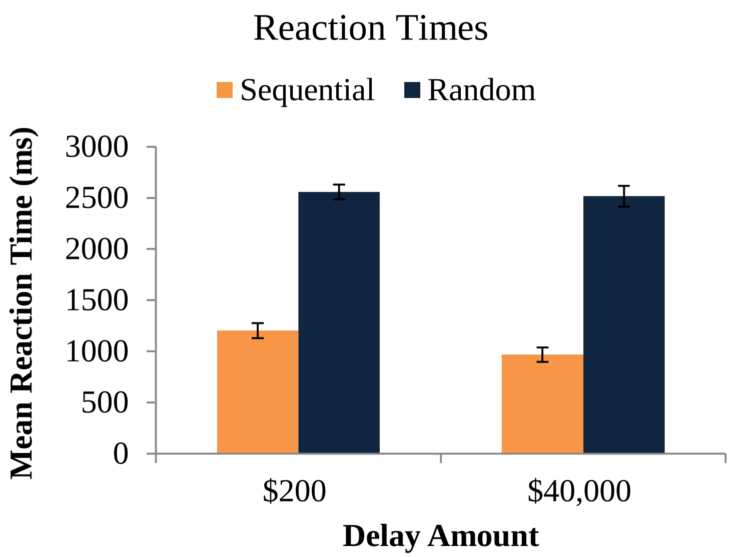
*Figure 3*. Mean proportion of intransitive responses made for each presentation method for the $200 and $40,000 delay amounts.




***Reaction times***. Hypothesis 3 stated that reaction times should be higher in the random presentation method relative to the sequential presentation method, which was supported in by the results of the current experiment. A multivariate regression with OPSPAN and APM as predictor variables and mean reaction times for each of the four conditions revealed that both working memory and *g*F were related to reaction times for the $200, $R^2$ = .14, *F*(2, 57) = 4.56, *p*. = .01, or $40,000 delay amounts for the sequential presentation method, $R^2$ = .20, *F*(2, 57) = 6.81, *p*. < .01, as well as for the $200, $R^2$ = .18, *F*(2, 57) = 6.14, *p*. < .01, random presentation method and $40,000 delay amount, $R^2$ = .22, *F*(2, 57) = 7.80, *p*. < .01, with HWM and gF individuals making their choices more quickly than individuals with LWM and gF. Quicker responding may be the result of HWM and *g*F individuals' ability to more efficiently encode information during the discounting task compared to individuals with LWM and *g*F, particularly during random presentation of delay amounts that were hypothesized to require more cognitive resources relative to the sequential presentation method.

A 2 (delay amount: $200 vs. $40,000) x 2 (presentation method: random vs. sequential) repeated measures ANOVA with blank as the dependent variable with mean reaction times as the dependent variable revealed a main effect of presentation method, $F$ (1, 57) = 206.36, $p < .01$, $\eta_p^2 = .78$, with reaction times being faster in the sequential presentation method than the random presentation method. This finding was expected given the predictive nature of reward presentation during the sequential presentation method. Random presentation was expected to require participants to attend to more information on each presentation and therefore result in longer reaction times for the random presentation method. Because individuals can predict the next immediate amount, as well as the delay associated with that delay amount in the sequential condition, reaction times were expected to be quicker. There was also a main effect of delay amount, $F$ (1, 57) = 11.23, $p < .01$, $\eta_p^2 = .17$, with reaction times being longer for the $200 delay amount. This potentially suggests that the extreme values along with the $40,000 delay amount required little cognitive effort on behalf of the participants relative to the more miniscule values presented with the $200 delay amount, which may have required more time to choose a response if the participants did not have a clear preference for either of the monetary amounts. Furthermore, there was a significant interaction between presentation method and delayed amount, $F$ (1, 57) = 10.50, $p < .01$, $\eta_p^2 = 0.09$. Paired t-tests revealed that although there were no differences between the random presentation methods, $t(57) = 0.60$, $p > .05$, $d = .05$, there was a significant difference for the sequential presentation method, $t(57) = 6.95$, $p < .01$, $d = 0.40$, surprisingly with longer reaction times for the $200 delay amount.  This effect is somewhat consistent with the choice data. Individuals in both random and sequential presentation methods for the $40,000 delay amount exhibited similar low levels of discounting. However, there was more variability in responding for the $200 delay amount. Thus, participants may have been exhibiting more indifference for the $200 delay amount relative to the $40,000 delay amount.

*Figure 4*. Mean reaction times for each presentation method per delay amount.




**Attentional Processing**.

**Fixations**. Hypothesis 4 predicted that individuals with LWM and *g*F would display more fixations to the immediate reward and have shorter fixation durations for the immediate reward relative to individuals with HWM and *g*F. In contrast to the prediction regarding working memory and *g*F, a multivariate multiple regression with OPSPAN and APM as predictor variables and proportion of proportion of fixating on the immediate reward relative to the total number of fixations to all AOIs for each of the four conditions as the dependent variables suggested that neither construct was predictive of the average number of fixations to the immediate reward for the \$200 delay amount, $R^2$ = .09, $F(2, 51)$[3] = 2.41, $p. > .05$, or the \$40,000 delay amount for the sequential presentation method, $R^2$ = .10, $F(2, 51)$ = 2.69, $p. > .05$. However, for the \$200 delay amount, $R^2$ = .17, $F$ (2, 51) = 4.98, $p.$ = .01, and the \$40,000 delay amount for the random presentation method, $R^2$ = .26, $F$ (2, 51) = 8.70, $p. < .01$, the results suggest that working memory and *g*F are related to differences in average number of fixations to the immediate reward. This finding suggests that the random presentation method required more attentional resources because of the contrast in predictability of stimulus presentation relative to the sequential presentation method. Because the stimuli are presented randomly, participants likely had to attend to more areas of interest and therefore displayed more fixations when making decisions for the random presentation method.

Hypothesis 4 also predicted that the duration of fixations to the immediate reward would be related to working memory and *g*F. A multivariate multiple regression with OPSPAN and APM as predictor variables and proportion of fixation duration to the immediate reward value relative to the total duration of fixations to all AOIs for each of the four conditions as the dependent variables was conducted to test this prediction. The results reveal that neither working memory or *g*F were predictive of average amount of time spent fixating on the immediate option for the \$200 delay amount, $R^2$ = .10, $F(2, 45)$ = 2.36, $p. > .05$,[4] or the for the sequential presentation method for the \$40,000 delay amount, $R^2$ = .04, $F(2, 45)$ = 1.01, $p. > .05$. Results from the random presentation method also revealed that working memory and *g*F were not related duration of fixations to the immediate reward for either the \$200 delay amount, $R^2$ = .05, $F(2, 45)$ = 1.07, $p. > .05$, or the \$40,000 delay amount, $R^2$ = .09, $F(2, 45)$ = 2.19, $p. > .05$. The

[3] Average fixation data for the immediate reward was only able to be calculated for both random and sequential conditions for each delayed reward condition for 52 participants.

[4] Only 45 participants produced enough data to allow calculation for proportion of fixations to the immediate reward.

results are consistent with the prediction proposed in this experiment, more fixations were displayed by individuals with LWM and *g*F and these individuals did not have longer durations regarding fixations. This suggests that individuals with HWM and *g*F were better able to encode the information, thus requiring a lesser number fixations than individuals with LWM and *g*F. Individuals with LWM and *g*F appeared to require more fixations to encode the information relative to individuals with HWM and *g*F who were predicted to require a lower amount of fixations because of their ability to hold information in working memory more efficiently.

**Search patterns**. Hypothesis 5 predicted that individuals with LWM and *g*F would exhibit different search patterns than individuals with HWM and *g*F. A multivariate regression with OPSPAN and APM as predictor variables and search index scores (Payne, Bettman, & Johnson, 1988) for each of the four conditions as the dependent variables did not support the contention that either working memory or *g*F are related to search patterns for the $200 delay amount, $R^2$ = .02 $F(2, 57) = 0.64$, $p. > .05$, or the $40,000 delay amount for the sequential presentation method, $R^2$ = .02 $F(2, 57) = 0.65$, $p. > .05$. Similar results were observed for the $200 delay amount, $R^2$ = .09 $F(2, 57) = 2.64$, $p. > .05$, and $40,000 delay amount for the random presentation method, $R^2$ = .07 $F(2, 57) = 1.99$, $p. > .05$, further suggesting that neither working memory or *g*F are related to differences in search patterns. These results suggest that, similar to preferences in the delay discounting task, search patterns in the delay discounting task are not related to differences in working memory or *g*F.

**Pupil dilation**. Finally, Hypothesis 6 predicted that LWM and *g*F individuals would have larger differences in average pupil dilation when viewing the immediate rewards versus delayed rewards relative to individuals with HWM and *g*F. A multivariate regression with OPSPAN and APM as predictor variables and difference scores computed by subtracting pupil dilation when viewing immediate rewards from pupil dilation when viewing delayed rewards for each of the four conditions as the dependent variables was conducted to test this hypothesis.

The results indicate that working memory and *g*F were not predictive of differences in pupil dilation for the $200 delay amount, $R^2$ = .07, $F(2, 52)$[5] = 0.07, *p*. > .05, or the $40,000 delay amount for the sequential presentation method, $R^2$ = .02, $F(2, 52)$ = 0.57, *p*. > .05. Similarly, results from the random presentation method indicated that working memory and *g*F were not related to pupil dilation for either the $200 delay amount, $R^2$ = .02, $F(2, 52)$ = 0.24, *p*. > .05, or the $40,000 delay amount, $R^2$ = .00, $F(2, 52)$ = 0.08, *p*. > .05. These results are consistent with the other eye-tracking measures of attentional processing, suggesting that working memory and *g*F are not strong predictors of attentional processing during the delay discounting task.

Table 1: Comparison Across Presentation Methods: Average (standard deviation) Aggregate AOI Processing Variables for $200 delay amount and $40,000 delay amount are presented for both the sequential and random presentation methods.

| | $200 Delay Amount | | $40,000 Delay Amount | |
|---|---|---|---|---|
| AOI Processing Variables | Sequential | Random | Sequential | Random |
| AOI fixations to immediate reward | 0.43 (.01) | 0.44 (0.02) | 0.32 (.01) | 0.31 (.01) |
| Avg. AOI duration | 0.32 (.01) | 0.34 (.01) | 0.30 (.01) | 0.32 (.01) |
| Proportion of AOIs acquired | 0.57 (.16) | 0.90 (.09) | 0.53 (.16) | 0.90 (.10) |
| Search index (PBJ) | 0.11 (.31) | -0.12 (.34) | 0.23 (.32) | -0.11 (.34) |
| Pupil Dilation | 3.93 (.44) | 3.92 (.44) | 3.90 (.44) | 3.93 (.43) |
| Pupil Difference | 0.01 (.06) | -0.02 (.05) | 0.02 (.07) | -0.01 (.05) |

**Summary data**. Although the average proportion of fixations to the immediate reward were not found to share a significant relationship with either working memory or *g*F, as indicated

[5] 5 participants did not provide enough viable data to calculate summary some of the eye-tracking statistics. Therefore, those data will be based on 53 participants.

in the table, a2 (delay amount: \$200 vs. \$40,000) x 2 (presentation method: random vs. sequential) repeated measures ANOVA with proportion of fixations to the immediate reward as the dependent variable revealed a main effect of delayed reward, $F$ (1, 51) = 81.67, $p < .01$, $\eta$p2 = .62, with individuals displaying more fixations in the \$200 reward condition. Similarly, there was a main effect of delayed reward for the average proportion of time viewing the immediate reward, $F$ (1, 51) = 16.97, $p < .01$, $\eta$p2 = .27, as well as a main effect of presentation method, $F$ (1, 51) = 16.21, $p < .01$, $\eta$p2 = .26. Individuals in the \$200 condition looked more at the immediate reward and individuals in the random condition had longer latencies to the immediate rewards overall. Taken together, these results would seem to suggest that variables other than working memory or *g*F may share a stronger and more reliable relationship with attentional processing during the delay discounting task relative to the constructs being examined. When examining the proportion of the table acquired, a 2 (delay amount: \$200 vs. \$40,000) x 2 (presentation method: random vs. sequential) repeated measures ANOVA with proportion of cells acquired as the dependent variable demonstrated a main effect of presentation method, $F$(1, 57) = 364.69, p < .01, $\eta$p2 = .86, as well as delay amount, $F$ (1, 57) = 7.45, p < .01, $\eta$p2 = .12. Again, participants viewed more areas of interest in the random presentation method relative to the sequential presentation method. This result is consistent with random presentation requiring more cognitive resources because presentation of choices in the sequential presentation method is predictable. There was also an interaction between presentation method and delayed reward, $F$ (1, 57) = 6.26, p = .01, $\eta$p2 = .10. Participants in the random presentation methods did not differ for the \$200 and \$40,000 delay amount, $t$(57) = 0.76 $p > .05$, $d$ = .00. However, paired t-test individuals in the sequential presentation method viewed more areas of interest for the \$200 reward amount than the \$40,000 reward amount, $t$(57) = 2.79, $p < .01$, $d$ = .25. These results are also consistent with participants being indifferent when choosing between the $200 delay amounts and more consistent for the $40,000 amounts for the sequential presentation method. Similar results were found for PBJ scores in the current experiment. A 2 (delay amount: $200 vs. $40,000) x 2 (presentation method: random vs. sequential) repeated measures ANOVA with PBJ scores as the dependent variable revealed a main effect of presentation method, $F$ (1, 57) = 47.58, p < .01, $\eta$p2 = .45, as well as delayed amount, $F$ (1, 57) = 16.87, p < .01, $\eta$p2 = .23. The random presentation method produced more within option searching and the sequential presentation method produced more between option searching. Furthermore, there was more searching between options for the $40,000 delay amount relative to the amount of searching between options for the $200 delay amount. The random presentation likely required more searching within options because of the amount of information that had to be attended to. As depicted in the table, the main effect of delay amount is due to the large difference for the $40,000 delay amount in the random presentation method. In similar vein, there was also a significant interaction between presentation method and delayed reward, money, $F$ (1, 57) = 13.72, p < .01, $\eta$p2 = .19. As previously inferred, paired t-tests indicated there was no difference in the random presentation methods, $t(57) = -0.88$, $p > .05$, $d = -.03$, however, there was a significant difference between the $200 and $40,000 delay amounts for the sequential presentation method, $t(57) = -4.20$, $p < .01$, $d = -0.62$, with individuals searching between options more for the $40,000 delay amount. Again, this may be because individuals didn’t have to acquire as many areas of interest to make a decision relative to the random condition. However, searching more between options for the $40,000 amount is inconsistent with the choice data and not readily explained by the earlier interpretation that individuals were more indifferent in the $200 condition.

## General Discussion

Results from the current study elucidate a variety of interesting findings. Primarily, the current study does not support the contention that working memory and *g*F are related to differences in delay discounting decisions. More specifically, lower working memory individuals were not indicative of higher rates of delay discounting. In similar vein, individuals with higher working memory scores did not reflect lower levels of delay discounting. Although previous research has demonstrated that differences in both working memory and *g*F are related to differences in delay discounting (Shamosh et al., 2008), the current study is consistent with the postulated capacity limits of working memory (Cowan, 2001) and with other previous studies (Franco-Watkins, Pashler, & Rickard, 2006; Franco-Watkins et al., 2010) that have demonstrated working memory is not necessarily related to more impulsive responding on the delay discounting task.

Additionally, the current study did not find evidence that working memory and *g*F are highly related constructs, which contrasts other previous research (e.g. Ackerman et al., 2005; Kane et al., 2005), but provides additional evidence that working memory and *g*F may not be related to differences in delay discounting. Working memory has been posited to facilitate the maintenance of goal relevant information while completing a secondary task, attenuating proactive interference, selectively attending to task relevant information while inhibiting irrelevant information, and avoiding interference. It is noteworthy to mention here that all of these aspects are related to control of attention.

Interestingly, the current study deviates from previous studies in one important aspect. Assuming that working memory is related to attentional processing (e.g. Engle et al., 1999), and that eye-movements are directly related to attention (Deubel & Schneider, 1966), the current study incorporated eye-tracking technology to investigate the potential relationship between working memory and *g*F with delay discounting and attentional processing . There were several variables of interest in the current study involving attentional processing that were measured using eye-tracking technology. The results from the current study revealed that none of the following attentional processing variables were statistically significantly related to working memory or *g*F. First, the current study found no statistically significant differences between higher and lower working memory and *g*F scores and the number or duration of fixations allocated to the immediate reward for sequential presentation. However, random presentation, which likely places more demand on cognitive resources, was related to the average number of fixations to the immediate reward. Secondly, the relationship between search patterns with working memory and *g*F was also not statistically significant. If these constructs were related to differences in delay discounting then lower working memory individuals should have spent more time searching within options, particularly the immediate option, relative to individuals with higher working memory scores. Finally, changes in pupil dilation has been proposed to be related to the subjective pleasantness of an item (Hess & Polt, 1960), so if individuals scoring lower on measures of working memory had a preference for the immediate reward then they should show larger changes in pupil dilation. However, pupil dilation was not related to either working memory or *g*F. In summary, only average number of fixations to the immediate reward in the random presentation method was related to differences in working memory and *g*F, which raises some doubt about the theoretical implications derived from previous studies that did not actually use eye-tracking to account for attentional variables.

First, the relationship between working memory and *g*F needs to be evaluated cautiously. Although some researchers claim that the two constructs are highly related (Engle et al., 1999), the results from the current experiment suggest that researchers should exhibit caution when making strong claims concerning the relatedness of working memory and *g*F. Furthermore, the lack of a relationship between working memory, *g*F and delay discounting may suggest that researchers should attempt to identify other possible factors influencing differences in delay discounting, potentially via latent variable analysis to determine what factors are likely to contribute to differences observed on the delay discounting task. Results from the current study suggest that presentation method and reward amount are significantly related to performance and attentional processing, but further examinations of other factors should also be conducted. Furthermore, the lack of statistically significant relationships between the attentional measures gathered in the current study should suggest that working memory and attention are not of particular interest when comparing differences in delay discounting. The results from the current study do not negate findings suggesting that working memory is related to attentional control, but these results do question the claim that working memory or attentional control are related to differences in delay discounting.

However, there were some potential limitations to the current findings. Previous research that has found a relationship between working memory and *g*F with delay discounting utilized measures of working memory and *g*F that differed from the current experiment. More specifically, Shamosh et al. (2008) used a variation of the n-back task (Gevins and Cutillo, 1993), a 3-back task to be more specific, as a measure of working memory. One limitation with using different measures may be that each task is actually measuring a different aspect of the working memory construct. For example, Baddeley (1986) describes working memory as a system capable of temporary storage and manipulation of information. This aspect of working memory can be measured by span task such as the Operation Span Task (Turner & Engle, 1989; Unsworth, Heitz, Schrock, and Engle, 2005). Another aspect of working memory, which can be measured by the n-back task, is the ability to continuously monitor and update information (Owen, McMillan, Laird, & Bullmore, 2005). At least one recent study has compared the two tasks and found only a weak correlation between the two measures (Kane, Conway, Miura, & Colflesh, 2007), suggesting that the two tasks to do not measure a single aspect of working memory and could provide a possible reason why the measure of working memory used in the current study did not share a relationship with differences in delay discounting. Another possible limitation was that the current study used a 12-item version of the Raven's Advanced Progressive Matrices (APM; Arthur & Day, 1994), which was not significantly correlated with the OSPAN, However Kane et al. used an 18-item version of the Raven's Advanced Progressive Matrices and found a moderate correlation[6] between the Raven's and OSPAN. Therefore, the more truncated version used in the current experiment could have contributed to the lack of correlation found between working memory and *g*F. In fact, the mean, median, and mode were all very similar in the version used for the current experiment, which limited the variability and potentially limited the predictive power of the measure.

Therefore, researchers conducting future studies regarding working memory, *g*F, and delay discounting should interpret their results cautiously and only generalize them to the specific measures or variations of different measures used in their experiments. Also, using

[6] $r\,(60) = .33$, $p < .05$.

different values and presentation methods may help to clarify when and which factors contribute to differences in delay discounting. As mentioned previously, lower rewards are discounted at a greater rate than larger rewards. The current study used similar values to those used by Shamosh et al., (2008) and did not find any relationship between higher and lower working memory or *g*F individuals. The values used in both experiments deemed it likely that differences in delay discounting for the $200 and $40,000 delay amounts would be observed because previous research has demonstrated that lower monetary amounts are discounted at a greater rate than larger ones (e.g., Green, Myerson, & Ostaszewski, 1999). However, other researchers have demonstrated that even the addition of a secondary task to tax working memory would have only lead to more intransitive responding and not higher rates of discounting delayed rewards in the current experiment (Franco-Watkins, Pashler, & Rickard, 2006; Franco-Watkins et al., 2010).

In conclusion, researchers should interpret differences in the ability to delay gratification with caution. Several factors can influence the degree to which individual differences on particular measures may or may not influence decision making on the delay discounting task. As previously mentioned, reward values, presentation methods, and executive functioning measures should be considered when attempting to generalize findings from a single study to the ability to delay gratification. Consequently, researchers should exercise caution when attempting to generalize findings from any given sample to real-world situations involving the ability to delay gratification. Different parameters and methods may be used to determine under what circumstances constructs such as working memory and *g*F are capable of contributing to differences in delay discounting. However, researchers should also consider other factors that may have a more robust influence on delay discounting and may be more generalizable to real-world difficulties involving the ability to delay gratification (e.g., pathological gambling and substance addictions). The inconsistencies found between working memory and *g*F with delay discounting would suggest that these variables likely only have a minimal impact on the ability to delay gratification and that these effects are likely artifacts of different measures, values, presentation methods, and participant samples used in a given experiment. Therefore, other factors should be considered before making broad generalizations based on a single study conducted on a single sample to a broader population including individuals suffering from addictions.

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