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The Effect of working memory and math ability on decision making

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THE EFFECT OF WORKING MEMORY AND MATH ABILITY ON DECISION MAKING

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ABSTRACT

The Effect of Working Memory and Math Ability on Decision Making

by

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Previous research has indicated that people use various strategies when making decisions. A majority of the research has involved the idea that people use a heuristic when making decisions. Kahneman and Tversky have illustrated that there are instances that people respond with an answer that appears to be indicative of usage of the representativeness heuristic. One of the purposes of the current paper is to gain insight into the actual strategies that are used in these instances. Another purpose of the current experiment is to see if math ability and working memory capacity influence the strategy that a person selects to use. Experiment 1 indicated that people were more accurate on these tasks than expected. On certain tasks, it appears that participants found a simpler strategy than the representativeness heuristic that produces an accurate answer. In experiment 2, the stimuli were adjusted to make sure that the simpler strategy would not work on all trials. The reaction time and response data indicated that the representativeness heuristic was used when other strategies failed to produce a definitive answer. It was also found that the participants who were worse at math defaulted to the representativeness heuristic when the simpler strategy did not result in a definitive answer and that the participants who were better at math were more likely to respond with the correct answer regardless of whether or not the simpler strategy resulted in a definitive answer.

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CHAPTER 1

INTRODUCTION

The task of making a decision is common among everyday activities. Making a decision does not always have to be some sort of challenging task; making a decision can be as simple as choosing which route you will take to arrive at work. However, there are some situations in which people must make decisions that may have life-altering consequences. While it is understood that some people are better at making decisions than others, the reason for this is not as well understood. Considering the fact that many decisions require a person to consider probabilities and to keep track of many alternatives at the same time, it can be deduced that both math ability and working memory capacity can influence a person's ability to make decisions. The purpose of the current paper is to summarize the research in the field of decision making and to discuss how math ability and working memory capacity are related to a person's ability to make decisions.

Decision Making

Gilovich and Griffin's (2002) review of the history of decision making research indicates that one of the initial models of decision making was Simon's (1955) model of rational choice. The rational choice model indicates that after a person calculates the probability of each possible outcome when making a decision, the person will choose the outcome with the highest probability that is also the most useful. In other words, the person not only calculates the probability of each outcome but also forms a ratio of probability to usefulness and selects the most appropriate outcome. In the rational choice model probability is the likelihood of the event occurring and usefulness indicates whether or not the alternative will be applicable for the person's individual situation. For example, if a person is deciding on which presidential candidate to vote for, they are likely to look at each candidates' position on many issues and calculate which candidate has the highest probability of having similar views as themselves. However, the person may find that the candidate that has the highest probability as them does not have a good chance at winning the election (e.g., they represent a small political party). Then the person will select the candidate that has the highest probability but also has a chance at winning the election. The person is calculating a ratio of probability to agreement (on issues) to chance at winning the election (usefulness).

According to the rational choice model, people are good at making decisions (Simon, 1955). The rational choice model goes on to state that when a person does make an error in judgment the error is random, instead of systematic (Gilovich & Griffin, 2002). For the rational choice model to be correct, there are two assumptions that must be made. The first is that people are skilled at figuring out probabilities. Not only does the person need to possess basic knowledge on how to calculate probabilities but the person must be able to convert these probabilities into a ratio of likelihood to usefulness. This first assumption is based on the idea that people are fairly skilled at math, or at least skilled enough to perform the appropriate calculations to make the correct decision.

The second assumption is that people will need to do probability calculations in working memory and hold the probability of each outcome in working memory to determine which of the outcomes has the highest ratio of likelihood to usefulness. This task may be difficult and will require a large amount of working memory resources in order to complete the task efficiently. Evidently, even one of the earliest of models of decision making had an underlying assumption that people will have sufficient math knowledge and a large enough working memory capacity to be able to effectively make decisions.

It appears that there are some flaws with the rational choice model. As stated earlier, the rational choice model assumes that all people are good at making decisions. If *all* people are good at making decisions, people that are well versed in a particular area should do extremely well in making decisions that pertain to their area of expertise. Meehl (1954) analyzed the decisions of clinicians and found that they did not perform as well as decisions based strictly on mathematical formulas when making predictions or decisions about a particular diagnosis. Meehl's (1954) research provided evidence for the fact that people are error prone when making decisions, even concerning topics in which they are well versed. Since experts are prone to making errors in their area of expertise, Meehl's (1954) research implied that perhaps people do not use the appropriate probability calculations when making decisions.

Later, Simon (1955) discussed that there are several cognitive limitations that arise when people are making decisions. Both the difficulty of the task and environmental constraints can impact a person's ability to make a decision. While the difficulty of the task may surpass the ability that a person possesses, the environment may not have all necessary information to make a decision and require the person to make the decision in a relatively short amount of time. Therefore, there are several factors that could have a negative impact on the person's ability to make an accurate decision.

Despite the several challenges people face when making decisions, there are many people that are able to make correct decisions. With such challenges in mind, Meehl (1957) suggested that statistical theories for making decisions are flawed. Meehl (1957) indicated that rational behavior is a result of the way a person perceives and thinks about a decision as opposed to using calculations to make a decision. Instead, Meehl (1957) continued to indicate that certain situations require a person to use heuristics when making a decision due to limited computational capacity and/or environmentally caused cognitive limitations. This thinking lead to the recognition of two types of heuristics: heuristics that are based more on probability and statistical reasoning (more objective) or heuristics that allow a person's experiences to impact the way that they make their decisions (more subjective). Much of the research on the more probabilistic and statistical types of heuristics (more objective) was done by Tversky and Kahneman (e.g., 1974; among other researchers) while the heuristics that allow personal experiences to influence a person's decision (more subjective) were researched heavily by Gigerenzer (e.g., 1993; among other researchers). There are three main heuristics on which Kahneman and Tversky did extensive research, representativeness, availability, and anchoring and adjustment. In the following section, these three heuristics will be discussed in detail followed by the Gigerenzer's fast and frugal heuristics.

Representativeness Heuristic

The representativeness heuristic (Tversky & Kahneman, 1971) is in use when a person estimates the likelihood of an event by comparing it to the overall population of same/similar events. An experimental example could be a situation in which a person is supposed to verify which of two sequences of coin flips is more likely: *TTTHHH or THTHTH.* A person that is strictly using the representativeness heuristic may say that the second alternative is more likely because it appears to be more representative of the population of events. In other words, people will think that a string of consecutive heads and then consecutive tails is less representative than alternating heads and tails. According to basic probability theory, both sequences are equally likely, given an infinite sample.

Another manner in which a person could use the representativeness heuristic is when a person determines the likelihood of an event by comparing the event to the prototype of similar events that are stored in memory. For example, a person might say that in the United States there are more robins than chickens. While both of them are birds, a robin is probably more similar to a person's prototype of a bird that is stored in memory (Rosch, 1975). Therefore, people can use the representativeness heuristic in two different ways. The first is when a person makes a decision by comparing an event to what they assume is likely of the population of events. The second is when a person determines the probability of an event by comparing the event to the mental representation prototype. The appeal of the representativeness heuristic is that it is less time consuming when compared to calculating the actual probability. While the representativeness heuristic expedites the decision making process, the heuristic is more likely to make errors than actually calculating the probability of the event.

As stated earlier, some of the initial models in decision making assumed that people are good at making decisions because people are efficient at calculating probabilities. To test the idea that people are efficient probability calculators, Tversky and Kahneman (1971) asked psychological researchers the following question:

> *"Suppose you have run an experiment on 20 subjects, and have obtained a significant result which confirms your theory ($z= 2.23$, $p < .05$, two-tailed). You now have cause to run an additional group of 10 subjects. What do you think the*

probability is that the results will be significant, by a one-tailed test, separately for this group?"

Their logic was that if people are good at calculating probabilities, then certainly people who spend their careers doing research would answer this question accurately, at least according to statistical theory. The majority of the respondents answered that the probability was approximately .85 while the correct answer, according to statistical theory, was roughly .48. In this situation, the participants determined the likelihood of the event by comparing it to the already significant findings in the question, instead of calculating the actual probability of the event. Therefore, the participants determined the likelihood of an event by making it representative of the information that they were already given. Also, it appears that people made their decision without taking the size of the sample into account and instead simply compared the event in question to the overall population of events. The results of this experiment indicated that the participants were using the representativeness heuristic. Tversky and Kahneman (1971) provided evidence that even people that use statistics and probabilities regularly in their profession make incorrect judgments of the probability of an event occurring, even when the scenario is similar to something that they might run into everyday in their profession.

According to the rational choice model, people are skilled at making decisions using probability calculations in order to come to a decision. Apparently, though, people do not always use such calculations. To explain this phenomenon Kahneman and Frederick (2002) discuss that there are two cognitive systems that could be used when making a decision. The first system (System 1) is the less effortful of the two systems. System 1 is automatic and can occur while a person is simultaneously working on another task. The second system (System 2) is the more effortful of the two systems and involves a slower, more methodical process that is governed by some set of rules. The rules vary depending on the situation. In the case of the representativeness heuristic, System 1 is utilized. When making decisions, comparing the alternatives to a prototype or the overall population of events is a fairly effortless process and can be done while simultaneously working on another task.

Tversky and Kahneman (2002) tested to see if people are prone to making errors when using System 1 and more specifically using the representativeness heuristic. The "Linda Problem" was presented to participants to determine how efficient people were while using the representativeness heuristic. The "Linda Problem" appears below:

Linda is 31 years old, single, outspoken, and very bright. She majored in philosophy. As a student, she was deeply concerned with issues of discrimination and social justice, and also participated in anti-nuclear demonstrations.

Linda is a teacher in an elementary school.
Linda works in a bookstore and takes yoga classes.
Linda is active in the feminist movement. (F)
Linda is a psychiatric social worker.
Linda is a member of the League of Women Voters.
Linda is a bank teller. (T)
Linda is an insurance salesperson.
Linda is a bank teller and is active in the feminist movement. (T & F)

Considering the two systems that a person could use to make a decision, discussed above, there are two different ways that the "Linda Problem" could be solved. The first (using System 2) would be to examine all of the different scenarios and calculate which are the most likely to occur (what percentage of women in the world are psychiatric social workers?) and then order the level of representation of each statement according to these percentages. The second way would be to use System 1 and find some sort of heuristic that could be used. Here, the representativeness heuristic could be used to judge the character summary of Linda and see how representative the summary is for each of the alternatives.

It appears that people use system 1 when answering questions like the "Linda Problem". The results of Tversky and Kahneman (2002) indicated that the alternative labeled (T & F) was selected more often than the alternative labeled (T). According to probability theory, it is impossible for a conjunction of multiple items to be more probable than one of the constituents. For example, in the "Linda Problem" it is impossible for being a bank teller and being active in the feminist movement to be more likely than being a bank teller, because to be both she would have to be a bank teller, but being just a bank teller does not necessitate also being part of the feminist movement. Therefore, many of the participants must have been using the representativeness heuristic or System 1 instead of computing the probability of each alternative to solve the problem. The results from Kahneman and Tversky (2002) indicated that people were likely to use heuristics and that the use of heuristics may result in people answering incorrectly. The error in judgment that the respondents made is known as the conjunction fallacy. The conjunction fallacy is when a person estimates that a conjunction of multiple constituents is more likely than only one of the constituents. This type of error can only be the result of using a heuristic because probability calculations will result in people realizing that the conjunction of multiple constituents could not have a higher probability than one of the individual constituents.

Another decision making task in which participants may use the representativeness heuristic is the coin toss task, mentioned earlier. In this task a person is asked which string of coin tosses is more likely (ex. *HTHT* or *TTTT*). Here, using System 1 (in this case the representativeness heuristic) would lead the person to the former alternative because it "seems" more random. However, if a person were to use System 2 they would find that each outcome has a 1/16 (½ x ½ x ½ x ½) chance of occurring; therefore the alternatives are equally likely. Essentially, people are likely to pick the outcome that they surmise is more representative of what would happen in the population instead of computing difficult calculations to figure out which of the outcomes is more likely (Kahneman & Tversky, 1972). It appears that System 2 is more accurate while System 1 is less time consuming but produces more errors.

Because System 1 is easy to use, people are also prone to using System 1 when they are gambling. Roulette is a popular table game in which a person bets on where they predict a small metal ball will land on a large spinning wheel. One of the types of bets that a person can make is on which color the ball will land. Approximately half of the spots are red and half are black. Throughout the course of the game the ball may land on a certain color (say red) in several consecutive trials. When this situation occurs, many people will start to place their bets on the opposite color (in this case black). This is done under the assumption that because the ball has landed on the same color a large number of times, the ball needs to land on the opposite color for the sample to be more representative of the expected 50:50 ratio. This is known as the Gambler's Fallacy. The Gambler's Fallacy is when a sample of observations has deviated from what should be the norm, than the sample will automatically correct itself in later trials (Edwards, 1961).

When a person is using the representativeness heuristic they will make a decision on the next event based on how similar the events are to what is representative of the population of events, which will cause them to assume that the string of events will "self-correct" to be more representative. However, the laws of probability reject the idea the there will be an immediate correction in the direction of the norm. The probability of the ball landing on a particular color is identical every time the ball spins around the wheel. The probability of where the ball will land does not change based on previous trials. Thus, the Gambler's Fallacy appears to be an erroneous way of thinking.

Recently, though, Hahn and Warren (2009) discussed an experiment that examined why people were so prone to making errors when using the representativeness heuristic. Consider the coin toss example where many people believe that a sequence of events that appears to be irregular (e.g., *THTH)* is more probable than a sequence that is consistent (e.g.,. *HHHH*), as seen in Kahneman and Tversky (1972). Hahn and Warren's (2009) idea is similar to the idea of sample size. According to the law of large numbers the more observations a person makes, the more representative the sample is of the population (Boring, 1941). Therefore, a small sample may not be representative of the population. The same could be thought of with probabilities. When a person takes an infinite number of observations the person is likely to have an equal number of each possible sequence. However, if the person is taking a finite number of samples then the rules of probabilities change. In other words, in an infinite sample of coin tosses a sequence of *HHHH* has the same probability of occurring as *HHTT*. Conversely, in a finite sample, the probability of a sequence of *HHHH* occurring is not the same as a sequence of *HHTT*. Through rigorous calculations, Hahn and Warren (2009) found the "wait time" for various different sequences. "Wait time" is the average number of coin flips a person would have to wait in order to find a particular sequence. The average wait time for *HHTT* was sixteen coin tosses while the average wait time for *HHHH* was thirty coin tosses. This indicates that *HHTT* is a more likely sequence than *HHHH* when there are a finite number of coin tosses. Hahn and Warren (2009) also indicated that given a finite sample, the more regular a sequence is (*HHHH*), the longer the "wait time" and the less likely the sequence is to occur in small samples.

The findings in Hahn and Warren's (2009) article may have more external validity than most probability research for two reasons. First, people are never in a situation in which they are witnessing an infinitely long sequence. Therefore, it seems that a person's answer when using the representativeness heuristic is more accurate than if the person had calculated the probability of each option. Second, even if there were a situation in which a person does see an infinitely long sequence, a person can only store a limited number of observations in memory. Therefore, a person will only have access to several of the trials in memory. Thus, a person's reality will be more similar to a finite number of trials than an infinite number of trials, meaning that some strings of coin tosses should be more likely than other strings of coin tosses in an individual's reality. It appears that Hahn and Warren's (2009) study supports the actions of the desperate gambler that places all of his money on black after a long string of consecutive reds.

There is evidence that people make errors due to considering finite samples when it may be more appropriate to analyze an infinite sample size (Hahn & Warren, 2009). There is also evidence that when people are made aware of a finite sample size they still make errors due to the representativeness heuristic. Tversky and Kahneman (1974) gave participants the following scenario:

A certain town is served by two hospitals. In the larger hospital about 45 babies are born each day, and in the smaller hospital about 15 babies are born each day. As you know, about 50 percent of all babies are boys. However, the exact percentage varies from day to day. Sometimes it might be higher than 50 percent, sometimes lower.

For a period of one year, each hospital recorded the days on which more than 60 percent of the babies born were boys. Which hospital do you think recorded more such days?

- *The larger hospital (21)*
- *The smaller hospital (21)*
- *About the same (that is within 5 percent of each other) (53)*

The values that are in parentheses are the number of participants that selected that option. In this hospital scenario, a 50-50 male to female ratio for each hospital is seen as representative. Therefore, it is logical that the number of days in which there is an extreme number of boys born in the hospital should be about the same for each hospital. However, statistically, when a sample is large it is more likely to be representative of the population, while a smaller sample is more likely to have extreme scores or be unrepresentative of the population. Therefore, basic statistics knowledge would lead a person to indicate that the smaller hospital is more likely to record more extreme days of male births (which is the correct answer). The results of this experiment indicate that even though a participant is aware of the size of the sample, the participants are still prone to errors when using the representativeness heuristic. People are not only prone to making errors when they are comparing a scenario to how well it represents what they depict should happen in the population, people are also prone to making errors due to comparing how easily a scenario can be retrieved from memory.

Availability Heuristic

Another one of the heuristics that was studied extensively by Tversky and Kahneman (1974) is the availability heuristic. The availability heuristic is used when a person is unsure of the correct answer and, therefore, determines the likelihood of an event by how easily similar instances or situations can be retrieved from memory (Schwartz & Vaughn, 2002). Situations, instances, or examples that are retrieved from memory more easily are seen as more likely than those situations, instances or examples that cannot be retrieved from memory easily. Gilovich and Griffin (2002) pointed out that the availability heuristic could lead to errors when more salient memories are retrieved more easily than accurate memories. For example, there are many people who are afraid to fly in an airplane but who are not afraid to travel in a car. If you ask such people why they are afraid to fly, they are likely to indicate that they fear a fatal airplane crash. It is a commonly known fact that every year there are more people that die in a car accident than there are that die in a plane accident. However, airplane fatalities tend to be big news stories resulting in the memory of fatal airplane accidents to become more salient than of fatal car accidents. That is what biases people to think traveling by airplane is more dangerous than traveling by car. There have been several laboratory experiments that test how people perform when using the availability heuristic.

A person's decision may be biased when using the availability heuristic due to the person choosing an alternative based on the number of instances that they can retrieve from memory. To determine if people make decisions on the likelihood of events based on the number instances of each alternative that could be retrieved from memory, Tversky and Kahneman (1974) gave participants the following question:

Consider the letter R. Is R more likely to appear in

- *the first position?*
- *the third position?*
    - *(check one)*
- *My estimate of these two values is __:1.*

The participants saw this same question, separately, for five different English letters. For all five letters, the letter appears more frequently in the third position than in the first position among English words. However, the participants responded that the letters appeared in the first position more frequently than in the third position. Here, people seem to be more likely to retrieve words that start with the letter R from memory than words that have the third letter as the letter R, resulting in participants thinking that there are more words that start with the letter than have the letter in the third position of the word. These results indicated that people are prone to making errors when using the availability heuristic. The Tversky and Kahneman (1974) article also contained an experiment that sought to determine if people will judge how common an event was based on the salience of the event.

In Tversky and Kahneman's (1974) experiment, participants listened to previously recorded lists of names. They used a 2 x 2 design in this study in which the first independent variable was gender and the second independent variable was amount of popularity, such that some of the names were of very famous people (entertainers) while the other group was less famous (public figures, e.g., William Fullbright). Essentially, each list consisted of more of the less popular names and fewer of the very popular names. It was found that the participants recalled more of the very famous names and fewer of the less famous names in all conditions. It was also found that when the participants were asked if there were more males' or females' names on the list, 80 out of the 99 participants erroneously answered the gender that consisted of the very famous names. The fact that the vast majority of participants judged the frequency of gender in a biased way, using the availability heuristic, indicates that people may be prone to making errors in judgment when using the representativeness heuristic. This result was confirmed in McKelvie's (1997) study. Not only do people make errors in judgment based on how easily examples can be retrieved from memory, but people seemed to be easily influenced by external cues when making a decision.

Anchoring and Adjustment Heuristic

The final Tversky and Kahneman heuristic that will be discussed in this paper is the anchoring and adjustment heuristic (Tversky & Kahneman, 1974). Tversky and Kahneman (1974) describe the anchoring and adjustment heuristic as a situation in which a person is presented with an initial value and makes a decision by adjusting their estimate based on the initial value. In some situations in which a person is making a decision, the person is presented with some information that they may use as an aid in making their decision. Many times this cue is not exactly accurate and instead should be used as a starting point from which the respondent should adjust in order to reach their final answer. Therefore, when people use the anchoring and adjustment heuristic, they use the cue to anchor their decision and then they adjust. It has been found that people are prone to make errors when using the anchoring and adjustment heuristic, such that people tend to err in the direction of the anchor (Chapman & Johnson, 2002).

When doing research involving the anchoring and adjustment heuristic, the difference between the anchor and the correct answer is very important (Jacowitz & Kahneman, 1995). If the anchor is too far from the correct answer the person might not use the anchor because it seems like blatantly irrelevant information. This indicates that people are not too easily influenced but are still susceptible to errors when anchors are present.

Jacowitz and Kahneman (1995) indicated that when doing research involving the anchoring and adjustment heuristic there needs to be an initial calibration group. The initial calibration group is asked a series of questions in which they are told to estimate a quantity. The participants were asked to make such estimates as the "Length of the Mississippi River (in miles)" or the "Height of Mount Everest (in feet)." From this initial group medians are calculated from each question. Using the answers from the initial group low and high anchors are calculated using the 15^{th} and 85^{th} percentile responses for each question. The experimental group is then given the same questions but instead the questions are in the form of: Is the length of the Mississippi River (in miles) higher or smaller than X and if so estimate the length of the Mississippi River. In this example, the X is the anchor.

Jacowitz and Kahneman (1995) found that the anchors did influence the participants' estimates. The results indicated that 27% of participants being shown the high anchor had extremely high estimates compared to only 15% of the calibration group. Therefore, anchors can cause people to make estimates that go against what they would estimate if they were not presented with an anchor. This was not the case for the low anchors. Only

14% of respondents gave extremely low estimates when the anchor was low, compared to 15% of people that were not presented with anchors. For all questions, the median of the estimates from the low anchor was always lower than the median from the calibration group and the median of high anchor estimates was higher than the median estimate by the calibration group. Jacowitz and Kahneman (1995) also indicated that "the median subject moved almost halfway toward the anchor, from the estimate that the subject would have made without it" (p. 1163), indicating that the participants used the anchor to judge the estimate but adjusted the anchor only half as much as was needed in order to make the correct estimate. It appears that for a person to make a more accurate estimate they will need to ignore the anchor and base their estimate on their own knowledge instead of the cue. Tversky and Kahneman (1974) showed that the same information, presented differently, could result in people coming up with different answers that could bias their judgment.

Tversky and Kahneman (1974) had participants quickly estimate the answers to the same math problem (8!) that was presented in a different format to each group. Some participants were told to rapidly answer 1 x 2 x 3 x 4 x 5 x 6 x 7 x 8 while another group was told to rapidly answer 8 x 7 x 6 x 5 x 4 x 3 x 2 x 1. To rapidly answer the question the participants do the first few calculations (going from left to right). These first few calculations serve as an anchor for their estimate of what the final answer would be. Because the first several calculations for the ascending ordered problem leads to a smaller answer, the people that were presented with the ascending list should estimate a smaller number than people that were presented with the descending ordered problem.

Tversky and Kahneman's (1974) results confirmed this in that the ascending group had much lower estimates.

Considering the above mentioned experiments, it appears that one of the problems with using the anchoring and adjustment heuristic is that people tend to bias their judgment based on this heuristic. The bias in judgment in the direction of the anchor indicates that people may not be adjusting enough. Epley and Gilovich (2006) hypothesized that people have a range in which they are comfortable answering the question. Once the person reaches their range of comfort, they will stop adjusting their answer. Therefore, the person will give a high estimate when exposed to a high anchor and give a low estimate when they are exposed to a low anchor. However, Epley and Gilovich (2006) also found evidence that it is not insufficient adjustment that is responsible for inaccurate estimates, but instead adjustment is indicative of how available information, that is consistent with the anchor, is in memory. Apparently, the anchoring and adjustment heuristic and the, aforementioned, availability heuristic are related, in that the amount of adjustment is based on how available the anchor is in memory. In other words, the availability heuristic is used to indicate the likelihood or accuracy of the anchor. The higher the likelihood, the less the anchor is adjusted, the lower the likelihood the more the anchor is adjusted.

It appears that whether the anchor is higher or lower than the actual answer is not the only characteristic of the anchor that influences how the person responds to a question. Janiszewski and Uy (2008) gave participants detailed real-world scenarios that either included a rounded anchor (ex. $5,000) or a precise anchor, no more than ±3% of the rounded anchor (ex. $5,015). The results indicated that a person's estimate was numerically further from the rounded anchor than from the precise anchor. Therefore, people adjusted their estimate more for the rounded anchors than for the precise anchors.

The representativeness, availability, and anchoring and adjustment heuristics were three of the more researched heuristics by Tversky and Kahneman (1974). All three of these heuristics require fewer resources from working memory than using complicated calculations to come to a more accurate conclusion. On many occasions, these heuristics result in people making an accurate decision; however, as seen in the previous examples, there are many ways in which these heuristics may result in a person making an inaccurate decision. The heuristics are based on the assumption that people are comparing their decisions to that of basic probability calculations. In other words, heuristics are based on the assumption that people should use statistics to make decisions and that when a person makes a decision that deviates from the "correct" statistical outcome they are making an error in judgment. Other researchers, such as Gigerenzer (1993) seem to focus decision making research on the idea that people are usually in situations in which they are not given perfect information and therefore, cannot employ statistical techniques to make decisions. However, even without all information required for a person to make a completely educated decision people are still able to make correct decisions. It appears that researchers that share the same school of thought as Gigerenzer consider decision making to be a more subjective task while researchers like Tversky and Kahneman view decision making as a more objective task. The Gigerenzer school of thought thinks that the person's experiences in the world aid them in making accurate decisions, while people in the Kahneman and Tversky school of thought think that people are should act more like computation machines that solely use probability and statistical information to come up with a final answer.

Fast and Frugal Heuristics

Many situations in which a person is making a decision can be analogous to a detective solving a case. While detectives do not have all of the necessary information to solve a case, detectives must use the clues that are available to them and some deductive reasoning to solve the case. The difference between the Tversky and Kahneman (1974) heuristics (discussed above) and the Fast and Frugal heuristics is based on Simon's (1956) idea of bounded rationality. Simon's (1956) article discusses the idea that people are more likely to use a subjective rationality than objective rationality, where objective refers to using more statistical or probabilistic strategy and subjective refers to people relying on personal experiences. While using a more objective rationality may lead a human to predict the more likely alternative, subjective rationality is needed due to the limited amount of time and information that a person may have when making a decision. The Probabilistic Mental Model (PMM) explains that when people make judgments in situations in which they do not have all of the necessary information, they use a subjective rationality (Gigerenzer & Goldstein, 1996).

Fast and frugal heuristics fall within the PMM. The Tversky and Kahneman (1974) heuristics do not fall within the PMM because Tversky and Kahneman assume that people make better judgments when they ignore subjective thoughts and rely more on objective rationality. PMM theory involves heuristics that work in situations in which a person does not have all the information necessary to use proper calculations to solve the problem. PMM theory also involves heuristics that are optimal in situations in which a person must make a decision quickly and may not have the cognitive resources available to use more complex calculations. There are many situations in which a person must calculate an answer but would need a calculator in order to make the calculations. Considering that people are not always carrying a calculator that could make these calculations (unless the iPhone has an app for that), people may not have the capacity (either externally or cognitively) to perform the proper calculations. Gigerenzer (1993) gave an example in order to explain PMM theory:

Which city has more inhabitants?

(a) Heidelberg

(b) Bonn

While there are few people that know the population of each of the two cities, people may have knowledge about the two cities other than the population. People may use the information that they do know as probability cues. Probability cues are pieces of information that a person could use in order to make a decision. Probability cues vary in terms of ecological validity, and the type of heuristic that a person uses indicates the order in which they analyze the probability cues. When people are asked a question in which they do not know the answer, Simon (1955) would argue that people could use a heuristic known as satisficing to obtain an answer.

The idea of bounded rationality and the PMM lead to Simon's (1955) idea of satisficing. Satisficing is a combination of the words sufficing and satisfying (Gigerenzer & Goldstein, 1996). Simon's (1955) initial idea of satisificing described how people make decisions when they are confronted with time limitations, do not have all of the information needed, and have a limited working memory capacity. People have learned to adapt to these limitations and have devised tricks to use these limitations as an advantage instead of a disadvantage. Therefore, the original idea of satisficing involves people accurately making decisions in situations in which the person does not have enough information or time to calculate the correct answers using basic statistic or probability algorithms. When a person is satisficing they must use deductive reasoning to make a decision in situations in which there is a limited amount of time and information.

Using the above mentioned “which city has more inhabitants” problem, when a person is satisficing they would use relevant information that they know to deduce an answer. For example, people may know about professional soccer teams and then may ask themselves if each of the cities has a professional soccer team. If one city does not have a professional soccer team, while the other does, then the person may decide that the city that has a professional soccer team is likely to have more inhabitants than a city that does not. In this scenario, whether the city has a soccer team is known as a probability cue, such that, while a person may not know about the population of a city, they could use information about professional soccer teams to help them distinguish population size between cities.

If both of the cities have a professional soccer team then the person could move on to a different probability cue, such as: Is the city the capital of the country? A person can come up with many probability cues in the decision making process. However, in many situations, a person will have a limited amount of time to come to a decision, therefore when satisficing, in Simon’s (1955) original use of the term, a person could use their limited knowledge to deduce an answer. This idea of satisficing has lead researchers to come up with several different Fast and Frugal heuristics.

Several of the fast and frugal heuristics involve multiple probability cues when making a decision. There are several steps that a person should follow when they are using a fast and frugal heuristic (Gigerenzer, Czerlinski, & Martignon, 2002). The first step is to make a decision about a minimal score that must be met in order for an alternative be chosen. In many heuristics, the minimal score would be that the probability cue is true for one alternative but not for the other. Then the person searches through the probability cues and chooses an alternative based on the probability cues. Different heuristics utilize the probability cues in different ways. Gigerenzer (2008) indicates that the fast and frugal heuristic known as satisficing stops searching through the probability cues once a probability cue is found that differentiates between the alternatives (as does the Take the Best heuristic). When a person is using the satisficing heuristic, the person is searching through the probability cues in a random order in an attempt to differentiate between the alternatives.   Therefore, when a person is satisficing they do not need to know all possible information to make a decision. In fact, the person does not analyze all of the information to which they have access. The person stops analyzing probability cues after the criterion score is met indicating that any probability cues that would have been analyzed later in the serial order will never be analyzed if a preceding probability cue distinguishes between alternatives. While this type of heuristic appears to have many flaws, according to probability and statistical theory, the satisficing heuristic has the ability to be accurate despite not having all necessary information and appears to be efficient in situations that involve a limited amount of time.

According to Gigerenzer, Czerlinski, and Martignon (2002), there are three basic building blocks for fast and frugal heuristics. The first is that there are step-by-step procedures. In other words, when a person is using a fast and frugal heuristic they serially look through information. If the information is enough to make a decision then the person stops looking through information; if the information is not enough then they look for more information. Because people want to come to a decision quickly and do not have enough time to look through all information, they only use as much information as necessary to make a decision. The second building block is that there are simple stopping rules. A simple stopping rule means that once a criterion is met the person will stop looking for relevant information. That is, once one of the probability cues distinguishes between the alternatives a person will make a decision and no longer look for additional information. The final building block is one-reason decision making. One-reason decision making means that once a person has stopped looking for information a person will make their decision based on the final piece of information that was analyzed. This means that the person can perform any calculation or comparison using the last piece of information that was found but will only use the last piece of information found to make the decision.

In conclusion, fast and frugal heuristics are based on the idea that, in the real world, when people are in a situation in which they need to make a decision, they do not have all of the information necessary to make the decision. Along with not having all necessary information, people usually need to make a decision in a relatively short period of time. Essentially, when making real world decisions, people are in situations in which they do not have sufficient information and need to make the decision quickly (Gigerenzer, et al. 2002). When the information available to a person is inadequate, it is difficult for a person to use probability and statistical analyses in order to calculate the most appropriate alternative when making a decision. Therefore, people must use a heuristic that can optimize their ability to make a quick decision when they do not have all the information needed to make a decision.

There are several heuristics that researchers have labeled as fast and frugal heuristics. However, research has indicated that the Take the Best heuristic has outperformed all of the other fast and frugal heuristics (Gigerenzer, et al, 2002). Therefore, in the current paper the only Fast and Frugal heuristic that will be discussed is the Take the Best heuristic. In the following section the Take the Best heuristic will be discussed in depth.

Take the Best Heuristic

The Take the Best heuristic also falls within the PMM. The Take the Best heuristic is very similar to the satisficing heuristic in that they are both used in situations in which the person does not have all the necessary information and must rely on the use of probability cues to make a decision. The difference between the satisficing and the Take the Best heuristic is that in the latter, the order in which the person uses the probability cues in the evaluation process is in a particular order as opposed to the satisficing heuristic in which the probability cues are analyzed in a random order. The first thing that a person does when using the Take the Best heuristic is to use the recognition principle (Gigerenzer & Goldstein,1996). When using the recognition principle, if a person can only recognize one of the alternatives, then that alternative is chosen. If both of the alternatives are recognized then the person moves on to the second step. The second step is to determine the ecological validity of each probability cue and then put them in order from highest level of ecological validity to lowest level of ecological validity (Gigerenzer, 2008). After the person has made the order of probability cues, the person evaluates each alternative based on the probability cue in order. If the probability cue differentiates between the alternatives then a decision is made. If the probability cue with the highest ecological validity does not differentiate the alternatives, then the person moves on to the probability cue with the second highest ecological validity, and so on. Once a cue discriminates between the alternatives then a person stops going through the list of probability cues and makes a decision. If none of the cues can discriminate between the alternatives then an alternative is chosen at random.

Using a different example, suppose a participant is asked to determine which city has more inhabitants, Cleveland or Cincinnati. The participant may have access to several probability cues. Assume that the participant has access to the following probability cues: a) professional football team, b) professional basketball team, c) professional baseball team, d) is the city a state capital and e) median household income. For the purpose of this example, suppose that each had ecological validity values of .86, .93, .65, .70, and .74, respectively. The ecological validity value is the probability (determined by the decision maker) that the probability cue can distinguish between alternatives. Therefore, the first probability cue analyzed would be to see if each city has a professional basketball team. Currently, of the two cities only Cleveland has a professional basketball team, therefore, the participant would decide that Cleveland has more inhabitants than Cincinnati. Because the probability cue that has the highest level of ecological validity (professional basketball team) distinguishes between the two alternatives, the person would stop analyzing the probability cues and make the decision that Cleveland has a larger population than Cincinnati.

For the sake of the current discussion, imagine that the two probability cues with the highest ecological validity, in the above example were reversed. In this case, the probability cue (pro football team) is true for both cities, so the cue with the second highest level of ecological validity is used, and so on until a probability cue that distinguishes between the alternatives is found. While the description of the Take the Best heuristic appears to be inferior when compared to computational formulas, the Take the Best heuristic appears to be an extremely efficient tool.

When people are using the Take the Best heuristic they are not using all available knowledge to make a decision. If a person is not using all of the available knowledge than it is impossible for them to utilize proper statistical or probability theory, therefore, the Take the Best heuristic may consistently lead people to inaccurate answers. However, research indicates that the Take the Best heuristic is not only efficient in terms of ease of use and not requiring a lot of time, but is also efficient in terms of accuracy. Gigerenzer et al. (2002) compared the minimalist heuristic, Dawe's Rule, multiple regression and the Take the Best heuristic. The minimalist heuristic is the same exact thing as the satisficing heuristic discussed above in that it searches through probability cues randomly until one of them differentiates between the alternatives, after which it stops looking for new information. Dawe's Rule searches for all relevant probability cues and then gives each alternative a score of 1 or 0 based on each cue. After a score has been given to each alternative on each cue, the score from each alternative is added together, the alternative with the highest score is used. Notice that Dawe's Rule may seem quick but it involves a lot of working memory capacity to keep all these scores online, therefore, is fast, but hardly frugal. Multiple regression is a statistical technique in which beta weights are assigned to all variables and the variables are put into a regression equation. Gigerenzer et al. (2002) considers each of the probability cues as a variable and uses statistical analyses to obtain beta weights for each of the possible probability cues. The larger the beta weight, the more important that probability cue is in the regression equation. Therefore, to come to an answer using multiple regression the person would multiply each probability cue by the beta weight and a decision would be based on all of the probability cues. The Take the Best heuristic is the same as was described above.

Gigerenzer et al. (2002) used twenty “real-world environments” and found that when there was a training session before the experimental session, the fast and frugal heuristics either outperformed multiple regression, or were barely behind it in terms of accuracy. Therefore, it was found that fast and frugal heuristics can be as accurate as statistical models. Gigerenzer et al. (2002) also found that in many situations the Take the Best heuristic had higher levels of accuracy than the Dawe’s Rule. In one of the situations in this experiment, Dawe’s Rule used all six probability cues while the Take the Best heuristic only used 2.4 cues to make a decision. It appears that when the cues that have less ecological validity are used it makes the accuracy of the decision making process lower than when only using the probability cue that differentiates between alternatives with the highest level of ecological validity. Gigerenzer et al. (2002) used situations in which all of the information was known. Gigerenzer and Goldstein (1996) used situations that seem to be more similar to the real world; not all of the information was known. It was found that the Take the Best heuristic works more optimally when less information is available than when more information is available.

It appears irrational that a heuristic in which not all of the information is used to make a decision is better than heuristics in which all of the information is used. Therefore, Gigerenzer and Goldstein (1996) asked colleagues that did research in the fields of statistics and economics to create decision making algorithms that would be more accurate than the Take the Best heuristic. Five algorithms were made by such colleagues: Tallying, weighted tallying, unit-weight linear model, weighted linear model, and multiple regression. When using the tallying algorithm, probability cues that are true for the alternative are given a score of one, if not true a score of zero is given. All of the scores from all of the probability cues are tallied. The alternative with the highest score is chosen. Weighted tallying is similar to tallying except that each cue has a weight given to it that is associated with how ecologically valid the probability cue is. The score for each cue is multiplied times its weight and then summed together. The alternative with the highest value is then chosen. The unit-weight linear model involves three possible scores for each probability cue. If the probability cue is true of the alternative than a score of +1 is given, if it is false a score of -1 is given, and if the answer to the probability cue is unknown for the alternative than a score of 0 is given. The scores are summed and the alternative with the highest sum is chosen. The weighted linear model is the same as the unit-weight linear model except that each cue is given a weight according to its ecological validity. The same scoring system as the unit-weight linear model is used except the score is now multiplied by its ecological validity weight. Like the unit-weight model, in the weighted linear model the scores for each alternative are summed and the alternative with the highest sum is taken. Finally, the multiple regression model creates beta weights. These weights are not the same as ecological validity weights. Instead, a beta weight assesses the covariances between the probability cues and calculates the best possible ways that the cues could be integrated together to make the best decision.

Because the Take the Best algorithm involves using fewer pieces of information than all of the algorithms created for the Gigerenzer and Goldstein (1996) experiment, it is obvious that the Take the Best heuristic is much quicker than the other algorithms. Each algorithm had performed at peak levels (in terms of accuracy) when the value of all possible probability cues is known. It was found that the Take the Best algorithm performed equally if not better than all of the more complicated algorithms, in terms of accuracy, when the values of all of the probability cues are known. The experiment also included circumstances in which varying amount of information is known about the probability cues. Across all levels, the Take the Best algorithm performed better than all of the created algorithms except for the weighted tallying algorithm, in which it performed at an equal level. Because the Take the Best algorithm can be performed at a much quicker pace than the weighted tallying algorithm, the Take the Best algorithm is seen as superior because the Take the Best algorithm is less time consuming than the weighted tallying algorithm. Therefore, the Take the Best algorithm is superior to all competitors, even when algorithms are created with the specific intention of being able to perform at a higher level than the Take the Best algorithm.

Conclusion of Heuristics

In the previous section there were four heuristics that were discussed in detail: representativeness, availability, anchoring and adjustment, and the Take the Best heuristics. The representativeness, availability, and anchoring and adjustment heuristic (brought to popularity by Kahneman and Tversky, 1974) suggest that people should ignore all subjective information and focus solely on more objective information while the Take the Best heuristic and other fast and frugal heuristics suggest that people can capitalize on their subjective experiences to make accurate decisions. Gigerennzer and Goldstein (1996) suggest that in most situations people do not have all the necessary information in order to benefit from objective analyses and indicated that the Take the Best heuristic is better than statistical analysis (multiple regression) when not all information is present. While it seems that the fast and frugal heuristics are taken from a more subjective viewpoint (when compared to the Kahneman and Tversky heuristics), Gigerenzer and Goldstein (1996) used formulas to prove which algorithm is superior. Gigerenzer and Goldstein (1996) found that the Take the Best heuristic is superior to all other algorithms that could be created.

The purpose of the remainder of the paper is to discuss how people's working memory capacity and their math ability can influence how a person performs on decision making tasks. The discussion will start by reviewing previous working memory research then discussing how a person's working memory capacity can influence their performance on decision making tasks. After reviewing working memory, discussions on how people's math ability can influence their performance on decision making tasks will follow.

Working Memory

While most constructs are difficult to define, it appears that the construct known as working memory has proven to be particularly difficult to define, conceptually. There are two main theories of working memory that are of interest to the current paper. The first working memory model that will be discussed in this paper is the multicomponential model developed by Baddeley (Baddeley & Hitch, 1974). The other is a more general model created by Cowan (Cowan, 1988). While both assume that working memory consists of a limited capacity store that can only work on finite number of tasks at a given time, there are several differences between the two models.

Baddeley's original model claimed that working memory consists of three components: the central executive and the two slave systems, the phonological loop and visuospatial sketchpad (Baddeley & Hitch, 1974). The first component, the central executive, is the largest of the three components. While in later publications the tasks that the central executive was responsible for became more specific, initially the central executive seemed to be a large amount of working memory resources that could be used by either of the slave systems. In the original model, the central executive seemed to be in charge of how and when the two other slave systems should be used. As Baddeley's model became more detailed, the central executive was described as being in charge of three main tasks (Baddeley, 2001). The first task is focusing the person's attention on a particular task (Baddeley, 2001). In other words, the central executive has the task of keeping a person focused on a task and preventing them from being distracted by another task. The second main task that the central executive is responsible for is controlling a person's divided attention (Baddeley, 2001). This indicates that the central executive aids people in their ability to work on multiple tasks at the same time. Therefore, the central executive is in charge of both divided and undivided attention. The third task that the central executive is responsible for is task switching (Baddeley, 2001). This implies that the central executive is responsible for determining which task has the highest priority and should be focused on at certain points in time. Essentially, the central executive is thought of as the largest component in the multi-component model that is in charge of the majority of the higher level functions. However, it should be noted that despite these recent specifications some researchers still consider the central executive to be somewhat of a homunculus.

The second piece of the multi-component working memory model is the phonological loop (Baddeley & Hitch, 1974). The phonological loop is mainly in charge of auditory information that is currently being worked on. Essentially, the phonological loop rehearses/stores auditory information so that the information does not fade out of working memory before the person is done using it. Rehearsal in the phonological loop could be thought of as repeating the information over and over. Some information is not transferred from working memory into long term memory. For a person to keep information online so that it can be used, it must be repeated so that it is not lost. Therefore, the rehearsal function of the phonological loop serves to keep information in working memory.

The third piece of Baddeley's multi-component model of working memory is the visuospatial sketchpad (Baddeley & Hitch, 1974). This component's function is to maintain visual and spatial information for a limited amount of time. The visuospatial sketchpad is thought to allow people to mentally manipulate the landscape of a scene (Baddeley, 2001). For example, consider a situation when a person is mentally working on a subtraction problem by visualizing the numbers. If confronted with a borrowing operation, the person must mentally subtract one from the digit on the left and place a one in front of the digit on the right. Theoretically, both of these manipulations are done within the person's visuospatial sketchpad. In this example, not only are the numbers being manipulated but the individual must remember all of the manipulations that have been done throughout the course of the problem to solve the problem accurately.

Conrad and Hull (1964) found that when the words in a list sound similar to one another, people have a difficult time accurately recalling the words in serial order. Also, Baddeley, Thomson, and Buchanan (1975) found that as the length of the words increased, the participants had a more difficult time recalling the words on the list. The longer that the words are, the fewer times each word could be rehearsed in a limited period of time. Therefore, the words are less rehearsed and more likely to be forgotten. While the visuospatial sketchpad has been studied less than the phonological loop, there has been evidence of a phonological loop. Baddeley, Grant, Wight, and Thomson (1975) found that visually following an object caused declines in performance on other spatial tasks. However, Brooks (1967) found that recall of spatial information was disrupted more by a visual task than an auditory task. These studies indicate that there are both a visual and an auditory system of working memory and that when two tasks involve the same system there are more cognitive deficits than if the two tasks require different slave systems.

There have been several questions about working memory that could not be answered by Baddeley's (Baddeley & Hitch, 1974) three component model. As stated earlier, there are a finite number of tasks or stimuli that a person can keep in working memory at a single point in time. There are several strategies that a person can utilize in order to increase the amount of information that could be stored in working memory at any given point in time. One such strategy is chunking. To increase the amount of information that can stay in working memory people can combine several individual pieces of information into a single, more complex, piece of information. For example, when a person is asked to remember a string of numbers they may try to group the single numbers into more complex numbers, like years (e.g., 1, 4, 9, and 2 can be combined into 1492). While the concept of chunking seems very basic (e.g. Miller, 1956), Baddeley's three component model could not explain the process of chunking (Baddeley & Hitch, 1974). In many situations, chunking converts more complex stimuli into more manageable pieces of information by relating the information to something that is already stored in long term memory. In the example above, 1492 is not a random year, but is stored in long-term memory as when Columbus set sail from Spain. Therefore, another component of working memory was required in order to answer questions about a working memory system that could retrieve information from long term memory.

More recently, the episodic buffer was added to Baddeley's working memory model (Baddeley, 2001). Initially, Baddeley and Hitch's (1974) model assumed that each of the two slave systems consisted of stores of limited capacity and that the main component (the central executive) mostly dealt with controlling how much attention a task is going to receive. However, none of these three systems is interacting with long term memory. Not only does the episodic buffer incorporate information that is currently in working memory with information that is in long term memory, but the episodic buffer also serves as a translator so the information in the two slave systems can be integrated together. Previously, it was assumed that the two slave systems were using two different types of code resulting in the two slave systems being unable to communicate with one another. The episodic buffer is able to integrate the information in the phonological loop and visuospatial sketchpad.

Cowan's (2005) more general model of working memory assumes that working memory is not divided into several components but instead, working memory includes a number of processes that can keep a limited amount of information accessible for a limited amount of time. Cowan (2005) points out that there are more types of information than just visuospatial and auditory. Therefore, there are an infinite number of possible slave systems that could be applicable to working memory, resulting in a more general working memory model being more appropriate than a more specific multi-componential model. However, Cowan's (1988) model did emphasize two main types of information that are in working memory. The first is the information that is currently active in working memory and the other type of information is the information that is the focus of attention. When there are several tasks that people are working on, there could be several pieces of information that are currently being used in working memory. Even if a person has several pieces of information in working memory at any point in time, only a small subset of that information could be focused on at any given point in time. Essentially, there are many pieces of information that are active in working memory; however, only several of those pieces of information have the attention of the person.

It appears that the main discrepancy between Cowan's (1988) working memory model and Baddeley's (Baddeley & Hitch, 1974) working memory model is the idea of specific functions are assigned to specific components in Baddeley's model but not in Cowan's model. Research involving working memory has indicated that verbal stimuli and visual stimuli do not cause as much disruption with one another as stimuli that come from the same domain. The lack of disruption is interpreted to mean that there are multiple components of working memory. Reisberg, Rappaport, and O'Shaughnessy

(1984) did a study in which participants used their fingers to hold information in working memory, indicating that people can use their fingers to work on information in working memory without interfering with information supposedly being held by the phonological loop or visuospatial sketchpad. Reisberg et al. (1984) found evidence that there is no limit to the number of slave systems that could be found for working memory. While there is some doubt about the various slave systems in Baddeley's model, Cowan's model is very general and non-committal. For the current paper, working memory will not be viewed as a multi-component model, but instead the idea of a finite amount of working memory resources will be the essential characteristic of working memory. Therefore, instead of looking at the more general construct of working memory, it is important to look more specifically at individual differences in working memory capacity.

Barrett, Tugade, and Engle (2004) indicated that the construct of working memory capacity is similar to that of the function of the central executive component of Baddeley's working memory model (Baddeley & Hitch, 1974). As stated earlier, the central executive is responsible for controlling and focusing a person's attention. Therefore, people with a larger working memory capacity should be better at controlling their attention than a people with a smaller working memory capacity. Also, people with a larger working memory capacity should be more skilled at focusing their attention on two separate tasks at the same time than people with a smaller working memory capacity. To test a person's working memory capacity, there have been many working memory span tasks that have been created. Many of the span tasks that are discussed in the following section are testing people's ability to focus their attention on two tasks at the same time. Earlier it was discussed that all of the working memory models have the underlying assumption that there are a finite amount of working memory resources. Therefore, when a person is working on multiple tasks, the tasks should compete for working memory resources (depending on the difficulty, familiarity, etc. of the tasks). The most important aspect of each of the following span tasks is that the processing component of each task must interfere with the rehearsal component of the task (Conway, et al., 2005). Because the tasks are competing for working memory resources, people with smaller working memory capacities will show deficits in performance on one, if not both, of the tasks that they are working on at the same time, while the people with larger working memory capacities will show fewer deficits in performance.

As stated earlier, working memory span tasks involve a person working on two tasks at the same time. More specifically, most span tasks involve maintaining information while processing information from another task simultaneously. One version of a working memory span task is the Operation Span (O-SPAN; Turner & Engle, 1989) Task. In this task a person is shown a math problem with a given answer; their task is to indicate whether or not the given answer is the correct answer for the stated math problem. Following the response to the math problem the person is shown a word. At the end of the math problem and word pair set, the person is asked to recall each of the presented words. The number of math problems and word pairs in a set typically varies between two and six pairings per set. While Unsworth, Heitz, Schrock, and Engle (2005) prefer to have the set size of the math problem and word pairings vary from set to set, others prefer to have the size of the sets increase, progressively, throughout the task. In the progressively increasing format of the O-SPAN, there are usually three sets of the two math problem and word pairings, then three sets of three math problem and word pairings, and so on. The benefit of the format used in Unsworth, et al. (2005) is that the participants are not able to predict the size of the subsequent set. However, the O-SPAN task is a difficult task and is built on the idea that people are focusing their attention on two separate tasks, if people are trying to predict how many pairings will be in the next set than there may be a third task that the person is working on. Therefore, it makes more sense to stick with the format in which the sets are presented in a progressively increasing order so that there are only two tasks that are competing for working memory resources.

The Reading Span (R-SPAN) task (Daneman & Carpenter, 1980) was one of the earlier working memory span tasks. In the R-SPAN the participants are told to read the sentences out loud and are told that they are expected to recall the last word of each sentence. At the conclusion of the set the participant is to recall the last word of each sentence. The number of sentences progressively increased from set to set. As stated earlier, span tasks are built on the assumption that one of the tasks involves processing information while the other task is maintaining information. In the original R-SPAN, it is difficult to tell if the person is actually processing the sentences or just reading the sentences out loud while only paying attention to the final word of the sentence. To make sure that the person is focusing attention on reading the sentences, the second experiment of Daneman and Carpenter's (1980) study required the participants to verify the validity of the sentence by responding true or false at the end of the sentence. The validation component of this experiment ensures that the participants are not only maintaining information but are also processing information simultaneously.

While the two previously discussed span tasks are more for adults, the Counting Span Task (Case, Kurland, & Goldberg, 1982) can also be used to test a child's working memory capacity. In their original counting span task the participants were given cards with dots on them. They were to count the dots on each card. At the end of the set, the participants were to recall how many dots were on each card. In the more current Counting Span Task, the participants are shown varying numbers of shapes and are told that they will be asked to remember the number of shapes for later recall (Conway, et al., 2005). The task starts at two counting and number recall pairs in a set, then three counting and number recall pairs in a set and progressively increases up to five. While this task is appropriate for children due to its low level of difficulty, the level of difficulty will cause a ceiling effect among adults. Therefore, the experiment was altered in order to be used on adults. On the adult version of the counting span task, an array of the same shapes in various colors is shown. The task is to count the number of shapes in a certain color while not being allowed to point at the array and the participants are asked to recall the number of shapes counted for each stimulus per set. As with the children's version, the sets become progressively larger throughout the task.

There have been many articles that have used working memory span tasks to assess a person's working memory capacity and many of them have used different scoring systems Conway, et al., 2005). Many studies used a criterion based system in which the participant must meet a certain criterion (example: 4 out of five correct). The criterion-based system assumes that within the span task the number of items in each set progressively increases throughout the task. If the participant were to correctly recall every answer in the set that included two, three, and four stimuli and then answered only three out of five correctly on the set of five pairings than the person would be given a working memory span of four. In a criterion based system, a person is given a span score based on the highest number of pairings in which the person was able to meet the criterion. While this method of scoring made it simple to group participants based on their working memory span, there was plenty of data that the participant recorded that is ignored because the person did not meet the criterion on those trials. Therefore, a better method of scoring needed to be developed.

Unsworth, et al. (2005) sought to find a more appropriate method of scoring. To ensure that the participants were paying attention to the processing component of the task, the participants must achieve 85% accuracy on the processing component of the task for the remainder of their data to be analyzed. A debate as to which is the best scoring procedure for the recall portion of the task arose where half of the debate was between an all-or-nothing versus a partial credit scoring system. As the names suggest, the all-or-nothing scoring system means that credit is given only if the entire item is correctly recalled while the partial credit scoring system still gave credit for partially correct answers. The other half of the debate was whether all items should count for the same credit (unit-based) or should the more difficult items be weighted so they count for more points (load-weighted). The results of the Unsworth, et al. (2005) experiment indicated that the partial scoring system proved to be superior over the all-or-nothing scoring system while the unit-based system showed only moderate advantages over the load-weighted scoring system. Also the unit-based system appears to be a more objective system than the load-weighted system. It appears that a unit-based partial scoring system is the most appropriate system for scoring a working memory span task.

While span tasks are good at determining a person's working memory capacity, dual task paradigms are a good way of determining how people perform on a task when they are unable to devote all of their attention to that single task. In a dual task paradigm there is a competition for working memory resources between the two tasks. The difference between a span task and the dual task paradigm is that the researchers are more interested in a person's working memory capacity in the span task, while in the dual task paradigm, researchers are more interested in determining how performance on a particular task is influenced when a person cannot devote all of their attention to that task. The dual task paradigm is an effective way for researchers to manipulate the working memory load of a task.

Pashler, Harris, and Neuchterlein (2008) note that when working on multiple tasks at the same time, a bottleneck may occur. This bottleneck causes declines in performance on both of the tasks. Pashler, et al. (2008) found that this was also the case in decision making tasks (Iowa Gambling Task; see Bechara, Damasio, Damasio, & Anderson, 1994 for a description). They found that in the dual task block of trials, people were slower at making decisions than in the control blocks of trials. While there is evidence that people are slower at making decisions in dual task trials than control trials, the nature of the Iowa Gambling Task makes it difficult to assess people's accuracy when making decisions in a dual task paradigm.

In the current experiment, a tone recognition task will be used in a dual task paradigm. In some of the experimental tasks, the tone recognition task will be paired with various decision making tasks, while in other experimental tasks, the tone recognition task will be paired with a subtraction task (discussed in detail in the methods section). It is important that the same secondary task is used throughout all experimental tasks in order to maintain consistent task difficulty. Considering Baddeley's (2001) multicomponent working memory model, it appears that the tone task will not interfere with the reading associated with the decision making task more than with the math computations associated with the subtraction task. The opposite is also true. Pashler (1994) notes that even a simple task can cause limitations in performance on the primary task. Since some of the tasks in the current experiment could be rather difficult, it makes sense that the secondary task be somewhat simplistic while not interfering more with one primary task than another primary task.

Working memory has been shown to be related to many other constructs that are used in the field of psychology. Working memory correlates significantly with comprehension (Daneman & Carpenter, 1980) and general intelligence (Jensen, 1980). This indicates that constructs that involve higher levels of processing by a person are also related to the construct of working memory capacity. Brewin and Beaton (2002) found that people with higher working memory spans were better at suppressing thoughts that were irrelevant to the task at hand than low working memory span individuals. Working memory span tasks (described above) essentially test the ability of a person to work on two tasks at the same time. Therefore, people that have high working memory spans are better at working on multiple tasks simultaneously than people with low working memory spans.

There are many studies that have indicated that a person's working memory capacity influences their ability to work on several tasks at the same time (Ashcraft & Kirk, 2001; Kane & Engle, 2000) This has especially been seen as the case when one of the tasks involves math (Ayres, 2001). The span tasks were built on the premise that people with larger working memory capacities would be better at working on several tasks at the same time (Unsworth, et al., 2005). When a person is working on multiple tasks, each of which requires working memory resources, a competition for the working memory resources ensues. The more difficult the tasks are, the more resources that they require (Ashcraft & Kirk, 2001).

Research has also indicated that people with smaller working memory spans use less difficult strategies when working on a reasoning task than people with larger working memory spans (Copeland & Radvansky, 2004). Knowing that people with larger working memory spans use more complicated strategies when working on a task than people with smaller working memory spans, Beilock and DeCaro (2007) conducted a study in order to determine the differences in strategy use between people with high working memory spans and low working memory spans in situations with various levels of pressure. Beilock, Kulp, Holt and Carr (2004) illustrated that environmental pressure can consume working memory resources, which will result in pressure and the task competing for working memory resources. Beilock and DeCaro (2007) found that when the situation did not involve pressure the low working memory span people used a simpler strategy while high working memory span people used more difficult strategies. However, when the situations did involve pressure, both the high and low working memory span participants used the simpler strategy. While the Copeland and Radvansky (2004) experiment implies that the size of someone's working memory span indicates how difficult of a strategy they will have the ability to use when working on a task, the Beilock and DeCaro (2007) experiment indicates that in addition to this, when there is a competition for working-memory resources people with high working memory spans perform tasks in a similar fashion to people with a low working-memory span.

Therefore, when tasks do not involve a competition for working memory resources, people with high working-memory spans can use more complex strategies than people with low working-memory spans. However, when there is a competition for working-memory resources, people with high and low working memory spans use similar types of strategies.

Daneman and Carpenter (1980) argue that it is not the size of working memory that is indicative of the differences in performance, but it is the efficiency that the person has at processing the stimuli. In other words, the differences between people in their working memory capacity is not determined by the amount of space that is available in working memory, but it is how efficient a person is at processing the stimuli and the type of strategy that they can use to work on the task. A person that is more efficient uses fewer resources to process the task while a person that is less efficient uses more resources to process the task. Therefore, processing efficiency could be another reason that people with larger working memory capacities have the ability to use more complicated strategies when working on a task than people with a smaller working memory capacity. For the reasons listed above, it is possible that working memory will have an impact on a person's ability to make decisions. In the following section some of the previous decision making tasks will be discussed as well as why it is expected that these tasks will be influenced by a person's working memory capacity.

Working Memory and Decision Making

While many constructs (e.g. intelligence) seem to be influenced by a person's working memory capacity, research on how working memory affects a person's ability to make decisions appears to be inconclusive. However, there appears to be some clear evidence about the relationship between working memory load and decision making. A researcher can manipulate working memory load in a variety of ways. Hinson, Jameson, and Whitney (2003) manipulated working memory load by varying the number of alternatives that are to be assessed when the participants were making their decision. In this task a person was given an option to take less money now or more money at later periods of time. The more alternatives that were available, the higher the working memory load. The results of the experiment indicated that as working memory load increased the participants became more impulsive (i.e., they preferred a smaller amount of money immediately rather than a larger sum of money that they would have to wait for). Therefore, the more working memory resources that a task requires, the more likely people are to act impulsively. Whitney, Rinehart and Hinson (2008) confirmed this finding and also found that the amount of working memory load that the task requires determines the heuristic that the person will choose to make the decision which ultimately determines how risky/impulsive of a decision the person will make.

De Neys (2006a and 2006b) found some interesting evidence for the role of working memory in decision making. In De Neys' (2006a) experiment the participants completed a syllogistic reasoning task, which was the primary task in a dual task paradigm; the secondary task was dot matrix recall task in which the participants were presented with a dot matrix prior to the syllogism and then had to recreate the matrix after answering the syllogism question. Some of the participants were not given the matrix recall task (no load), others saw easy to recall matrices (low load), while others saw difficult to recall matrices (high load). The participants in the low working memory load group performed better on the reasoning task than people in the high working memory load group. Also, the participants were grouped based on their scores on the operation span (O-span) task. It was found that the low span group showed greater decreases in performance with the high load than the high working memory span group. Considering Beilock and DeCaro's (2007) finding, one would think that the high span group would show more declines in performance than the low span group. The two experiments results may be different due to Beilock and DeCaro's experiment manipulating working memory load as a within subjects variable and De Neys' manipulating load as a between subjects variable.

De Neys' (2006b) sought to gain a better understanding of when people use System 1 versus when people use System 2 to make a decision. In the first experiment in this article participants were asked questions similar to that of the "Linda Problem" as well as other decision making tasks. It was found that participants that answered the "Linda Problem" correctly (presumably using System 1) took longer to give a response than people who committed the conjunction fallacy (presumably using System 2). In the third experiment in this article the decision making tasks were paired with a dot matrix recall task (similar to that in De Neys 2006a). One group of participants was asked to recall complicated matrices while the other group was asked to recall easier matrices; therefore, working memory load was a between subjects factor. The results of this experiment indicated that the more difficult the secondary task was, the more likely the participants were to fall victim to the conjunction fallacy. In this third experiment the participants were also subjected to the O-span task. It was found that working memory capacity had a positive relationship with their scores on the "Linda Problem", indicating that the higher a person's working memory capacity is, the more likely they are to give a correct response to problems like the "Linda Problem".

These experiment by De Neys (2006a and 2006b) have several implications. The first article (2006a) indicated that people with higher working memory spans are better at reasoning tasks than people with lower working memory spans. Also, this article illustrates that the amount of working memory resources that the task requires impacts how well a person performs on reasoning tasks. The second article (2006b) looks more at participants' performance on decision making tasks by using tasks that are in classic decision making research. It was found that people that have higher working memory capacities are less prone to making errors in decision making tasks. The results from this experiment also indicate that the amount of resources that the task requires impacts task performance. It was also found the people in the low load group made fewer errors, in accordance with the conjunction fallacy, than people in the high load group. It was found that the two groups did not differ in terms of working memory capacity, therefore, the differences in responses between the working memory load groups was due to the load of the problems and not due to differences in capacity.

These articles seem to integrate the research from Copeland and Radvansky (2004) and Beilock and DeCaro (2007). Remember Copeland and Radvansky's research indicated that people with higher working memory capacities could use more complicated strategies when working on a task than people with lower working memory capacities, which was supported by the ideas in both of the De Neys (2006a and 2006b). Beilock and DeCaro found that higher capacity people use more complicated strategies when the working memory load of the task is low but revert to more simplistic strategies (like low span participants) when the task had a high working memory load. It is hypothesized that if working memory load was manipulated as a within subjects variable in the De Neys studies that the high span group would regress to perform in the same matter as the low span participants. The De Neys articles theorize that people use heuristic responding as the default response, but will use more complicated strategies in situations when they have the available knowledge or resources to do so, which seems to coincide with the results of the Beilcok and DeCaro study.

While there appears to be clear evidence that the amount working memory load can influence how a person makes decisions, the evidence is not as straight forward for working memory capacity. Bröder (2003) had subjects participate in a fairly complicated stock market game and found that neither working memory capacity nor working memory load influenced the strategy that a person used to arrive at a decision. The fact that working memory load did not influence the person's decision making strategy is counterintuitive to the previously mentioned research. Considering Copeland and Radvansky's (2004) finding that working memory capacity influences strategy use, it is of interest that Bröder (2003) did not find that strategy use is a function of working memory capacity. However, Bröder's (2003) task seemed very complicated. As discussed earlier, Beilock and DeCaro (2007) found that when the situation consumes a substantial amount of working memory resources, even the high working memory span people opt for more simple strategies. Because Bröder's (2003) task was so difficult, it may have forced high working memory span participants to regress to simpler strategies, which may be why no difference was observed between the span groups.

In many situations in which people must make a decision, people need to make probability judgments. Dougherty and Hunter (2003) provided participants with a menu and then indicated what a group of regular customers ordered from the menu of thirty-two items over a 74 day period. The participants were then shown a regular customer paired with a menu item and were asked to judge the probability of the person ordering that item. Later, the participants were shown each menu item, one at a time, and asked to judge the probability that the menu item was ordered. A judgment was determined to be subadditive if the sum of the person's judged probabilities deviated from one hundred. While this is hardly a decision making task, this experiment is showing how well people can make judgments of probabilities. It was found that working memory capacity was significantly correlated with probability judgments, such that people with higher working memory capacities were less subadditive (deviated less from 100) than people with lower working memory spans. As discussed earlier, many heuristics require people to make probability judgments. Therefore, working memory capacity should have an influence on a person's ability to make a decision when using heuristics. In a second experiment, Dougherty and Hunter (2003) asked participants to make judgments on how likely a person was to be from a particular state under different time constraint conditions. Participants were to use knowledge of the populations of the state in order to make this judgment. It was found that when there was no time constraint, the correlation between working memory span and the judgments was not significant. However, this correlation was significant when there were time constraints. When there was no time constraint the participants must have regressed to performing in the same manner as lower working memory span people, but when there was a time constraint the high working memory span participants could use more complicated strategies than the low span people. This seems to go against the findings of Beilock and Decaro (2007). Dougherty and Hunter discussed that the results from their experiment also indicate that working memory span has an impact on the number of alternatives that a person can compare when making a decision.

Thomas, Dougherty, Sprenger and Harbison (2008) discuss that a person's working memory capacity determines the upper limit of alternatives that a person can maintain at any point in time. Therefore, when there are a lot of alternatives that must be analyzed in order to make a decision, people with a higher working memory span will have a clear advantage because they have the ability to analyze more options than people with lower working memory spans. Salthouse (1992) found a negative correlation between working memory capacity and processing speed, such that as working memory capacity increased, the amount of time that it took to process the task decreased. This negative correlation implies that people that have a higher working memory span should be able to come up with more alternatives than people with lower working memory spans. Therefore, when there is a limited amount of time to make a decision, people with higher working memory spans will have more information to utilize than people with lower working memory spans.

Several of the decision-making tasks that are found in the classic decision making literature appear to be vulnerable to differences in a person's working memory capacity. For the purposes of this paper, people are making a decision any time that they are asked to choose between several options. In these situations people should calculate the likelihood for each of the options and then choose the option that is best for them (Gilovich, Griffin, & Kahneman, 2002). As discussed above, there are many situations in which a person does not have all of the necessary information and has a limited amount of time to make a decision. In the following section, each of the above detailed heuristics will be discussed again to determine how a person's working memory capacity can influence their performance. Instead of presenting the same reason that working memory capacity will influence a person's performance for each heuristic, it should be assumed that the reasons that working memory capacity could influence people's decision making performance are similar for all heuristics.

Representativeness Heuristic and Working Memory

Recall that, the representativeness heuristic (Tversky & Kahneman, 1971) is when a person determines the likelihood of an event based on how similar the event is to the population of similar events. In many of the experiments on the representativeness heuristic, the participant must choose from an array of options. The "Linda Problem" is an example of a task in which people use the representativeness heuristic (Tversky and Kahneman's, 2002 "Linda Problem" can be found on page six of this paper).

Remember, participants in the "Linda Problem" experiment are asked to put the options in order of how much they represent the character sketch of Linda. Therefore, the participants will need to keep the order of the options online in working memory and update the list after each subsequent option is read. The tasks of (1) reading and analyzing each option and (2) storing and updating the order of the options will compete for working memory resources. This competition should result in people with larger working memory spans performing better on this task than people with smaller working memory spans. The competition for working memory resources may cause the people with smaller working memory spans to rely on the representativeness heuristic while the people with larger spans may attempt a more difficult strategy, such as utilizing statistical or probability theories.

Another finding in the “Linda Problem” is that people are prone to making the conjunction fallacy. The conjunction fallacy may be due to people with low working memory spans going to a default heuristic instead of carefully thinking about each of the options. People with higher working memory spans may have more working memory resources available to work on the “Linda Problem” and could use those resources to check for errors, like the conjunction fallacy. Therefore, it is possible that when decision making tasks result in a competition for working memory resources, the participants that have a high working memory capacity will have a distinct advantage and will perform at higher rates of accuracy than people with low working memory capacities. Because the difficulty of a task like the “Linda Problem” is high, people with higher working memory spans should be able to use more complicated strategies than people with lower working memory spans (Beilock & DeCaro, 2007).

There are many experiments that have found that the more that something is practiced the more automatic the task becomes (e.g., Shiffrin & Schneider, 1977). When something is done automatically it requires fewer working memory resources (Spelke, Hirst, & Neisser, 1976). Therefore, when people have a lot of experience in a certain field, the decision that they make in their field should become somewhat automatic, or at least require fewer working memory resources. Tversky and Kahneman (2002) discussed an experiment in which they gave physicians a scenario and asked them to rate the options in terms of how representative they are of the scenario; similar to the format used in the aforementioned “Linda Problem”.

Tversky and Kahneman (2002) presented physicians with a series of scenarios. The physicians task was to rank a list of diagnoses from most to least likely. The results indicated that roughly 20% of the time the physicians chose the option that consisted of the conjunction of the unlikely and likely subcomponent over the option that only consisted of the unlikely subcomponent. As stated earlier, the combination of two subcomponents is never as likely as just one of the individual subcomponents. Because the physicians in this experiment should have an expertise in answering these types of questions, it would make sense that when working on this task these physicians should have working memory resources left-over that would be able to find the error in judgment and make a correction. Instead, it seems that the physicians became reliant on the heuristic. It is possible that physicians with a higher working memory capacity would be less likely to fall for the conjunction fallacy than the physicians with lower working memory capacities. Differences in performance may not be due to people with higher working memory capacity having a “fact checker” but instead it may be that people with higher working memory spans are using different strategies than people with lower working memory spans. Because this type of task should be automatic for physicians the task should not have a high level of difficulty, therefore, people with higher working memory capacities will be able to use more complicated strategies for making a decision than the lower span people. Research is needed to determine why it is that physicians responding in accordance with the conjunction fallacy.

Tversky and Kahneman (2002) indicated that expertise did not prevent people from using heuristics instead of more complex strategies, instead there must be some other factor that influences the type of strategy a person will use when making a decision. Copeland and Radvansky's (2004) finding that people with larger working memory capacities are able to use more complex strategies than people with smaller working memory capacities combined with the Tversky and Kahneman (2002) finding has led to the idea that it is not a person's expertise that predicts the type of strategy a person will use, instead it is their working memory capacity.

As discussed earlier, there are two different systems that a person can use when making a decision. System 1 is less effortful and allows people to work on multiple tasks at the same time, therefore requiring fewer working memory resources. System 2 is more effortful, involves more complicated calculations, and requires more working memory resources. Considering that people with higher working memory capacities can utilize more complicated strategies than people with lower working memory capacities, it appears that people with higher working memory capacities are better able to use System 2 while people with lower working memory capacities will be more likely to use heuristic based strategies (System 1). Consider the coin tossing example discussed earlier. Suppose that a participant is asked to determine which sequence of coin tosses is more likely: HTHT or HHTT. When the people with lower working memory capacities would make a decision as to which coin toss sequence is more likely they would probably use System 1 for making a decision and claim that the first sequence (HTHT) is more likely because it appears more similar to the population of events. However, a person with a higher working memory span will be more likely to utilize System 2 and, thus, may use a more complicated calculation. A person with a higher working memory span might be able to use the appropriate calculation of ½ x ½ x ½ x ½ for each of the two alternatives (HTHT and HHTT), indicating that both of the alternatives are equally likely. Therefore, it is possible that because the people with higher working memory capacities are more likely to use a more complex strategy, this will make them more accurate than those people with lower working memory capacities, who are more likely to use System 1.

Availability Heuristic and Working Memory

It appears that a person's working memory capacity may also influence their ability to use the availability heuristic in order to make a decision under uncertainty. Again, when people are using the availability heuristic they judge the likelihood of an event by how easily instances similar to that event could be retrieved from memory. Similarly to the representativeness heuristic, people that have higher working memory capacities will be more likely to have a "fact checking" type of function and use more complicated strategies while people with lower working memory capacities will not have a "fact checking" function because they will rely on the less complicated System 1. In addition to that advantage, when using the availability heuristic people with higher working memory capacities will have another advantage over people with lower working memory capacities.

There are several experiments that indicate that people with higher working memory capacities are better at ignoring irrelevant information. For example, Kane and Engle (2003) used a Stroop task and found that participants with low working memory spans exhibited longer reaction times and had higher error rates than the participants with higher working memory capacities. Due to the simplicity of the task, it is clear that the participants lost sight of the goal of the experiment (naming the color of the font) and instead switched to the more automatic task (reading the word on the screen aloud) while the higher span participants did not lose sight of the goal of the experiment.

As discussed earlier, Tversky and Kahneman (1974) presented participants with lists of male's and female's names of varying popularity and the goal of the participants was to not only recall as many names as they could but to also determine whether there were more male or female names presented on the list. The results indicated that the participants determined the frequency of the gender names by the popularity of the names on the list instead of by the number of names on the list. Apparently, the participants were forgetting the goal of the task and instead were basing their decision on popularity of the names. Therefore, people with higher working memory capacities should be better at determining the frequency of each gender in this task than people with lower working memory capacities. Even though it is easier for a person to remember a more popular name than it is for them to remember a less popular name, people with higher working memory capacities should have an easier time of ignoring the irrelevant information (popularity of name) and focus more on the relevant information (the number of names in each gender). Thus, the idea that people with higher working memory capacities are able to ignore irrelevant information and focus on the task at hand may also be a factor when a person is using the anchoring and adjustment heuristic.

Anchoring and Adjustment Heuristic and Working Memory

Now consider the use of the anchoring and adjustment heuristic. In many experiments people are placing too much emphasis on the anchor and are therefore adjusting their answer in the direction of the anchor. Therefore, it may be beneficial to ignore the anchor and focus their attention on their estimate instead of the anchor. It is possible that the people with a higher working memory capacity will be better at ignoring the anchor than people with a smaller working memory capacity. In the 8! example listed above, people with higher working memory capacities should be more likely to ignore the order of the presentation of the question (1 X 2 X 3 X 4 X 5 X 6 X 7 X 8 versus 8 X 7 X 6 X 5 4 X 3 X 2 X 1) and focus more of their attention on the math problem. Low working memory span people will most likely rely too much on the anchor. While the first several calculations would serve as an anchor for the low working memory span people, the high working memory span people would be able to make greater adjustments to the anchor because they would (a) get through more of the calculations than the lower span people and (b) be able to adjust their answer more appropriately because they would pay more attention to all of the numbers, overall, instead of being hyper-focused on the anchor (first few calculations).

Take The Best Heuristic and Working Memory

Working memory span tasks (e.g., Turner & Engle, 1987), essentially, determine how well a person is at working at multiple tasks concurrently (Unsworth, et al., 2005). When a person is using the Take the Best heuristic they must think of as many probability cues as possible, order them in terms of ecological validity, and then assess the alternatives based on the probability cues (in order). For a person to use the Take the Best heuristic, they must work on several tasks concurrently. Because people with higher working memory spans are better at working on multiple tasks at the same time, it is possible that people with a higher working memory capacity should be better at using the Take the Best heuristic than people with a lower working memory span.

Salthouse's (1992) experiment found a positive correlation between working memory capacity and processing speed. Remember, when using the Take the Best heuristic participants' search their memory for probability cues that will help them make a decision. Considering Salthouse's (1992) findings, it would make sense that people with higher working memory spans will be able to find more probability cues than people with a lower working memory span. The more probability cues that a person has access to increases the likelihood of having a probability cue that has a high level of ecological validity that distinguishes between the alternatives. Therefore, people with higher working memory spans are likely to have access to more probability cues that will allow them to make better decisions than people with lower working memory spans

Summary of Working Memory and Heuristics

It appears that there are several ways that a person's working memory capacity can influence their ability to make decisions. A person's working memory capacity influences how many items a person can keep online at any point in time and also influences the type of strategy a person can use when working on a task. Working memory capacity not only influences whether or not a person will be able to ignore irrelevant information but also influences how many tasks a person can work on simultaneously. Many of the heuristics that have been discussed in this paper appear to have a mathematical component. In the following section there will be a description of why it is thought that mathematical ability can influence a person's decision making ability.

Math Ability and Decision Making Ability

Obviously a person who performs at a higher level on standardized math tests is more skilled at math than people that score lower on standardized math tests. Research has also indicated that as math ability increases so does the number of math classes taken at both the high school and college levels (Hembree, 1990). Therefore, people who are more skilled at math are exposed to a wider variety of math topics and acquire a greater number sense than people who are less skilled at math. While many students are exposed to basic probability theories in grade school, many students do not take advance probability or statistics courses, which indicates that many people probably do not have a firm understanding of probabilities or statistics. Many of the heuristics (that are described above) appear to be influenced by basic probability and statistical theorems. Hypothetically, people who are exposed to these types of mathematical courses should be better prepared to make decisions than people who have not been exposed to such classes. Also, because people who are better at math take more math classes they use their math skills much more frequently than people who are not as skilled at math, indicating that people who are better at math have a lot more practice at math than people who are not as skilled at math. Therefore, math should become a more automatic process and should consume fewer working memory resources for people who are more skilled at math than for people who are less skilled at math.

Consider the representativeness heuristic. Tversky and Kahneman (1974) presented participants with a question involving the number of male and female babies born in two different hospitals (see page 10). A basic statistics course will teach students that the larger the sample size, the more likely it is to be representative of the population. The reverse also must be true; the smaller the sample size the less likely it is to be representative of the population. Therefore, the answer to the above scenario is obviously the smaller hospital. However, without being exposed to a basic statistics course the answer is not obvious. Even for people who have taken a basic statistics course the answer may not be obvious. However, to a person who has taken several statistics courses, the answer should be obvious. In fact, someone without knowledge of statistics is likely to answer that the hospitals will record an equal number of such days, indicating that there is a fifty-fifty chance. As indicated above, most decisions require a person to choose between alternatives and a person must decide which scenario is more likely. These types of decisions become increasingly more difficult without a basic knowledge of statistics and probability.

Now, consider the coin toss example and the idea of the gambler's fallacy. Based on an infinite number of coin tosses, which sequence is more likely: *HTHT* or *HHTT*? Basic knowledge of probability will teach someone that to solve this problem one must multiply the ratio of the number of observations to the number of possible outcomes for each individual coin toss. Therefore, the math calculation is the same for each sequence (½ x ½ x ½ x ½), indicating that each sequence has a 1 in 16 chance of occurring. While the solution to this problem may seem simple to people with a basic knowledge of probability, people who have not been taught the basic principles of probability will be forced to use the representativeness heuristic to solve the problem and will come to the decision that the *HTHT* sequence is more representative of the population of events than *HHTT* and is, therefore, more likely.

The anchor and adjustment heuristic appears to be mathematical in nature at its core. Essentially, a person is making judgments based on a numerical answer to a stated problem. People who have taken more math classes are exposed to numbers more often, should become more confident in their estimation abilities and therefore should do better on estimation tasks. People who have better estimation skills, and have taken more math classes should also have a better number sense. In other words, people who are better at math should have a better understanding of numbers resulting in them having a greater ability in judging distances, lengths, and other essential estimation abilities. Because people who are better at math should have a better number sense, they should have a greater sense of how much to estimate answers and should therefore not be as influenced by the anchor as much as people who have less of a number sense. It is assumed that people who are better at math will have more accurate answers and will be less influenced by the anchors than people who are worse at math.

The Take the Best heuristic is based entirely on a person's ability to rank order probability cues in terms of ecological validity. Therefore, a person must estimate (online) how often a certain concept distinguishes two alternatives from one another. Consider the number of inhabitants of Cleveland and Cincinnati example discussed above. First the person searched for various probability cues that may be able to distinguish the number of inhabitants in one city from the number of inhabitants in another city. After finding the probability cues, the person needs to estimate how efficient each cue is at predicting the number of inhabitants of cities, in general. Basically, a person needs to determine the probability that the cue can distinguish between cities. Therefore, a person must have a basic understanding of probability theory in order to rank each of the probability cues appropriately. The efficiency of using the Take the Best heuristic is dependent on how well a person can rank the cues in order of ecological validity. Due to the need of basic probability knowledge in order to use the Take the Best heuristic, and the idea that people that are better at math are more likely to take a probability course, it is possible that people that are better at math will be more efficient at using the Take the Best heuristic than people that are worse at math.

Conclusion

The current paper has reviewed several of the decision making heuristics. Within this paper there was a distinction made between the more objective heuristics (e.g., Tversky & Kahneman, 1974) and the more subjective heuristics (e.g., Gigerenzer, 1996). Both types of heuristics assume that when people are using a heuristic they are using a more simple strategy to make a decision than calculating the probability of each alternative. The distinction between the types of heuristics is found more in the way that people's decisions are evaluated. The proponents of the more objective heuristics seem to judge people to be poor decision makers because people have a tendency to make decisions that violate probability and statistical theory; the proponents of the more subjective heuristics appear to feel that people's subjective rationality aids them in their ability to make decisions and that people are good decision makers. Therefore, the distinction between the types of heuristics is not in the underlying cognitive processes used to make decisions but instead is the way decision makers are evaluated on their decisions.

While there has been an extensive amount of research on the representativeness, availability, anchoring and adjustment, and the Take the Best heuristics, research on why some people are better at making decisions than others has been lacking. The current paper discussed two constructs, working memory capacity and math ability, and how these two constructs may influence a person's ability to make decisions. While it may be that all people use heuristics regardless of their working memory capacity or math ability, it is of interest to see if these constructs are factors that a) determine whether or not people use heuristics or b) determine how well people can use these heuristics.

There are several reasons that a person's working memory capacity may influence a person's ability to make decisions. First, it appears that people with higher working memory spans are able to use more complicated strategies when working on a task than people with lower working memory spans (Copeland & Radvansky, 2004). One of the basic assumptions of decision making heuristics is that heuristics are easier than making calculations. Therefore, people with higher working memory spans may be able to use the more complicated, yet more accurate, calculations, while people with lower working memory spans will need to use easier, yet less accurate, heuristics.

When a person is using calculations to make a decision they are using a more precise strategy which should result in a higher level of accuracy than people that use a heuristic. Therefore, people with higher working memory spans will make more accurate decisions but may need more time to make a decision than lower working memory span people. As the task of making a decision becomes more and more difficult, people with higher working memory spans may regress to use heuristics, like the lower working memory span people. The remainder of the ways that working memory affects decision making, discussed in this section, are based on the assumption that the task is difficult enough that all people (low and high span) will be using a heuristic to make a decision.

Another reason that working memory capacity can affect a person's performance on a decision making task is that people with higher working memory spans are more skilled in working on multiple tasks at the same time than people with lower working memory spans. Aside from the anchoring and adjustment heuristic, in all of the decision making heuristics that have been discussed in this paper, people need to analyze several different options (or probability cues) simultaneously. Therefore, people with higher working memory spans should be better at using these heuristics than people with lower working memory spans.

The current paper also discussed the idea that people with higher working memory spans may have resources in working memory that are left-over from working on the decision making task, while people with low working memory spans will not. People with higher working memory spans could use this left-over capacity to serve as a “fact checker” which will prevent them from making mistakes (i.e., the conjunction fallacy) while people with lower working memory spans may still make this type of mistake. People with higher working memory spans are also better at ignoring irrelevant information (Kane & Engle, 2003). Therefore, people with higher working memory spans will be better at using heuristics that involve information that is not relevant to make the correct decision than people with lower working memory spans.

A person’s math ability may also influence their ability to make decisions. People that are better at math are likely to take more math classes than people that are not good at math (Hembree, 1990) and are, therefore, exposed to more types of math and are more practiced at math tasks. People that are better at math are more likely to take advanced statistics and probability classes. Considering that most decisions could be made more accurately with knowledge of statistics and probability, people that are better at math should also be better at making decisions.

In conclusion, the current paper has discussed research that leads to the deduction that people that have higher working memory spans should be better at making decisions than people with lower working memory spans. It can also be deduced that people that are better at math should also be better at making decisions than people that are worse at math. It is important to empirically test these possibilities to gain a better understanding of how people make decisions as well as understand what characteristics are important for a person to make accurate decisions.

Experiment

Research has indicated that people are prone to making errors when making decisions (Tversky & Kahneman, 2002; Kahneman and Tversky, 1972; etc.). However, the literature is unclear on both why people are bad at making decisions and why some people are better at making decisions than others. Research has indicated that a person's working memory capacity dictates the type of strategy that they can use (Copeland & Radvansky, 2004). Research has also indicated that working memory capacity and the amount of working memory resources that a task demands interact to determine the type of strategy that the person will use to make a decision (Beilock & DeCaro, 2007). Many decisions that people make seem to require some sort of math knowledge [e.g. the coin tossing example (Tversky & Kahneman, 1974) and the hospital scenario (Tversky & Kahneman, 1974), discussed above]. Therefore, it is hypothesized that both math ability and working memory capacity will influence a person's ability to make decisions. Many heuristics have been discussed in the current paper creating an entire line of research; the first experiment in the current line of research will focus on the representativeness heuristic. Considering that mathematical computations are required to find the correct answer in the scenarios in which Kahneman and Tversky (1972) state that people use the the representativeness heuristic, it was logical to start this line of research with the representativeness heuristic.   In the current experiment, participants will be making decisions that are generally associated with the representativeness heuristic. Participants will be grouped based on their working memory capacity and math ability.

CHAPTER 2

METHOD

Participants

A total of 118 participants were recruited for this experiment. Thirteen of those participants were removed from the analysis due to not meeting the minimum requirements (discussed later). Therefore, the data from 105 participants were used in this experiment. There were forty-five male participants and sixty female participants. The average age of the participant was 20.25, ranging from eighteen to forty-seven. The ethnic breakdown was as follows: ten classified themselves as African-American (9.5%), fifteen classified themselves as Hispanic/Latino (14.3%), one classified herself as Native American (1%), twenty classified themselves as Asian/Pacific Islander (19%), fifty-seven classified themselves as Caucasian (54.3%), and two classified themselves as bi-racial (1.9%).

Materials and Procedure

Participants responded to a (11-item) subject information sheet that asked them for demographic information as well as questions about their previous math experience. The participants also participated in the O-span Task (discussed earlier; Turner & Engle, 1989), the math subsection of the Wide Range Achievement Test (WRAT), a series of questions like the hospital problem (discussed above) in a dual task paradigm, a series of questions in which participants read a character description and were asked to judge if the person was more likely to be an engineer or a lawyer in a dual task paradigm, and a series of questions in which the participants were asked to judge which sequence of coin flips was more probable (as described above).

Subject Information Sheet

The subject information sheet asked participants various questions about their background such as: Age, gender, number of math classes taken in high school and college, their grades for both their high school and college math courses, what types of math classes they have taken, their college rank, and their ethnicity.

Operation Span Task

In the current experiment, a modified version of the Turner and Engle (1989) O-span task was used. In this task, the participants were shown a math problem with a given answer. Their task was to press the left mouse key if the given answer was correct for the stated equation or the right button if the given answer was wrong. After the participants responded to the math problem they were shown a word. The participants were to remember the word until a prompt asked them to recall all the words that were presented to them. The number of math problem and word pairs in a set increased progressively throughout the task. The participants started with two pairs in a set and progressed all the way through six pairs in a set. There were three trials for each set size. An example of a trial with a set size of two would be: (5 X 2) + 1 = 11, CARE, (10 / 1) – 5 = 7, ARM, Type in the 1st word, Type in the 2nd word. In this example the math problems, words, and recall prompts were centered on separate screens using E-prime software (Schneider, Eschman, & Zuccolotto, 2002). To answer the given example correctly, the participants must click the left mouse key for the first math problem, the right mouse key for the second math problem, and then type in "Care" at the first recall prompt and "ARM" in the second recall prompt. The participants used a standard QWERTY keyboard to type in their responses. Incorrectly spelled responses were still counted as correct as long as the incorrect spelling did not form a completely different word. Also, homophones of a given word (e.g., typing “eight” when the given word was “ate”) were accepted as correct responses. All of the math problems and words to be recalled were randomly selected separately for each participant.

There were several differences between the original Turner and Engle (1989) O-span and the O-span task that was used in the current experiment. First, in the original O-span, the stimuli were presented on a projection screen and the subjects were required to read the equations and words aloud. In the O-span in the current experiment, the participants were presented with the stimuli on a computer screen and were not asked to read all equations and words aloud. Also, all responses were made via a computer mouse and keyboard in the current experiment, while in the original O-span the responses were made in a paper and pencil format. Also, the original O-span was presented in a group format while in the current experiment participants were run individually. In the current O-span task, the maximum set size was six equations and word pairings in a set while the maximum in the original O-span was five pairings in a set.

Essentially, the O-span task was testing a person’s ability to work on multiple tasks at the same time. In this task, a person must calculate answers to math problems while rehearsing words for later recall. To make sure that the participants were really working on the math problems, participants must have answered 85% of the math problems correctly to be included in the study. If a person achieved 85% correct on the math portion of the task then one point will be given for each word that was correctly recalled in the correct position. All of the correct responses, in the word recall task, were summed to determine the participants’ working memory span score. For a response to be considered correct, the word must be recalled in the order it was presented. A total of sixty-six words were presented to participants, therefore, the highest possible score was a sixty-six.

WRAT

The Math Computation Subtest from the WRAT 4 (fourth edition) was used in this experiment. This subtest consisted of forty math problems. There are eight lines on this test with five questions on each line. The problems increase in difficulty throughout the test, such that the first problem is the easiest ($1 + 1 =$ ____) and the last problem is the most difficult [$(r^2 - 5r - 6) / (r + 1)$]. This subtest served as a test of math ability.

Dual Tasks

The remainder of the tasks in this experiment were done in a dual task paradigm. All primary tasks were paired with a secondary task known as the tone identification task. Prior to all of the dual tasks, the participants were trained on the tone identification task. There were six tones that were used in this study, three that were classified as high and three that were classified as low. The three high tones were at the frequencies of 1760, 1860, and 1960 Hertz (Hz) while the low frequency tones were at 440, 340, and 240 Hz. In a tone identification task used by Schumacher and Schwarb (2009), participants were told to respond “low” to a 440-Hz tone and “high” to a 1760-Hz tone. To make the task slightly more difficult (require more working memory resources), there were three tones in each category instead of one. The participants were trained to determine which of the tones were high and which are low. The participants did not move on to the experimental task until they proved that they understood the difference between the low and high tones (must answer at least 80% of tone test questions correctly). The participants were allowed three attempts at the tone identification test. If they could not get at least 80% correct on any of the three tests then they were dismissed from the experiment. Only one participant could not get at least 80% correct on any of their three attempts and was dismissed.

In the dual task trials, the tones were presented on a separate computer than the primary tasks. The participants used a computer mouse to respond to the tones. The left mouse button was labeled “High” and the right mouse button was labeled “Low”. For the primary task, the participants responded vocally, into a microphone. The microphone was used solely for collection of reaction time data. After a response was made, a prompt for the experimenter to type in the participants’ response was presented on the screen. The typed in responses were shown on the screen as the experimenter was typing the responses. The typed in responses will be used for error rate analysis. While the participants were responding to the primary task the tones were presented at random intervals.

In most dual task paradigms there are three separate blocks of trials for each primary task. The three blocks of trials are one block in which the participant is to respond to the primary and secondary task, one in which the participant only responds to the primary task, and a final block in which the participant responds only to the secondary task. Considering that all of the primary tasks are paired with the same secondary task, in the current experiment, for each different primary task there was not a block of trials in which the participant only responded to the secondary task.

Hospital Problems

The participants were presented with twelve problems that are similar to the hospital in Tversky and Kahneman's (1974) article. One of the three problems is an exact copy of the question asked by Tversky and Kahneman (1974):

A certain town is served by two hospitals. In the larger hospital about 45 babies are born each day, and in the smaller hospital about 15 babies are born each day. As you know, about 50 percent of all babies are boys. However, the exact percentage varies from day to day. Sometimes it might be higher than 50 percent, sometimes lower.

For a period of one year, each hospital recorded the days on which more than 60 percent of the babies born were boys. Which hospital do you think recorded more such days?

- *The larger hospital*
- *The smaller hospital*
- *About the same (that is within 5 percent of each other)*

The remainder of the problems in this task consisted of scenarios that are similar to the hospital problem, in that in each of them the participants needed to pay attention to the size of the samples (groups) in order to obtain the correct answers. The problems that are similar to the hospital problem were manipulated for difficulty. In these problems there were two levels of difficulty. For the easiest problems, percentages in the description were always even decades. As indicated by Janiszewski and Uy (2008) people paid more attention to the more precise numbers than the more rounded ones. Since these problems involved rounded percentages they should have been seen less salient and therefore, should have been less distracting as irrelevant information. The most difficult problems had very precise percentages (rounded to the hundredth of a decimal place) and have sample sizes that were not rounded to the nearest decade (e.g., an ice skating rink that has roughly 728 patrons per day). The logic was that the more salient the irrelevant information was, the more difficult it would be for the participants to ignore the information. For a complete list of the problems see Appendix A.

In each trial, the description of the scenario was presented on the first screen. After the participant had finished reading the description they were to say the word “next” out loud. After they said “next” the researcher pressed the space bar on a keyboard and then the question appeared on the screen beneath the description of the scenario. The reaction times consist of the time it took from the presentation of the question to the time the person spoke the answer out loud.

These problems were in a dual task paradigm where the secondary task was tone identification (discussed above). There were two blocks of trials: the dual task block and the decision-making-only block. In the decision making only block of trials the participants still listened to tones but were told that all of the tones should be classified as high, that way they can focus all of their attention on the hospital problems. In each block of trials, each participant saw two trials at each level of difficulty, for a total of four trials per block. Both error rates and reaction times were analyzed in mixed model ANOVA.

It is hypothesized that the high math ability participants will have taken more math classes, resulting in a better understanding of probability theory, which will allow them to be more accurate and use the representativeness heuristic less than the low math ability participants. Since it is hypothesized that the low math ability participants are more likely to use the representativeness heuristic, their reaction times should be faster than the high math ability participants.

Career Identification Task

The Career Identification Task was popularized by Kahneman and Tversky (1973). Kahneman and Tversky presented participants with scenarios in which 70% of the sample is lawyers and 30% of the sample is engineers. Then the participants were given character descriptions and asked to determine the likelihood that the person in the description is an engineer. In this task, people should have used the aforementioned percentages to assess how likely the person is to be an engineer but instead, it was found that people ignored the prior probabilities and focused more on the character description. Therefore, it was assumed that people were using the representativeness heuristic to solve the problem.

In the current experiment participants were given character descriptions, presented individually, and asked the probability that that person was one of the 30 engineers in a sample of 100 people or one of 70 lawyers in a sample of 100. These problems were presented in the same type of dual-task scenario as the previous task. Again, there were two blocks of trials: The dual task, and the career identification-only task.

Pilot data was collected which asked participants what they thought were characteristics of engineers and lawyers. The most frequently recorded terms that were used for each occupation were used to create the character sketches. As in the hospital problems task, this task also had a difficulty manipulation. For the easy level, the character sketches included only one career stereotype and several other characteristics that were not stated by the pilot data to be a stereotype of an engineer or a lawyer. For the difficult problems, the character sketches included three career stereotypes and several other characteristics that were not stated by the pilot data to be a stereotype of an engineer or a lawyer. There were both positive and negative career stereotypes. According to the pilot data, examples of career stereotypes are that engineers are good at math and are handy. An example of a positive career stereotype for an engineer would be that "in college, Jon tutored other students in math". An example of a negative career stereotype for a lawyer would be "Sam hates to do home repairs" (see Appendix B for examples of these questions). The former example is a positive characteristic because engineers are good at math while the latter is a negative stereotype for a lawyer because since engineers are handy and Sam hates doing home repairs than he must not be an engineer and the only other option is a lawyer. There were an equal number of characteristics (either career stereotypes or filler) in each character sketch. In the same logic as the Janiszewski and Uy (2008) article, the more descriptive or precise something is the more salient that should be. Considering that the character sketch is irrelevant information, the more salient it is the more distracting it should be. Therefore, the more characteristics there were in a character sketch, the more difficult it should have been for the person to ignore the character sketch and estimate the correct probability.

As in the hospital problems task, career identification was also done in a dual task paradigm. The secondary task in the dual task paradigm was the tone identification task (discussed above). There were two blocks of trials: the dual task block and the decision-making-only block. In the decision making only block of trials the participants still listened to tones but were told that all of the tones should be classified as high, that way they can focus all of their attention on the hospital problems. In each block of trials, each participant saw four trials at each level of difficulty, for a total of eight trials per block. Both error rates and reaction times were analyzed in mixed model ANOVA.

In each trial, the character sketch was presented on the first screen. After the participant had finished reading the sketch they were to say the word “next” out loud. After they said “next” the researcher pressed the space bar on a keyboard and then the question appeared on the screen beneath the character sketch. The reaction times consist of the time it took from the presentation of the question to the time the person spoke the answer out loud.

It is hypothesized that the high working memory span participants are better at ignoring irrelevant information so they will have higher rates of accuracy than the low working memory span participants. Since the low working memory span participants are worse at ignoring irrelevant information, it is hypothesized that the low working memory span will be more likely to use the character sketch to calculate a probability, therefore, the low working memory span participants will be more likely to use the representativeness heuristic on this task. It appears that ignoring the irrelevant information may be quicker than using the representativeness heuristic on this task, therefore, it is hypothesized that the high working memory span participants will be quicker on this task than the low working memory span participants.

Coin Tossing Task

As Kahneman and Tversky (1972) indicated, people have a tendency to predict that an alternating coin flip sequence (e.g., THTH) is more likely than a consistent sequence (e.g., TTTT). In the current experiment, participants were exposed to different stimuli in which they were asked to predict which of two coin flip sequences was more likely.

Each participant saw four trials in both the control and dual task blocks of trials. There were four levels of difficulty in each block of trials. Difficulty was manipulated by the number of tosses in a sequence. In each block there was one trial that involved one, two, four, and six tosses per sequence. An example of a question is: If you were to flip a coin 4 times which of the following sequences is more likely (H = heads and T = tails). They were then presented with three options, one that seemed representative of the overall population of events (i.e., H T H T), one that grouped the heads together and the tails together (i.e., H H T T) and one option that said Equal. The correct answer in each trial was "Equal", the answer indicative of using the representativeness heuristic was the one that appeared representative of the overall population of events, and the wrong answer was the option that grouped the heads and tails together. See Appendix C for examples of these questions.

As in the two previously mentioned tasks, the coin tossing task was presented in a dual task paradigm. The dual task block of trials consisted of one trial of each difficulty level while simultaneously discriminating between low and high tones. Before the control block of trials the participants were told that each tone was a high tone and to respond accordingly while also responding to the four trials (one at each level of difficulty). Both error rates and reaction times were analyzed in mixed model ANOVA.

It is hypothesized that people that are better at math will have a better understanding of probability theory and will be more likely to answer these questions correctly. It is also hypothesized that the low math ability participants will be more likely to use the representativeness heuristic than the high math ability participants. Because the low math ability participants are more likely to use the representativeness heuristic, the low math ability participants should respond to the questions more quickly than the high math ability participants.

<u>Weighted Coin Tossing Task</u>

The weighted coin tossing task was similar to the coin tossing task. Like the coin tossing task, there were four levels of difficulty (one, two, four, and six tosses in a sequence) in both the control and dual task block of trials. The difference between the weighted coin tossing task and the coin tossing task was that in the weighted coin tossing task the participants were instructed that the coin was weighted such that the 60% of the time the coin would land on heads and 40% of the time it would land on tails. Therefore, to obtain the correct answer the participant should calculate the probability of each sequence. If a sequence were H T H H, the participant should do the following calculation: 3/5 x 2/5 x 3/5 x 3/5. This calculation should be done for each sequence in a trial and the sequence that has the higher probability should be selected. The trial that had the lower probability appeared more representative of the overall population of events (see above) and was therefore indicative of a person using the representative heuristic. The final option was the word equal, which was always the incorrect answer. See Appendix D for examples of these questions. As in the previous three tasks, the weighted coin tossing task was also in a dual task paradigm. The dual task block of trials consisted of one trial of each difficulty level while simultaneously discriminating between low and high tones. Before the control block of trials the participants were told that each tone was a high tone and to respond accordingly while also responding to the four trials (one at each level of difficulty). Both error rates and reaction times were analyzed in mixed model ANOVA. The hypotheses for the weighted coin tossing task are the same as they are for the coin tossing task.

Exit Survey

Following all of the tasks, the participants were interviewed in order to gain some insight into the strategies that they used on the various tasks. The exit survey gave an example of each type of question and after each example was read aloud to the participant the participant was asked to recall the answer that they gave. Next, the participants were asked the strategy that they used to arrive at their answer. Some of the participants' responses were vague, therefore the researchers were trained to ask follow-up questions so that the participants could clearly indicate the strategy that they used. See Appendix E for a copy of the exit survey.

CHAPTER 3

RESULTS

Before the results of Experiment 1 are detailed, it may be beneficial to point out a few things. Many of the hypotheses of Experiment 1 were not met. In fact, for some of the hypotheses the exact opposite was true (e.g. the low working memory span participants were more accurate than the high working memory span participants). This may have been because the hospital problems and career identification task questions tricked participants to respond in a certain way (discussed later). Also, a large percentage of the participants that were removed from the analyses due to not answering eighty-five percent of the math problems correct on the operation span task would have been classified as low math ability participants. It appears that this criterion altered the sample so that there were not as many low math ability participants in the sample as there are in the population. In Experiment 2, the criterion that a participant must correctly answer eighty-five percent of the math problems on the operation span task was removed to create a more representative sample.

The most beneficial finding from Experiment 1 was from the exit interviews. The exit interviews indicated that on the weighted coin tossing task, the participants were counting the number of heads in each sequence to answer the questions. Experiment 2 was created to determine what strategy a participant would use when this strategy did not work. The remainder of this section will detail the results of Experiment 1.

It was hypothesized that there would be a significant positive correlation between math ability and working memory span. This hypothesis was supported by a significant correlation between scores on the Wide Range Achievement Test and scores on the

Operation Span Task, $r(103) = .248$, $p = .011$. The correlation indicates that as scores on the math subsection of the Wide Range Achievement Test increased, scores on the Operation Span Task also increased. Considering the significant correlation between math ability and working memory span, it was hypothesized that if the participants were split into high and low math ability groups that the high math ability participants would have higher working memory span scores than the low math ability participants. It was also assumed that if the participants were split into high and low working memory span groups that the high working memory span participants would have higher math ability scores than the low working memory span participants. Before addressing these hypotheses, the procedure that was used to group the participants into high or low working memory span group and high or low math ability group will be discussed.

Math Ability was determined by scores on the math subsection of the Wide Range Achievement Test (version 4). For the Wide Range Achievement Test, there was a sample mean of 32.21, a median of 32, and a standard deviation of 4.24. A median split procedure was used to place participants into the high or low math ability group. Those participants that earned a score at or below the median were placed in the low math ability group, while those that scored higher than the median were placed in the high math ability group.

The participants' working memory span was determined by the Operation Span Task. For the Operation Span Task, there was a sample mean of 54.10, a median of 55 and a standard deviation of 7.39. A median split procedure was used to group participants into the low or high working memory span group. The participants that scored at or above the median were placed in the high working memory span group, while the participants that scored below the median were placed in the low working memory span group. All of the analyses reported in the following sections are based on the above mentioned criteria for math ability groups and working memory span groups.

Using the aforementioned criteria, the working memory span groups were compared in terms of math ability and the math ability groups were compared in terms of working memory span. While there was no difference between the working memory span groups in terms of their math ability $t(103) = -1.43$, $p = .16$, there was a difference in the math ability groups in terms of their operation span scores, $t(103) = -2.77$, $p = .007$. The low math ability group scored lower on the operation span task (52.22 words recalled correctly) compared to the high math ability group (56.10). This indicates that the high math ability participants had higher working memory spans than the low math ability participants.

In the current experiment there were several different tasks. The design, method of analysis, and method for detecting extreme scores varied for each task. Therefore, before the results for each task are discussed, a brief synopsis of the design, method of analysis, and process for detecting extreme scores will be discussed.

Hospital Problems

For the hospital problems, each participant completed two difficult and two easy problems in both the control and dual-task blocks of trials, for a total of eight trials. Each trial consisted of a problem in which the participant had to make a judgment as to which scenario was more probable (see methods section for an example of the scenarios). The correct answer in each problem was the scenario that consisted of the smaller sample. The three options the participants had to choose among were each of the mentioned scenarios (e.g., the large hospital and the small hospital) and an option labeled "Equal". A response of equal was considered to be evidence that the participant was using the representativeness heuristic. The difficulty of the problem was manipulated by whether the size of the samples and the numbers in the percentages were rounded numbers or more "precise" numbers. The problems consisting of all rounded numbers (i.e., percentages rounded to the nearest unit digit and sample sizes rounded to the nearest decade or half-decade) were considered the easy problems, while the problems that consisted of more "precise" numbers (rounded to the nearest hundredth for the percentages and sample sizes that were rounded to the nearest unit digit) were considered the difficult problems. To analyze the hospital problems data, several analyses of variance were calculated. For this task, a separate analysis of variance was calculated with the dependent variables reaction time, accuracy, and responses consistent with the representativeness heuristic. Also, Stuart-Maxwell tests for homogeneity of marginal distributions were calculated. Stuart-Maxwell tests can be thought of as a within-subjects chi square. These were calculated to see if the participants were using different types of responses within each difficulty level and between each difficulty level. The response tendencies can be found in Tables 1, 2, and 3.

Analysis of Variance

Accuracy

A 2 (math ability group) x 2 (working memory span group) x 2 (task) x 2 (difficulty) mixed model analysis of variance was calculated with accuracy as the dependent variable. There was a main effect for difficulty, $F(1, 101) = 23.78$, $p < .05$, $\eta_p^2 = .187$. Ironically, the difficult problems (25.8%) were answered correctly more often than the easy problems (12.4%). Janiszewski and Uy (2008) found that the differences between the anchor and the participants' responses were smaller when problems involved more precise numbers than when problems involved more rounded numbers. The fact that people responded closer to the anchor when the anchor was a more precise number indicates that the participants were more likely to use a heuristic when problems involved more precise numbers than rounded numbers. This idea led to the hypothesis that people would be more likely to use the representativeness heuristic when the problems involved more precise numbers than when they involved more rounded numbers. In the current task, it appears that people viewed the more precise numbers as more important for the task and therefore used an algorithmic strategy more when the numbers were precise than when the numbers were rounded.

Representativeness Heuristic

A 2 (math ability group) x 2 (working memory span group) x 2 (task) x 2 (difficulty) mixed model analysis of variance was calculated with usage of the representativeness heuristic as the dependent variable. Again, there was a main effect for difficulty, $F(1, 101) = 23.78$, $p < .05$, $\eta_p^2 = .191$. The representativeness heuristic was used more often on the easy problems (54.3%) than on the difficult problems (40%). Since the representativeness heuristic is thought to be a less cognitively demanding strategy that is used to solve a problem, this finding is further evidence that the less precise the numbers were in the scenarios the less likely the participants were to strain themselves (cognitively) on the task. The hypothesis that participants would use more complex strategies on the easy problems while utilizing a less cognitively demanding strategy (representativeness heuristic) on the difficult problems was rejected by this finding.

The main effect of working memory span group reached marginal significance, $F(1, 101) = 3.29$, $p = .073$, $\eta_p^2 = .032$. This main effect indicates that the high working memory span participants (53.4%) used the representativeness heuristic more often than the low working memory span participants (40.9%). Copeland and Radvansky (2004) showed that people with higher working memory spans could use more complicated strategies than low working memory span participants. The results from the current experiment seem to be the opposite of Copeland and Radvansky's (2004) findings. However, the representativeness heuristic may be a more logical strategy than other strategies that are used in this task. This will be discussed in more detail in the discussion section. Also, there was a marginally significant task x difficulty x working memory group x math ability group interaction, $F(1, 101) = 3.61$, $p = .060$, $\eta_p^2 = .035$ (see Figures 1a and 1b).

Reaction Time

For the reaction time data, a reaction time was considered an outlier if it fell two and a half standard deviations above or below the mean of the math ability group from the condition the reaction time is from. Also, if a reaction time was quicker than 250 milliseconds then the trial was considered a microphone error and treated as if it were an outlier. The outliers were removed within each condition within the 2 (math ability group) x 2 (working memory span group) x 2 (task) x 2 (difficulty) and replaced with the mean of the math ability group from that condition (for a list of the outliers see Table 4).

A 2 (math ability group) x 2 (working memory span group) x 2 (task) x 2 (difficulty) mixed model analysis of variance was calculated with reaction time as the dependent variable. There was a main effect of difficulty, $F(1, 88) = 9.34$, $p < .05$, $\eta_p^2 =$

.096. This indicates that the easy problems were responded to more quickly (12482 msec) than the difficult problems (13555 msec). Considering that the representativeness heuristic was used more often on the easy problems than on the difficult problems and that using the representativeness heuristic is thought to be a quick process, it is logical that the easy problems were answered quicker than the difficult problems.

It was also found that there was a main effect of working memory span groups, $F(1, 88) = 5.44$, $p < .05$, $\eta_p^2 = .058$. This main effect indicates that the low working memory span participants (13664 msec) took longer to respond to the questions than the high working memory span participants (12372 msec). Considering that the high working memory span participants used the representativeness heuristic more often, it is intuitive that they also have quicker reaction times.

Stuart-Maxwell Tests

A Stuart-Maxwell test was done to determine if the distribution of responses (correct answer, representativeness heuristic answer, or wrong answer) by the participants was different within the easy and difficult problems and to see if the pattern of responding was different between the easy and difficult problems. The pattern of results for all participants, $\chi^2(2) = 323.10$, $p < .05$, indicated that there is not marginal homogeneity between participants' responses on the easy and difficult problems. This means that the distribution of scores between the easy and difficult problems is different among the types of responses. The source of this difference appears to be that while on the easy problems the participants used the representativeness heuristic significantly more than being correct or being wrong; on the difficult problems participants used the representativeness heuristic slightly more than they were wrong but much more frequently than using a strategy resulting in the correct answer. Also, the representativeness heuristic was used more on the easy problems than the difficult problems. The low math ability participants, $\chi^2(2) = 187.94$, $p < .05$, showed extremely similar patterns of responses except that on the difficult problems the low math ability participants answered the problems incorrectly more than used the representativeness heuristic. The high math ability participants, $\chi^2(2) = 135.20$, $p < .05$, used the representativeness heuristic more than any other strategy on both the easy and difficult problems but the discrepancy between using a strategy resulting in the correct answer and using the representativeness heuristic was smaller for the difficult problems than for the easy problems.

Summary

The independent variable that seemed to have the largest impact performance of the hospital problems was the difficulty of the problem. However, the impact of the difficulty factor was the opposite of what was predicted. It was hypothesized that the participants would be less accurate, more likely to use the representativeness heuristic, and quicker on the difficult problems than on the easy problems. However, the participants were more accurate on the difficult problems than the easy problems, responded with an answer indicative of using the representativeness heuristic more for the easy problems than the difficult problems, and were quicker on the easy problems than the difficult problems. This indicates that when the problems involved more precise numbers participants spent more time on them resulting in more accurate responses. When the problems involved rounded numbers people were more likely to go through the problems more expeditiously resulting in them using what appears to be the representativeness heuristic, or wrong answer for low working memory span participants.

The working memory span group factor also influenced performance on the hospital problems. While the high working memory span participants were quicker to solve the problems, they were also more likely to use the representativeness heuristic. This implies that while one of the benefits of having a high working memory span is that you process tasks quickly, one of the risks is overlooking more accurate answers and instead utilizing only the first strategy that comes to mind. It was interesting that the low working memory span participants were wrong so frequently. This implies that they were using a different strategy to answer these problems. The working memory span group by math ability group by difficulty by task interaction (see Figures 1a and 1b) appears to have reached marginal significance due to the low span/high math ability participants used the representativeness heuristic more than the low span/low math ability participants on the control problems but the low span/low math ability participants used the representativeness heuristic more than the low span/high math ability participants on the dual task problems.

Career Identification Task

In the career identification task participants were presented with several character sketches. After they read each character sketch, they were presented with a question regarding the probability that the man was either an engineer or a lawyer. The participants were to respond in the form of a number. For the answer to be considered correct the participant must have responded with the number that was stated in the question. There were several conditions that needed to be met for a response to be considered indicative of using the representativeness heuristic. If the characteristics in the character sketch represented the career stated in the question, then a number larger than the number in the question was considered indicative of using the representativeness heuristic. If the characteristics in the character sketch were incongruent with the career in the question, then a response of a number smaller than the number in the question was indicative of usage of the representativeness heuristic. All other types of responses were considered incorrect. The difficulty of the problem was manipulated by the number of career stereotypes that were in the character sketches. The easy problems only had one career stereotype while the difficult problems had three career stereotypes. For this task, a separate analysis of variance was calculated with the dependent variables reaction time, accuracy, responses consistent with the representativeness heuristic, and the difference between the correct score and the stated answer. For a breakdown of how participants responded to the various stimuli see Tables 5, 6, and 7.

Analysis of Variance

Representativeness Heuristic

A 2 (math ability group) x 2 (working memory span group) x 2 (task) x 2 (difficulty) mixed model analysis of variance was calculated with usage of the representativeness heuristic as the dependent variable. There was a significant main effect for difficulty, $F(1, 100) = 12.06$, $p < .05$, $\eta_p^2 = .108$. This main effect illustrates that participants used the representativeness heuristic more on the difficult problems (56.7%) than on the easy problems (50.5%). Also, the difficulty by math ability group interaction was marginally significant, $F(1, 100) = 3.09$, $p = .08$, $\eta_p^2 = .03$ (see Figure 2). This interaction indicates that the low math ability participants used the representativeness heuristic considerably more on the difficult problems (59.5%) than the easy problems (50.5%) while the high math ability participants only used the representativeness slightly more on the difficult problems (53.9%) than the easy problems (50.9%).

Difference

Unique to the career identification task, participants were able to answer on a continuous scale of measurement, as opposed to the multiple choice format for all of the other decision making tasks. A difference score was calculated by taking the absolute value of the difference between the response and the correct answer. A 2 (math ability group) x 2 (working memory span group) x 2 (task) x 2 (difficulty) mixed model analysis of variance was calculated with the difference score as the dependent variable. There was a main effect of difficulty, $F(1, 100) = 9.49$, $p < .05$, $\eta_p^2 = .087$. This main effect indicated that the participant's responses were further from the correct answer for the difficult problems (26.8) than the easy problems (24.4).

Reaction Time

For the reaction time data, a reaction time was considered an outlier if it fell two and a half standard deviations above or below the mean of the working memory span group (low or high) for that condition. Also, if the reaction time on a trial was quicker than 250 milliseconds then it was considered a microphone error and treated as if it were an outlier. The outliers were removed within each condition from the factorial design discussed above and replaced with the mean of the working memory span group for that condition. For a list of the outliers, see Table 8.

The main effect for task reached significance, $F(1, 96) = 8.89$, $p < .05$, $\eta_p^2 = .085$. This main effect indicates that the dual task trials (3867 msec) were responded to quicker than the control trials (4224 msec). This may be due to the fact that the participants were slightly more accurate on the control trials (26.4%) than the dual task trials (24%), $F(1, 100) = 1.08$, $p = .30$, and the participants used the representativeness heuristic slightly more on the dual task trials (54.2%) than on the control trials (53%), $F(1, 100) = .329$, $p = .568$. This indicates that the representativeness heuristic may result in quicker but less accurate responding. The task by math ability group by working memory span group interaction reached significance, $F(1, 96) = 4.33$, $p < .05$, $\eta_p^2 = .043$ (see Figures 3a and 3b). In this interaction, for the control block of trials, the reaction times of the low working memory span participants is the same, regardless of math ability but of the high working memory span participants the ones with high math ability were quicker than the ones with low math ability. In the dual task block of trials, of the low working memory span participants the ones with high math ability were quicker than those with low math ability while the reaction times of the high working memory span participants was the same regardless of math ability. Therefore, on the control trials math ability influenced the high working memory span participants only, but only influenced the low working memory span participants on the dual task trials.

The difficulty factor interacted significantly with working memory span groups, $F(1, 96) = 19.64$, $p < .05$, $\eta_p^2 = .170$. This interaction illustrates that the difficulty of the problems had exact opposite effects on the high working memory span participants as it did on the low working memory span participants. While the low working memory span participants answered the easy problems (3791 msec) quicker than the difficult problems (4169 msec), the high working memory span answered the difficult problems (3950 msec) quicker than the easy problems (4270 msec). This was not supported by the representativeness heuristic responding data. Actually, even though it was not at all significant, $F(1, 100) = .006$, $p = .938$, the low working memory span participants used the representativeness heuristic more on the difficult problems (56%) than the easy problems (50%) and the high working memory span participants also used the representativeness heuristic more on the difficult problems (58%) than the easy problems (51%). Therefore, high working memory span participants were quicker on the trials in which they were more likely to use the representativeness heuristic while the low working memory span were quicker on the trials in which they were less likely to use the representativeness heuristic.

Summary

As in the hospital problems task, the difficulty of the problems is the factor that influenced performance the most. However, among the data from the career identification task, the main effects of difficulty coincided with the hypotheses. The participants used the representativeness heuristic more on the difficult problems than the easy problems and reported answers that were further from the correct answer on the difficult problems than on the easy problems. Difficulty also interacted with math ability on the representativeness heuristic such that the low math ability participants used the representativeness heuristic much more on the difficult problems than the easy problems while the high math ability participants used the representativeness heuristic only slightly more on the difficult problems than the easy problems. The fact that the participants took longer to respond to the control trials than the dual task trials seemed slightly confusing until it was found that the participants were slightly more accurate on the control trials and used the representativeness heuristic slightly more often on the dual task trials. Also, the task by math ability by working memory capacity interaction within the reaction time data clearly indicated that a person's math ability and the amount of working memory resources needed to complete the task influences low working memory span participants and high working memory span participants differently. Apparently when the task consumes more working memory resources, math ability influences the low working memory span participants' reaction time but not the high working memory span participants' reaction time. However, when the task consumes less working memory resources, math ability influences the high working memory span participants' reaction time but not the low working memory span participants' reaction time.

Coin Toss Task

In the coin tossing task, each participant was presented with four coin tossing questions in each of the dual and control blocks of trials. In each block, they were asked a question about sequences of one, two, four, and six tosses. Each stimulus gave them three options for possible outcomes. Aside from the one toss outcomes, each trial consisted of one correct answer ("Equal"), one answer that seems representative of the overall population of events (e.g. "HT"), and one wrong answer (e.g. "HH"). For the one toss sequences, it was impossible to have an answer that was representative of the overall population of events so there was one correct answer ("Equal") and two incorrect answers ("T" or "H"). For this task, a separate analysis of variance was calculated with the dependent variables accuracy, responses consistent with the representativeness heuristic, and reaction time. Also, Stuart-Maxwell tests for homogeneity of marginal distributions were calculated. Stuart-Maxwell tests can be thought of as a within-subjects chi square. These were calculated to see if the participants were using different types of responses within each difficulty level and between each difficulty level. See Tables 9, 10, and 11 for a breakdown of participants' responses.

Analysis of Variance

Accuracy

For the coin tossing task, it was hypothesized that people who were better at math would answer more questions correctly than people who were worse at math. To test this hypothesis a 2 (math ability group) x 2 (working memory span group) x 2 (task) x 4 (number of tosses) mixed model analysis of variance was calculated with accuracy as the dependent variable. It appears that the current hypothesis was not validated, such that, there was no difference between the math ability groups in terms of their accuracy rates on the coin toss problems, $F(1, 98) = .161$, $p = .69$. However, it does appear that the difficulty level of the problems was manipulated successfully, as the number of coin tosses in a sequence did produce a significant main effect, $F(3, 294) = 13.58$, $p = 0.00$, $\eta_p^2 = .122$. When there was only one coin toss, participants were extremely accurate (90% correct), while when there were two, four, or six coin tosses participants were much less accurate (68.4%, 71.3%, and 69.6%, respectively). Rather than stating the correct answer, "Equal", the participants were responding with the representativeness heuristic option 24.6%, 22.7%, and 22.7% of the time for two, four, and six toss sequences respectively. The remainder of the time the participants were responding in a manner that was incorrect and were not utilizing a strategy similar to the representativeness heuristic (7%, 6.6%, 6%, and 7.7%, for one, two, four, and six toss sequences, respectively).

Representativeness Heuristic

A 2 (math ability group) x 2 (working memory span group) x 2 (task) x 2 (difficulty) mixed model analysis of variance was calculated with accuracy as the dependent variable. The task (control or dual) by number of tosses interaction was marginally significant, $F(2, 198) = 2.795$, $p = .064$, $\eta_p^2 = .027$, see *Figure* 4. It appears that for the two toss sequences participants used the representativeness heuristic more in the control trials (28.4%) than in the dual task trials (20.7%). However, on the four toss sequences, the participants used the representativeness heuristic in the dual task trials (27.2%) more than in the control trials (18.2%). On the six toss sequences, the participants used the representativeness heuristic (roughly) equally in the control trials (23.1%) and in the dual task trials (22.2%).

Reaction Time

The analysis of variance of the reaction time data for the coin tossing task required outliers to be removed for each condition in the 2 (Task: control and dual) x 2 (Math Ability: High or low) x 2 (Working Memory Group: Low or High) x 4 (Coin Tosses: 1, 2, 4, and 6) factorial design. Scores were considered to be outliers if they were two and a half standard deviations above or below the mean of the math ability group for that condition. Outliers were removed from each condition in the above mentioned 2 x 2 x 2 x 4 factorial design. Also, if a reaction time fell below 250 msec it was considered a microphone error and treated as an outlier. In each condition, the outliers were replaced with the mean of that condition from the math ability group from which the outlier was found (see Table 12).

The time it took participants to answer the questions was influenced by both factors that manipulated the difficulty of the problem. In terms of math difficulty, the more difficult (determined by number of tosses) the sequences were, the longer the participants took to answer the question, $F(3, 244) = 24.33$, $p < .05$, $\eta_p^2 = .299$. This increase in time was fairly linear; the average reaction time (in milliseconds) was 4324, 5079, 5623, and 6011 for one, two, four, and six coin tosses, respectively.

There was a main effect for the task factor, $F(1, 99) = 5.06$, $p = .03$, $\eta_p^2 = .051$. This main effect illustrated that the participants were quicker to reply to the coin toss sequences in the control block of trials (5066 msec) than in the dual task block of trials (5453 msec). This suggests that solving the coin toss questions requires working memory capacity.

One hypothesis of the current study was that the high math ability participants should be quicker at answering the problems than the low math ability participants. In support of this hypothesis, it was found that the high math ability participants were quicker at answering the coin toss sequences (4822 msec) than the low math ability participants (5697 msec), $F(1, 100) = 1576.51$, $p = 0.00$, $\eta_p^2 = .94$. Since both the high and low math ability groups had such high accuracy rates, it seems that the high math ability people were quicker at calculating the answers than the low math ability participants.

Math ability interacted with both factors that determined the difficulty of the problem (task and number of tosses). For the task factor, while the low math ability participants solved the coin toss sequences quicker in the control block of trials (5322 msec) than in the dual block of trials (6061 msec), the high math ability participants recorded roughly the same reaction time in the control trials (4799 msec) as in the dual task trials (4845 msec), $F(1,99) = 3.91$, $p = .05$, $\eta_p^2 = .038$. This indicates that the amount of working memory resources the task required influenced the performance of the low math ability participants but not the high math ability participants, which is consistent with the result that the high math ability people had higher working memory spans than low math ability participants (stated above).

The math ability factor also interacted significantly with the number of coin tosses in the sequences, $F(3, 244) = 3.92$, $p < .05$, $\eta_p^2 = .048$. This interaction indicated that the low math ability group increased in reaction time as the number of coin tosses in a sequence increased more than the high math ability group, see *Figure* 5. This is another example of how the difficulty of the problem influenced the low math ability participants more than the high math ability participants.

Stuart-Maxwell Tests

Stuart-Maxwell tests were done to determine if the pattern of responding (correct answer, representativeness heuristic answer, or wrong answer) was different within the two, four, and six toss sequences and between the two, four, and six toss sequences. The Stuart-Maxwell test that included all of the participants, $\chi^2(2) = 179.96$, $p < .05$, indicated that there is not marginal homogeneity between participant's responses on the two, four, and six toss sequences. The source of this difference appears to be that the participants were correct on more trials than they were wrong or used the representativeness heuristic on all sequence lengths.

Analysis consisting only of the high math ability participants, $\chi^2(2) = 91.5$, $p < .05$, showed a similar pattern of results, such that, the high math ability participants used a strategy to obtain the correct answer on a higher percentage of trials than using the representativeness heuristic or a strategy resulting in a wrong answer. Of all of the coin sequences, the high math ability participants used the representativeness heuristic on the highest percentage of trials on the two toss sequences. The low math ability participants, $\chi^2(4) = 91.35$, $p < .05$, were correct on a higher percentage of trials than using the representativeness heuristic or using a strategy that resulted in a wrong answer on all sequence lengths. Of all sequence lengths, the low math ability participants used the representativeness heuristic most on the six toss sequences.

Summary

As with the hospital problems and career identification task, the difficulty factor seemed to be the factor with the largest influence on performance on the coin tossing task. The participants were extremely accurate on the one toss sequences. While the participants were also fairly accurate on the two, four, and six toss sequences, they also used the representativeness heuristic on over twenty percent of the trials on each of those sequence lengths. Also, the time it took participants to answer the questions increased as the number of tosses in the sequence increased. This increase in reaction time across the lengths of coin toss sequences was found in both the low and high math ability participants, with the low math ability participants' reaction time increasing more than the high math ability participants. This seems to imply that the representativeness heuristic is not a quicker strategy than calculating the answer.

Weighted Coin Toss Task

As in the coin toss task, in the weighted coin toss task, participants were exposed to four coin tossing sequences in each block (control and dual) of trials. The sequences included one, two, four, or six tosses. Each stimulus was presented with three choices.

Aside from the one toss sequences, each trial consisted of one correct answer (the one with the highest probability), one answer that seems representative of the overall population of events (e.g. "HT"), and one incorrect answer ("Equal"). For the one toss sequence, it was impossible to have an answer that was representative of the overall population of events so there was one correct answer (the one with the highest probability) and two incorrect answers (the other coin toss sequence and "Equal"). For this task, analyses of variance were calculated on the accuracy, responses consistent with the representativeness heuristic, and the reaction time data. Also, Stuart-Maxwell tests for homogeneity of marginal distributions were calculated. Stuart-Maxwell tests can be thought of as a within-subjects chi square. These were calculated to see if the participants were using different types of responses within each difficulty level and between each difficulty level. See Tables 13, 14, and 15 for a breakdown of participants' responses.

Analysis of Variance

Accuracy

There was a main effect for number of coin tosses in a sequence, $F(3, 96) = 10.86$, $p < .05$, $\eta_p^2 = .253$. The participants answered accurately 81.3%, 74.6%, 58.1%, and 93.4% of the time for one, two, four, and six toss sequences, respectively. This means that the participants answered more accurately for the easiest and most difficult problems and answered less accurately on the medium levels of difficulty. Usually, as problems become more difficult, participants decrease in accuracy, but this was not the case in the current experiment. The fact that participants were decreasing in accuracy as the number of tosses in a sequence increased implies that the participants were using some sort of computational based strategy for the one, two, and four toss sequences. The fact that accuracy increased on the six toss sequences implies that the participants defaulted into a heuristic-like strategy that resulted in high levels of accuracy.

The main effect for working memory span groups reached marginal significance, $F(1, 32) = 3.35$, $p = .077$, $\eta_p^2 = .095$. It appears that the low working memory span participants (84.6%) answered the problems correctly more often than the high working memory span participants (69%). It was assumed that participants with a higher working memory span would be more accurate on this task than people with low working memory but the data appears to imply otherwise. It appears that the low working memory span participants were more likely to use the heuristic-like strategy. This heuristic-like strategy must require fewer working memory resources and result in high levels of accuracy.

Representativeness Heuristic

Similarly to the analysis for the accuracy of the weighted coin toss problems, there was also a significant main effect of number of tosses in the representativeness heuristic usage data, $F(2, 64) = 4.44$, $p < .05$, $\eta_p^2 = .122$. Participants used the representativeness heuristic 15.3% and 19.1% of trials on the two and four toss sequences, respectively, but only 3.9% of the time on the six coin toss trials. Considering that the participants were more accurate on the six toss sequences than on the two and four toss sequences and that the participants used the representativeness heuristic less often on the six toss sequences than on the two and four toss sequences it appears that the students must have used a different strategy on the easy problems than on the difficult problems. Because accuracy increased and representativeness heuristic usage decreased on the most difficult level of difficulty, the participants must have used the heuristic-like strategy on the most difficult problems.

Reaction Time

Similarly to the coin tossing task, the analysis of variance of the reaction time data for the weighted coin tossing task required outliers to be removed for each condition in the 2 (Task: control and dual) x 2 (Math Ability: High or low) x 2 (Working Memory Group: Low or High) x 4 (Coin Tosses: 1, 2, 4, and 6) factorial design. Scores were considered to be outliers if they were two and a half standard deviations above or below the mean. Also, if a reaction time fell below 250 msec it was considered a microphone error and treated as an outlier. In each condition, the outliers were replaced with the mean of that condition from the math ability group from which the outlier was found (see Table 16).

There was a significant main effect for the difficulty of the problems (number of tosses in the sequences), $F(3, 90) = 7.62$, $p < .05$, $\eta_p^2 = .203$. This main effect showed that the participants were quickest at the one toss sequences (8838 msec). There was a small increase in reaction time from the one toss sequences to the two toss sequences (9383 msec) followed by a steep increase in reaction time on the four toss sequences (11519 msec). Finally there was a decrease in reaction time from the four toss sequences to the six toss sequences (9226 msec). Considering the accuracy data (discussed above) it appears that aside from the six toss sequences, the quicker the participants were at responding to the questions, the more accurate the participants were. The decline in reaction time for the six toss sequences implies that the participants used a more algorithmic strategy on the one, two, and four toss sequences and then used a heuristic-like strategy on the six toss sequences.

Stuart-Maxwell Tests

Stuart-Maxwell tests were done for all participants, the high math ability participants, and the low math ability participants. Stuart-Maxwell tests were done to determine if the pattern of responding (correct answer, representativeness heuristic answer, or wrong answer) was different within the two, four, and six toss sequences and between the two, four, and six toss sequences. For the analysis that included all of the participants, $\chi^2(4) = 63.50$, $p < .05$, the participants used a strategy resulting in the correct answer more than the representativeness heuristic or a strategy that resulted in the wrong answer on all sequence lengths. The sequence length that the participants were least likely to use the representativeness heuristic was the six toss sequences. A similar pattern of results was found for the low math ability participants for all toss sequences, $\chi^2(4) = 41.30$, $p < .05$, as found for all the participants. However, the low math ability participants used a strategy resulting in a wrong answer more on the four toss sequences than on any other sequence length. The high math ability participants, $\chi^2(4) = 24.01$, $p < .05$, used a strategy resulting in the correct answer on a higher percentage of trials than any other strategy on all sequence lengths. However, the high math ability participants were wrong or used the representativeness heuristic on the four toss sequences than on any other sequence length.

Summary

In a similar manner to all of the other tasks in this experiment, the difficulty factor appeared to have the largest effect of all of the factors. The most interesting finding of the weighted coin tossing task data was that the participants were most accurate, quickest, and used the representativeness heuristic on the six toss sequences. It was expected that on the most difficult trials participants would be most likely to use the representativeness heuristic. It would appear that the participants found a quick strategy that resulted in the correct answer.

CHAPTER 4

DISCUSSION

Raghubar, Barnes, and Hecht's (2010) review paper on the relationship between working memory and math ability concluded that regardless of the difficulty of the math task, working memory capacity is related to math ability. The current experiment supports this claim by illustrating a positive correlation between working memory capacity and math ability. While the correlation was significant, the correlation did not seem to be very strong ($r=.248$). In order to gain a better understanding of the relationship between math ability and working memory capacity two t-tests were also done. First the participants were split into working memory span groups (based on the median split described in the previous section) and scores on the math subsection of the Wide Range Achievement Test were used as a continuous dependent variable. It was found that the working memory span groups did not differ in terms of math ability. However, when math ability groups were created using a median split, there was a difference between the math ability groups in terms of working memory span. These findings indicate that while math ability and working memory span are related, it is easier to predict someone's working memory capacity when their math ability is known than it is to predict their math ability when their working memory span is known.

For the remainder of the experiment one discussion section the data pertaining to the decision making tasks will be discussed. This will begin with a discussion of how working memory capacity influenced decision making. Therefore, the discussion will focus mainly on performance on the hospital problems task and the career identification task. Next, there will be a discussion on how math ability influenced performance on the decision making tasks, therefore, this part of the discussion will focus on the coin tossing task and the weighted coin tossing task. Also, the data from the exit survey will be introduced and discussed in this section. Because the participants' responses were converted into categorical data, the data consists of comparing percentages and did not seem appropriate for the results section.

Of all of the decision making tasks that were assessed in the current experiment, the career identification task is the task which people seemed to be most susceptible to using the representativeness heuristic. According to our analysis of variance, participants used the representativeness heuristic more often on the difficult career identification problems than they did on the easy problems. While participants' reaction times on the difficult problems were not significantly different than the easy problems [$F(1, 100) = .144$, $p = .705$], the participants were slightly quicker on the easy problems (4031 msec) than the difficult problems (4060 msec). As discussed above, System 1 is in use when someone uses a heuristic because it is a less cognitively demanding and quicker strategy. System 2 usually involves more complex algorithms and therefore is more cognitively demanding and takes more time than a heuristic. The finding that participants were slightly slower on the types of problems that they were more likely to use the representativeness heuristic indicates that the representativeness heuristic may not be a problem solving strategy that utilizes System 1. Instead, the representativeness heuristic may be as, if not more, complex as other strategies that participants utilize.

The self-report data for the career identification task yielded some interesting findings. While it was hypothesized that the low working memory span participants would be more likely to use the representativeness heuristic than the high working memory span participants, more of the high working memory span participants (75%) reported using the representativeness heuristic than the low working memory span participants (60%). While the main effect of working memory span was not found to be significant, $F(1,100) = .101$, $p = .751$, it was found that the high working memory span participants used the representativeness heuristic (54.6%) on more trials than the low working memory span participants (52.7%). It is interesting that the group that used the representativeness heuristic more (high working memory span participants) was quicker on the difficult problems than the easy problems and used the representativeness heuristic more on the difficult than the easy problems. Considering that most difficult problems should demand more resources, the most difficult problems should also demand more attention and take longer to solve. It appears that the among the high working memory span participants the representativeness heuristic is a simpler strategy. This was evidenced by the fact that when the task became more difficult and the high working memory span participants defaulted to the simpler strategy.

The low working memory span participants did not show a similar pattern of responses. The low working memory span participants used the representativeness heuristic more on the difficult problems but were also slower on the difficult problems. Remember, for the career identification task, to use the representativeness heuristic the participant must use the career stereotypes to determine the career of the person. To get the correct answer the participants must ignore the career stereotypes and state the number that is in the question. It appears that the low working memory span participants initially use the number in the question on all trials. On the easy trials, the low working memory span participants were satisfied with the answer that this strategy yields. On the difficult problems, the career stereotypes are so enticing that the low working memory span participants were not satisfied with their initial strategy and instead used the representativeness heuristic. The fact that the low working memory span participants are using two strategies on the difficult problems and only one on the easy problems would explain why they take longer on the trials that they are more likely to use the representativeness heuristic (difficult problems) than when they do not use the representativeness heuristic (easy problems). The high working memory span participants must use the representativeness heuristic to start on all trials and on the trials that contain more stereotypes they are more confident in their answer and respond quicker but are less confident when there are fewer stereotypes and take longer to decide if the representativeness heuristic will result in the correct answer.

According to the exit survey, on the career identification task a lager percentage of the low working memory span participants (24%) reported using a strategy resulting in the correct answer (stating the number that is given in the question) than the high working memory span participants (17%). While not significant, $F(1,100) = .118$, $p = .732$, the low working memory span participants were correct on a higher percentage of trials (26.4%) than the high working memory span participants (23.9%). This seems counterintuitive to the findings of Copeland and Radvansky (2004) that people with a higher working memory capacity could use more complicated strategies than people with a lower working memory capacity. One possible explanation is that the career identification task involves a situation in which the representativeness heuristic requires a more complicated strategy than using a strategy that results in the correct answer. Considering the format of the questions, the correct answer is readily available. If people could not think of a way to solve the problem, then stating the only readily available answer may be simpler than trying to calculate the probability that the person in the description has a particular career. It appears that the high working memory span participants were trying to use the career stereotypes to calculate some sort of answer to the problem while the low working memory span were looking for the simplest answer that did not involve any sort of calculation. If this is the case, it would support the findings of Copeland and Radvansky (2004) and indicate that the career identification task is a situation where the representativeness heuristic is neither the quickest nor simplest readily available strategy. The idea that the representativeness heuristic is a more difficult strategy than answering correctly would explain why both the high and low working memory span groups took longer to respond to the types of problems in which they were more likely to use the representativeness heuristic.

For the career identification task, it was hypothesized that high working memory span participants would be better at ignoring the irrelevant information (career stereotypes) resulting in higher rates of accuracy. Considering that the high working memory span participants were more prone to using the representativeness heuristic than the low working memory span participants, apparently high working memory span participants are not as good as the low working memory span participants at ignoring irrelevant information. However, these questions do seem to have an element of trickery. Considering that the majority of the information in the questions is irrelevant, the participants may have assumed that there would be no reason to ask such a question if the majority of the information was irrelevant. Therefore, the way that people respond to these questions may not be indicative of decision making strategies. However, it is interesting that the high working memory span participants were quicker on the trials that they were more likely to use the representativeness heuristic on while the low working memory span participants were slower on the trials in which they were more likely to use the representativeness heuristic. This would indicate that for the high working memory span participants the representativeness heuristic is a less cognitively demanding process than algorithmic strategies. It appears that the low working memory span participants must initially use a more complicated strategy on all trials but when that strategy does not result in an answer that they are satisfied with they then switch to a different strategy. Apparently, the high working memory span participants are more skilled at quickly finding the strategy they are most satisfied with than the low working memory span participants.

On the hospital problem task both the high and low working memory span groups used the representativeness heuristic more on the difficult problems than on the easy problems. This was confirmed by the Stuart-Maxwell Test. The Stuart-Maxwell test indicated that the high span, $\chi^2(2) = 158.13$, $p < .05$, used the representativeness heuristic on a higher percentage of easy problems than difficult problems but still used the representativeness heuristic more on the difficult problems than any other strategy. The low working memory span, $\chi^2(2) = 169.46$, $p < .05$, used the representativeness heuristic more than any other strategy on the easy problems but used a strategy resulting in the wrong answer, presumably the "law of small numbers" (discussed later), on the difficult problems. Interestingly, the low working memory span participants were quicker on the easy problems than the difficult problems while the high working memory span participants were quicker on the difficult problems than the easy problems. Therefore, the high working memory span participants were quicker on the problems that they used the representativeness heuristic on while the low working memory span participants were slower on the trials in which they used the representativeness heuristic. This is similar to the findings from the career identification task.

These findings can mean one of two things. First, it may mean that the representativeness heuristic is a less cognitively demanding procedure for some people but not for others. Second, it may mean that the representativeness is not always the first strategy that people try. It may be that on all trials the low working memory span participants initially tried to use an algorithm and were able to use an algorithm correctly on the easy problems. However, on the difficult problems the low working memory span participants failed to figure out how to use an algorithm, so they defaulted to the simpler representativeness heuristic. The high working memory span participants may have been able to differentiate the difficult problems from the easy problems and initially tried an algorithm on the easy problems and the representativeness heuristic on the difficult problems. As with the career identification task, it appears that the high working memory span people quickly determine the strategy that they will use and stick with it while low working memory span people will work through several strategies before selecting an answer that they are satisfied with. From this finding, one could assume that working memory span may be related to how confident a person is in their strategy selection.

Working memory span also appeared to affect performance on the weighted coin tossing task. The low working memory span participants were more accurate than the high working memory span participants on the weighted coin tossing task. Even though the main effect of working memory span groups was not significant among the representativeness heuristic data, the high working memory span group (16.2%) used the representativeness heuristic on a higher percentage of trials than the low working memory span group (9.4%), $F(1, 32) = 1.76$, $p = .194$. Also, the high working memory span participants (8846 msec) were marginally significantly faster than the low working memory span participants (10638 msec), $F(1, 32) = 3.70$, $p = .06$, $\eta_p^2 = .104$. As with the career identification task, the participants appeared to find a strategy that was even simpler than the representativeness heuristic. The participants could simply count the heads in each sequence to infer that the sequence that contained more heads was more probable. Again, as Copeland and Radvansky (2004) illustrated, people with higher working memory capacities can use more difficult strategies to solve problems. This "count the heads" strategy and the possible shortcomings of using this strategy will be discussed in more detail in the discussion of differences in performance between the math ability groups.

The current experiment appears to illustrate that the high working memory span participants are quicker on trials in which they are more likely to use the representativeness heuristic and the low working memory span are slower on the trials that they used the representativeness heuristic. While the representativeness heuristic has been thought to be a quicker strategy, it appears that is only the case for the high working memory span participants. It appears that the high working memory span participants are able to quickly discover the strategy that they find most appropriate to solve the problem and only utilize that strategy. The low span participants appear to start with the same strategy on all problems and if the initial strategy that they chose does not result in a desired outcome then they default to an easier strategy, in this case, the representativeness heuristic. This indicates that, when making decisions, people that have a high working memory span are quicker at choosing the strategy that they will use to answer the questions.

For the career identification task, it was hypothesized that there would be differences in performance between the working memory span groups. While there were differences between the working memory span groups, there also appeared to be some differences in performance between the math ability groups. Among the representativeness heuristic data, the problem difficulty by math ability interaction reached marginal significance. Upon inspection of the 95% confidence intervals within this interaction, it became clear that while the high math ability participants' performance on the easy and difficult problems was not significantly different from one another, the low math ability participants used the representativeness heuristic significantly more on the difficult problems (59.5%) than on the easy problems (50.5%).   If the representativeness heuristic is a quicker strategy than the low math ability participants should have quicker reaction times on the difficult problems than on the easy problems. The low math ability participants displayed similar reaction times on the easy and difficult problems and were accurate on a similar percentage of the easy and difficult problems. This implies that among low math ability participants the representativeness heuristic in not a less cognitively demanding strategy.

The main hypothesis for the hospital problems involved the math ability groups. It was hypothesized that the high math ability participants will be more likely to have an understanding of the "law of large numbers" making them more likely to answer these questions accurately than the low math ability participants.   The exit surveys indicated that only fourteen percent of the high math ability participants answered correctly (in accordance with the "law of large numbers") while sixteen percent of the low math ability participants stated in the exit interview that they answered correctly. Fifty-one percent of the high math ability participants stated in the exit interview that they used the representativeness heuristic while only thirty-seven percent of the low math ability participants stated that they used the representativeness heuristic. While the high math ability participants were more likely to use the representativeness heuristic, the low math ability participants seemed to utilize a different strategy that resulted in the wrong answer.

Forty-four percent of the low math ability participants claimed to use a strategy in which they identified the scenario that had a larger sample and selected that scenario. This "law of small numbers[1]" strategy was used by only twenty-seven percent of the high math ability participants. This was confirmed by the Stuart-Maxwell test (discussed above). The Stuart-Maxwell test indicated that while the high math ability participants used the representativeness heuristic on the majority of both the easy and difficult problems, the low math ability group used the representativeness heuristic more on the easy problems but chose the larger sample more often on the difficult problems. This indicates that the low math ability participants switched from using the representativeness heuristic on the easy problems to using the "law of small numbers" strategy on the difficult problems. Apparently, even though the high math ability participants were

[1] This strategy was coined the Law of Small Numbers because the Law of Large Numbers points out that the larger the sample the more representative it is of the population while the low math ability participants appear to think that the smaller the sample the more representative it is of the population.

more likely to use the representativeness heuristic than the low math ability participants, the high math ability participants still had a better understanding of probability theory than the low math ability participants.

The current experiment illustrated that math ability influences performance on the coin tossing task. It appears that the difficulty of the problems influenced the high math ability participants and the low math ability participants differently. The data indicated that as the number of coin tosses in a sequence increased, the low math ability participants' reaction time increased more than the high math ability participants. This indicates that the difficulty variable influenced performance for the low math ability participants more than for the high math ability participants. While both the low and high math ability groups were accurate on this task, the reaction time data implies that the high math ability participants' cognitive processes remained consistent across levels of difficulty while the low math ability participants' cognitive processes were contingent on the level of difficulty of the task.

Again, the participants seemed to be extremely accurate on the coin tossing task. According to the exit survey data, more of the low math ability participants (83%) claimed to use the correct strategy than the high math ability participants (76%). Also, a higher percentage of the high math ability participants (18%) claimed to use the representativeness heuristic than the low math ability participants (13%). This confirmed the Stuart-Maxwell test findings (described above) that the low math ability participants used a strategy resulting in the correct answer more than the high math ability participants. Considering that knowing how to calculate the correct answer to the coin flip sequences requires an understanding of probability (a topic that people that are better at math should be more familiar with), the high math ability participants should have been more likely to use the correct strategy than the low math ability participants. The fact that low math ability participants were more accurate than high math ability participants may indicate that participants were using a strategy that results in the correct answer other than calculating the probability of each sequence.

Initially, the weighted coin tossing task was created to be a more math intensive task than the coin tossing task. It was hypothesized that to answer correctly students would need to calculate the probability of each sequence. For the six toss sequences, the participants would need to multiply six fractions together in order to calculate the probability of each sequence. Even for people that have an extremely high level of math ability, this could be a fairly daunting task. Since there was such a high accuracy rate on the six toss sequences of the weighted coin tossing task, the participants must have been using a strategy other than calculating the probability of each sequence. Upon analysis of the exit survey data it became evident that the alternative strategy involved participants counting the number of heads in each sequence and responding with the sequence that contained more heads. A higher percentage of high math ability participants claimed to use this "count the heads" strategy (78%) than low math ability participants (67%). It appears that as math ability increases so does the ability to find an alternate algorithm that results in a correct response. Also, more high working memory span participants (76%) claimed to use the "count the heads" strategy than the low working memory span participants (68%). This indicates that as working memory capacity increases, so does the ability to find an alternate algorithm which results in a correct response. Combining this finding with Copeland and Radvansky's (2004) finding, it appears that not only does having a higher working memory span allow people to use a more complicated strategy to solve a problem but it also allows them to develop an alternative strategy that results in accurate responses.

It appears that math ability has a large influence on making decisions. While people that are better at math used the representativeness heuristic more often on the hospital problems task, the high math ability participants did appear to have a better understanding of probabilities than low math ability participants. Also, according to the exit survey data for the weighted coin tossing task, it appears that high math ability participants are more likely to find an alternative strategy that results in accurate responses. Apparently math ability not only influences a person's ability to make calculations but it also influences strategy selection and knowledge base that aids in estimating probabilities to make decisions.

It is interesting that the participants found a more accurate strategy ("count the heads") than the representativeness heuristic that is simpler than the algorithmic strategy. As discussed earlier, there was some evidence that when the representativeness heuristic is used it is not the initial strategy that was used. Considering that on the problems in experiment one the "count the heads" strategy resulted in a correct answer, it would be interesting to see if participants would take longer and respond with answers consistent with using the representativeness heuristic on problems in which the "count the heads" strategy did not result in a definitive answer. If participants took longer and were more likely to use the representativeness heuristic on problems in which the "count the heads" strategy did not work then there would be evidence that the representativeness heuristic is not a strategy that participants use from the onset of the task but is instead more of a contingency plan if other strategies to find the answer fail.

A major flaw of the current experiment was that a large percentage of the participants that did not meet the criterion to have their data used in the study would have been classified as low math ability. Remember, if the participants did not answer eighty-five percent of the math problems on the operation span task correctly they were removed from the analyses. This is standard operating procedure in working memory studies (i.e., Unsworth, et al., 2005). In the current study, thirteen participants were removed from the study for not achieving a minimum score of eighty-five percent on the processing portion of the operation span task. Of the thirteen participants that were removed, ten of them earned scores on the math subsection of the Wide Range Achievement Test that would have placed them in the low math ability group (according to the above mentioned median split criteria). One would think that if the low math ability participants that did poorly on the OSPAN were removed from the analysis that there would be no differences between the math ability groups in terms of working memory span. Despite a substantial portion of the low math ability participants being removed from the analysis, the high math ability group had significantly higher working memory spans than the low math ability participants. This indicates just how much the math ability groups differed in working memory span. However, the math ability variable may have interacted differently with other variables on the decision making tasks had more of the low math ability participants qualified for the study. In the future, not using the eighty-five percentage cut-off should be used in studies that are analyzing the effect of math ability because the cut-off dilutes the effect by removing many of the low math ability participants from the study.

The data from the career identification task and the hospital problems indicated that people with a high working memory span and high math ability were more likely to use the representativeness heuristic. This may have more to do with the questions than the participants' working memory span and/or math ability. For the career identification task, the participants may have been confused due to the task consisting of "trick questions". To answer the questions correctly the participants needed to ignore the information in the character sketch and reply using basic probability knowledge. This makes the entire character sketch useless when solving the problem. There is a chance that participants have basic probability knowledge but assumed that the entire purpose of the character sketch was to use the information available to make a probability judgment. Fichhoff and Bar-Hillel (1984) surmised that utilizing all of the information in a problem is an automatic problem solving strategy. To answer the career identification task problems, participants must suppress an almost reflexive behavior. The career identification problems appear to be trick questions because these questions are testing a participant's ability to suppress a reflexive behavior and not their ability to make a decision. Because the problems were trick questions, it is difficult to claim that this task is a decision making task and therefore makes it difficult to make claims about decision making strategies from this task.

For people to answer the hospital problems correctly they must have a basic understanding of the law of large numbers. Considering the large percentage of low working memory span participants that stated in the exit interview that they responded with the scenario that involved the larger sample, it appears that the low working memory span participants did not have the knowledge that was needed to answer these problems correctly. Therefore, the hospital problems and the career identification task did not seem to provoke the cognitive processes that are indicative of making decisions but instead seem to either trick the participants or are above the ability levels of many of the people that participated in this experiment.

While the career identification task and the hospital problems did not appear to be decision making tasks, both of the coin tossing tasks did seem elicit decision making strategies in participants. Even though the coin tossing and the weighted coin tossing task elicited decision making strategies in participants, the participants did not use the representativeness heuristic as much as anticipated. It may be that the task was too simple. Kahneman and Tversky (1972) stated that among all possible sequences of six coin tosses only H T T H T H (and, presumably, it's opposite: T H H T H T) appear really random. They also discussed that sequences of fewer than six tosses may not appear random at all. If the tosses did not appear to be random then participants would be less likely to use the representativeness heuristic and instead use a different strategy (i.e., the "count the heads strategy") that many participants claimed to use on the weighted coin tossing task. Therefore, the differences in representativeness heuristic usage between the math ability groups from the coin tossing task and the weighted coin tossing task may not have been clear because the coin tossing sequences in the experiment may not have appeared random enough. Experiment 2 takes this into account and uses sequences of six, eight, ten, and twelve coin tosses per sequence in both the coin tossing task and the weighted coin tossing task.

As discussed above, on the weighted coin toss task, many of the participants admitted to using a "count the heads" strategy. In the first experiment, all of the trials in the weighted coin tossing task had one sequence that had more heads than the other sequence. In the next experiment, in both the coin tossing task and the weighted coin tossing task, half of the trials had both sequences with the same number of heads while the other half of the trials consisted of two sequences that did not have the same number of heads as one another. This was done to determine which strategy a person would use when the "count the heads" did not result in a definitive answer. It was hypothesized that there will be longer reaction times and higher usage of the representativeness heuristic when the trials have the same number of heads in each sequence than when the trials do not have the same number of heads in each sequence. If this is the case, there will be evidence that the representativeness heuristic is used when participants have attempted other strategies that did not work and then defaulted to a strategy that gives them a reasonably correct answer.

CHAPTER 5

EXPERIMENT 2

The participants in experiment one stated that they were using a strategy other than a computational strategy or the representativeness heuristic to respond to the questions in the weighted coin tossing task. This strategy entailed participants counting the number of heads in each sequence and then selecting the sequence that contained more heads. Therefore, this strategy was dubbed the "count the heads" strategy. The purpose of Experiment 2 is to assess what the participants would do when the "count the heads" strategy no longer resulted in a definitive answer. For Experiment 2, the coin tossing task and the weighted coin tossing task were manipulated to analyze what strategy would be used if the "count the heads" did not result in a definitive answer. Because the dual task paradigm did not seem to have an effect in experiment one, it was not used in experiment two.

CHAPTER 6

METHODS

Participants

The participants were recruited from the University of Nevada, Las Vegas (UNLV) using the Psychology Department's subject pool. Forty participants were tested in this experiment. The mean age of the participants was 20.28. Nine of the participants were male and the remaining thirty-one were female. Seven of the participants identified themselves as African-American, six identified as Hispanic/Latino, nine identified themselves as Asian/Pacific Islander, while the remaining eighteen identified themselves as Caucasian.

Materials and Procedure

Participants responded to a (11-item) subject information sheet that asked them for demographic information as well as questions about their previous math experience. The participants also participated in the Operation Span Task (discussed earlier; Turner & Engle, 1989), the math subsection of the Wide Range Achievement Test (WRAT), and two blocks of trials in which the participants were asked to judge which sequence of coin tosses was more probable.

Subject Information Sheet

The subject information sheet asked participants various questions about their background such as: age, gender, number of math classes taken in high school and college, their grades for both their high school and college math courses, what types of math classes they have taken, their college rank, and their ethnicity. The questions were the same as Experiment 1. To keep the time of the experiment under an hour, in the current experiment the subject information questionnaire was presented on the computer instead of a paper-pencil format, as in experiment one.

Operation Span Task

The Operation Span Task is the same as described in Experiment 1 and was used to separate the participants into either the low or high working memory span group. The were two differences between the Operation Span Task in Experiment 1 and the Operation Span Task in Experiment 2. The first was that in Experiment 2 participants that did not correctly answer at least 85% of the math questions were not removed from the analysis. The reason that this criterion was not used was to ensure that a large percent of the low math ability participants were not removed from the analysis. The second difference was that the highest possible score on the word recall task was sixty in Experiment 2 while it was sixty-six in Experiment 1.

WRAT

In Experiment 1, the math subsection of the Wide Range Achievement Test 4th Ed. was used. In the current experiment the math subsection of the Wide Range Achievement Test 3rd Ed. was used. The tests have the same number of questions (40) but the third edition seems to have more difficult problems than the fourth edition. Hopefully, a more difficult test will differentiate the math ability groups better.

Weighted Coin Tossing Task

The weighted coin tossing task had the same format as in Experiment 1. There are two differences between the weighted coin tossing task in Experiment 1 and in Experiment 2. First, in Experiment 1, the participants saw four questions: one involving two sequences with one toss per sequence, one with two tosses per sequence, one with four tosses per sequence and one with six tosses per sequence. In the current experiment, the participants saw four questions but one contained six tosses per sequence, one contained eight tosses per sequence, one with ten tosses per sequence, and one contained twelve tosses per sequence. As discussed in the discussion section of the previous experiment, the reason that there are more tosses per sequence is that Kahneman and Tversky (1972) noted that coin toss sequences that involve fewer than six tosses cannot appear random. Therefore, if there are fewer than six tosses in a sequence then it is unlikely that participants will use the representativeness heuristic. The second difference between the weighted coin tossing task in the current experiment and the weighted coin tossing task in Experiment 1 is that in Experiment 2 half of the trials involved two sequences that has the same number of heads in each sequence (even) while the other half of the trials involved two sequences that did not have the same number of heads in each sequence (uneven; see Appendix F for an example of an even and an uneven trial). The trials that involved eight or twelve tosses in a sequence had an equal proportion of heads in each sequence while the trials that involved six or ten tosses in a sequence did not have the same number of heads in each sequence. As stated in the discussion section from experiment one, many of the participants claimed to use the "count the heads" strategy. The purpose of manipulating the congruency of the number of heads in each trial was to see what strategy the participants would use when the "count the heads" strategy does not result in a definitive answer.

In this task, on the even trials, the correct answer was the option labeled equal, the representativeness heuristic answer was the option that appeared representative of the overall population of events, and the wrong answer was the remaining option. For the uneven trials, the correct answer was the option that had the greater probability after doing the calculation described in Experiment 1, the representativeness heuristic answer was the option that seemed representative of the overall population of events, and the wrong answer was the option labeled equal.

Coin Tossing Task

The coin tossing task is similar to Experiment 1. Just as the weighted coin tossing task was changed from Experiment 1 to Experiment 2, the coin tossing task was changed in the same manner. Instead of there being one trial with one, one trial with two, one trial with four, and one trial with six tosses per sequence, there was one trial with six, one trial with eight, one trial with ten, and one trial with twelve tosses per sequence. Also, half of the trials consisted of the options having the same number of heads in each sequence while the other half consisted of options that have a different number of heads in each sequence. In the coin tossing task the trials that had six or twelve tosses in a sequence had the same proportion of heads in each sequence while the trials with eight or ten tosses in a sequence did not have the same proportion of heads in each sequence. The reasoning for this manipulation is the same as discussed above for the weighted coin tossing task. In this task, the correct answer is the option labeled equal, the representativeness heuristic answer was the option that seemed representative of the overall population of events, and the wrong answer was the option in which the heads and the tails were grouped together. See Appendix G for examples of these problems.

CHAPTER 8

RESULTS

As in Experiment 1, there was a significant positive correlation between working memory capacity and math ability, $r(40) = .393$, $p < .05$. The correlation indicates that as scores on the math subsection of the Wide Range Achievement Test increased, scores on the Operation Span Task also increased. Also, as in Experiment 1, participants were grouped based on their performance on the math subsection of the Wide Range Achievement Test and their scores on the Operation Span task. For the math subsection of the Wide Range Achievement Test, the median of the participants' scores was 29.5. Participants that scored twenty-nine or below were place in the low math ability group while participants that scored thirty or above were placed in the high math ability group. For the Operation Span task the median of the participants' scores was forty-five. The participants that earned a score of forty-five or above were place in the high working memory span group while the participants that earned a score of forty-four or below were placed in the low working memory span group. Considering there was a significant correlation between working memory span and math ability, it was of interest to see if the math ability groups differed in terms of working memory capacity and if the working memory span groups differed in terms of math ability. As in Experiment 1, there was a difference between the math ability groups in terms of their operation span scores, $t(38) = -3.56$, $p < .05$, such that the high math ability participants (48.1 words recalled correctly) scored higher on the operation span task than the low math ability participants (41 words recalled correctly). Unlike Experiment 1, there was a difference between the working memory span groups in terms of their scores on the math subsection of the Wide Range

Achievement Test, , $t(38) = -3.37$, $p < .05$, such that the high working memory span participant (31.81) answered more items correctly than the low working memory span participants (27).

Coin Tossing Task

In the coin tossing task, each participant was presented with four coin tossing questions; one that involved six tosses per sequence, one that involved eight tosses per sequence, one that involved ten tosses per sequence, and one that involved twelve tosses per sequence. Each stimulus gave them three options for possible outcomes. Each trial consisted of one correct answer ("Equal"), one answer that seems representative of the overall population of events (e.g. "H T H H T H T T"), and one wrong answer (e.g. "H H H H T T T T"). For this task, a separate 2 (math ability group) x 2 (working memory span group) x 4 (number of tosses in a sequence) mixed model analysis of variance was calculated with the dependent variables accuracy, responses consistent with the representativeness heuristic, and reaction time. Also, a separate 2 (math ability group) x 2 (working memory span group) x 2 (proportion of heads in a sequence: even or different number of heads in a sequence) mixed model analysis of variance was calculated with the dependent variables accuracy, responses consistent with the representativeness heuristic, and reaction time. Stuart-Maxwell tests for homogeneity of marginal distributions were calculated. Stuart-Maxwell tests can be thought of as a within-subjects chi square. These were calculated to see if the participants were using different types of responses within each difficulty level and between each difficulty level. See Tables 17, 18,19, 20, 21, and 22 for a breakdown of participants' responses.

Analysis of Variance

Accuracy

The main effect of math ability group reached significance, $F(1,36) = 5.18$, $p < .05$, $\eta_p^2 = .126$. The high math ability participants (52.3%) were more accurate at the coin tossing task than the low math ability participants (21.7%). Considering the drastic differences in performance between the math ability groups on this task, math ability appears to influence participants' performance on the coin tossing task.

Representativeness Heuristic

The main effect of math ability reached significance, $F(1,36) = 3.98$, $p = .05$, $\eta_p^2 = .100$. This main effect indicates that the low math ability participants (71.7%) used the representativeness heuristic more often than the high math ability participants (43.8%). The main effect of working memory span reached marginal significance, $F(1, 36) = 3.085$, $p = .088$, $\eta_p^2 =.079$. The high working memory span participants used the representativeness heuristic (70%) more often than the low working memory span participants (45.4%). While both math ability and working memory span influenced how often people used the representativeness heuristic on this task, it appears that math ability had a larger influence. It is also interesting that being better at math makes people less likely to use the representativeness heuristic but having a higher working memory span makes people more likely to use the representativeness heuristic.

It was of interest that the number of coin tosses in a sequence did not reach significance. As stated earlier, because participants from Experiment 1 claimed to use the "count the heads" strategy, half of the questions would involve sequences that had the same number of heads in a sequence and half involved sequences that had a different number of heads in a sequence. While, among the representativeness heuristic data, the number of tosses in a sequence did not reach significance, $F(3, 108) = 1.44$, $p = .234$, $\eta_p^2 =.039$, there was a marginally significant difference in performance between the trials that had the same number of heads in each sequence and the trials that had a different number of heads in each sequence. The participants used the representativeness heuristic more on the trials that had a different number of heads in each sequence (64.9%) than on the trials that had the same number of heads in each sequence (50.5%), $F(1, 36) = 3.88$, $p = .057$, $\eta_p^2 =.097$. This is the exact opposite of what was expected. It appears that the "count the heads" strategy was not used on the coin tossing task.

Reaction Time

For the coin tossing task, outliers were removed from each condition in the 2 (Math Ability: High or low) x 2 (Working Memory Group: Low or High) x 4 (Coin Tosses: 6, 8, 10, and 12) factorial design. Scores were considered to be outliers if they were two and a half standard deviations above or below the mean. Also, if a reaction time fell below 250 msec it was considered a microphone error and treated as an outlier. In each condition, the outliers were replaced with the mean of that condition from the math ability group from which the outlier was found. See Table 23 for a breakdown of the outliers.

Within the reaction time data the number of tosses by working memory span groups interaction reached marginal significance, $F(3, 108) = 2.55$, $p = .06$, $\eta_p^2 =.066$, see Figure 6. In this interaction the high working memory span participants increased in a nearly linear pattern from the six toss sequences (5592 msec) through the eight toss sequences (6012 msec) to the ten toss sequences (6740 msec). The high working memory span participants were quicker on the on the twelve toss trials (5871 msec) than the ten toss trials. The low working memory span participants' reaction time did not have a distinctive pattern. The low working memory span participants increased in reaction time from the six toss sequences (6109 msec) to the eight toss trials (7167 msec) and then were quicker on the ten toss sequences (5608 msec). Finally the low working memory span participants took longer on the twelve toss sequences (8277 msec) than the ten toss sequences. The high working memory span participants reaction times are indicative of using an algorithm for the six, eight, and ten toss sequences and then using a heuristic for the twelve toss sequences, the low working memory span participants do not seem to be using a consistent strategy across trials.

Stuart-Maxwell Tests

Stuart-Maxwell tests were done to determine if the pattern of responding (correct answer, representativeness heuristic answer, or wrong answer) was different within the six, eight, ten, and twelve toss sequences and between the six, eight, ten, and twelve toss sequences. The Stuart-Maxwell test that included all of the participants, $\chi^2(2) = 56.78$, $p < .05$, indicated that there is not marginal homogeneity between participant's responses on the six, eight, ten, and twelve toss sequences. The source of this difference appears to be that the participants used the representativeness heuristic more than any other type of strategy on the eight ten and twelve toss sequences and used representativeness heuristic or a strategy that resulted in the correct answer equally on the six toss sequences.

The low math ability participants, $\chi^2(2) = 26.99$, $p < .05$, showed similar patterns of results. There were two main differences between the low math ability participants and the overall sample of participants. The first was that the low math ability participants used the representativeness heuristic more than a strategy resulting in the correct answer on the six toss sequences. The second difference was that the discrepancy between the number of times representativeness heuristic was used and the number of times a strategy resulting in the correct answer was used on the twelve toss sequences was larger for the low math ability participants than when all the participants were involved in the analysis. The high math ability participants, $\chi^2(2) = 34.38$, $p < .05$, showed a different pattern of results. On the six and twelve toss sequences, the high math ability participants were correct more than using the representativeness heuristic while on the eight and ten toss sequences the high math ability participants used the representativeness heuristic more than they used a strategy resulting in the correct answer. It appears that the data for the high math ability participants supports the marginally significant main effect for the proportion of heads among the accuracy data.

It was of interest to see if the participants used different strategies on the problems that had the same number of heads in a sequence and the problems that had more heads in one sequence than the other sequence. When all of the participants were in the analysis, χ^2 $(2) = 12.05$, $p < .05$, on both the trials that had the same number of heads in a sequence and the trials when one sequence had more heads in a sequence than the other, participants used the representativeness heuristic more than any other strategy. However, it appears that people used the representativeness heuristic more on the trials in which there were more heads in one sequence than the other. The low math ability participants, χ^2 $(2) = 12.58$, $p < .05$, used the representativeness heuristic more on both types of trials while the high math ability participants, χ^2 $(2) = 2.03$, $p > .05$, *NS*, used the representativeness heuristic more on the trials in which there was an unequal proportion of heads in the sequences, but were correct more often than used the representativeness heuristic on the trials that had an equal proportion of heads in each sequence.

Summary

Math ability had a large influence on performance on the coin tossing task. The high math ability participants were more accurate and used the representativeness heuristic less than the low math ability participants. It was interesting that the Stuart-Maxwell test indicated that the low math ability participants used the representativeness heuristic more on all types of problems while the high math ability participants seemed to use the representativeness heuristic more on the trials with an unequal proportion of heads in the sequences and a strategy resulting in the correct answer more on the trials that had an equal proportion of heads in the sequences. While math ability appeared to influence the strategy that people used, math ability did not appear to influence how long it took for participants to solve the problems.

Weighted Coin Tossing Task

As in the coin tossing task, in the weighted coin tossing task each participant was presented with four coin tossing questions; one that involved six tosses per sequence, one that involved eight tosses per sequence, one that involved ten tosses per sequence and one that involved twelve tosses per sequence. For the trials in which the proportion of heads was the same in both sequences, the option that consisted of the word "Equal" was the correct answer, the option that consisted of the heads and tails grouped together (i.e., H H H T T T) was considered the wrong answer, and the option that looked random (i.e., H T T H T H) was considered indicative of the participant using the representativeness heuristic. For the trials in which one sequence had a higher proportion of heads than the other sequence, the option that looked random (i.e., H T T H T H) was considered indicative of the participant using the representativeness heuristic, the option that consisted of the heads and tails grouped together (i.e., H H H H T T) was considered the correct answer, and the option with the word "Equal" was the considered the wrong answer. On the weighted coin tossing task, on each trial the participants were told that the coin was weighted so that sixty percent of the time it would land on heads and forty percent of the time it would land on tails. For this task, a separate 2 (math ability group) x 2 (working memory span group) x 4 (number of tosses in a sequence) mixed model analysis of variance was calculated with the dependent variables accuracy, responses consistent with the representativeness heuristic, and reaction time. Also, a separate 2 (math ability group) x 2 (working memory span group) x 2 (proportion of heads in a sequence) mixed model analysis of variance was calculated with the dependent variables accuracy, responses consistent with the representativeness heuristic, and reaction time. Stuart-Maxwell tests for homogeneity of marginal distributions were calculated. Stuart-Maxwell tests can be thought of as a within-subjects chi square. These were calculated to see if the participants were using different types of responses within each difficulty level and between each difficulty level. See Tables 24, 25, 26, 27, 28, and 29 for a breakdown of participants' responses.

Analysis of Variance

Accuracy

There was a significant main effect for number of tosses in a sequence, $F(3, 108) = 9.28$, $p < .05$, $\eta_p^2 = .205$. The participants were more accurate on the six (79%) and ten (68%) toss trials than on the eight (43%) and twelve (27%) toss trials. On the eight and twelve toss trials there were the same number of heads in each sequence in the trials while there was a different number of heads in each sequence on the six and ten toss trials. When the data was collapsed such that the accuracy on the six and ten toss trials were combined and the accuracy on the eight and twelve toss trials were combined there was a significant main effect for proportion of heads between sequences, $F(1, 36) = 21.59$, $p < .05$, $\eta_p^2 = .375$. This main effect indicated that the participants were more accurate on the trials in which one sequence had a higher proportion of heads than the other (73.3%) than on the trials in which both sequences had the same number of heads (35.3%). The main effect of proportion of heads in a sequence implies that when the count the heads strategy did not work (on the sequences with equal proportions of heads) they were less accurate than on the trials in which the "count the heads" strategy did result in a definitive answer (trials with uneven proportions of heads in a sequence).

Representativeness Heuristic

There was a marginally significant main effect for number of tosses in a sequence, $F(3, 108) = 2.67$, $p = .05$, $\eta_p^2 = .068$. The participants used the representativeness on 19%, 35%, 31%, and 49% of the six, eight, ten, and twelve toss sequences, respectively. For the analysis involving the proportion of heads per sequence, the participants used the representativeness heuristic more on the trials in which there were the same number of heads in each sequence (42%) than on the trials in which there was a different number of heads in each sequence (25%), $F(1, 36) = 6.15$, $p < .05$, $\eta_p^2 = .146$. This indicates that on the weighted coin tossing task, participants relied more on a heuristic when counting the number of heads in a sequence did not result in a definitive answer than when it did result in a definitive answer. There was also a marginally significant interaction between the math ability groups and whether there was the same number of heads in each sequence, $F(1, 36) = 3.16$, $p = .08$ $\eta_p^2 = .081$. According to the 95% confidence intervals the low math ability participants used the representativeness heuristic more on the problems that had the same number of heads in a sequence (55%) than on the trials that had a different number of heads in each sequence (27%). However, according to the 95% confidence intervals the high math ability participants used the representativeness heuristic roughly the same percentage of trials that had the same number of heads per sequence (28%) as they did on the trials that had a different number of heads in each sequence (23%). This implies that the high math ability participants used the same strategy on all trials and the low math ability participants used the representativeness heuristic on the trials that the count the heads strategy did not result in a definitive answer while they used the count the heads strategy on trials in which the "count the heads" strategy resulted in a definitive answer.

Reaction Time

As with the coin tossing task, for the weighted coin tossing task, outliers were removed from each condition in the 2 (Math Ability: High or low) x 2 (Working Memory Group: Low or High) x 4 (Coin Tosses: 6, 8, 10, and 12) factorial design. Scores were considered to be outliers if they were two and a half standard deviations above or below the mean. Also, if a reaction time fell below 250 msec it was considered a microphone error and treated as an outlier. In each condition, the outliers were replaced with the mean of that condition from the math ability group from which the outlier was found. See table 24 for a breakdown of the outliers.

There was a significant main effect for number of tosses in a sequence, $F(3, 108) = 8.03$, $p < .05$, $\eta_p^2 = .182$. The participants were quicker on the six (9196 msec) and ten (9747 msec) toss sequences than on the eight (13303 msec) and twelve (14150 msec) toss sequences. This main effect is explained by the main effect of proportion of heads in a sequence (see below). There was also a marginally significant number of tosses per sequence by math ability group by working memory span interaction, $F(3, 108) = 8.03$, $p = .059$, $\eta_p^2 = .066$ (see Figure 7a and 7b). This interaction appears to reach marginal significance due to the strong main effect of the proportion of heads in a sequence.

For the analysis consisting of the proportion of heads factor, there was a main effect of the proportion of heads in a sequence, $F(1, 36) = 23.42$, $p < .05$, $\eta_p^2 = .394$. The participants were quicker on the trials that had a different number of heads in each sequence (9471 msec) than the trials that had the same number of heads per sequence (13726 msec). This supports the hypothesis that participants tried the count the heads strategy but when that did not result in a definitive answer a different strategy was then used.

There was also a significant math ability group by working memory span group by proportion of heads per sequence interaction, $F(1, 36) = 5.51$, $p < .05$, $\eta_p^2 = .133$, see Figures 8a and 8b. For the low math ability participants, neither the high nor low working memory span participants appear on the uneven problems than the even problems. For the high math ability participants, while the high working memory span participants recorded similar reaction times on both the even and uneven problems, the low working memory span participants were quicker on the uneven problems than on the even problems. Therefore, as problems increase in difficulty, working memory span appears to affect performance for the high math ability participants but not the low math ability participants.

Stuart-Maxwell Tests

Stuart-Maxwell tests were done to determine if the pattern of responding (correct answer, representativeness heuristic answer, or wrong answer) was different within the two, four, and six toss sequences and between the six, eight, ten, and twelve toss sequences. The Stuart-Maxwell test that included all of the participants, $\chi^2(2) = 53.45$, $p < .05$, indicated that the participants used a strategy resulting in the correct answer more than the representativeness heuristic on the six and ten toss sequences but used the representativeness heuristic more than a strategy resulting in the correct answer on the eight and twelve toss sequences. This same pattern was found for the low math ability participants, $\chi^2(2) = 26.23$, $p < .05$, and the high math ability participants, $\chi^2(2) = 28.03$, $p < .05$.

The Stuart-Maxwell tests were also done comparing the trials that had the same number of heads in each sequence to the trials that had a different number of heads in each sequence. When all the participants were involved in the analysis, $\chi^2(2) = 24.47$, $p < .05$, the participants used the representativeness heuristic more on the trials that had the same number of heads in each sequence but used a strategy resulting in the correct answer more on the trials that had more heads in one sequence than the other. The discrepancy between using a strategy resulting in the correct answer and using the representativeness heuristic was larger on the problems in which there were more heads in one sequence than the other than in the trials in which there were the same number of heads in each sequence. The patterns for the low math ability patterns, $\chi^2(2) = 11.26$, $p <$

.05, were nearly identical. However, there were very different patterns for the high math ability participants. The high math ability participants, $\chi^2(2) = 13.9$, $p < .05$, used a strategy resulting in the correct answer more than the representativeness heuristic on both types of problems. The discrepancy between the percentage of trials that the high math ability participants used the representativeness heuristic and the percentage of trials that they were correct was larger on the uneven trials than on the even trials. However, the high math ability participants illustrated that they have a strong understanding of probability theory and use this understanding to answer the problems correctly, regardless of the difficulty of the problem.

Summary

The overall sample participants used the representativeness heuristic more on the problems that had the same number of heads in a sequence than on the problems in which one sequence had more heads than the other sequence. While the low math ability participants used the representativeness heuristic more on the trials with the same number of heads in each sequence than on the trials that had more heads in one sequence than another, the high math ability participants used a strategy resulting in the correct answer than any other strategy regardless of whether the sequences had the same number of heads or not. This appears to mean that when the low math ability participants could not use the “count the heads” strategy that they were likely to default to the representativeness heuristic. However, when the “count the heads” strategy did not work for the high math ability participants they used a different strategy that resulted in the correct answer.

CHAPTER 9

DISCUSSION

There were two main purposes of Experiment 2. The first is to see if there would be math ability effects if the coin toss sequences appeared more random than they did in Experiment 1. The second was to see how participants would react if the "count the heads" strategy no longer resulted in a definitive answer. On the coin tossing task, the high math ability participants were more accurate than the low math ability participants. Also, the low math ability participants answered with responses in line with usage of the representativeness heuristic more often than the high math ability participants. Considering that the coin toss sequences looked more random in Experiment 2 than in Experiment 1, it appears that the randomness of the sequences induced the effects that we had originally predicted, that the high math ability participants would be more accurate and less likely to use the representativeness heuristic than the low math ability participants.

Also, on the coin tossing task participants used the representativeness heuristic more on the trials that had a different number of heads in each sequence than on the trials that had the same number of heads in each sequence. It was hypothesized that if participants were using the "count the heads" strategy that they would default to the representativeness heuristic on the trials that had the same number of heads in each trial because the "count the heads" strategy would not result in a definitive answer. Therefore, it appears that participants were not using the count the heads strategy on the coin tossing task.

The weighted coin tossing task was originally thought to be more math intensive than the coin tossing task. However, Experiment 1 illustrated that the participants were using the “count the heads” strategy to arrive at a correct answer. This “count the heads” strategy is simpler than calculating the probability of each sequence. On the weighted coin tossing task in Experiment 2 it was found that the participants used the representativeness heuristic more on the trials that had the same number of heads in each sequence than on the trials that had a different number of heads in each sequence. Also, participants took longer on the trials that had the same number of heads in each sequence than on the trials that had a different number of heads in each sequence. These findings imply that participants initially tried to use the “count the heads” strategy and then defaulted to the representativeness heuristic when the “count the heads” strategy did not result in a definitive answer.

In the representativeness heuristic data, there was also a math ability by proportion of heads in a sequence interaction. This interaction indicated that the source of the main effect of the proportion of heads factor could be found among the low math ability group data. The low math ability participants used the representativeness heuristic more on the trials that had the same number of heads in a sequence compared to the trials that had a different number of heads in a sequence, while the high math ability participants used the representativeness heuristic in both types of trials roughly the same percentage of times. In fact, the interpretation of the Stuart-Maxwell test pointed out that the high math ability used a strategy resulting in the correct answer more regardless of the proportion of heads in a sequence while the low math ability participants used the representativeness heuristic more often when there were the same number of heads in each sequence but appeared to use the “count the heads” strategy on the problems in which one sequence had more heads than the other. Because the high math ability participants seemed to use the same strategy consistently across trials and because they were more accurate, the high math ability participants seem to have a better understanding of probability theory than the low math ability participants, resulting in high math ability participants making better decisions than low math ability participants.

The participants’ performance on the coin tossing task clearly indicates that people that are better at math have a better understanding of probability theory. The weighted coin tossing task presented participants with a situation in which the basic probability knowledge needed is readily available. The calculation that is needed to utilize this knowledge was fairly daunting, therefore, the participants found an easier strategy (“count the heads”) to arrive at the correct answer. When this strategy did not differentiate the sequences, the low math ability participants defaulted to using representativeness heuristic while the high math ability participants continued to get the majority of the questions correct. This implies that when people do not have the skill set to arrive at an answer the representativeness heuristic is utilized in a similar fashion to the Take the Best heuristic. As stated earlier, when using the Take the Best heuristic people rank strategies to find an answer in terms of ecological validity and then use each strategy in turn until a definitive answer is found. The results from Experiment 2 imply that the representativeness heuristic is deemed to have low ecological validity and is only used when all other possible strategies fail to result in a definitive answer.

CHAPTER 10

GENERAL DISCUSSION

The premise of the current study was to see if math ability and working memory span influence a person's ability to make decisions. The decision making tasks were based on Kahneman and Tversky's research (Tversky & Kahneman, 1974; Kahneman & Tversky, 1972, & 1973). The logic behind the premise was that people that are good at math have a better understanding of probability theory. This better understanding of probability theory gives people that are good at math the ability to determine which outcomes are more likely, resulting in people that are good at math being better at making decisions than people that are bad at math. Also, people that have a higher working memory capacity are less distracted by irrelevant information and should, therefore, be better at focusing on the information necessary to make correct decisions than people with a lower working memory capacity.

In Experiment 1, participants were extremely accurate on both the coin tossing task and the weighted coin tossing task. It was surmised that participants were accurate because coin tossing sequences of six or fewer cannot appear random enough to trigger participants to use the representativeness heuristic. This was taken into account in Experiment 2 and the sequences were not only longer but precautions were taken to make them appear more random than they appeared in Experiment 1. Experiment 1 also indicated that there may be a strategy other than an algorithmic calculation or the representativeness heuristic that people may be using on these tasks. In Experiment 1, on the weighted coin tossing task, participants clearly indicated that they were counting the number of heads in each sequence and selecting the sequence that had more heads as the more probable sequence.

In Experiment 2, usage of the “count the heads” strategy was taken into account when designing the stimuli. On the coin tossing task in Experiment 2, the high math ability participants were more accurate and were less likely to use the representativeness heuristic than the low math ability participants. Apparently, when the trials appear random, math ability influences a person’s ability to make accurate decisions. On the weighted coin tossing task in Experiment 2, participants used the representativeness heuristic more on the trials that had the same number of heads in each sequence than on the trials in which one sequence had more heads than the other sequence. Also, participants were quicker on the trials with an unequal proportion of heads between sequences than on the trials that had an equal proportion of heads between sequences. The longer reaction times on trials in which participants used the representativeness heuristic implies that participants initially tried to use the “count the heads” strategy and when that did not result in a definitive answer the participants then used the representativeness heuristic.

Interestingly, the high math ability participants used a strategy resulting in the correct answer more than any other strategy regardless of the proportion of heads in a sequence. However, the low math ability participants appeared to use the count the heads strategy more on the trials with an unequal proportion of heads between sequences but used the representativeness heuristic on the trials that had an equal proportion of heads between sequences. Apparently, participants that are better at math used their knowledge of probability to figure out the answer when the “count the heads” strategy did not work while the low math ability participants used the representativeness heuristic when the "count the heads" strategy did not work. These findings imply that people that are better at math are also better at making decisions.

In Experiment 1, the results from the career identification task and the hospital problems seemed fairly inconclusive. This may be because these tasks appear to be "trick" questions. The questions in the career identification task involved detailed descriptions of people. All of the information given was irrelevant considering the correct answer and was there for the sole purpose of distracting the participants from using a more accurate strategy. The hospital problems task required people to have a basic understanding of the law of large numbers to arrive at the correct answer. This seemed to be too much to ask of the participants in this experiment, most notably for the low math ability participants. The purpose of the current study was to gain insight into the cognitive processes that people use when making decisions. Considering that the career identification task appears to dupe participants and that the students did not have the knowledge base to do the hospital problems task effectively, these two tasks did not appear to give insight on the cognitive processes involved in making decisions.

While performance on the hospital problems did not appear to be indicative of a decision making process, performance on the hospital problems did give some insight into how the characteristics of a stimulus can trigger people to use a particular strategy to answer the question. When the hospital problems were easy, participants sped through the problems and utilized the simplest strategy possible. However, on the difficult problems, participants paid more attention to the question and utilized a more algorithmic type of strategy. Apparently, when a problem appears to be easy, people tend to not pay much attention to the task and deploy a simple strategy but when the problems are more difficult, the participants may pay more attention to the question, resulting in them using a more complicated strategy. Considering that the high working memory span participants were both quicker and more likely to use a simple strategy, it appears that having a high working memory span may result in people being overconfident in their simple strategy and may need to slow down and focus more of their attention on a task before responding.

Aside from determining how math ability and working memory capacity influence decision making, the current experiments are unique for two reasons. First, the experiments in the current paper are the first to manipulate the difficulty of the stimuli in decision making tasks. In Experiment 1, on the hospital problems, the difficult problems consisted of more precise numbers than the easy problems. This manipulation clearly indicated that when the problems were easy that participants paid very little attention to the task, resulting in them using a simple (heuristic) strategy. On the difficult problems, participants spent more time working on the problem which resulted in more accurate responses. Tversky and Kahneman's (1971) experiment showed that expert statisticians are vulnerable to using the representativeness heuristic in hospital-type problems. However, the population sizes in their experiment involved rounded numbers. The results of the current experiment indicate that the expert statisticians in Tversky and Kahneman's (1971) experiment may have sped through the questions, resulting in usage of the representativeness heuristic. Apparently, Tversky and Kahneman's (1971) findings clearly showed how to trick experts into responding in a certain manner instead of indicating how people make probability based decisions.

On the career identification task, the difficult problems had more career stereotypes than the easy problems. Participants' probability estimates were closer to the correct answer on the easy problems than on the difficult problems. Also, participants used the representativeness heuristic more on the difficult problems than on the easy problems. For the weighted coin tossing task in Experiment 2, the difficulty of the trials was manipulated by whether or not the "count the heads" strategy would differentiate between the two sequences. The low math ability participants used the representativeness heuristic more on the problems that had the same number of heads in each sequence but not on the trials in which one sequence had more heads than the other sequence. For both the career identification task and the weighted coin tossing task in experiment 2, when the problems were more difficult, participants were more likely to use the representativeness heuristic. It appears that people attempt a different strategy than the representativeness to solve problems but default to the representativeness heuristic when the problems become too challenging to calculate the correct answer.

The second unique aspect of the current experiment is that reaction times were collected. As discussed throughout this paper, research has indicated that heuristic strategies are quicker than using an algorithm to calculate the correct answer. However, before the current experiment, there has not been any empirical evidence that supported that using heuristic-based strategies was quicker than using computation-based strategies. The results from the weighted coin tossing task in Experiment 2 clearly indicated that participants were quicker on the trials that they used the "count the heads" strategy than on the trials that they used the representativeness heuristic. Theoretically, counting the number of heads in both of the sequences should take longer than deciding which of the sequences appears to be more random.

It seems nonsensical to believe that it would take a person less time to count the number of heads in each sequence, compare the two numbers, and finally select the sequence that has more heads than it would take to identify the sequence that appears more random. As stated earlier, Kahneman and Fredrick (2002) proposed a model in which there were two systems that are utilized when making a decision. System 1 is a less effortful and quicker system, while System 2 is more effortful and takes longer to compute the answer. From these descriptions, it appears that the "count the heads" strategy is a more effortful strategy than the representativeness heuristic. If the "count the heads" strategy is more effortful, then why does it take participants less time to use the "count the heads" strategy than the less effortful representativeness heuristic? Considering that on half of the trials the "count the heads" strategy was an effective strategy and on half of the trials it was ineffective, clearly, the participants initially attempted to use the "count the heads" strategy and defaulted to the representativeness heuristic when the "count the heads" strategy failed.

This finding has a major implication. It appears that the representativeness heuristic is not the initial strategy that people utilize. Instead, the representativeness heuristic is used in a manner similar to the Take the Best Heuristic (Gigerenzer & Goldstein, 1996). Apparently, people identify all possible strategies that can be used to solve the problems. The strategies are then placed in order based on their ecological validity. People then use the strategy with the highest ecological validity. If the strategy with the highest ecological validity fails, then they move on to the strategy with the second highest ecological validity, and so on. The data from the weighted coin tossing task in Experiment 2 supports the idea that people initially used the “count the heads” strategy. When the “count the heads” strategy failed to differentiate between the two sequences, the participants moved on to the next strategy. Because the participants attempted the “count the heads” strategy before attempting the representativeness heuristic, participants took longer on the trials that they responded consistently with the representativeness heuristic than on the trials that they responded consistently with the “count the heads” strategy. This does not imply that the representativeness heuristic requires System 2 processing. Considering that the “count the heads” strategy still seems fairly simple, the fact that the representativeness heuristic took longer than the “count the heads” strategy implies that System 1 processes are not done simultaneously but are instead done serially.

Considering that the representativeness heuristic is not the initial strategy used, it appears that the ordering of the strategies, in terms of ecological validity, is what separates a good decision maker from a poor decision maker. In Experiment 2, the high math ability participants were more accurate on the coin tossing task. Also, in Experiment 2, on the weighted coin tossing task the low math ability participants used the representativeness heuristic when the “count the heads” strategy did not work while the high math ability participants continued to answer the problems correctly when the “count the heads” strategy did not work. Considering, that the “count the heads” strategy was a quick strategy that resulted in the correct answer, it is logical to rank that strategy highest, in terms of ecological validity. It appears that the high math ability participants ranked an algorithmic strategy second, while the low math ability participants ranked the representativeness heuristic second, in terms of ecological validity. Considering that high math ability participants have a better understanding of probability, it is logical that high math ability participants would be better at ranking decision making strategies in order of ecological validity than low math ability participants. The data from Experiment 2 supports this logic.

It appears that math ability does influence people's ability to make decisions. In the future, research should use decision making tasks that are more indicative of decisions that people make in their day-to-day activities. For example, Sheldrick (2004) used a task called "Chicken" in which participants were placed in front of a computer and were asked to decide whether a car should stop or continue driving through an intersection as the traffic light turned from green to yellow. Another example of everyday decisions would be Langer and Tubman's (1997) research that assessed participants' ability to make risky sexual decisions. It is hypothesized that people that are better at math are better at judging all types of probabilities, including those that involve the likelihood of getting in a car accident in a variety of situations or the probability of contracting a sexually transmitted disease.

The current experiment clearly illustrates that math ability influences decision making ability. Math tasks usually involve a person attempting various strategies to solve a problem. Therefore, it is logical that high math ability people are well practiced at quickly finding strategies that result in correct answers. The current study indicates that people that are better at math are also better at detecting effective strategies to make decisions. Apparently, learning math in high school not only influences a person's ability to get into college but also influences their ability to make decisions throughout their life.

APPENDIX A

EXAMPLE PROBLEMS

Problem 1: A certain town is served by two hospitals. In the larger hospital about 45 babies are born each day, and in the smaller hospital about 15 babies are born each day. As you know, about 50 percent of all babies are boys. However, the exact percentage varies from day to day. Sometimes it might be higher than 50 percent, sometimes lower.

For a period of one year, each hospital recorded the days on which more than 60 percent of the babies born were boys. Which hospital do you think recorded more such days?

- The larger hospital
- The smaller hospital
- About the same (that is within 5 percent of each other)

Problem 2: There are two jars full of jelly beans. Each has 50% red jelly beans and 50% blue jelly beans. Jar A has a total of 1000 jelly beans while Jar B has 500 total jelly beans.

For 10 days I pull out 10 jelly beans from each jar and then place them back into the jar. Which of the two jars will record more days where at least 6 of the ten jelly beans that were pulled out are red?

- Jar A
- Jar B
- About the same

Problem 3: In a small city there are two ice cream parlors. Each of the ice cream parlors only has the flavors of chocolate and vanilla. Each parlor reports that they typically sell 50% chocolate and 50% vanilla. Parlor A has an average of 20 patrons per day, while Parlor B has an average of 40 patrons per day. Over the course of a year, which parlor is more likely to report more days in which they sell 80% chocolate?

- Parlor A
- Parlor B
- Both parlors are equally likely

Problem 4: A person is holding a typical six sided die. Half of the sides contain an even number, while the other half contain an odd number. On Monday, the person rolls the die 200 times and on Tuesday the person rolls the die 400 times. On which day is the person more likely to roll the die and land on an odd number 70% of the time?

- Monday
- Tuesday
- Both days are equally likely

Problem 5: There are two ice skating rinks in a city. Rink A has an average of 325 patrons per day while Rink B has an average of 728 patrons per day. In both rinks 68.84% of people fall while they are skating. Over the course of a year, which rink is likely to have more days in which more than 85% of patrons fall while skating?

Rink A
Rink B
Both rinks are equally likely

Problem 6: There are two soda companies. It has been reported that 74.29% of consumers drink diet soda while the remaining 25.71% percent of consumers drink regular soda. Fizzy Soda has an average of 1374 customers per day, while Bubbly Soda has an average of 2347 customers per day. Over the course of a year, which soda company is more likely to report more days in which at least 85.93% of soda sold is diet soda?

Fizzy Soda
Bubbly Soda
Both sodas are equally likely

Problem 7: In a small town there are two different gas stations. Each gas station reports that 89.94% of customers purchase unleaded gasoline while the remaining 10.06% purchase leaded gasoline. Smelly Gas has an average of 464 customers while PU Gas has 967 customers. Over the course of a year, which gas station is more likely to record more days in which at least 98.62% purchase unleaded gasoline?

Smelly Gas
PU Gas
Both gas stations are equally likely

Problem 8: Classes at UNLV average having 86.25% of students passing the class and 13.75% failing the class. There are two Psychology 101 classes at UNLV taught by the same professor. One has 73 students and the other has 32 students. Which class is more likely to have 3% of students failing?

A) The larger class
B) The smaller class
C) Both classes are equally likely

Instructions (Taken from Kahneman and Tversky, 1973):

A panel of psychologists have interviewed and administered personality tests to 30 engineers and 70 lawyers, all successful in their respective fields. On the basis of this information, thumbnail descriptions of 30 engineers and 70 lawyers have been written. You will be presented with five descriptions, chosen at random from the 100 available descriptions. For each description, please indicate the probability that the person described is an engineer, on a scale from 0 to 100.

Character Descriptions (the first taken from Kahneman and Tversky, 1973; the rest will be created from results of pilot data):

Jack is a 45-year-old man. He is married and has four children. He is generally conservative, careful, and ambitious. He shows no interest in political and social issues and spends most of his free time on his many hobbies which include home carpentry, sailing, and mathematical puzzles.

The probability that Jack is one of the 30 engineers in the sample of 100 is ____ %.

Mike is a 48-year-old man. He is not married. He is generally hardworking, smart, but quite a liar. He was on the debate team in high school and spends the majority of his free time on his many hobbies which include playing softball and watching movies but avoids any task that involves fixing or building.

The probability that Mike is one of the 70 lawyers in the sample of 100 is ____ %.

Pete is a 44 year old man. He is married with no children. He is generally hard-working, smart, and efficient. He enjoys working with his hands and spends the majority of his free time on his many hobbies such as bird watching, cheering for his favorite football team, and watching movies.

The probability that Pete is one of the 30 engineers in the sample of 100 is ____ %.

Chris is a 37 year old man. He is married with one child. He is generally conservative, laid-back, and organized. He avoids all political conversations and spends the majority of his free time on his hobbies such as playing video games, spending time with his family, and volunteering at a homeless shelter.

The probability that Chris is one of the 70 lawyers in the sample of 100 is ____ %.

If you were to flip a coin 1 time which outcome is more likely (H=heads and T=tails):

1. H (heads)
2. T (tails)
3. Equal

If you were to flip a coin 2 times which outcome is more likely (H=heads and T=tails):

1. TH
2. TT
3. Equal

If you were to flip a coin 4 times which outcome is more likely (H=heads and T=tails):

1. THTH
2. TTTT
3. Equal

If you were to flip a coin 6 times which outcome is more likely (H=heads and T=tails):

1. HTHTHT
2. HHHTTT
3. Equal

Imagine that you were given a “trick” coin. This “trick” coin is weighted such that 60% of the time it will land on heads and 40% of the time it will land on tails.

If you were to flip the “trick” coin 4 times which outcome is more likely (H = heads and T = tails):

A) THTH
B) THHH
C) Equal

Imagine that you were given a “trick” coin. This “trick” coin is weighted such that 60% of the time it will land on heads and 40% of the time it will land on tails.

If you were to flip the “trick” coin 6 times which outcome is more likely (H = heads and T = tails):

A) THTHTH
B) HHHTHT
C) Equal

The following questions will be answered in a discussion format. Please answer them aloud. The researcher may ask follow-up questions based on your responses. You responses are being recorded so that at a later time a researcher can categorize your responses.

1. Earlier you saw the question:

In a small city there are two ice cream parlors. Parlor A has an average of 20 patrons per day, while Parlor B has an average of 40 patrons per day. Each of the ice cream parlors only has the flavors of chocolate and vanilla. Each parlor reports that they typically sell 50 percent chocolate and 50 percent vanilla. When customers order ice cream, the percentage of people that order chocolate ice cream can vary. Sometimes it might be higher than 50 percent, sometimes lower.

For a period of one year, each ice cream parlor recorded the days on which more than 60 percent of the ice cream sales were for chocolate ice cream. Which of the two ice cream parlors do you think will record more such days?

A) Parlor A

B) Parlor B

C) Both parlors are equally likely

1a) What was your answer?

1b) How did you arrive at your answer? What strategy did you use?

2. Earlier you saw the question:

Al is a 46-year-old man. He is not married. He is generally good with numbers, liberal, and sociable. He scored well on the math section of the SAT and spends his free time on hobbies such as volunteering by building homes for Habitat for Humanity, watching football and playing volleyball.

The probability that Al is one of the 30 engineers in the sample of 100 is ____ %.

2a) What was your answer?

2b) How did you arrive at your answer? What strategy did you use?

3. Earlier you saw the question:

If you were to flip a coin 2 times which outcome is more likely (H=heads and T=tails):

A) HH

B) TH

C) Equal

3a) What was your answer?

3b) How did you arrive at your answer? What strategy did you use?

4. Earlier you saw the question:

Imagine that you were given a "trick" coin. This "trick" coin is weighted such that 60% of the time it will land on heads and 40% of the time it will land on tails.

If you were to flip the "trick" coin 2 times which outcome is more likely (H=heads and T=tails):

1. TH
2. TT
3. Equal

4a) What was your answer?

4b) How did you arrive at your answer? What strategy did you use?

An example of a trial with a different number of heads in each sequence:

Imagine that you were given a “trick” coin. This “trick” coin is weighted such that 60% of the time it will land on heads and 40% of the time it will land on tails. If you were to flip the “trick” coin 6 times which outcome is more likely (H=heads and T=tails):

A) H T T H T H

B) H H H H T T

C) Equal

An example of a trial with the same number of heads in each sequence:

Imagine that you were given a “trick” coin. This “trick” coin is weighted such that 60% of the time it will land on heads and 40% of the time it will land on tails. If you were to flip the “trick” coin 8 times which outcome is more likely (H=heads and T=tails):

A) T T T T H H H H

B) H T H H T H T T

C) Equal

Examples of trials with the same number of heads in each sequence:

If you were to flip a coin 6 times which outcome is more likely (H=heads and T=tails):

D) H T T H T H

E) H H H T T T

F) Equal

If you were to flip a coin 12 times which outcome is more likely (H=heads and T=tails):

A) H T H T H H T H T T H T

B) H H H H H H T T T T T T

C) Equal

Examples of trials with a different number of heads in each sequence:

If you were to flip a coin 8 times which outcome is more likely (H=heads and T=tails):

D) T T T T T H H H

E) H T H H T H T T

F) Equal

If you were to flip a coin 10 times which outcome is more likely (H=heads and T=tails):

A) H H H H H H T T T T

B) H T H H T H T T H T

C) Equal

APPENDIX B

FIGURES AND TABLES

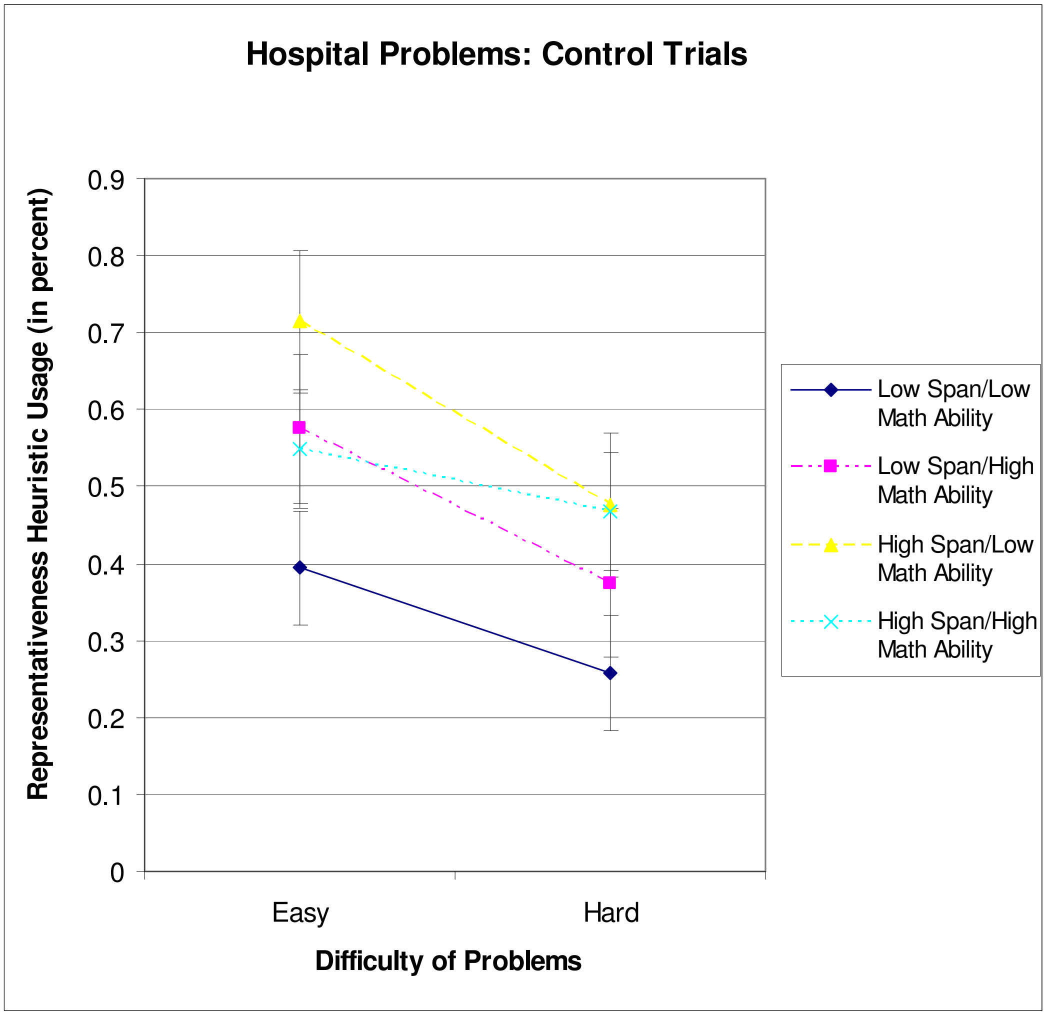

Figure 1a. The percentage of trials the Low Working Memory Span/Low Math Ability, Low Working Memory Span/High Math Ability, High Working Memory Span/Low Math Ability, and High Working Memory Span/High Math Ability used on the easy and difficult problems in the control block of trials.

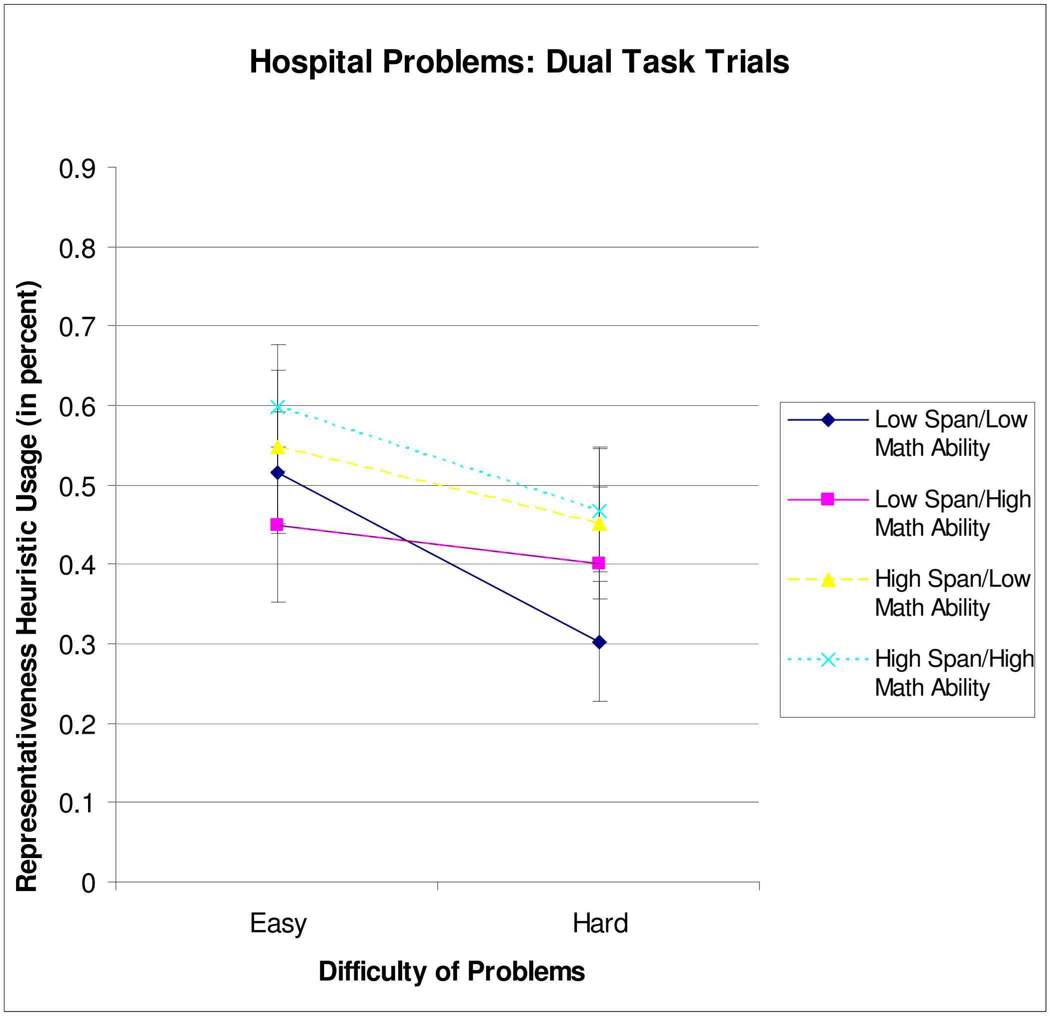

Figure 1b. The percentage of trials the Low Working Memory Span/Low Math Ability, Low Working Memory Span/High Math Ability, High Working Memory Span/Low Math Ability, and High Working Memory Span/High Math Ability used on the easy and difficult problems in the dual task block of trials.

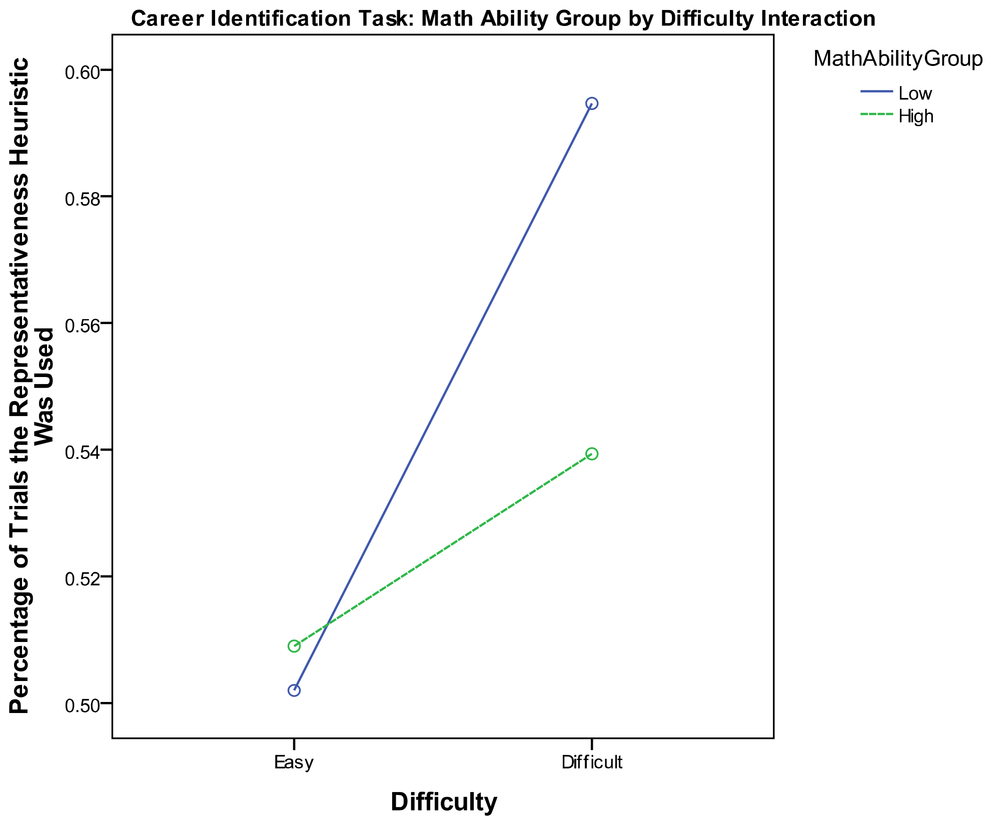

Figure 2. The percentage of trials that the representativeness heuristic was used on each level of difficulty of the career identification task by each math ability group.

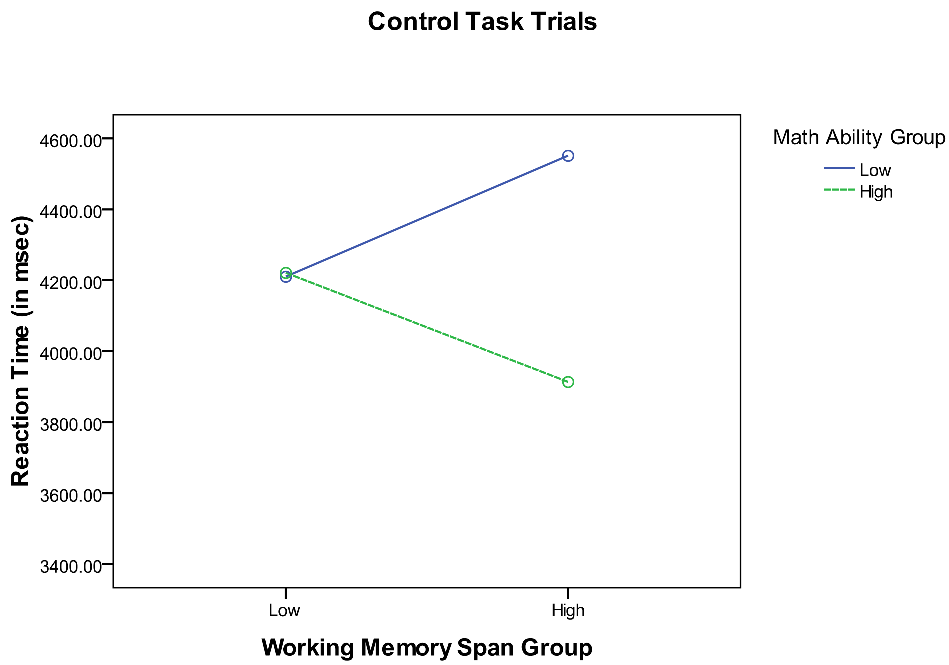

Figure 3a. The reaction time on the career identification task for each math ability group as a function of working memory span group on the control task trials.

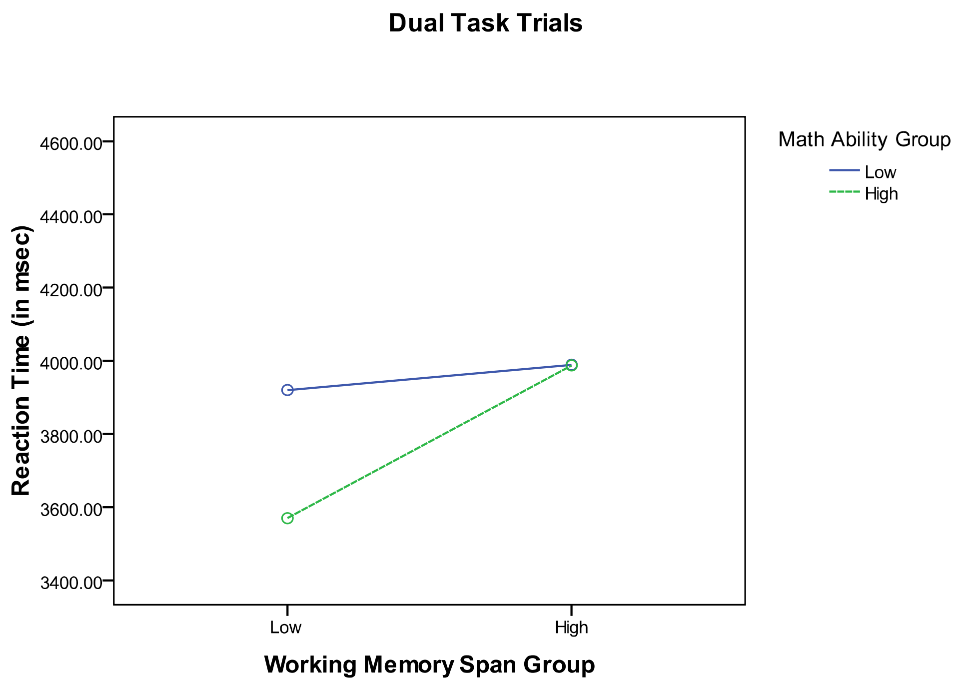

Figure 3b. The reaction time on the career identification task for each math ability group as a function of working memory span group on the dual task trials.

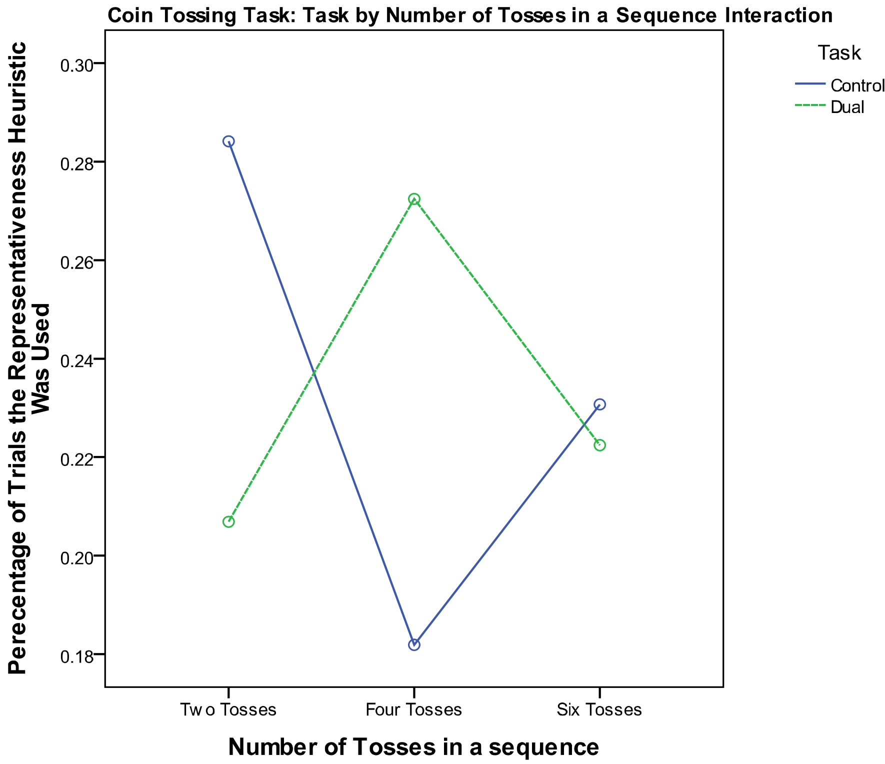

Figure 4. The percentage of trials that the representativeness heuristic was used in the two, four, and six toss sequences on each task.

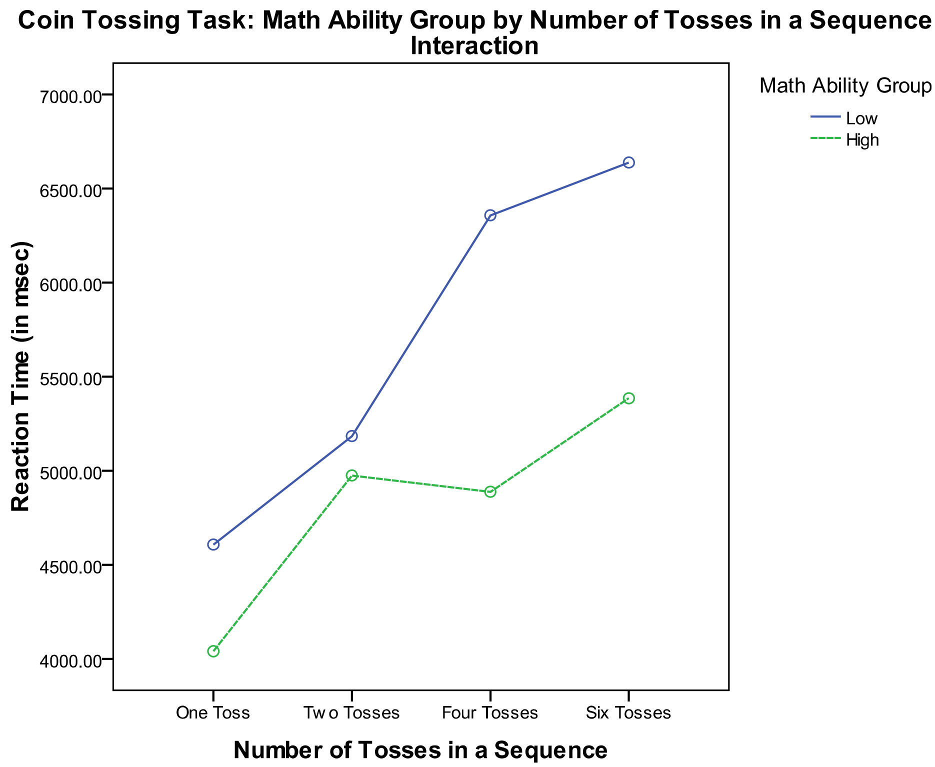

Figure 5. The average reaction time for each math ability group on the one, two, four, and six toss sequences on the coin tossing task.

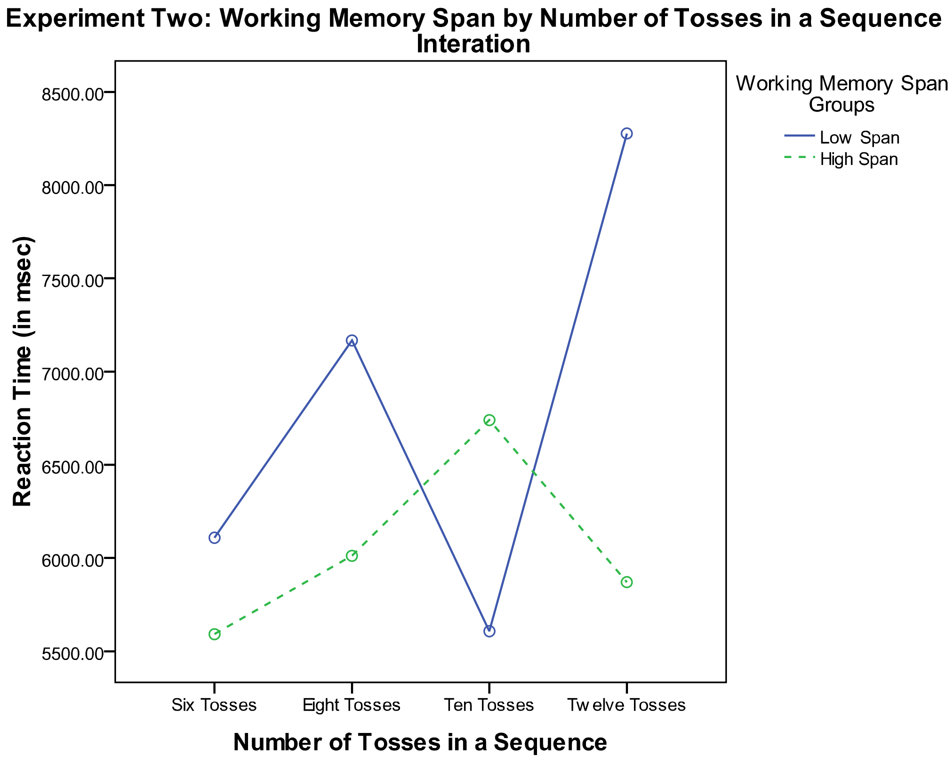

Figure 6. The average reaction time of each working memory span group on each sequence length.

Experiment Two Weighted Coin Tossing Task: Math Ability Group by Working Memory Span Group by Number of Tosses in a Sequence Interaction

Low Math Ability Group

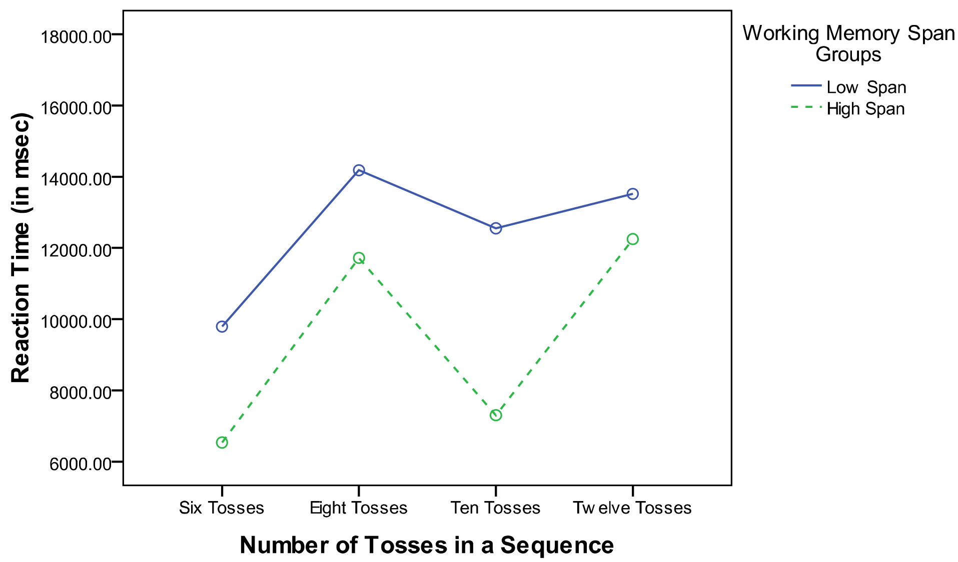

Figure 7a. Of the low math ability participants, the average reaction time for the low and high working memory span groups on each sequence length.

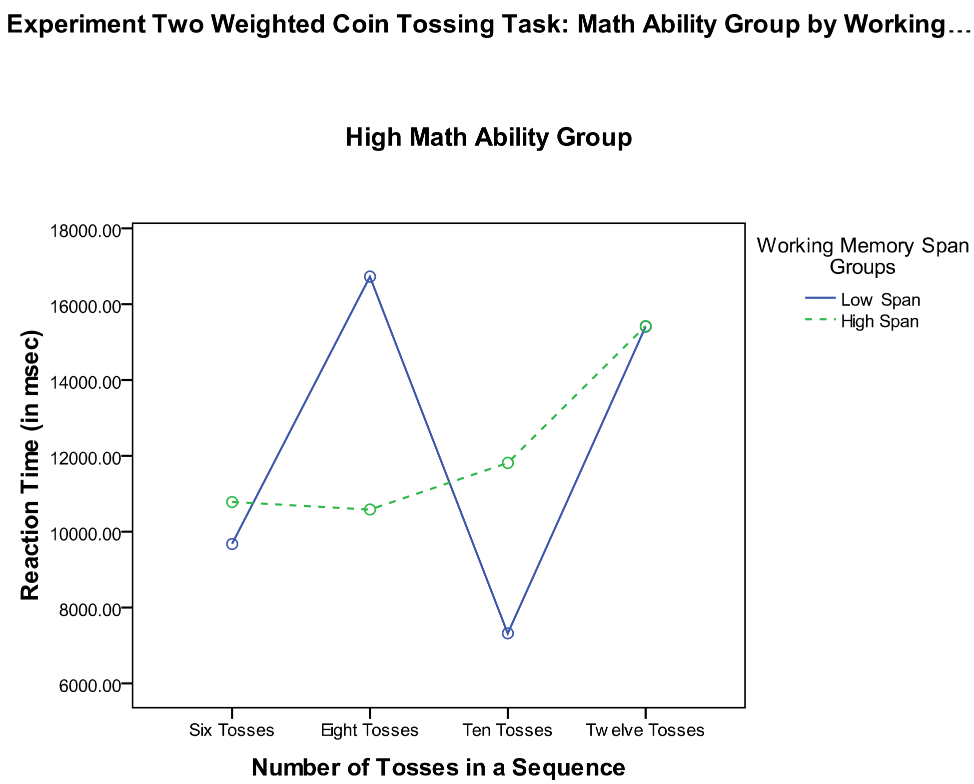

Figure 7b. Of the high math ability participants, the average reaction time for the low and high working memory span groups on each sequence length.

Weighted Coin Tossing Task: Math Ability Group by Working Memory Span Group by Proportion of Heads in a Sequence Interaction

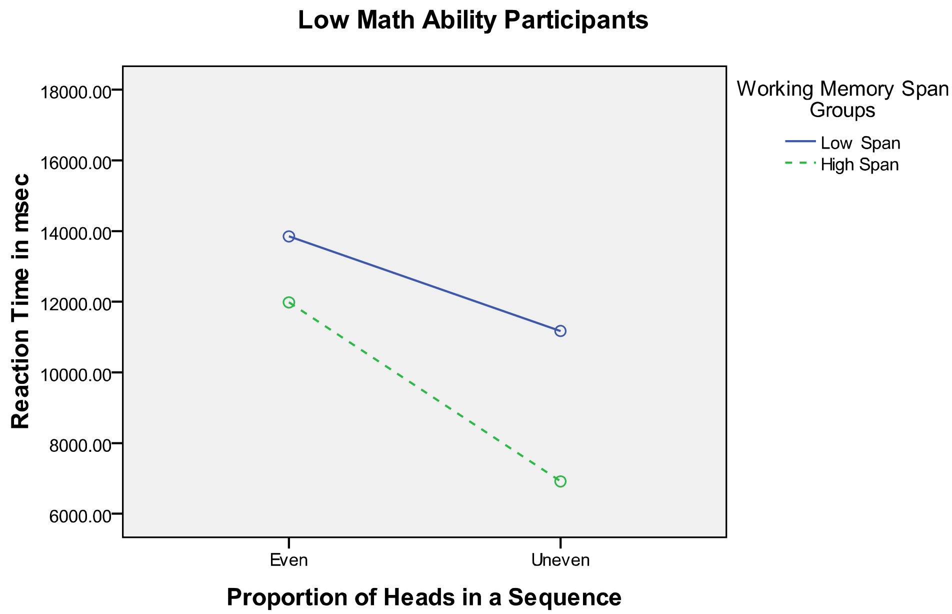

Figure 8a. Of the low math ability participants, the average reaction time for the low and high working memory span groups on the problems that had the same number of heads in each sequence and on the problems that had a different number of heads in each sequence.

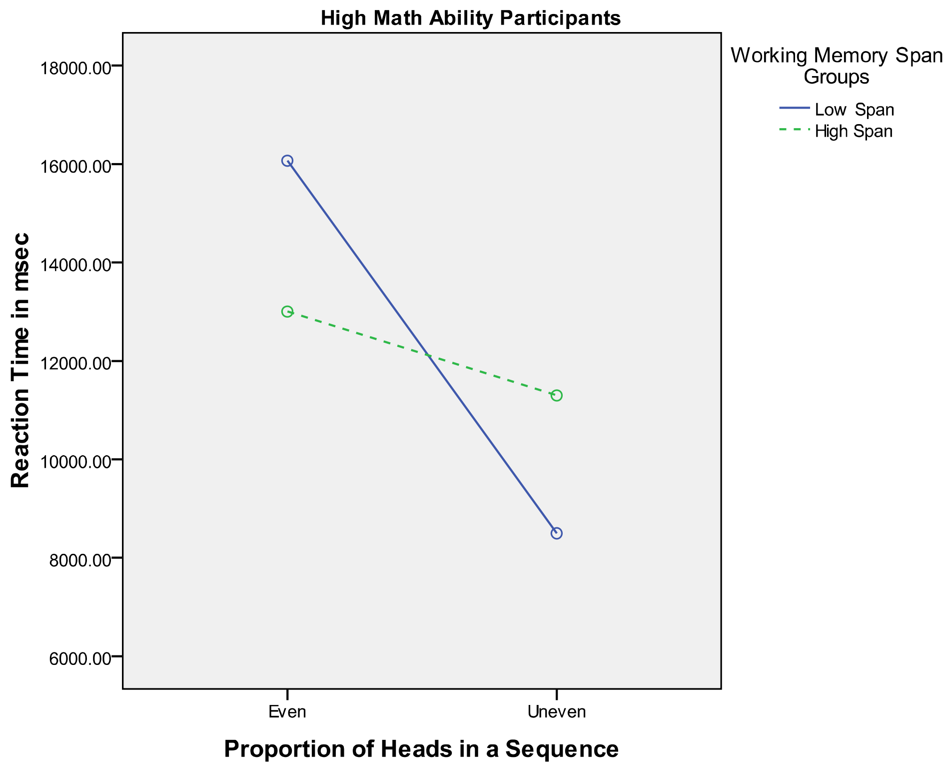

Figure 8b. Of the high math ability participants, the average reaction time for the low and high working memory span groups on the problems that had the same number of heads in each sequence and on the problems that had a different number of heads in each sequence.

	Easy Problems	Difficult Problems
Correct	51	109
Representativeness Heuristic	225	165
Wrong	144	146

Table 1. The total number of each type of response on both the easy and difficult hospital problems for all participants.

	Easy Problems	Difficult Problems
Correct	21	52
Representativeness Heuristic	113	76
Wrong	82	88

Table 2. The total number of each type of response on both the easy and difficult hospital problems for the low math ability participants.

	Easy Problems	Difficult Problems
Correct	30	57
Representativeness Heuristic	112	89
Wrong	62	58

Table 3. The total number of each type of response on both the easy and difficult hospital problems for the high math ability participants.

	Control		Dual	
	Easy	Difficult	Easy	Difficult
Low Math Ability	2	2	0	1
High Math Ability	2	2	2	2

Table 4. Outliers for Each Math Ability Group in Each Condition of the hospital problems task.

	Easy Problems	Difficult Problems
Correct	204	209
Representativeness Heuristic	421	469
Wrong	206	153

Table 5. The total number of each type of response on both the easy and difficult career identification task problems for all participants.

	Easy Problems	Difficult Problems
Correct	102	107
Representativeness Heuristic	207	233
Wrong	107	76

Table 6. The total number of each type of response on both the easy and difficult career identification task problems for the low working memory span participants.

	Easy Problems	Difficult Problems
Correct	102	107
Representativeness Heuristic	207	233
Wrong	107	76

Table 7. The total number of each type of response on both the easy and difficult career identification task problems for the high working memory span participants.

	Control		Dual	
	Easy	Difficult	Easy	Difficult
Low Working Memory Span	0	0	2	1
High Working Memory Span	1	0	0	0

Table 8. Outliers for each math ability group in each condition of the career identification task.

	Two Tosses	Four Tosses	Six Tosses
Correct	144	150	146
Representativeness Heuristic	51	48	49
Wrong	13	12	15

Table 9. The total number of each type of response on the two, four, and six toss sequences for all participants on the coin tossing task.

	Two Tosses	Four Tosses	Six Tosses
Correct	77	78	73
Representativeness Heuristic	20	21	27
Wrong	9	9	8

Table 10. The total number of each type of response on the two, four, and six toss sequences for the low math ability participants on the coin tossing task.

	Two Tosses	Four Tosses	Six Tosses
Correct	67	72	73
Representativeness Heuristic	31	27	22
Wrong	4	3	7

Table 11. The total number of each type of response on the two, four, and six toss sequences for the high math ability participants on the coin tossing task.

	Control				Dual			
	One Toss	Two Tosses	Four Tosses	Six Tosses	One Toss	Two Tosses	Four Tosses	Six Tosses
Low Math Ability	4	8	0	2	4	6	2	4
High Math Ability	5	3	4	1	2	1	6	4

Table 12. Outliers for each math ability group in each condition of the coin tossing task

	Two Tosses	Four Tosses	Six Tosses
Correct	53	41	67
Representativeness Heuristic	11	14	3
Wrong	8	17	2

Table 13. The total number of each type of response on the two, four, and six toss sequences for all participants on the weighted coin tossing task.

	Two Tosses	Four Tosses	Six Tosses
Correct	28	24	33
Representativeness Heuristic	5	4	1
Wrong	1	6	0

Table 14. The total number of each type of response on the two, four, and six toss sequences for the low math ability participants on the weighted coin tossing task.

	Two Tosses	Four Tosses	Six Tosses
Correct	25	17	34
Representativeness Heuristic	6	10	2
Wrong	7	11	2

Table 15. The total number of each type of response on the two, four, and six toss sequences for the high math ability participants on the weighted coin tossing task.

	Control One Toss	Two Tosses	Four Tosses	Six Tosses	Dual One Toss	Two Tosses	Four Tosses	Six Tosses
Low Math Ability	1	0	0	0	0	1	0	1
High Math Ability	0	0	0	2	0	0	0	1

Table 16. Outliers for each math ability group in each condition of the weighted coin tossing task.

	Six Tosses	Eight Tosses	Ten Tosses	Twelve Tosses
Correct	18	13	15	16
Representativeness Heuristic	18	24	24	22
Wrong	4	3	1	2

Table 17. The total number of each type of response on the six, eight, ten, and twelve coin toss sequences for all participants on the coin tossing task in Experiment Two.

	Six Tosses	Eight Tosses	Ten Tosses	Twelve Tosses
Correct	7	5	6	4
Representativeness Heuristic	10	13	13	14
Wrong	3	2	1	2

Table 18. The total number of each type of response on the six, eight, ten, and twelve coin toss sequences for the low math ability participants on the coin tossing task in Experiment Two.

	Six Tosses	Eight Tosses	Ten Tosses	Twelve Tosses
Correct	11	8	9	12
Representativeness Heuristic	8	11	11	8
Wrong	1	1	0	0

Table 19. The total number of each type of response on the six, eight, ten, and twelve coin toss sequences for the high math ability participants on the coin tossing task in Experiment Two.

	Same Number of Heads Per Sequence	Different Number of Heads Per Sequence
Correct	34	28
Representativeness Heuristic	40	48
Wrong	6	4

Table 20. The total number of each type of response for the trials that had the same number of heads per sequence and the trials that had a different number of heads per sequence for all participants in the coin tossing task in Experiment Two.

	Same Number of Heads Per Sequence	Different Number of Heads Per Sequence
Correct	11	11
Representativeness Heuristic	24	26
Wrong	5	3

Table 21. The total number of each type of response for the trials that had the same number of heads per sequence and the trials that had a different number of heads per sequence for the low math ability participants in the coin tossing task in Experiment Two.

	Same Number of Heads Per Sequence	Different Number of Heads Per Sequence
Correct	23	17
Representativeness Heuristic	16	22
Wrong	1	1

Table 22. The total number of each type of response for the trials that had the same number of heads per sequence and the trials that had a different number of heads per sequence for the high math ability participants in the coin tossing task in Experiment Two.

	Six Tosses	Eight Tosses	Ten Tosses	Twelve Tosses
Low Math Ability	2	2	1	1
High Math Ability	0	2	1	1

Table 23. Outliers/microphone errors for each math ability group in each condition of the coin tossing task in Experiment Two.

	Six Tosses	Eight Tosses	Ten Tosses	Twelve Tosses
Correct	32	17	27	10
Representativeness Heuristic	7	15	12	21
Wrong	1	8	1	9

Table 24. The total number of each type of response on the six, eight, ten, and twelve coin toss sequences for all participants on the weighted coin tossing task in Experiment Two.

	Six Tosses	Eight Tosses	Ten Tosses	Twelve Tosses
Correct	16	6	13	4
Representativeness Heuristic	4	11	6	10
Wrong	0	3	1	6

Table 25. The total number of each type of response on the six, eight, ten, and twelve coin toss sequences for the low math ability participants on the weighted coin tossing task in Experiment Two.

	Six Tosses	Eight Tosses	Ten Tosses	Twelve Tosses
Correct	16	11	14	6
Representativeness Heuristic	3	4	6	11
Wrong	1	5	0	3

Table 26. The total number of each type of response on the six, eight, ten, and twelve coin toss sequences for the high math ability participants on the weighted coin tossing task in Experiment Two.

	Same Number of Heads Per Sequence	Different Number of Heads Per Sequence
Correct	27	59
Representativeness Heuristic	36	19
Wrong	17	2

Table 27. The total number of each type of response for the trials that had the same number of heads per sequence and the trials that had a different number of heads per sequence for all participants in the weighted coin tossing task in Experiment Two.

	Same Number of Heads Per Sequence	Different Number of Heads Per Sequence
Correct	10	29
Representativeness Heuristic	21	10
Wrong	9	1

Table 28. The total number of each type of response for the trials that had the same number of heads per sequence and the trials that had a different number of heads per sequence for the low math ability participants in the weighted coin tossing task in Experiment Two.

	Same Number of Heads Per Sequence	Different Number of Heads Per Sequence
Correct	17	30
Representativeness Heuristic	15	9
Wrong	8	1

Table 29. The total number of each type of response for the trials that had the same number of heads per sequence and the trials that had a different number of heads per sequence for the high math ability participants in the weighted coin tossing task in Experiment Two.

	Six Tosses	Eight Tosses	Ten Tosses	Twelve Tosses
Low Math Ability	1	2	0	0
High Math Ability	3	1	0	0

Table 30. Outliers/microphone errors for each math ability group in each condition of the weighted coin tossing task in Experiment Two.

APPENDIX C

IRB APPROVALS

UNLV
UNIVERSITY OF NEVADA LAS VEGAS

UNLV IRB
Approved
AUG 24 2009
Expires
AUG 23 2010

Social/Behavioral IRB – Expedited Review Approval Notice

NOTICE TO ALL RESEARCHERS:

Please be aware that a protocol violation (e.g., failure to submit a modification for any change) of an IRB approved protocol may result in mandatory remedial education, additional audits, re-consenting subjects, researcher probation suspension of any research protocol at issue, suspension of additional existing research protocols, invalidation of all research conducted under the research protocol at issue, and further appropriate consequences as determined by the IRB and the Institutional Officer.

DATE:	August 24, 2009
TO:	**Dr. Mark Ashcraft**, Psychology
FROM:	Office for the Protection of Research Subjects
RE:	Notification of IRB Action by Dr. Paul Jones, Chair Protocol Title: **The Effect of Working Memory Capacity, Math Ability on Decision Making Ability** Protocol #: 0906-3135

This memorandum is notification that the project referenced above has been reviewed by the UNLV Social/Behavioral Institutional Review Board (IRB) as indicated in Federal regulatory statutes 45 CFR 46. The protocol has been reviewed and approved.

The protocol is approved for a period of one year from the date of IRB approval. The expiration date of this protocol is August 23, 2010. Work on the project may begin as soon as you receive written notification from the Office for the Protection of Research Subjects (OPRS).

PLEASE NOTE:
Attached to this approval notice is the **official Informed Consent/Assent (IC/IA) Form** for this study. The IC/IA contains an official approval stamp. Only copies of this official IC/IA form may be used when obtaining consent. Please keep the original for your records.

Should there be *any* change to the protocol, it will be necessary to submit a **Modification Form** through OPRS. No changes may be made to the existing protocol until modifications have been approved by the IRB.

Should the use of human subjects described in this protocol continue beyond August 23, 2010, it would be necessary to submit a **Continuing Review Request Form** *60 days* before the expiration date.

If you have questions or require any assistance, please contact the Office for the Protection of Research Subjects at OPRSHumanSubjects@unlv.edu or call 895-2794.

Office for the Protection of Research Subjects
4505 Maryland Parkway • Box 451047 • Las Vegas, Nevada 89154-1047

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