WORKING MEMORY AND INDIVIDUAL DIFFERENCES IN DECISION MAKING

By

TINA L. JAMESON

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The members of the committee appointed to examine the dissertation of TINA L. JAMESON find it satisfactory and recommend that it be accepted.

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Chair

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Abstract

by Tina L. Jameson, Ph.D.
Washington State University
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Chair: Paul Whitney

A working memory load has been shown to impact the formation of somatic markers, affective reactions that help guide decision making. When a working memory load (such as a set of digits that must be remembered) is introduced into a decision making situation, the somatic marker fails to form and decision making performance subsequently declines. The purpose of the present research is to explore this finding in greater detail with an individual differences approach. To accomplish this goal, two experiments were conducted in which participants performed several working memory tasks as well as a decision making task known as the gambling task. In the first experiment, results replicated prior research showing that a working memory load does yield poorer performance on the gambling task. However, no relationship was found between the working memory tasks and the gambling task. The second experiment differed from the first only in that a physiological measure of performance, the skin conductance response, was recorded during the gambling task in addition to the behavioral performance. Results of the second experiment did not replicate the finding that a working memory load affects performance, nor was there any relationship found between the working memory tasks and the gambling task.

TABLE OF CONTENTS

PAGE

LIST OF TABLES

LIST OF FIGURES

WORKING MEMORY AND INDIVIDUAL DIFFERENCES IN DECISION MAKING

SECTION 1: Introduction to Decision Making

Throughout each day, we all face a staggering range of options from which to choose, and must make numerous decisions both large and small. One of the difficulties inherent in making these decisions is that, in general, many of these decisions do not have a clear or foreseeable outcome. That is, we do not always know what the long-term consequences of our decisions may be at the time the decisions are made. Instead, we must wait to discover if the outcome of our decision was good or bad. For example, if we need to choose a stock to add to an investment portfolio, we generally are not certain if the value of the stock is going to rise or fall after we purchase it. This means that we must make a decision and await the outcome. In our daily lives we almost always engage in decision making under uncertainty and risk. Because decision making is such an integral part of everyone's daily life, and because decisions can have such a profound impact on the quality of life, judgment and decision making has been the subject of intensive study for decades in a variety of disciplines ranging from economics to psychology (Goldstein & Hogarth, 1997).

The principal question considered in the decision making literature concerns *how* people choose between the many options they encounter. In other words, what influences the decision maker in his choice? In order to answer this question, some decision researchers have focused on those segments of the population with compromised decision making abilities. For instance, many substance abusers make exceptionally poor decisions in their daily lives as evidenced by their choice of abusing substances rather than maintaining steady employment or taking care of their family and friends (Bechara, 2003; Bolla et al., 2003; Clark & Robbins, 2002; Grant, Contoreggi & London, 2000). In the neuropsychological literature the focus has been on those with damage to particular areas of the brain. Specifically, much of the focus has been on how damage to certain areas of the prefrontal cortex (PFC) can negatively impact an individual's decision making ability. Bechara, Damasio and colleagues have been studying decision making in patients with ventromedial prefrontal cortex (VM) damage for over a decade (A. Damasio, Tranel, & H. Damasio, 1991; Bechara, H. Damasio, A. Damasio & Lee, 1999). These patients have very impaired day-to-day decision making; specifically, patients with VM damage tend to make decisions that lead to negative consequences both personally (e.g., loss of a job) and socially (e.g., loss of friends). These patients never seem to learn from these negative consequences, and this inability to learn from poor decisions significantly impacts their quality of life. The problems of these VM patients have been characterized as "myopia for the future". That is, these patients seem to be insensitive to the future consequences of their behavior (Tranel, Bechara & Damasio, 2000). Even when these patients may *know* that the future consequences of their actions will be negative (e.g., a family member points out the future negative consequences such as the loss of a job or friend) the VM patients behavior may still be driven by short term rewards (e.g., the pleasure derived from continued gambling or drug use). While VM patients make poor decisions in their daily lives, when brought into the laboratory their performance is intact on a wide variety of standard neuropsychological measures such as the Wisconsin Card Sort Task (WCST) and the Tower of London (TOL). Because existing laboratory tasks were not sensitive to the severe decision making deficits of these

VM patients, Bechara and colleagues developed a simulated gambling task (GT; Bechara, A. Damasio, H. Damasio, & Anderson, 1994) that could imitate real life in the way uncertainty in the wins and losses were factored into the task.

SECTION 2: Assessing Decision Making; the Bechara Gambling Task

In the original version of the Bechara and colleagues (1994) GT, participants were seated at a table across from the experimenter. Placed on the table in front of each participant were four decks of cards. Each deck contained 40 cards, and participants were free to choose from any of the decks on any of their choices. Participants were given a $2000 stack of play money and were told that the goal of the task is to gain the greatest amount of money possible by choosing cards one at a time from any of the four decks. After each card choice had been made, participants were given the amount of money that they had won on that trial, and on certain trials they were both given money, and had some money taken away. This procedure was followed for the 100 trials it took to complete the task. Participants did not know how many trials they would complete, nor were they told how to choose from the four decks; rather, they needed to learn over time that two of the decks are *bad* and the other two decks were *good*. The bad decks were those in which there were immediate large gains, but even larger long-term losses. In other words, the bad decks may have appeared good at the beginning of the task, but over time as participants sampled from the various decks they needed to learn that the decks with the higher immediate yield led to long-term losses. The good decks had much smaller immediate gains, but an overall net gain instead of a net loss. In order to perform optimally on this task, a participant needed to learn to, and be willing to, forgo the large immediate gains for the smaller gains that will ultimately lead to optimal performance.

Participants who performed disadvantageously on this task were choosing more cards from the bad decks and therefore losing money in the long-run. This means that in the GT there is the attraction of a large immediate reward, but delayed negative consequences if a participant continues to make the same choice, thereby assessing the 'myopia for the future' displayed by VM patients.

Since its development, the GT has been used on a wide variety of populations that exhibit real-life decision making deficits. In addition to VM patients (Bechara, H. Damasio, A. Damasio, & Lee, 1999; Bechara, H. Damasio, Tranel, & Anderson, 1998), the GT has been used on those with substance dependence (Bechara & Damasio, 2002; Bechara, Dolan, Denburg, Hindes, Anderson, & Nathan, 2001; Clark & Robbins, 2002; Rogers et al., 1999) boys with psychopathic tendencies (Blair, Colledge & Mitchell, 2001), and patients with Huntington's Disease (Stout, Rodawalt, & Siemes, 2001; Busemeyer & Stout, 2002). While all of these populations tend to make poor decisions both on the GT and in their daily lives, the VM patients are perhaps the most interesting in that although they perform poorly on the GT when compared to control participants, they appear to have preserved intellectual abilities, and are able to perform normally on delayed response and delayed non-matching to sample tasks that are designed to assess working memory (Bechara et al., 1998).

The dissociation between GT performance and performance on tasks designed to assess working memory is important because working memory is another cognitive function that has been closely tied to the PFC (Baddeley, Della Sala, Pagagno, & Spinnler, 1997). While a wide variety of working memory models exist (e.g., Baddeley & Hitch, 1974; O'Reilly, Braver & Cohen, 1999), working memory is generally viewed as being the ability to buffer phonological, visual-spatial and semantic codes and to allocate attention to these codes as necessary (Shah & Miyake, 1999). What distinguishes working memory from the more classic notion of a short-term memory buffer is the addition of executive control to the buffering capabilities. Working memory can be viewed as a more complex short term memory system that manipulates and maintains information ‘online’ for short periods of time. Executive control is the portion of the working memory system that regulates the allocation of attentional resources to the performance of a complex cognitive task. Some of the proposed functions of the central executive include the allocation of attention to ongoing working memory tasks, and the management of the ability to switch between tasks. A number of studies have shown that the PFC is active during the performance of working memory tasks (D’Esposito, Postle, & Rypma, 2000; Rypma, Prabhakaran, Desmond, Glover & Gabrieli, 1999). For instance, Pochon and colleagues (2001) performed a functional Magnetic Resonance Imaging (fMRI) study in which they had their participants perform a visuospatial reproduction task as a measure of working memory. Their functional brain-imaging results revealed that the PFC was active during this reproduction task.

The two working memory tasks utilized by Bechara and colleagues (1998) to assess working memory function in their VM patients were a delayed response task and a delayed non-matching to sample task. The delayed response task required participants to view four cards on a computer screen. Initially two of the cards were face-down and the other two face-up with either a red or black color showing. The two face-up cards were randomly positioned and randomly changed (both in color and position) from one trial to the next. After the participant was given a chance to view the cards for several seconds, all the cards disappeared and then reappeared face-down. The participant then had to choose two of the cards. The goal of the task was for the participant to learn that they needed to choose the two cards that had previously been face-up. After the learning trials, where the participants needed to reach the criterion of a correct response on five consecutive trials, a time delay between viewing and choice was introduced and randomly alternated between 10, 30 and 60 seconds. A distractor was also introduced during the time delay.

In the delayed non-matching to sample task, the procedure was virtually the same. The primary difference was that one card was initially face-up with either black or red showing, then all four cards were face-up. The participant needed to choose the two cards that were opposite in color to the card that was shown initially. In other words, if a red card was showing, participants needed to learn to choose the two black cards. Upon reaching criterion (again, a correct response on five consecutive trials) the distractors and delay were introduced. Impaired performance on both of these WM tasks was considered to be a percent correct that fell below 80% at the 60 second delay. Ventromedial patients perform normally on these working memory tasks, yet are seriously impaired on the gambling task.

SECTION 3: Explaining Impaired Decision Making Performance: The Somatic Marker Hypothesis

Ventromedial prefrontal cortex patients often perform normally on tasks that assess working memory, yet are seriously impaired in their ability to make good decisions both on the GT and in their daily lives (Damasio et al., 1991; Bechara, et al., 1998). For example, Damasio and colleagues (1991) studied a patient known as EVR who underwent a bilateral ablation of the ventromedial prefrontal cortices in order to remove a meningioma (a type of tumor). After surgery, EVR was unable to make rapid choices and the choices he did make were often random in nature. On conventional tests of learning and memory, however, he performed normally. From this seminal work with EVR Damasio and colleagues developed the *somatic marker hypothesis* (Damasio, 1994; Bechara, H. Damasio, & A. Damasio, 2000).

According to the somatic marker hypothesis, the prefrontal cortex is required in decision making because it links external stimuli with internally experienced emotional or somatic states. When a situation that includes those same external stimuli recurs, neural systems recreate the previously experienced emotional states. The neural systems that are necessary for this emotional re-enactment include the ventromedial prefrontal cortex, amygdala, insular and somatosensory cortices and the peripheral nervous system. In terms of decision making, the question becomes, then, how does the somatic marker assist in making decisions according to Damasio’s hypothesis? The activation of the somatic states associated with external stimuli act as biasing signals, or markers, that mark the various choice options with a value. These biases can then assist in the selection of advantageous responses. As an illustrative example, consider the following. Suppose you make a choice that leads to a negative consequence. For instance, you make an investment in what you think is a good stock. However, that particular stock very quickly drops in value and this leads to a large loss of your hard-earned money. This loss produces an unpleasant ‘gut’ feeling. This unpleasant feeling then becomes associated with the choice to make an investment in that stock, thereby biasing you from making that choice again in the future.

Because the somatic marker is a change in somatic states, this physiological response can be measured. Skin conductance response (SCR) is the most commonly used means of assessing the somatic marker (Bechara, Tranel, H. Damasio, & A. Damasio, 1996; Hinson, Jameson & Whitney, 2002). Skin conductance is measured via electrodes attached to a participant's hand. The electric potentials generated by the participant's somatic states are recorded with specialized equipment (Tranel & Damasio, 1994), and this is how the activation of the somatic states can be recorded for subsequent analysis.

Without the biases created by a properly functioning somatic marker, the choice options become equalized. In other words, there is no one way to distinguish one option as being better than another, the various choice options are the same. This means that decision making may depend, instead, on slower and perhaps more overt reasoning processes. This also means that the options may be too numerous, or the reasoning processes too complex, for the decision maker to make a good choice. Therefore, the decision maker may make a random choice, may neglect making a choice altogether, or may make a choice based on a simplified or suboptimal strategy (Bechara, 2001).

In the case of Bechara's GT, a choice from a deck that leads to a loss creates that same 'gut' feeling thereby leading to the establishment of a somatic marker that, in the future, will lead the decision maker away from the bad deck. Without the somatic marker to help guide performance on the GT, performance becomes suboptimal. The reason that VM patients are so poor at making decisions, according to the somatic marker hypothesis, is because they have lost a critical component of the somatic marker neural system and, thus, they are unable to form a somatic marker. This means that they rarely do well on the GT and also tend to make poor decisions in their daily lives.

SECTION 4: Decision Making and Working Memory

Although data from Damasio and colleagues have shown that people can have decision making deficits without concurrent working memory deficits, recent research with a modified version of the gambling task that was appropriate for use with a neurologically intact college population has shown that working memory and decision making are interdependent (Hinson, Jameson, & Whitney, 2002).

The modified GT used by Hinson et al. (2002) was computerized and probabilistic in nature. The decisions were made more difficult than in the original Bechara GT because the participant population was neurologically intact and would have little difficulty with the original version of the task. The increased difficulty was accomplished by making the discrimination between 'good' and 'bad' decks more difficult. We used three decks: One deck was 'good', one 'bad' and one 'intermediate'. Unlike the bad deck, the intermediate deck yielded long-term monetary gains, but the gains were not as large as those of the good deck. In order for participants to make the best possible choices, they needed to distinguish between the two options that both led to gains in the long run (the intermediate and good decks), but only one choice was optimal (the good deck). In order to assess working memory's relationship to decision making, secondary tasks were performed concurrently with each block of gambling trials. The secondary tasks included a working memory load of five digits, a digit randomization task, and a control condition consisting of a simple keypress. The use of working memory loads and randomization task have been widely used as a means of disrupting WM (Baddeley, Chincotta & Adlam, 2001; Vandierendonck, De Vooght & Van der Goten, 1998). If a relationship does exist between working memory and decision making, then in the two conditions that taxed working memory, GT performance should decline when compared to the keypress control condition. Consistent with this idea, we found a decrement in gambling performance in both the randomization and the digit maintenance conditions compared to the keypad control condition. In addition to the impact the secondary task had on behavioral performance, we also found that the somatic marker was affected by the external working memory load; specifically, the somatic marker was not evident in the load conditions. The working memory load appeared to prevent the development of the somatic marker.

Although a WM load approach can establish the role of WM in another cognitive process such as decision making, the technique is limited in that WM loads may be affecting several potentially dissociable WM processes at once. The typical interpretation of load effects is that the WM loads use attentional capacity that the central executive components of WM need to allocate to the primary task (Baddeley, 1986; Oberauer, Sub, Schulze, Wilhelm, & Wittman 2000). For example, Anderson, Reder and Lebiere (1996) had participants perform an algebra task while holding 2, 4, or 6 digits in memory. They found that performance decreased with increasing load sizes. This effect of memory load on performance of a concurrent task is a robust finding (Baddeley, 1986) that holds in a wide variety of situations (Baddeley, 1996).

It should be noted that preventing the formation of the somatic marker is very different from what Damasio and colleagues have done. However, one of the limitations of Damasio and colleagues' research, as well as that of Hinson and colleagues', is that none of these approaches have taken into account the idea that there may be dissociable executive control functions.

A variety of studies in cognitive neuroscience suggest that executive control of WM is not based on a single ability, but rather several dissociable abilities. For example, according to Frank, Loughry and O'Reilly (2001), working memory requires both selective and rapid updating, as well as maintenance (i.e., buffering and coordination). The rapid and selective updating has been hypothesized to be achieved via a gating mechanism. Selective gating provides a mechanism, perhaps implemented in the basal ganglia (Frank et al., 2001), that allows only certain information into working memory while other information is actively maintained. With a selective gating mechanism, however, there may be different rates at which inputs can be gated into working memory, and this leads to potential executive control problems. For example, information in working memory can either be overwritten too quickly, or it may be too robust so that old information remains longer than it should. Chiappe, Hasher and Siegel (2000) refer to these issues as the access and deletion functions of working memory, where access is control over what is allowed into working memory, and deletion refers to the removal of no longer relevant information from WM, or the removal of information that is not relevant.

In order to measure individual differences in these potentially dissociable control functions, we (Whitney, Jameson, & Hinson, 2004) developed a task that yields separate indices of several aspects of executive control of WM. This new task, the continuous memory scanning task (CMS), is an adaptation of the classic Sternberg procedure (1969). In the original Sternberg task participants maintain a set of letters or digits in memory. This set of letters (termed the *memory set*) is varied by increasing the number of set members. Following the memory set is a single probe item to which a participant must respond *yes* or *no* depending on whether the probe item was in the memory set or not, and reaction time is recorded. What Sternberg found was that as the memory set size increased, reaction time increased in a linear fashion. The slope of this line is the rate of search for an item in working memory.

Like the original Sternberg task, the CMS also has different memory set sizes (either two or four letters). However, instead of following the memory set with a single probe, seven probe items are presented one after another. Participants make a yes or no response to each of the seven probes, and the reaction time to each response is recorded. With the CMS we can obtain the same information as in the traditional Sternberg task, as well as some additional information obtained through the manipulation of the probe sequences and the relationships between trials.

The sequence of seven probes can be manipulated by repeating an item not in the memory set. This repeated item is known as a 'foil' and requires a 'no' response. If the participant's problem is that working memory is overwritten too easily, then this repeated foil will be disruptive. In other words, the participant may take longer to decide that the repeated foil was a part of the probe sequence and not a member of the memory set. On the other hand, if the participant's working memory is too robust, meaning that information remains in working memory longer than it should, this can be assessed by manipulating the relationship between trials. In order to do this, a letter is presented both as a member of two consecutive memory sets as well as the associated probe sequences. This letter then appears as a foil on the next trial. This foil will be disruptive because it has been 'biased' by being a target, and therefore requiring a 'yes' response, on several prior trials, even though it is a foil on the current trial.

In summary, executive control has several potentially dissociable functions. These dissociable functions could have implications to performance on a wide variety of cognitive processes including decision making. Previous research has shown that working memory and decision making do have a relationship with one another. The precise nature of this relationship, however, is not clear. On the surface, it seems that in order to make a decision, a person must be able to choose between two or more choice options. This implies the storage of these choices in memory as well as a mental comparison of the choices to make a judgment between them. If there are more options to choose from, making a decision becomes more difficult since there are more items to compare. Exactly how these WM processes interact with the processes that establish the somatic markers studied by Damasio and colleagues is not clear. Perhaps working memory serves as the point of integration for both affective and non-affective task relevant information. To better understand the relationships among WM processes, somatic markers, and decision-making, it would be useful to have a profile of the WM abilities that characterize people who perform well on the GT, and who form somatic markers, as well as a profile of those who perform poorly on the GT, and who fail to form somatic markers.

SECTION 5: The Goals of the Present Study

Research done by Hinson, et al. (2002) has shown that working memory influences performance on the GT, as well as the formation of the somatic marker that is used to guide performance. However, as noted earlier, with a WM load approach we may not be able to discriminate between several potentially dissociable aspects of executive function that may be influencing performance. Therefore, it is the goal of the present research to attempt to identify the different aspects of working memory that may differentially contribute to decision making performance on the GT. Two measures of individual differences in WM ability were used: (1) Our novel measure, the CMS, and (2) a more traditional measure, the digit ordering task (DOT; Almor, Kempler, MacDonald, Anderson & Tyler, 1999). The DOT measures general capacity by loading working memory with increasingly larger sets of digits that must be placed in ascending order. The task continues until the number of digits exceeds the participant's ability to accurately perform the task. The DOT is a useful general index of WM ability, but it does not allow for separate indices of different kinds of WM input and output difficulties.

Thus, the goal of the present research is to attempt to distinguish between those working memory indices that may differentially contribute to GT performance. Specifically, it may be working memory capacity that distinguishes good and poor performers on the GT. If this is true, then the standard slope measure obtained from the CMS and the DOT measure should differ between good and poor GT performers. If, however, it is other aspects of working memory executive control that are responsible for any differences, this should be evident from the other CMS indices, specifically the foil and bias slopes. Of course, there may also be some combination of capacity and gating that influences GT performance.

SECTION 6: The Experiments

Experiment 1

The purpose of Experiment 1 is to investigate the potentially dissociable aspects of working memory that may play a role in decision making. Specifically, an individual differences approach was taken to create a profile of ability that would explain the differences between poor and optimal performers on the gambling task.

Method

Participants

Ninety-six Washington State University undergraduate students participated for course credit. All participants were native English speakers. There were 43 male participants and 53 female participants. The average age for this group of participants was 20.26 (SD = 4.32).

Tasks and Procedure

Three tasks were administered in a single session. Groups of participants (ranging from 8-15 in a given session) performed the two working memory tasks (CMS and DOT) and the GT in a counterbalanced order. Participants were monitored by the experimenter to insure that they remained on task throughout the experiment.

The Modified Bechara Gambling Task (BGT): Bechara's original task was modified so that it could be administered on a computer and so that the outcomes were no longer scripted, rather, they were probabilistic in nature. Specifically, in the modified BGT there are two decks that are considered to be good, and two decks that are bad. The long run payoffs are the same as those used by Bechara et al. (1994). However, the way in which the payoffs are administered was changed from the original scripted version. The good decks are good in the sense that they will ultimately lead to gains if the participant chooses primarily from these two decks. The only difference between the two good decks is that one deck has greater variability in terms of payoffs. That is, one good deck has a single large loss and the other good deck has several smaller losses. The overall net gains in the two decks are equivalent; they simply differ in how they are received. The same logic applies to the two bad decks. These decks are bad in the sense that they will ultimately lead to losses if consistently chosen. One deck has a single large loss and the other deck has a few smaller losses. As with the good decks, the overall net losses of the two bad decks are the same. The payoff parameters for the BGT may be found in Table 1.

The BGT was administered on a computer with participants making their responses (1, 2, 3 or 4) on the numeric keypad on the side of the keyboard. The task was divided into two blocks of trials, with the order of the blocks counterbalanced. In one block of trials the participants performed the gambling task alone. In the other block of trials a secondary task consisting of a 5-digit working memory load was added. Prior to each gambling task trial participants were given a different, randomly chosen, 5-digits to hold in memory during the gambling trial, for instance, “5-3-4-1-2”. After they made their gambling choice participants were asked to recall the number by asking a question such as “What was the number to the right of 5?” The number they were asked to recall was randomly chosen from positions 1 through 4 of the previously presented 5-digits. The rationale for using a secondary task was twofold; to replicate prior research as well as to determine whether the effects of individual differences in WM on GT performance was similar to the effect of an external load. An example of a single BGT trial may be found in Figure 1.

Continuous Memory Scanning Task (CMS): The CMS was used to assess the different gating and capacity indices of working memory. In this task, participants are shown sets of either two (low load) or four (high load) letters to maintain in memory for four seconds. A series of seven probe letters, separated by a 500 ms fixation point, follow the memory set. Each probe is presented for 4 seconds, or until a response is made, whichever occurs first. Each letter requires a yes (indicated by pressing the '1' key on the numeric keypad) or a no (indicated by pressing the '2' key) response as quickly as possible and the reaction time of this response is recorded.

The probe sequences were constructed so that there are both spaced and adjacent foils. This means that within the 7-probe sequence some letters are repeated with the restriction that they be spaced at least two letters apart (spaced foils). There are also letters that are repeated immediately (adjacent foils). The purpose of the adjacent foils was to make sure that participants did not develop a strategy that was related to probe repetition. There were either spaced and adjacent foils in all the probe sequences, with a total of 48 spaced and 48 adjacent foils.

In addition to manipulating the probe sequences, the memory sets are also manipulated to create blocks in which a particular target letter was *biased*. In order for a block of trials to be biased, a particular letter appeared in the first two trials as an item in the memory set and was probed at least once on each trial. In the *bias absent condition* the biased target occurred as a probe item on one of the last two trials in the block, but it was absent from the memory set. For the *bias present* condition, the biased target letter appeared in the memory set and was a probe item on one of the last two trials of the block. An example of a single CMS trial may be found in Figure 2. The CMS was constructed so that a set of 3 trials (i.e., the memory sets and their attendant 7-letter probe sequences) constituted a block of trials. There were a total of 24 blocks of trials in the present experiment. Of these 24 blocks, twelve were biased in the manner described above, yielding a total of 12 biased foils for the data analysis. Finally, half the trials were high working memory load trials (i.e., the memory set consisted of 4 items), and the other half were low working memory load trials (2 items).

Digit Ordering Task (DOT): The digit ordering task provided an additional measure of working memory capacity (Almor, Kempler, MacDonald, Andersen, & Tyler, 1999; MacDonald, Almor, Henderson, Kempler & Andersen, 2001). In this task, as it was originally used by Almor and colleagues, participants must rearrange sets of digits into ascending numerical order and repeat back the rearranged sequence to the experimenter. For instance, if a participant hears the sequence “5-9-6-1-4”; the answer the participant would need to repeat back to the experimenter is “1-4-5-6-9”. In terms of a traditional working memory perspective this task has both buffering and coordination components. However, because the digit ordering task has been used primarily on an Alzheimer’s patient population, it is of necessity easier than what would typically be used for a normal population. Almor and colleagues have piloted a version with a set size of seven on a population of normal participants and found that there was an increased level of difficulty (Almor, personal communication). Therefore, the DOT was modified from the original to include a set size of seven. It was also modified so that it could be given in a group format. The DOT was programmed with E-prime experimental software and presented on an overhead screen a rate of one digit per second. Following the digit presentation, participants wrote their responses in a booklet. Participants were monitored by the experimenter so that they did not try to write down the digits prematurely. There were four trials per set size, with the set size ranging from 2 to 7 digits. A trial was considered to be correct only if the participant placed all the digits in the correct ascending order. The final score of the participant was the total number of correct trials.

Results and Discussion

Results Section 1: Replication of Prior Results.

Prior to analysis of the individual difference data, performance on the BGT was examined to determine if the Hinson et al. (2002) results were replicated. Consistent with the prior study, errors on the digit load (secondary) task across the 100 trials were relatively low, M = 16.77 (SD = 14.42), indicating that participants were not ignoring the secondary task to focus on the primary task.

Figure 3 illustrates the proportion of good choices across four blocks of 25 trials for the two task conditions (digit load and no load control condition). Performance in the digit load condition did appear to decline across successive blocks of trials while performance in the control condition improved. By the third block of trials performance in the control condition is superior to that of the digit load condition. However, inspection of the error bars reveals a great deal of variability even though the overall pattern of results is very similar to that of Hinson and colleagues.

A two-way repeated measures analysis of variance was conducted to examine the effect of secondary task condition by trial block. As indicated by Mauchley's test for sphericity, the sphericity assumption was violated; therefore, the Greenhouse-Geisser correction was applied to the degrees of freedom. There was a significant main effect of secondary task condition [F (1,95) = 4.83, $p < 0.05$], but no significant main effect of trial block [F (2.75, 261.66) = 0.30]. There was a significant secondary task condition by trial block interaction [F(2.66, 252.46) = 4.22, $p < 0.05$]. In order to investigate this significant interaction further, four paired- sample t-tests were conducted and the Bonferroni technique was used to control for familywise error. The paired-sample t-tests revealed significant differences between the control condition and the digit condition for the third block of trials *t* (95) = 2.59, p < .0125 as well as the fourth block of trials *t* (95) = 2.89, p < .0125. These results replicate those of Hinson and colleagues that revealed an effect of working memory load on gambling task performance. Specifically, a working memory load resulted in poorer BGT performance when compared to the control condition as participants progressed through the task.

Results Section 2: Individual Differences in BGT Performance

This experiment has replicated the earlier findings of a working memory load affecting performance on the GT. However, with a load approach it is not clear what aspects of WM may be influencing final (i.e., the proportion of good choices during the final 25 trials on the gambling task) BGT performance. A limit to WM capacity could account for these performance decrements with a WM load, but other aspects of working memory, such as the gating of information into and out of WM, could also account for these performance decrements. In order to determine what aspects of WM may be influencing performance, two hierarchical regression analyses were conducted. The first regression predicted final BGT performance in the control condition (i.e., no digit load) with the CMS indices entered first, followed by the DOT in a second block. The second regression analysis was identical, but the dependent variable was final BGT performance in the digit load condition.

The CMS indices used as predictors were obtained in the following way. Reaction times from correctly answered trials on the CMS were used to derive a slope and an intercept measure for each of the following conditions: bias foil, repeated foil and standard Sternberg condition. All the reaction times for correctly answered trials were used; there were no real outliers in terms of reaction time in this set of data. In order to determine the slope for each of these conditions, the following equation was used:

$$(RT_{high}-RT_{low})/(Load_{high}-Load_{low})$$

In this equation RT is referring to the mean reaction time and Load is the memory set size, either 4 (high) or 2 (low). Please refer to Table 2 for the means and standard deviations for these indices. The slopes do indicate that the foil manipulations (bias and repeated) were having their desired effect. Scanning rates were higher for these two conditions when compared to the standard Sternberg condition, which is consistent with the results of Whitney et al. (2004), and there was a significant difference between the slope measures, $F(2, 284) = 6.34$, $p < 0.01$. As in the Whitney et al. study, the intercepts for each of the three CMS conditions were combined to create a single index of speed of processing. The intercepts were combined in order to create as reliable a measure of processing speed as possible. This combined intercept was then entered into the first block of the hierarchical regression along with the other CMS indices (bias foil slope, spaced foil slope and standard Sternberg slope). The traditional measure of WM, the DOT, was entered in the second block.

Results from both regressions indicate that none of the variables entered were able to predict final BGT performance. Table 3 contains the results for the regression analysis. The fact that no relationship between the BGT and WM emerged was surprising; therefore, the question of why no relationship was found needs to be addressed. A number of factors could have contributed to this lack of a relationship. For instance, was there sufficient variability in the tasks to find any differences? Was the variance truncated in the WM tasks in comparison to prior studies? Comparing the CMS indices to Whitney et al. (2004) revealed means and standard deviations that were not terribly dissimilar. For instance, the standard slope mean from Whitney et al. was 68 (SD = 24) and the standard intercept was 450 (SD = 74) compared to a standard slope of 47 (SD = 30) and standard intercept of 518 (SD = 110) in the present study. The overall means in the present experiment were slightly lower, but the direction of the effect and the standard deviations were quite similar. For instance, in the biased foil condition the slope was 93 (SD = 89), intercept 442 (SD = 216) compared to the present study with a slope of 73 (SD = 90) and intercept of 483 (SD = 226).

In terms of the DOT, the overall mean in this set of data was 20.82 (SD = 2.79) out of a possible total score of 24. This is comparable to that of MacDonald et al. (2001). Out of a possible total score of 20 in MacDonald and colleagues study (their version of the task did not include a set size of 7 as their participants were patients with Alzheimer's disease), they had a mean of 18.1 (SD = 1.59). Because of this agreement with prior studies, it does not seem that there was a truncation of variance in comparison to prior studies.

While it appears that a decrease of variance in the WM tasks is not the source of the problem in this set of data, the issue of whether or not there was enough variability in the BGT data set needs to be addressed. While the overall proportion of good choices for BGT performance was rather low, it did seem that there was sufficient variability to detect differences in this task. The results of the present study were comparable to that of

Hinson and colleagues (2002). The proportions of responses were roughly the same, between 0.20 and 0.55.

One final reasonable question to address is whether or not the DOT and CMS are actually assessing WM. Table 4 provides the Pearson correlations for the DOT and the CMS indices. Overall, most of the correlations were modest for the CMS indices. The DOT correlated significantly with the bias and repeated CMS indices, and not the standard or intercept indices. This would seem to indicate that the DOT and CMS are at least, in part, assessing the same ability. Further evidence that the DOT is assessing WM capacity can be found in Figure 4. In this figure, DOT performance has been divided into tertiles (low, medium and high). It appears that the poorest performers on the DOT (those in the lowest tertile) were also making the greatest number of digit load errors on the BGT. As digit load has been conceptualized as an extrinsic means of manipulating working memory, this provides further evidence for the digit load and DOT assessing the same ability, specifically that of working memory capacity. Perhaps this group of individuals, in the lowest tertile of DOT performance, is experiencing greater difficulty with working memory capacity. That is, both DOT performance and digit load performance are troublesome for this group of participants.

Figure 5 may also provide some insight as to why the predicted results were not obtained. In this figure final BGT performance for three groups of BGT performers (low, medium and high) across the two task conditions (control and digit load) are represented. For poor and medium performers on the BGT, performance stays roughly the same in both the control and digit load conditions. This is not true of the upper third of gambling task performers. Instead, those who performed well on the BGT in the control condition are those who appear to be affected by the digit load. This observation is potentially very important and could indicate why the predicted results were not obtained. Only those participants who fell into the upper third of performance, and were therefore doing a better job on the BGT then their peers, were the ones who were affected by working memory load. There are several potentially relevant explanations for this finding. One possibility why the two lower tertiles of BFT performers may have performed so poorly could be because there was a floor effect for these participants. That is, perhaps the task was simply too difficult. Another possibility is that the participants in the lowest two tertiles were utilizing a strategy on this task that did not involve working memory and was subsequently suboptimal. This would explain why there was no effect of WM load and why performance was so poor.

Figure 6 also shows that those who had more WM resources available (the upper tertile of performance), as measured by the DOT, performed better on the BGT than those with fewer WM resources. This corroborates the earlier finding that WM resources are essential for optimal performance on the BGT. Taken together, perhaps these figures reveal that a strategy involving working memory is essential for optimal performance on this task.

Experiment 2

The purpose of Experiment 2 was to further investigate the relationship of working memory to decision making by looking for the formation of a somatic marker in good and poor performers on the BGT. Additionally, this second experiment represented an attempt to see if the working memory-BGT individual difference relationships that were not found in Experiment 1 could be obtained.

Method

Participants

101 Washington State University Students participated for partial course credit. All participants were native English speakers. There were 47 males and 54 females. The average age of the participants was 19.40 (SD = 1.34).

Tasks and Procedure

The tasks utilized in Experiment 1 were also used for Experiment 2. The DOT and CMS were administered in series of group sessions with the order of presentation counterbalanced. At the end of each group session, participants signed up for an additional session where they performed the gambling task while SCR data was being collected. The gambling session was conducted one-on-one with the experimenter in a room that contained a desk, computer, several chairs and the skin conductance equipment. SCR was collected via a Contact Precision Instruments SC5 SA skin conductance monitor.

Participants were given demographic data questionnaires to complete upon arrival for the second session. This allowed the participants approximately 15 minutes to relax prior to the SCR data collection. This was important as many of the participants rushed to the testing session from classes or other prior engagements. After completion of the questionnaire, the two fingers on which the electrodes were going to be placed were cleaned with an alcohol wipe to guarantee a clean surface. Participants then had two electrodes, approximately 1 cm in diameter, placed on the index and middle fingers of their left hand with a drop of conductivity gel placed between the electrode and contact point on the finger. A double-sided adhesive ring was used to hold the electrode to the participants' fingers. The computer sampled the serial port to which the skin conductance equipment was connected every 0.05 seconds to obtain the measure of skin conductance response. The procedure of Hinson and colleagues (2002) was followed to determine the changes in SCR amplitude as a measure of affective responsiveness

Results and Discussion

Section 1: Replication of Prior Results

As in Experiment 1, performance on the BGT was examined to determine if the Hinson, et al. (2002) results were replicated. First, performance on the secondary task, the digit load, was examined to determine if the overall number of digit load errors were similar to that of the prior study as well as similar to Experiment 1. Errors across the 100 trials were roughly the same as Experiment 1, M = 15.52 (SD = 10.92).

Figure 7 illustrates the proportion of good choices across four blocks of 25 trials for the two task conditions (digit load and control). As can be seen in this figure, the results of this experiment differed from those of Experiment 1. Performance in the digit condition does not appear to decline across blocks as in Experiment 1. Rather, performance appears to remain roughly the same in the digit load condition across the four blocks of trials. While there does appear to be some minimal improvement in performance in the control condition, this improvement is not as clear as in Experiment 1 and overall variability is quite high, as revealed by inspection of the error bars.

To see if there were any significant differences in this set of data, a two-way repeated measures analysis of variance was conducted to examine the effect of secondary task condition by trial block. Because there was a violation of the sphericity assumption as indicated by Mauchley's test for sphericity, the Greenhouse-Geisser correction was applied to the degrees of freedom. There was a significant main effect of secondary task condition [*F* (1,100) = 7.64, $p < 0.01$] indicating that, in this experiment, unlike Experiment 1, performance in the digit load secondary task was better. There was no significant main effect of trial block [*F* (2.73, 272.60) = 1.65]. The secondary task condition by trial block interaction was also not significant [*F*(2.68, 268.30) = 0.39].

Neither the results of Hinson et al., nor the effects of Experiment 1 were replicated in Experiment 2. Participants did not learn to choose more cards from the good decks across the block of trials. Independent t-tests between the two orders of presentation of blocks were conducted on good choices for the four blocks of trials to test for a potential effect of the order in which the control and digit load condition were administered. These t-tests yielded non-significant results for all four blocks, so the order of presentation does not account for the null results.

Since order effects do not account for the lack of significant results in this experiment, other factors need to be considered. A number of anecdotal comments made by participants in this experiment seem to point toward their concentration on the task being much greater in the digit load condition than in the control condition. This observation is supported by inspecting Figure 7. Overall performance did appear to be better in the digit load condition. Many participants stated that they grew bored in the control condition and were not trying as hard on the task as perhaps they could. Thus, motivation to perform the BGT could be a factor, with motivation being low for most of the participants. While this may be one explanation for the anomalous results, inspection of the graph seems to support the idea that choices in the digit load condition were simply random, and this is why there was no change in performance across the four blocks of trials.

Section 1.2: Replication of SCR Results

While the BGT behavioral results do not replicate either prior studies or Experiment 1, it is worth analyzing the SCR data to determine if participants developed a somatic marker in the current experiment. Figure 8 depicts SCR amplitude for good and bad choices by trial block. Inspection of this graph reveals a great deal of variability in all the conditions represented. To determine if there was a somatic marker present in any of the blocks, difference scores were calculated from the SCR amplitude for each of the four trial blocks. Specifically, the SCR amplitude to the bad choice was subtracted from the SCR amplitude to the good choice for each block within each condition. These values were then used in a two-way repeated measures analysis of variance for secondary task condition by trial block. Because there was a violation of the sphericity assumption as indicated by Mauchley's test for sphericity, the Greenhouse-Geisser correction was applied to the degrees of freedom. This analysis revealed no significant differences for secondary task condition [F (1,100) = 0.957], trial block [F (2.75,274.46) = 0.556] or the interaction of the two [F (2.80,279.64) = 2.44].

This lack of the formation of a somatic marker merely reinforces the findings of no significant differences in the behavioral data. Participants never truly improved on the gambling task in Experiment 2; therefore, the lack of a somatic marker is hardly surprising. Again, order effects do not explain the findings in this experiment; rather, it may be some interaction of task difficulty and participant motivation that accounts for the non-significant results.

Results Section 2: Individual Differences in BGT Performance

As in Experiment 1, two hierarchical regression analyses were conducted. In the first regression analysis, final BGT performance in the control condition (i.e., no digit load) was predicted with the CMS indices entered into the analysis first as a block, followed by the DOT. The second regression analysis was identical, but the dependent variable was final BGT performance in the digit load condition. Again, the results did not reveal any relationship between the BGT and WM. The results of these two regression analyses may be found in Table 5.

As in Experiment 1, no relationship was found between WM and BGT performance, but there are some interesting trends. For instance, inspection of Figure 9 shows that those participants in the highest BGT group outperformed the other three groups on the DOT, a measure of working memory capacity, again indicating that WM is necessary for optimal performance on the BGT.

Additionally, as depicted in Figure 10, those in the high working memory group as assessed by the DOT, made fewer errors on the digit load secondary task than those in the low working memory group, just as was found in Experiment 1. In this case however, there does not appear to be a great deal of difference between good DOT performers and average DOT performers. But, those who performed poorly on the DOT also made more digit load errors.

Finally, upon inspection of Figure 11, when final BGT performance for the three groups of BGT performers is examined across the two task conditions (control and digit load), for those in the middle tertile of BGT performance, their performance stayed roughly the same in the digit load condition and in the control condition. This is not true of the extreme groups. Instead, those who performed well in the control condition are the people who appear to be affected by the digit load with performance decrements, while those who performed poorly in the control condition seemed to do *better* with a digit load.

In one last attempt to find evidence of a somatic marker, the upper third of BGT performers (N = 34) were examined alone. Again, a repeated measures ANOVA was conducted to determine if a somatic marker had formed in these better performers. Even in this group of performers, it does not appear that a somatic marker developed as the repeated measures ANOVA revealed no significant differences.

General Discussion

As in previous research, Experiment 1 of the current study showed that decision making under conditions in which working memory has been taxed is worse than in a control condition. However, these results were not replicated in Experiment 2, nor was there evidence of a somatic marker in Experiment 2. Further, the present study has shown that a profile of poor and optimal performers on this version of the Bechara Gambling Task cannot be generated based on measures of working memory. None of the working memory measures were able to predict BGT performance. Does this mean, then, that WM does not play a role in the decision making process? Not necessarily. The effect of digit load on decision making was replicated in Experiment 1, indicating that there is an effect of working memory load, thereby pointing toward some role for working memory. While a significant effect was not found for Experiment 2, the same trend was evident. If working memory is involved in the decision making process in some way, then why was this not revealed in a profile of different abilities for different groups? There are a number of issues that could have impacted the results of the present study. First, overall performance on the BGT was extremely poor for most participants, typically falling below a proportion of 0.50 good choices. Approximately one third of the participants learned how to perform well on the BGT (in most gambling task studies, performance at or greater than a proportion of .55 choices from the good decks; c.f. Hinson, Jameson & Whitney, 2002) while the other two thirds never achieved optimal performance. Interestingly, of those who did achieve optimal performance on the control condition of the BGT, most were members of the high working memory group, when such groups were generated based on DOT performance. This holds true for both Experiment 1 and Experiment 2. Those who performed optimally on the BGT, also fell into the upper range of DOT performance.

Another interesting trend can be seen when we look at the three groups of BGT performers and the final BGT performance for these groups across the two task conditions (control and digit load). As can be seen in Figures 5 and 11, performance stays the same in the digit load condition for those in the lower and middle tertile of BGT performers. This does not hold for the upper tertile of gambling task performers. Instead, those who performed optimally in the control condition are the people who appear to be affected by the digit load. This could indicate that these are the people who are actually utilizing a strategy that relies on working memory resources, and with the addition of the digit load they are forced to abandon that optimizing strategy. The other two groups of BGT performers could be utilizing some other type of non-optimal strategy that does not involve working memory and is therefore not affected by the addition of the working memory load. One way to test this hypothesis would be to provide participants with a working memory strategy and see if this improves performance for those low performers in the control condition. For instance, one way to provide participants with a working memory strategy is to tell them that they need to keep a running total of the four decks. This would impose an external strategy on their performance.

While this trend holds for both Experiment 1 as well as Experiment 2, there is an interesting anomaly that appears in Experiment 2. In this experiment, participants in the lowest BGT performance group appear to get *better* with the addition of a digit load. While this effect cannot be easily explained, several participants did comment upon completion of the BGT that they thought they had done better in the load condition because it had forced them to concentrate and they were not as bored as they were in the other condition. However, the other reasonable explanation is that participants in this case were simply choosing from the decks at random.

These anecdotal comments point toward a participant's motivation being a factor in the current study. What was an individual's motivation, in the classic sense, to do the task? Based on participant comments, levels of motivation were fairly low. Perhaps participants found the task to be very boring, and were not trying to perform to the best of their ability. This hypothesis could be tested in future studies by providing participants with an external motivator (perhaps money) that functions differently from that of simply receiving credit for their class. If participants were more motivated to do the task, they may have done a better job and a pattern of individual differences could potentially be discovered.

Finally, in future studies it might be a good idea to use some different measures of working memory. Perhaps the working memory measures utilized in the present study were not sensitive enough to detect any differences. If this is the case, perhaps future research could explore the relationship between working memory and decision making with more reliable and sensitive measures.

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Table 1. Payoff parameters for choices in the Modified Bechara Gambling Task.

Deck	Min	Max	M	SD
Bad 1	-250	100	-25	140
Bad 2	-1150	100	-25	395
Good 1	-50	50	25	41
Good 2	-200	50	25	79

Table 2. Descriptive statistics for CMS indices Experiment 1.

Condition	Slope (SD)	Intercept (SD)
Standard	47 (30)	518 (110)
Repeated Foil	75 (47)	435 (117)
Bias Foil	73 (90)	483 (226)

Table 3. Regression analysis results for Experiment 1.

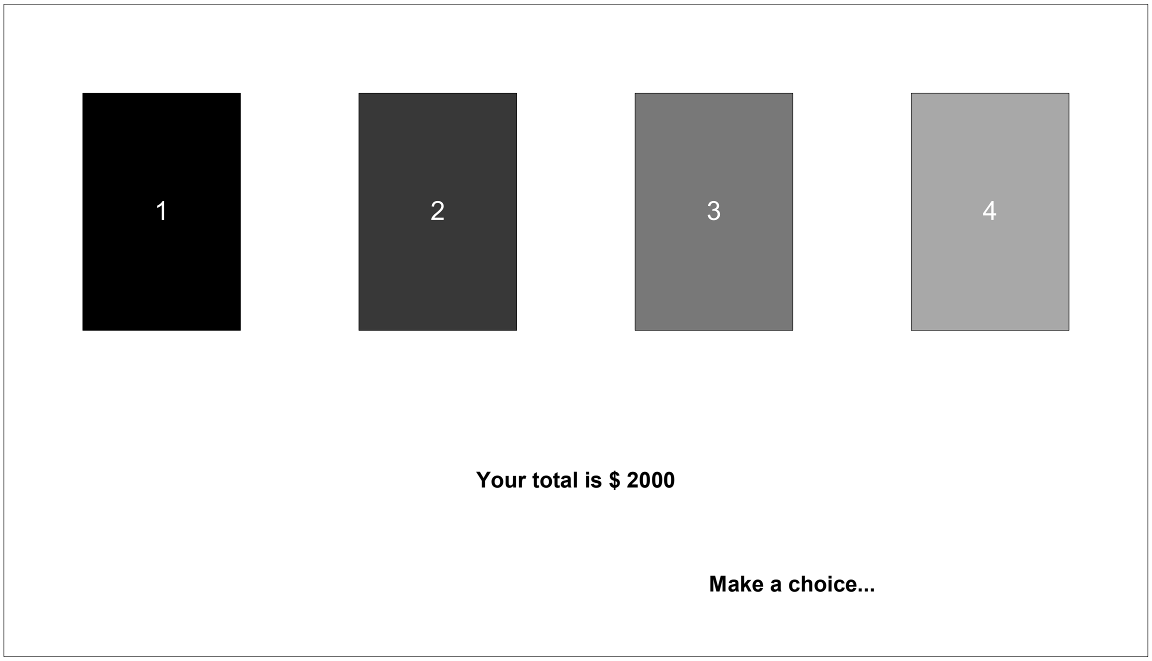
Block	Variables Entered	R	F-Change	(df)	p
Predicted Variable: Final BGT Control Performance					
1	Intercept Standard Repeated Foils Biased Foils	0.224	1.191	(4,90)	ns
2	DOT	0.226	0.089	(1,89)	ns
Predicted Variable: Final BGT Digit Load Performance					
1	Intercept Standard Repeated Foils Biased Foils	0.120	0.331	(4,90)	ns
2	DOT	0.148	0.671	(1,89)	ns

Table 4. Correlations among CMS predictors and DOT for Experiment 1.

Predictor	Intercept	Standard	Bias	Repeat	DOT
Intercept	-----	-.21**	-.69**	-.31**	.04
Slope:					
Standard		-----	.28**	.34**	-.19
Bias			-----	.41**	-.21*
Repeat				-----	-.32**

Table 5. Regression analysis results for Experiment 2.

Block	Variables Entered	R	F-Change	(df)	p
Predicted Variable: Final BGT Control Performance					
1	Intercept Standard Repeated Foils Biased Foils	0.125	0.379	(4,96)	ns
2	DOT	0.186	1.870	(1,95)	ns
Predicted Variable: Final BGT Digit Load Performance					
1	Intercept Standard Repeated Foils Biased Foils	0.195	0.952	(4,96)	ns
2	DOT	0.209	0.546	(1,95)	ns



Your total is $ 2000

Make a choice...

Figure 1. Example of a Bechara Gambling Task trial.

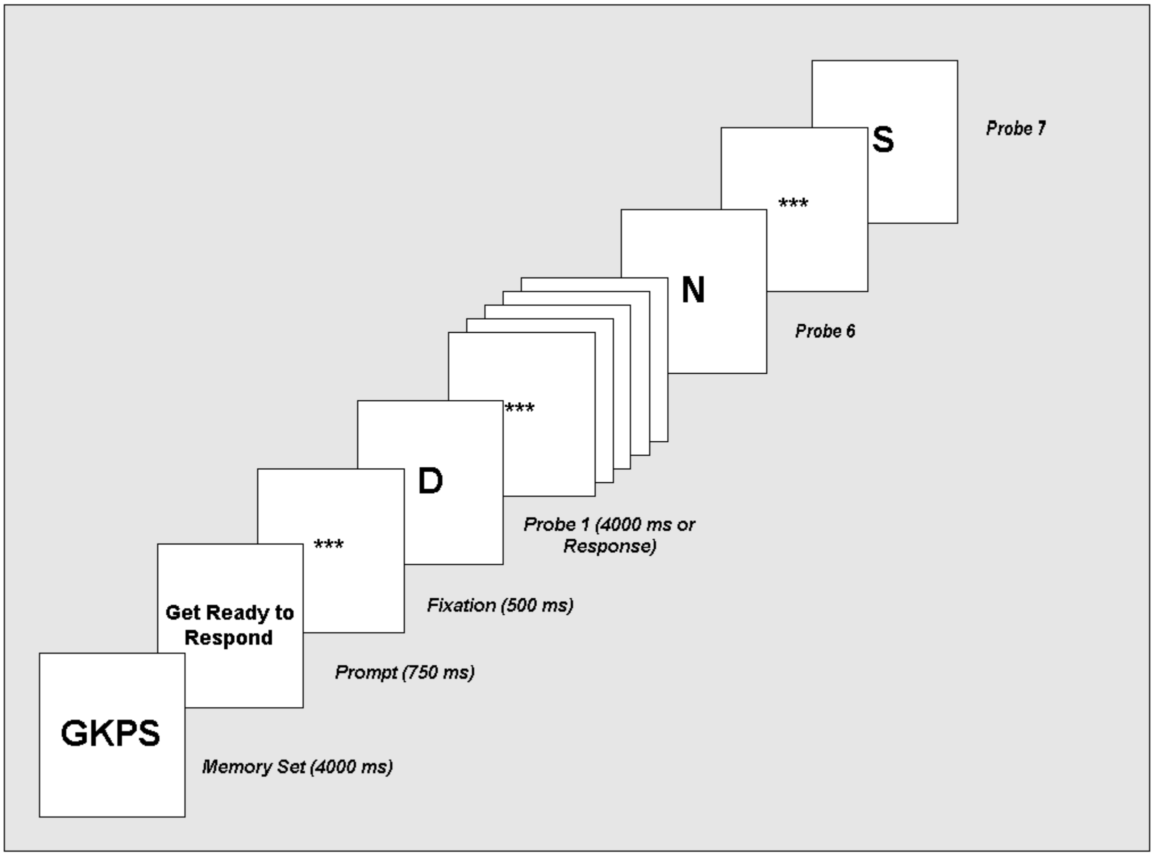


Figure 2. Example of a Continuous Memory Scanning trial.

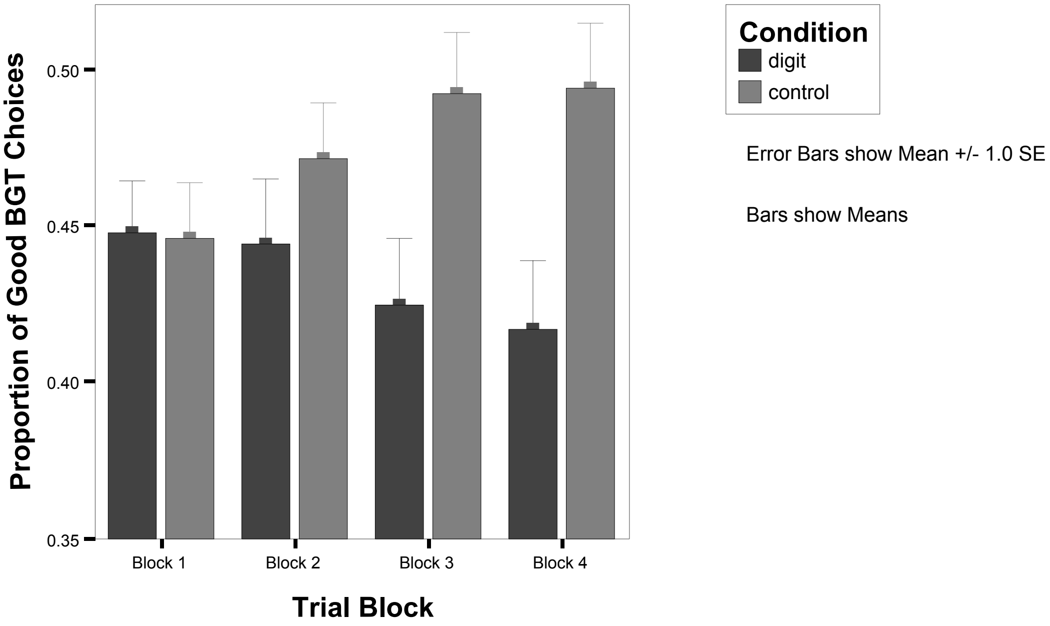


Figure 3. Proportion of good choices by trial block for Experiment 1.

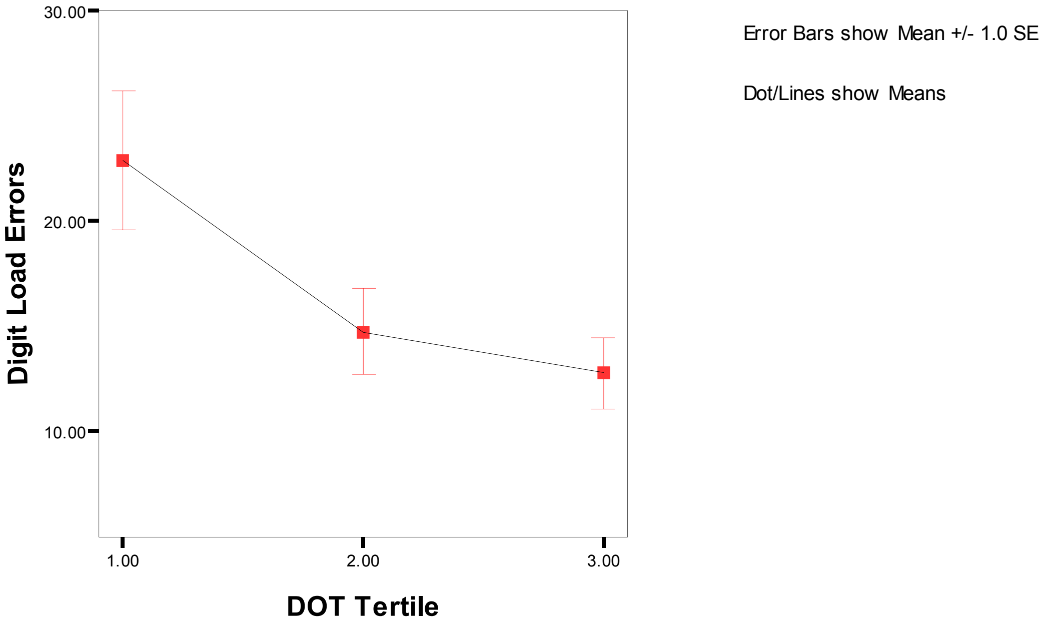


Figure 4. The number of digit load errors by Digit Ordering Task tertile.

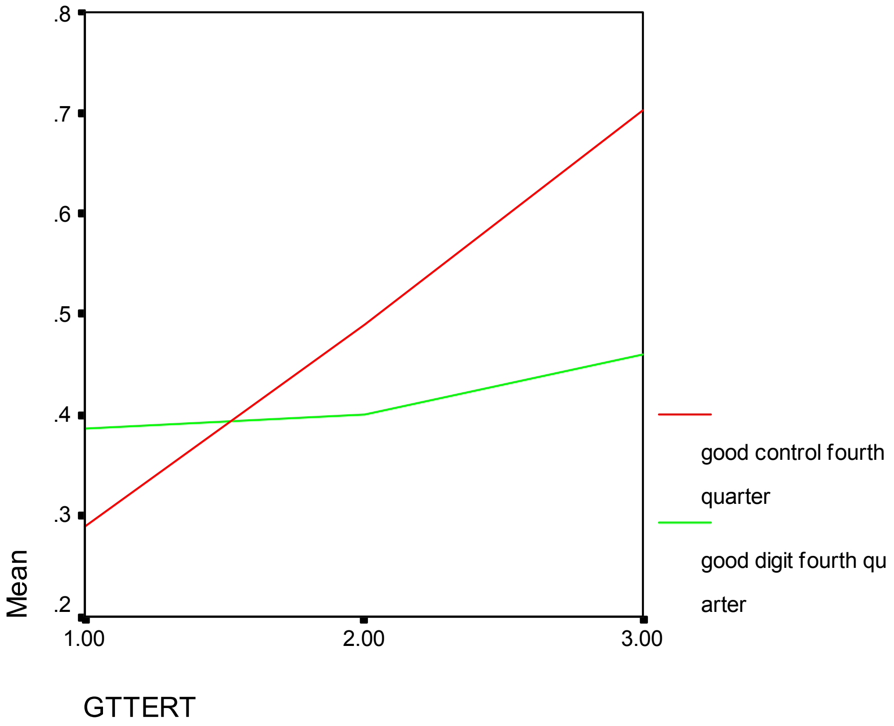


Figure 5. Final Bechara Gambling Task performance for digit and control conditions by Bechara Gambling Task performance tertiles.

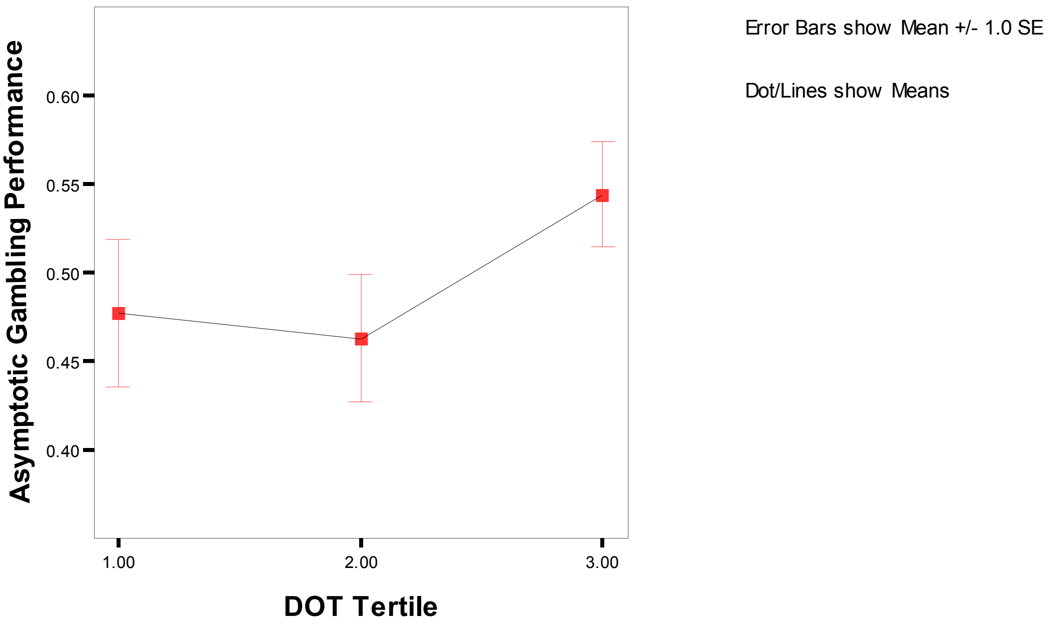


Figure 6. Final Bechara Gambling Task performance by Digit Ordering Task tertile for Experiment 1.

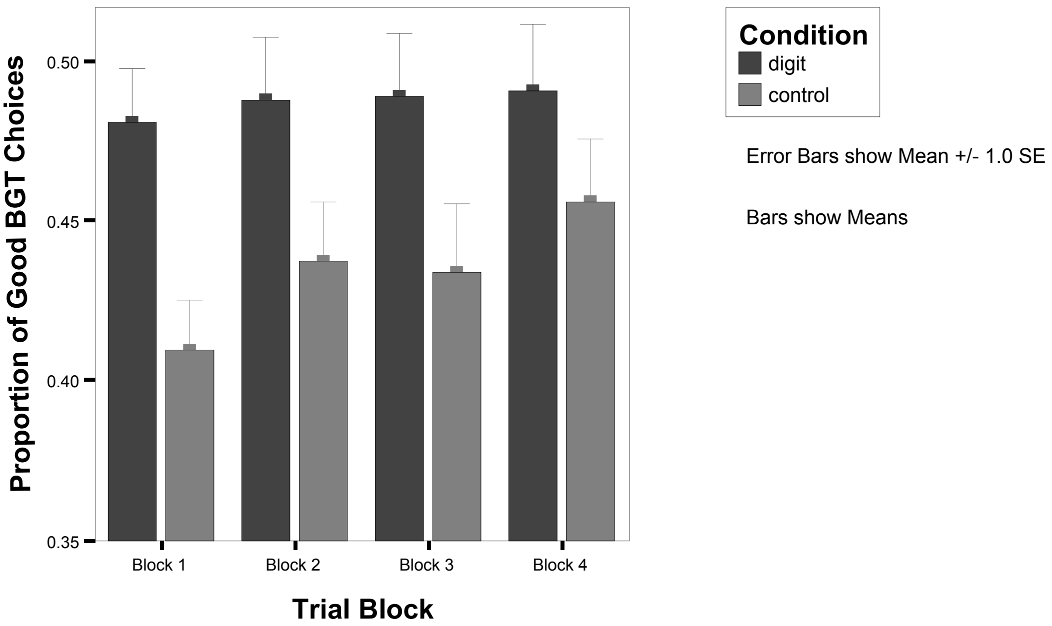


Figure 7. Proportion of good choices by trial block for Experiment 2.

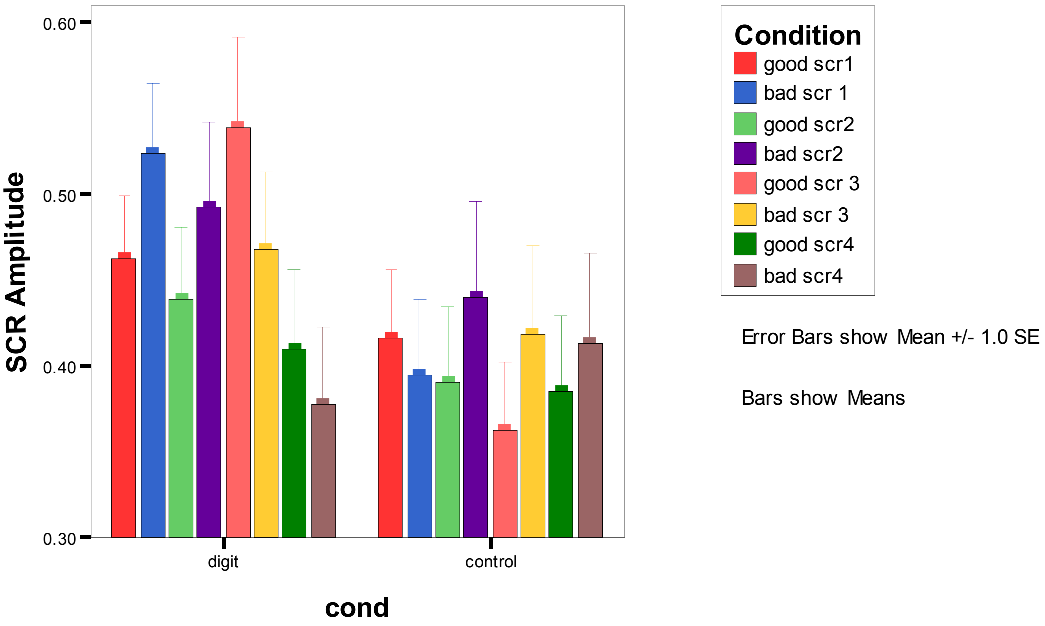


Figure 8. SCR amplitude for each trial block (1-4) by condition, digit load or control.

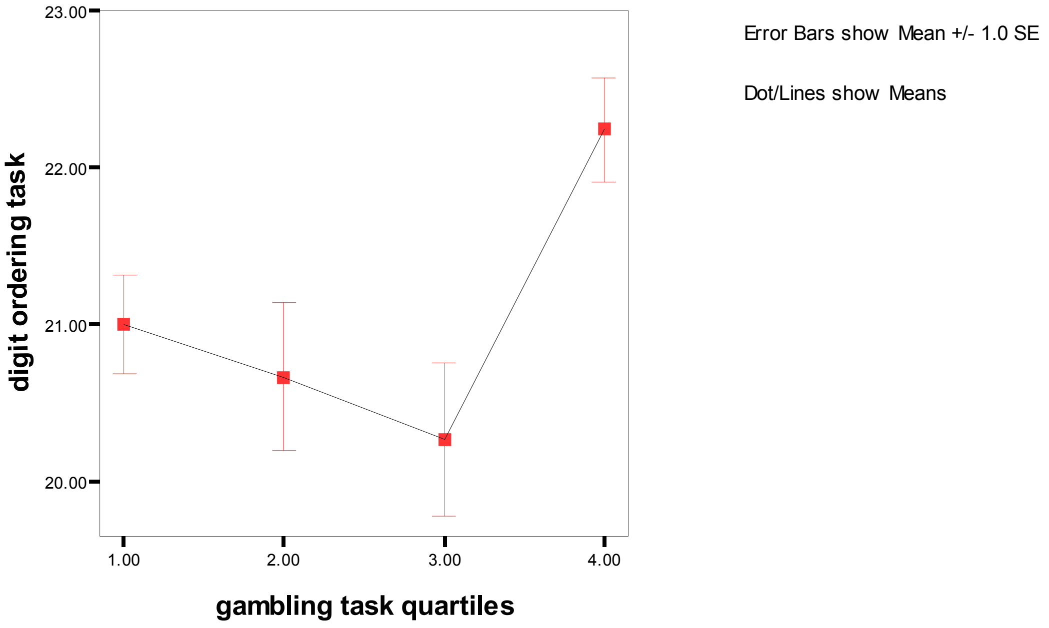


Figure 9. Digit Ordering Task performance by Bechara Gambling Task quartile. Those in the upper quartile of Bechara Gambling Task performance had higher Digit Ordering Task scores.

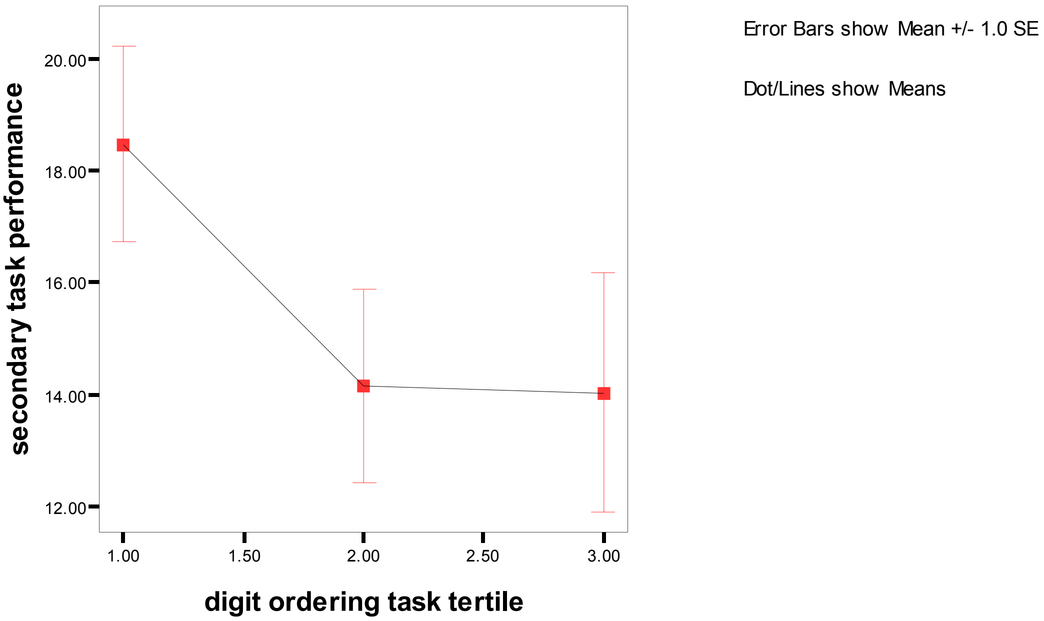


Figure 10. Digit load errors by Digit Ordering Task tertile.

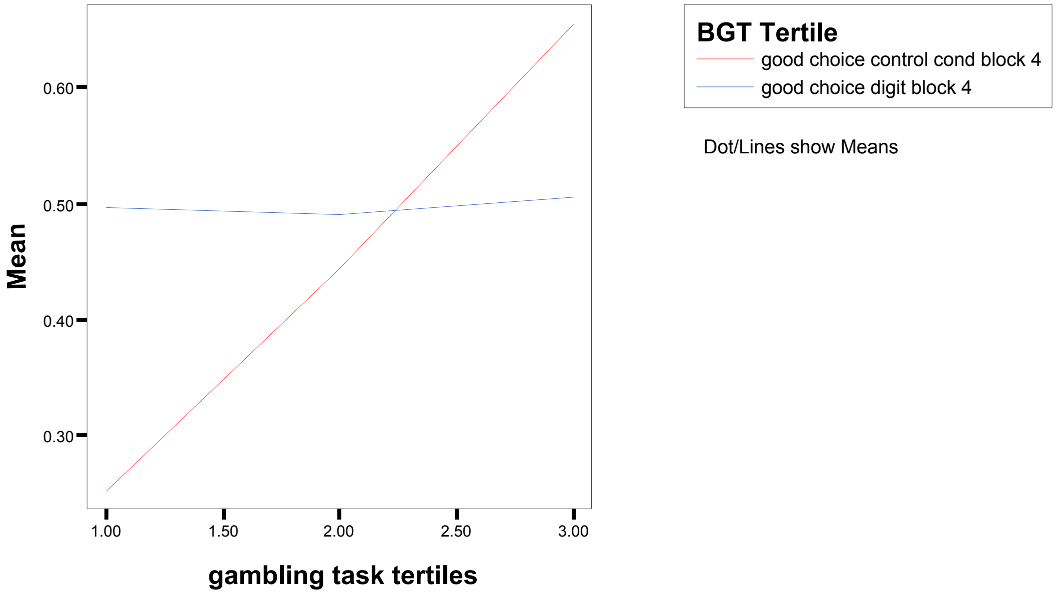


Figure 11. Bechara Gambling Task performance by Bechara Gambling Task tertile.

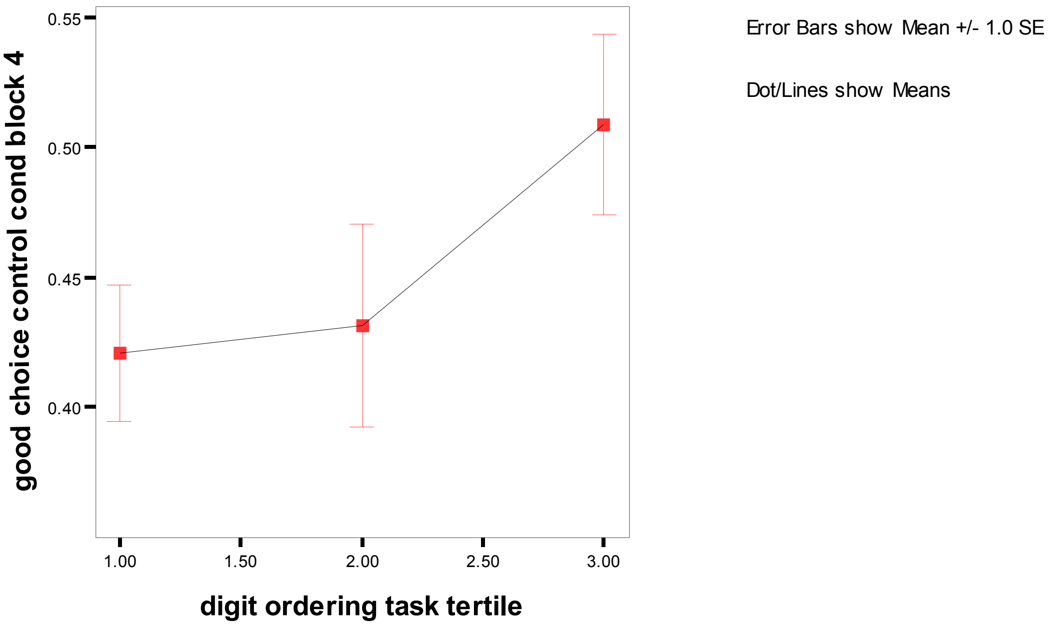


Figure 12. Final Bechara Gambling Task performance by Digit Ordering Task tertile for Experiment 2.