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Adaptive Mechanisms of Superior Judgment under Uncertainty: Rational Choices from Simple Heuristics and Elaborative Strategies

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ADAPTIVE MECHANISMS OF SUPERIOR JUDGMENT UNDER UNCERTAINTY: RATIONAL CHOICES FROM SIMPLE HEURISTICS AND ELABORATIVE STRATEGIES

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ABSTRACT

Several studies demonstrate a consistent, positive relationship between cognitive ability measures and normatively superior judgment and decision behavior. However, little is known about the cognitive processes and mechanisms that give rise to these individual differences or more generally produce rational judgments under uncertainty. In a series of two experiments, protocol analysis and individual difference measures were used to demonstrate that, in contrast to the processes predicted by a rational theory (i.e. expected value calculations), rational choices often arise from combinations of simple considerations. These processes are similar to those predicted by the priority heuristic although the priority heuristic otherwise predicted choices poorly, at or below chance levels. Critically, individual differences in elaborative processes (e.g. more and more varied combinations of simple considerations) were strongly positively related to rational choices and fully mediated the cognitive ability and rational choice relationship. Implications for descriptive and process level models of choice are discussed.

INTRODUCTION

People do not always behave “rationally.” To a significant extent, this results from our limited psychological capacities and knowledge- our bounded rationality (Simon, 1956; 1957; 1990). Yet some individuals do seem to make consistently better judgments and decisions. Some people better approximate normative models, are more likely to avoid judgment and decision biases, and more effectively adapt to a variety of cognitive demands (Frederick, 2005; Kahneman, 2003; Stanovich & West, 2002). Theoretically, some of the causes of these performance advantages include stable individual differences in basic cognitive abilities and capacities. However, considerable evidence casts doubts on purely innate and fixed capacity interpretations of cognitive abilities (Ericsson & Charness, 1994; Ericsson, Roring, & Nandagopal, in press; Howe, Davidson, & Sloboda, 1998). Moreover, research demonstrates that strategic control processes (e.g. optional task strategies, effective goal representations) can causally alter functional cognitive performance parameters and in some cases account for large performance differences (Cokely, Kelley, & Gilchrist, 2006; Ericsson & Kinstch, 1996; Jacoby, Kelley, & McElree, 1999; Kieras & Meyer, 2000; Hertzog & Dunlosky, 2004; Sternberg, 1997; Vigneau, Caissie, & Bors, 2005). What are the mechanisms that give rise to rational judgment under uncertainty?

Traditionally, the estimation of optimal and rational judgment outcomes is based on formal analyses and assumptions of a variety of utility theories, commonly known as rational theories of choice (Hastie, 2001; Shafir & Tversky, 1995). In general, these models suggest that with regard to decision-making and the analysis of trade-offs, rational processes are those that calculate expected values by *weighing and summing* probabilities to maximize utility (i.e. personal value). These functions are at the core of dozens of models spanning hundreds of years, including modern theories applied to motivation, attitudes, moral choices, and decisions (Gigerenzer & Selten, 2001; Goldstein & Gigerenzer, 2002). As well, since 1738, when Daniel Bernoulli introduced the idea of diminishing marginal utility, normative models also commonly reflect the notion that changes in value are not linear but show negative acceleration (e.g. the more money one has the less one values each additional unit of money).

In spite of long traditions and successes with rational theories of choice, hundreds of empirical studies demonstrate significant differences between theoretically normative predictions and descriptive accounts of judgment under uncertainty. For example, in what is now considered a classic demonstration, Meehl (1954) provided descriptive accounts of non-rational behavior in professionals who often showed poor performance and biased self-assessment relative to statistical and other formal methods. Similarly, a critical theoretical advance came from Herbert Simon (1956; 1957; 1990) who introduced the concept of *bounded rationality,* acknowledging our limited information processing capacities. Simon further suggested the notion that people often use decision and problem solving heuristics in order to cope with limited resources, cognitive and otherwise. This framework markedly contrasted with an assumption of multi-attribute utility and sophisticated probability calculations that other models assumed of rational decision makers. These and other discrepancies between rational and descriptive behavior have made decision theory increasingly open to, and shaped by, psychological theory and data, although normative choices remain the standard to which other choices are compared.

One of the most influential modern judgment and choice research programs follows a *heuristics and biases approach*, also sometimes referred to as the psychology of intuitive judgment (Kahneman, 2003). Early work in the 1970s cataloged a number of information processing biases that were used to systematically demonstrate the commonplace use of cognitive short-cuts and heuristics in human judgment. These included well-known and extensively investigated heuristics such as representativeness, availability, and anchoring and adjustment.

A key concept to emerge from the heuristic and biases framework was based on data indicating that decisions change based on how they are framed in one's mind. Research revealed an asymmetry in risky decisions such that individuals tended to behave as if *losses loomed larger than similar gains*. People tend to show risk aversion for gains yet a risk preference when considering losses of equal magnitudes. This finding, among others, violated the *description invariance* assumption of traditional rational models and led in part to the development of *prospect theory* (Kahneman & Tversky, 1979; see also cumulative prospect theory, Tversky & Kahneman, 1992), an empirically based descriptive model of human judgment under uncertainty. Indeed, this model has become one of the most popular and widely cited non-normative additions to, and modifications of, the subjective expected utility family of theories.

Prospect theory (Kahneman & Tversky, 1979) modifies core utility models in order to capture descriptive data of judgment under uncertainty, with only a few basic parameters. First, the theory describes behavior over changes in gains and losses without necessarily making reference to absolute wealth levels. Next, and perhaps most uniquely, the model predicts an asymmetry for gains and losses such that people behave as if risk taking for losses is preferred to similar risks for potential gains. As a result, these parameters predict behavior that often conflicts with rational choice predictions and yet nevertheless helps resolve descriptive and normative discrepancies. For example, prospect theory and the more general heuristics and biases approach has proven valuable to behavioral economists who consider investment and spending behavior (De Bondt & Thaler, 2002) and have struggled with real world rational anomalies such as the equity premium puzzles (i.e. non-rational differences between bond and stock market investment returns).

In spite of the success of prospect theory there are a number of boundary conditions. One central issue for this paper is the fact that ability measures consistently differentiate between individuals who behave more normatively and those who are best modeled by prospect theory. As an example, individuals who score highly on a three item math test with deceptive, easily accessible wrong answers, known as the *cognitive reflection task* (CRT), show a significantly different pattern of choices as compared to the classic risk aversion or asymmetry for gains and losses (Frederick, 2005) predicted by prospect theory (Kahneman & Tversky, 1979 Tversky & Kahneman, 1992). When given a choice between a certain gain of $100 or a 75% chance of a $200 gain, prospect theory predicts risk aversion and the selection of the $100 sure thing. This behavior is considered non-rational because the expected value calculation (i.e. the probability is multiplied by the potential risky gain) is higher for the risky choice and thus should be selected ($100 v. $150). However, when given similar choices significantly greater numbers of high CRT individuals do indeed select the risky option (estimated *d*= .6). Consistent with prospect theory, the majority choices still reflected risk aversion; however, this behavior includes the aforementioned systematic individual variation in choice outcome. Of note, the majority choice margin was narrow such that if given a different sample with more high CRT individuals, or perhaps a sample of non-college students who might have different absolute wealth levels, the majority choice could become normative. Alternatively, when the same choice is framed as a loss (-$100 v. 75% of –$200) prospect theory predicts that individuals will typically take the risk. In sharp contrast to prospect theory predictions, the majority of high CRT individuals tend to be significantly more rational and risk averse (estimated *d*= .7) for losses while the majority of low CRT individuals show clear risk preference behavior.

Analyses have attempted to disentangle cognitive reflection as assessed by the CRT from other cognitive ability factors. Across thousands of participants, Frederick (2005) assessed the relationship between CRT and the Scholastic Aptitude Test (SAT), the Need for Cognition Scale, and the Wonderlic Personnel Test (WPT; a short form instrument designed to measure general intelligence in the workplace). Correlations between instruments range from *r* =.22 with the NFC, to *r* =.46 for the SAT math and ACT tests, and *r* =.43 for the WPT. The correlation between the SAT math and ACT tests was *r* =.63. Moreover, the CRT was shown to demonstrate some small but unique predictive power beyond other measures and was the best predictor of time trade-offs, indicating that high CRT scores are associated with one's rational willingness to forgo immediate rewards for larger rewards in the future (e.g. $3000 today or $3400 next month). Still, it is possible that the remaining differences reflect at least in part other fluid ability, working memory, or strategic factors (Frederick, personal communication). Indeed, my colleagues and I have found strong relationships between the Raven's Progressive Matrixes and the CRT (*r* >.6). Overall, the data suggest consistent relationships with basic abilities and the CRT, and yet leave open questions about the specific cognitive mechanisms that give rise to the observed relationships (e.g. capacity, strategy, etc).

Setting aside for a moment any consideration of individual differences, the CRT and judgment under uncertainty data bring to light an important boundary of prospect theory: Prospect theory is not necessarily a cognitive process theory (Goldstein & Gigerenzer, 2002; Weber, Johnson, Milch, Chang, Brodscholl, & Goldstein, in press). The prospect theory framework only posits that people act "as-if" they evaluate losses with a steeper utility curve, and it does not identify the precise cognitive mechanism(s) at work (Brandstatter, Gigerenzer, & Hertwig, 2006). However, other cognitive process theories do suggest potential mechanisms of choice. For example, theory based on an adaptive, evolutionary perspective proposes that specific *fast and frugal* cognitive heuristics are at the core of most judgment under uncertainty behavior. These models make accurate descriptive predictions (i.e. capture the asymmetry for gains and losses) and as well challenge the 'summing and weighing' prediction of traditional rational theories by identifying and modeling simple step by step heuristic considerations that do not require complex or laborious computations.

Recent research from the fast and frugal perspective suggests that the best descriptive model of behavior in classic judgment under uncertainty tasks (i.e. gambles) is a model based on use of a *priority heuristic* (Brandstatter, Gigerenzer, & Hertwig, 2006). This heuristic carries the clear benefit of modeling both the actual majority behavior (descriptive model) and the specific decision making process (mechanistic process model). Specifically, the priority heuristic models decisions by predicting the order in which people consider reasons and decision factors (e.g. compare the minimum gains first) and also defining all stopping rules (e.g. stop if the difference is greater than 10% of the max. gain) for judgments under uncertainty (Brandstatter, Gigerenzer, & Hertwig, 2006). The priority heuristic is based on logical analyses and empirical evidence suggesting that in these tasks people tend to consider, in order (1) minimum gains, (2) probability of minimum gains, and (3) maximum gains. They further hypothesize that after each consideration is made, a decision rule may terminate the process if certain conditions are met. This decision rule is similar to Simon's satisficing parameter (1983; as cited in Brandstatter, et al.), and is defined by an aspiration level. For example, during a decision a participant will first consider the minimum possible gains relative to the maximum gain (i.e. select the larger minimum gain as long as the maximum gain is less than 10 times larger than the difference between minimum gains). If the process continues the probability of the minimum gain is next considered and the second stopping rule for probability evaluates and stops the process if the minimum gain probabilities differ by 10% or more. If neither stopping rule is initiated the maximum gain information will then be considered and a choice will be made such that the option with the highest possible gain is selected.

In a series of experiments, Brandstatter, Gigerenzer, and Hertwig (2006) tested the priority heuristic with uncommon success. Brandstatter, et al. show that with few free parameters and a relatively simple process they can account for the same data typically poorly predicted by multipart expected utility type theories or otherwise predicted by descriptive models such as prospect theory. In a number of competitions, the priority heuristic made novel predictions that other models did not predict and also outperformed more than a dozen other leading models, including original and cumulative prospect theories. For example, in one demonstration, using the original Kahneman and Tversky (1979) risk preference choice set, the priority heuristic predicted the majority choice for 100% of the problems (14 choice problems). Similarly, in other contests the priority heuristic was challenged to predict risk preferences in hundreds of choice problems (Lopes & Oden, 1999) with many different probability shapes (e.g. lowest gain larger than zero, all gains with same probabilities, extreme gains with high probabilities, large gains with low probabilities, etc.). In these cases, the priority heuristic predicted the majority response better than all other models, many of which were, at times, at chance performance levels. More generally, across four different competition sets, using large datasets from classic experiments, the priority heuristic averaged approximately 85% (range 75%-100%) correct prediction of majority choices, which was superior to all other models including prospect and cumulative prospect theories (range was chance to 90%).

The priority heuristic is impressive in that it predicts behavior quite well and yet also provides a simple process model of judgment and decision behavior. As such, this process model can be tested with process tracing methods, such as eye-tracking and verbal protocol analysis. However, in spite of the priority heuristic's demonstrated superior performance in terms of model fitting there are a number of potential limitations to consider. First, people do not always use the priority heuristic as reflected by the fact that it sometimes failed to predict majority decisions. Second, other research suggests that even majority decisions tend to reflect a variety of strategies and processes (Rettinger & Hastie 2001; 2003). Third, if the majority decisions are similar to those observed in Frederick's (2005) data, these choices will often reflect a rather narrow majority. Fourth, there is no process level data to support the priority heuristic's claims, with the exception of one reaction time study. Finally, it is unclear what the relationship is between the mechanisms of the priority heuristic and the more rational choice behavior predicted by cognitive ability instruments.

In the following set of experiments I will use a *strategic cognitive control approach* (Cokely, Kelley, & Gilchrist, 2006) to examine mechanisms of choice in a judgment under uncertainty task. I hypothesize that strategic control processes are mechanisms that contribute to more (and less) rational choices. Several related hypotheses and demonstrations over the last four decades suggest an influential role of strategic control variables in a wide range of abilities, laboratory tasks, and real world performances (Baron, 1985; Ericsson & Charness, 1994; Ericsson, Roring, & Nandagopal, accepted; Fernandez-Duque, Baird, & Posner, 2000; Flavell, 1979; Hertzog & Dunlosky, 2004; Kieras & Meyer, 2000; Meyer & Kieras, 1997; Sternberg, 1997; Williams, Blythe, White, Li, Gardner, Sternberg, 2002; Vigneau, Caissie, & Bors, 2006). However, I further hypothesize that the observed rational judgments under uncertainty result, at least in part, from *elaborative adaptive processes*. Adaptive processes are those that take into account our bounded rationality and other limited resources and thus tend to favor simple, fast, and frugal heuristics to facilitate judgment. In contrast to the alternative hypothesis which predicts that more able individuals will simply calculate expected values, I predict that rational choices will instead be the product of considering more aspects of each choice- using more and more varied fast and frugal heuristics.

To be specific, I hypothesize that elaborative adaptive processes are similar to the processes proposed by the priority heuristic but also include additional consideration cycles (e.g. consider minimum gains *and* probabilities *and* maximum gains), elaboration of different aspects of problems (e.g. note that the difference between potential gains could be considered a potential loss), and choice-aspect-recoding (e.g. considering a 70% chance of gain and recoding it as a 30% chance of no gain), among others. For example, making extra comparisons might help participants avoid overlooking other valuable information. Consider the fact that the priority heuristic often predicts that individuals make choices based on a single consideration, namely the relative difference between minimum gains (with respect to the maximum gain). However, this strategy becomes problematic if we examine trade-offs for choices involving high probability risky options, such as $100 gain for certain versus 99.9% of $800 gain. In this case, the priority heuristic predicts that participants would only consider the difference between the minimum gains ($100 v. 0) and would select the larger of the two because the maximum gain is relatively small (i.e. less than 10 times the difference). However, stopping at this point would cause participants to disregard the fact that the likelihood of the large gain is extremely high. In this case, the expected value (i.e. 799) is clearly much higher than the certain gain ($100) and thus the rational choice is to take the (slightly) risky choice. Failing to consider probability information will consistently yield non-rational choices.

A second potentially influential mechanism of elaborative adaptive processing may be the attenuation or opposition of the influence of choice framing effects. As noted, considerable research suggests that losses loom larger in decision making and thus we are more motivated, or at least act as if we are more motivated, to take risks in order to avoid losses (Kahneman, 2003; Levin, Schnieder, & Gaeth, 1998). I hypothesize that some individuals may engage in types of choice aspect elaboration and choice-aspect-recoding that cause changes in the framing of choices such that risk preferences become better aligned with rational choices. For example, consider a choice between $1000 for certain or a 90% chance to gain $4000. A participant who recodes the gamble to consider the difference in possible gains as a potential loss (i.e. if I take the $1000 I might be losing $3000) would reframe the problem in such a way as to make the risky, rational option more appealing in terms of prospect theory predictions. Similarly, simply recoding an 80% chance of a gain as a 20% chance to lose could also alter the influence of the initial frame. In these and other ways (Levin et al., 1998), more normative, rational choices may not be the result of what are traditionally considered rational processes (i.e. expected value computations). Instead, rational choices may result from simply engaging in more elaborative processing with adaptively tuned (simple, fast, and frugal) heuristics.

EXPERIMENT 1

The first experiment was designed as a conceptual replication and exploration of the previously observed individual differences in choice dynamics (Frederick, 2005). It was also designed to assess the contributions of adaptive processes to rational choices and examine the influence of specific math skills to rational choices. As well, it was designed to address a potential limitation of Frederick's study. Although CRT predicted overall rational choices in Frederick's data, these results may have been somewhat confounded with absolute wealth levels. Individuals from more elite, private and expensive universities tended to have much higher CRT scores. Thus, it may be that the CRT difference was not as important as differences in wealth. Therefore, this conceptual replication and extension was designed to allow for the assessment of the CRT under conditions to explore possible mechanisms in a more heterogeneous public university sample. Accordingly, participants were instructed to complete a number of cognitive ability, personality, and trait measurement instruments. Perhaps most importantly, participants were also instructed to make the series of judgments under uncertainty while thinking aloud. Frederick's set of choices was selected as it would allow model evaluations (competitions) across all choices for the priority heuristic and for a rational theory of choice, and more critically would enable model comparisons on a subset of specific trials for all three models of interest (prospect theory, priority heuristic, and the rational theory of choice).

My central hypothesis is that individual differences in elaborative adaptive strategies are related to rational choices. Therefore, I predict that the CRT would again show a positive relationship with rational choices and a negative relationship with prospect theory as in Frederick (2005). I hypothesize that this relationship reflects individuals' varying degrees of adaptive elaboration. However, I further predict that individual differences in a basic math skills task may account for unique variance in rational and prospect theory type choices. That is, individuals who lack the requisite math skills would be unable to compute expect values. Therefore, if rational choices are a product of expected value calculations a basic understanding of probability would be necessary for and may be related to rational choices. However, consistent with my hypothesis, I predict that the CRT will continue to account for variance beyond the math probability task, perhaps representing differences in elaborate adaptive processes. As well, to further test my hypothesis, I collected data on individual differences in a working memory span task. I chose this measure as my previous research (Cokely, Kelley, & Gilchrist, 2006) has suggested that working memory span specifically predicts elaborative memory encoding strategies. Because I hypothesize that some of the differences in rational choices results from differences in elaborative strategies, I predict that working memory span will also be positively related to rational choices and thus negatively related to choices predicted by prospect theory. Critically, I also predict that it will account for unique variance beyond math skills and perhaps beyond what is predicted by the CRT alone.

Because the CRT is a relatively new instrument its mechanisms and psychometric properties are not well understood. As part of an exploratory analysis, I tested the extent to which the relationship between choices and CRT scores were accounted for by other impulsivity measures. Specifically, I included measures of self-control and of the Big Five personality traits. It is possible that individuals who are, for example, more conscientious or who commonly exercise more self-control might also be more likely to engage in rational or elaborative adaptive processes (Baron, 1985). These differences might account for variance predicted by the CRT, working memory span, or basic math skills, or otherwise may predict unique variance in rational choices.

In order to more directly test process level predictions, Experiment 1 also collects concurrent verbal reports (i.e. participants think aloud while making choices). Given the explicit mechanisms proposed by the both the priority heuristic and the rational theory of choice, there are a number of testable predictions that are well suited to protocol analysis. For example, both rational and priority heuristic theories predict unique intermediate or final products that could be verbalized and would provide evidence against alternative models (e.g. the expected value product indicating rational processes; identifying 10% of the maximum gain indicating step one of the priority heuristic; identifying the difference in probabilities indicating step two of the priority heuristic). It is important to note that the absence of these products does not necessarily provide evidence for or against other models. However, the presence of these products, or the presence of verbalizations explicitly precluded by the models (e.g. consideration of the minimum versus maximum probabilities), can be unambiguously coded and will provide clear diagnostic evidence in favor of or against competing models.

Lastly, I further predict that the verbal reports will reveal evidence of the relationship between elaborative adaptive processes and more rational choices. These processes include strategies outlined by the priority heuristic (e.g. compare maximum gains, compare probabilities of gains) but as well are indicated when individuals consider more, and more varied, aspects of choices. Specifically, I predict that rational choices will be predicted by the number and types of verbalized considerations (e.g. probability, maximum gain, minimum gain, difference between gains/losses), and choice recoding operations (e.g. a 5% change of loss may be verbalized as a "95% chance of no loss"). As before, the absence of verbalizations does not necessarily indicate the absence of the processes, although the presence of other processes (i.e. expected value calculations) would be disconfirming evidence. To preview, concurrent verbal reports proved unrevealing in this study and thus a more detailed discussion of the proposed protocol analysis and coding schemes is saved for Experiment 2, which uses retrospective verbal reports.

Methods

Participants

Eighty-four undergraduate students from introductory psychology courses at Florida State University participated in partial fulfillment of course requirements and were tested individually.

Materials

Judgments under uncertainty. Following Frederick (2005), a randomized set of 18 gamble-type choice preference questions was presented to participants (see Frederick, 2005). These choice options were selected such that there was a blend of risky and sure choices with higher and lower expected values for gains as well as a number of choices with lower expected values for losses. Four critical trials were also initially constructed such that prospect theory and a rational theory of choice would make competing predictions and had the added benefit that the priority heuristic also made unique predictions (see Table 1). Across the entire set of choices both the priority heuristic and a rational theory of choice made unique and testable predictions. All problems possessed the same basic structure in which one sure gain/loss was compared to one risky gain/loss.

Cognitive Reflection Task (CRT). The CRT is a three question math task with deceptively intuitive, incorrect answers (Frederick, 2005). The CRT is known to be a predictor of general intellectual abilities. It is correlated with SAT scores, ACT scores, Need for Cognition scores, and the Wonderlic Personnel Test (i.e. a test of general intelligence widely used in personnel assessment). However, the CRT also predicts unique variance in intertemporal discounting rates, in that high CRT scores are associated with more normative discounting rates (Frederick, 2005). This difference is hypothesized to occur because the test measures not only differences in cognitive abilities but as well detects individual differences in participants tendency to use more intuitive (e.g. automatic) versus deliberative (controlled, analytical) processes during problem solving. Theoretically, the CRT is said to be a unique measure of cognitive impulsivity, or one's tendency to rely primarily on intuitive or deliberative processes.

Working Memory Span. The operation-span (OSPAN) task is used to assess individual differences in *working memory span*, or one's ability to simultaneously process and store information. The operation span task requires that participants alternate between verifying arithmetic questions (processing) and encoding to-be-remembered words (storage) across a number of trials of various lengths (2-5 operations per trial). Both math and memory accuracy are recorded for each trial. The working memory span score is calculated as the total number of words correctly recalled in order, for trials in which all words are recalled, so long as participants score at least 85% math accuracy. Theoretically, one's ability to both process and store information reflects one's capacity to actively maintain mental representations, control attention, or inhibit cognitive interference (Turner & Engle, 1989; Unsworth & Engle, in press). However, this task was selected primarily because other research also suggests that the operation span task predicts one's tendency to behave strategically such as using more elaborate encoding processes in a memory task, changing strategies in response to feedback, constructing better mental representations during learning, and considering multiple meanings during ambiguous sentence comprehension (Cokely, Kelley, & Gilchrist, 2006; Feldman-Barrett, Tugade, & Engle, 2004).

Slot Machine Probability Math Task. This six item math task was designed to assess whether participants possessed the necessary math skills required in order to compute rational choices (see Appendix B). The task asks participants to consider a number of slot-machines with explicitly defined pay-off rules. The slot machine rules and pay-off rates were selected as they were similar to choices in the judgment under uncertainty task. The task then requires that participants consider what the pay-off rate would be if they played a machine some exact number of times. The task ranges in difficulty from very simple problems (i.e. if it pays $100, 100% of the time, how much would you have after 5 games?) to moderately complex problems (i.e. if it pays $2000, 3% of the time, how much would you have after 100 games?) to the most complex problems (i.e. if it pays $2000, 3% of the time, how much would you have after 50 games). A participants' score is calculated as the proportion of problems answer correctly.

<u>Big Five Personality Inventory Short Form (BFSF).</u> The short-form Big Five personality questionnaire is a 10 item self-report instrument used to assess individual differences in stable personality factors including: extraversion (outgoingness), agreeableness, consciousness, neuroticism, and openness to experience. The instrument asks participants to use a seven point Likert scale to indicate how much they agree or disagree with statements such as "I see myself as enthusiastic, anxious, open to new experiences," and so on. The short-form of the instrument has been shown to correlate strongly with the full instrument (Gosling, Rentfrow, & Swann, 2003). Theoretically, each of the five broad personality factors that are measured are made of more specific traits. For example, and of note for the current study, the conscientiousness factor is argued to reflect one's self-regulation traits. Individuals who score low on this factor are argued to be more impulsive whereas a higher score reflects the habit of extensive and purposeful planning.

<u>Brief Self-Control Measure (BSCM).</u> The brief self-control instrument uses a 13 item self-report survey to assess individual differences in one's self-control habits and traits (Tangney, Baumeister, & Boone, 2004). Participants use a 5 point Likert scale to indicate the degree to which they agree with a variety of statements such as "I have a hard time breaking bad habits" or "I am able to work effectively toward long-term goals." The self control trait score is then computed by summing the total points, including several reverse scored items, for each participant. The instrument has been used to predict other survey-reported behaviors including reported grades, self-esteem, binge eating, alcohol use, and psychopathology, among others. Theoretically, this instrument reflects a number of traits including an individual's capacity for impulse control. The instrument is further argued to measure a self-control capacity that is independent of intelligence and yet, as some evidence suggests, contributes uniquely to some aptitude measures (i.e. university grades).

Procedure

All participants were individually tested by a single experimenter in a quiet, private room. The experimental session lasted on average approximately 50 minutes. Participants were first provided with an informed consent document and their basic demographic information was recorded, including their age, sex, and native language. Next, participants were instructed to wear a head-mounted microphone and were seated at a table facing a corner such that the experimenter and recording equipment were out of their view.

Verbal Report Instructions. Participants were told that "we are interested in knowing your thoughts as you come up with the answers to the problems in this experiment" and were given detailed instructions for providing concurrent think aloud verbal reports (see Appendix C). The instructions lasted on average approximately 10 minutes and included a number of examples and exercises designed to familiarize participants with thinking aloud and with the difference between thinking aloud and summarizing thoughts. Upon successfully completing at least 5 exercises, and based on the judgment of the experimenter, participants were told that they had completed their training and were asked if they had any final questions or concerns before they began the experiment. Finally, participants were informed that periodically, or if they ever became quiet, the experimenter would prompt them to "please think aloud," as a reminder.

Choices and Individual Differences. Following verbal report training, participants were given a questionnaire packet and were instructed to remember to think and read aloud until instructed otherwise. Participants first completed the CRT which was followed on a separate page with the randomized set of 18 choice questions. Participants next completed the math questionnaire and were instructed that they had completed all necessary verbal reports. Any unnecessary equipment was set aside. Participants next completed the operation span task on the computer, followed by the questionnaire short-form Big Five questionnaire and the Trait Self-Control instruments. Finally, participants were provided with a proof-of-participation and debriefing form.

Results and Discussion

An alpha level of .05 was used for all statistical tests. Following Brandstatter, Gigerenzer, and Hertwig (2006) a model competition was conducted for each of the 18 choice items. This analysis assessed the proportion of choices for which the majority choices were predicted by a rational theory of choice (M=.72) or by the priority heuristic (M=.33). Constraints of the problem set did not allow for a model competition test of prospect theory, except across critical trials. A non-parametric test of equal proportions indicated that the rational theory of choice predicted behavior significantly better than the priority heuristic, $\chi^2 = 5.46$, $p < .02$, $d = .9$. Binomial analysis indicated a trend in which the rational theory of choice showed a marginally-significant prediction of choices beyond chance (p=.10). An additional binomial analysis indicated that the priority heuristic did not significantly differ from chance (p>.20). These results contrast markedly with previous data and research on the accuracy of the priority heuristic and indicate that the priority heuristic is not likely the mechanism of majority choices for this problem set. Results further suggest that under some conditions the rational theory of choice may be a somewhat accurate descriptive model; however, results leave open the question of the mechanisms of rational choices.

Critical Trials and Individual Differences. Because I hypothesized that individual differences would influence judgment, additional planned analyses were designed to go beyond a simple comparison of majority judgments for each individual choice item (e.g. for choice one, what percentage of people made rational choices). Instead, in order to maximize power to detect individual differences, comparisons of the fit of each model were tested across all critical choices for each individual (e.g. how well did each participant's choices match a rational model). Specifically, I tested the models' predictions at the level of the individual such that each model received a *model-prediction-score* indicating the proportion of each participant's responses that were accurately predicted by each model (one score per model). One potential limitation of the proposed model-prediction-score analysis is that each accuracy score is not independent and is derived from the same dependent variable (i.e. same choices produce multiple model-prediction-scores). One other potential limitation is that each model-score is not necessarily normally distributed, a fact that is likely exaggerated due to the narrow range of responses (zero to four) in this small critical item set.

A repeated measures ANOVA omnibus analysis was used to test model accuracy on four critical trials and revealed significant differences in predictions among the three models, $F = (2, 166)\ 21.74$, $p < .001$, $\eta_p^2 = .21$. Subsequent pair-wise repeated measures analyses on critical trials indicated that prospect theory predicted participants' behavior (M=.57) significantly better than either the rational theory of choice ($M = .43$), $F\,(1,83) = 7.12$, $p < .01$, $\eta_p^2 = .08$, or the priority heuristic ($M = .29$), $F\,(1,83) = 72.40$, $p < .001$, $\eta_p^2 = .47$, although all models were essentially at or below chance performance (.50). Similarly, but again in contrast to previous research, the rational theory of choice also predicted critical choices significantly better than the priority heuristic on critical trials, $F\,(1, 83) = 12.24$, $p < .001$, $\eta_p^2 = .13$.

Additional analyses of four critical trials that allow for the comparison of each of the three models of interest, detected a significant positive correlation between CRT and rational choices, *r* (83) = .23 and thus a significant negative correlation between CRT and choices predicted by prospect theory *r* = (83) -.23. That is, the rational model and prospect model make the exact opposite predictions and thus will always be inversely correlated. No other significant relationships were detected (see Table 2), although working memory span exhibited trends in the predicted directions with a positive trend toward rational choices, *r* (83) = .18, *p* = .10, and a negative trend for choices predicted by prospect theory, *r* (83) = -.18, *p* = .10. Planned analyses next followed a common procedure for working memory research and split data into top and bottom quartiles (Kane & Engle, 2002). The extreme group span scores were split into the rough bottom (*N* = 16, *M* = 5.4, *Mdn* = 6, range = 4 to 7) and top quartiles (*N* = 18, *M* = 22.9, *Mdn* = 23, range = 18 to 37) such that no participant scores in the range of low or high groups would be excluded. As predicted, a univariate ANOVA revealed a significant effect of span (low, high) on rational choices, *F* (1,32) = 6.13, *p* < .02, $\eta_p^2 = .16$, such that high span participants exhibited significantly more rational choices (*M* = .53, *SD* = .23) than did low span participants (*M* = .31, *SD* = .28). As would be expected, a univariate ANOVA also revealed an effect of span (low, high) on prospect theory type choices, *F* = (1,32) = 6.13, *p* < .02, $\eta_p^2 = .16$, such that high span participants showed significantly fewer choices consistent with prospect theory (*M* = .47, *SD* = .23) as compared to low span participants (*M* = .69, *SD* = .28). These results indicate that the majority choices of higher ability individuals were rational choices, while the majority choices of lower ability individuals conform to prospect theory- a conceptual replication of Frederick (2005).

Next, a planned hierarchical multiple regression was used to test the extent to which math skills accounted for the relationship between other ability measures and rational or prospect theory type choices on the four critical trials. The regression equation was constructed with math as the first independent variable, followed by CRT and span and showed a significant relationship with rational choices, *F* (3, 80) = 2.73, *p* = .05. However, math scores failed to account for any unique variance $\beta = -.02$, *t* = -.21, *p* >.5. As predicted, CRT accounted for a significant amount of unique variance beyond math skill, $\beta = .24$, *t* = 2.23, *p* <.05, $R^2_{change} = .06$, and span exhibited a marginal relationship trend $\beta = .19$, *t* = 1.74, *p* <.10, $R^2_{change} = .04$. A second, redundant, hierarchical regression equation confirmed that the opposite relationship was true for math scores, CRT, and span scores as related to prospect theory.

To explore the extent to which these individual difference measures may have been redundant a subsequent stepwise multiple regression was conducted for the four critical trials. The planned analysis modeled rational choice as the dependent variable and math scores, CRT, span, Conscientiousness (from the Big Five), and trait self control as independent variables. Results revealed that CRT was the only consistent predictor of rational choices ($R^2 = .06$), although span was again marginally significant ($p < .10$, $R^2_{change} = .04$). As is expected, a second planned stepwise regression found the inverse relationship with the prospect theory choices.

The results of Experiment 1 suggest that the relationships between the CRT and rational or prospect theory choices are independent of all other tested variables, although some analyses indicate that working memory may contribute some unique variance beyond CRT. One potential limitation of these analyses is that the math skill scores were not normally distributed and showed some positive skew ($M = .47$, $= .28$, range = 0-100%, skewness = .4, Shapiro-Wilk's test of normality $W = .90$, $p <.05$). Moreover, it is possible that a restriction of range may have attenuated the observed correlations. However, this possibility seems less likely as fewer than 63% of participants were able to accurately solve even half of the six slot machine math questions. As well, there was no significant difference between the math scores of high ($M =.46$) and low span ($M =.42$) participants, and no significant relationship between math and CRT scores. An additional exploratory analysis was also conducted to examine the relationship between the math performance for the top ($M = .92$, $SD = .08$) and bottom ($M = .15$, $SD = .05$) quartiles and their relationship to rational choices. A univariate ANOVA indicated there was no significant difference in rational choices for the top ($M =.5$) or bottom ($M =.55$) math groups, F (1,40) < 1. These results suggest that many rational choices were made by individuals who were likely unable to calculate expected values. That is, consistent with my hypothesis, the results indicate that most participants, including high CRT and high rationality individuals, did not achieve rational choices through rational processes (i.e. expected value calculations).

One final limitation of the current study is that the transcription and analysis of the concurrent verbal reports proved unrevealing. Nearly all of the participants verbalized only their choice options and their subsequent choices. For this reason, formal protocol analysis was unable to inform or test any process model predictions.

In summary, across all 18 choice trials the rational theory of choice showed a marginally significant ability to predict choices beyond chance and was significantly better than the priority heuristic. The results are similar to those expected following a reanalysis of Frederick (2005). However, these results must be interpreted somewhat cautiously as the choice set was composed of nearly 70% gain choices. This asymmetry in the choice set may have over or underestimated the accuracy of each model such that priority heuristic may have done much better and rational theory much worse for losses. However, in subsequent analyses this limitation was to some extent avoided by examining only more balanced critical trials. The critical item analyses of Experiment 1 indicated that prospect theory significantly outperformed both priority heuristic and rational choice models on critical trials, although all models generally perform numerically around or below chance levels (50%). These results are qualified by the finding of individual differences in rational and prospect theory related choices as a function of cognitive ability measures (CRT and working memory). The majority of higher scoring individuals are more likely to conform to rational standards while the majority of lower scoring individuals tend to follow prospect theory. In all cases, these data depart from recent findings demonstrating the often remarkable accuracy of the priority heuristic. Indeed, the priority heuristic was uniformly the poorest performing model. However, consistent with the adaptive theory that serves as a theoretical basis for the priority heuristic, the Experiment 1 results indicate that rational choices, and the associated individual differences in rational choices, were not likely the product of rational processes (expected value calculations). Because most participants lacked the requisite math abilities, including high CRT and working memory span groups, these results suggest that other mechanisms, perhaps including elaborative adaptive processes, may at least in part give rise to the rational choices.

EXPERIMENT 2

Experiment 2 was designed to further examine the mechanisms of choice, particularly rational choice, and to test the elaborative adaptive strategy hypothesis. Experiment 1 indicated that cognitive ability measures reliably predicted rational choices. However, the probability math skills test indicated that the mechanism of the rational choice was not likely expected value calculation as the vast majority of individuals lacked the math skills to compute expected value; although the concurrent reports proved unrevealing and thus there was little converging evidence to support the elaborative adaptive strategy hypothesis. Therefore, the primary aims of Experiment 2 were to replicate Experiment 1 results using materials with fewer limitations and to extend this work by providing more converging evidence of the exact mechanism of rational choice via the collection of reaction times and retrospective verbal reports. As well, Experiment 2 allowed for additional assessments of the other process model, priority heuristic. Accordingly, participants were again asked to complete a number of cognitive ability measures and make a series of judgments under uncertainty. As well, a new choice set was developed in order to provide a thoroughly balanced choice set. The choice set drew on previous research (Frederick, 2005) but was also expanded to include a greater balanced number of higher and lower expected values options for both gains and losses (see Appendix G). The set was also designed such that it was relatively balanced with respect to a number of other key aspects, such as the relationship between risky and rational choices and the number of operations predicted by the priority heuristic. As in Experiment I, I predict a positive relationship between ability measures (CRT, Span) and rational choices and hypothesize that this difference will reflect, at least in part, differences in elaborative adaptive processes.

Another prediction of the elaborative adaptive process hypothesis, one that contrasts with the priority heuristic, is that reaction times may be different for rational versus non-rational choices. Because I hypothesize that rational choices are more likely to result from more elaborative considerations I predict that rational choices may on average take longer. While this evidence would only be correlational it would provide further converging support for the notion that rational choices tend to reflect more time consuming operations (e.g. multiple processes). The analysis of the reaction time data will also provide an additional test of the accuracy of the priority heuristic. The priority heuristic specifically defines the number of operations required to make certain choices predicting that reaction time should be shorter on choices that theoretically only involve one consideration (difference of minimum gain relative to maximum gain) as opposed to choices that involve the maximum number of considerations. In contrast, I predict that reaction time will not be related to the priority heuristic choice type because I hypothesize although individuals use adaptive processes they are not necessarily those defined by the priority heuristic.

To further examine the types of considerations participants make, I also collected retrospective verbal reports (Ericsson & Simon, 1980; 1993) in order to more exactly identify and trace choice processes. To review, in Experiment 1, concurrent verbal reports proved unrevealing. However, after the completion of Experiment 1, I conducted pilot testing on 16 participants. During these pilot experiments, using Experiment 1 choice sets, I compared concurrent and retrospective verbal instructions (see Appendix D), and also tested a thought listing method previously used for related research (Rettinger & Hastie, 2001; 2003). As before, concurrent reports were for the most part unrevealing. However, retrospective reports consistently produced more detailed verbal reports. As expected, these verbalizations appeared to preserve the order of participants' thoughts, when compared with the limited information produced during concurrent verbalizations (i.e. a few participants, on a few problems, generated similar concurrent and retrospective reports). To test and compare this method with the thought listing manipulation of Rettinger & Hastie (2001), I also asked participants to "try to [say] a list of rules or procedures that you could tell to someone else so that they would think about the choice the same way you did and reach the same conclusion about what to do." Although this procedure led to the greatest number of verbalized reasons some of the verbalizations or subsequent comments suggested that the task may have been reactive. For example, several participants noted that they "felt more confident" in their decision following thought listing because they had elaborated on their reasoning. As well, some noted that they felt they were generating more information about the choice following their initial decision. For these reasons, I propose that the retrospective verbal reports are likely to be the best source of process information for this choice set.

As described in Experiment 1, verbal reports are well suited to protocol analysis and hypothesis testing in a number of ways. Critically, all process models predict that participants should consider a variety of intermediate or final products when making their choices. For example, verbalization of an expected value is clear evidence for a process proposed by the rational theory of choice. Similarly, verbalization of 10% of the maximum gain is uniquely predicted by the priority heuristic. As well, the priority heuristic predicts that participants will, on specific trials, consider (or fail to consider) probabilities of minimum or maximum gains. These processes can be unambiguously coded and will provide another uniquely diagnostic indicator of process model accuracy.

Finally, I predict that verbal reports will reveal a difference in the number of adaptive considerations made for rational versus non-rational choices. As noted, I hypothesize that a mechanism of rational choice is the consideration of more, simple aspects of the problem such as recoding probabilities (30% chance is 70% no chance; see Appendix E for the exact coding scheme and Appendix F for sample analysis). However, because the verbal reports will be retrospective, some care must be taken to avoid coding participants' simple restatement of each problem. Therefore, coding will reflect and count only processes that clearly go beyond the basic problem (e.g. recoding probabilities, comparing maximum gains). This should not present any issues for most of the to-be-coded items (e.g. expected value calculations) but may obscure the analysis of other processes. For example, one potential limit may come from coding whether participants are considering probability for the priority heuristic or simply restating the problem. While this approach may limit the power to detect some processes, it has been designed to be conservative with regard to evidence that would reject other models. Again, only processes that clearly go beyond the basic problem structure will be identified and coded.

Methods

Participants

Eighty undergraduate students from introductory psychology courses at Florida State University participated in partial fulfillment of course requirements and were tested individually. Four participant's CRT scores were excluded because participants indicated they had seen the test before either in another experiment or as part of a classroom exercise. Four other participants did not receive operation span scores because of equipment failure or experimenter error. Two participants' verbal reports were lost due to equipment failure. Whenever possible, or except when otherwise noted, analyses included the maximum number of participants (e.g. 76 participants were available analysis of the relationship between CRT and choices).

Materials

Following Experiment 1, the experiment included both the operation span and the CRT. However, unlike Experiment 1 all choice and CRT data was collected via an automated computer program. This program was also designed such that it allowed for the collection of reaction times and precisely controlled the presentation rate and order of each choice on every trial.

Judgments Under Uncertainty. The stimuli included 40 choice problems and was constructed following an informal analysis of Frederick's (2005) choices. Specifically, the choice sets were designed to allow both priority heuristic and a rational theory of choice to make competing unique predictions across a number of dimensions. Specifically, the choice set was balanced wherein each theory made unique predictions on exactly half of the predicted choices and such that half of each of these predictions indicated a risky choice. All choice values were designed to be presented twice; once as a loss and once as a gain. Rational choices that required the selection of a risky option occurred equally often for gains and loses. However, one unavoidable issue is that the predicted priority heuristic choices are asymmetric with respect to gains and losses as the priority heuristic is designed to reflect to some extent the selection of more risky choices for losses than gains, following the predictions of prospect theory.

The choice set was also constructed such that the priority heuristic predicts that 60% of choices will involve only a single consideration (consider minimum gains relative to maximum gains) while the other 40% of trials require multiple processes. This allows for tests of the process model predictions via reaction time and protocol analysis. As well, a number of choices were constructed by multiplying choice gain or loss values by a constant (e.g. .80). This allowed for the presentation of a variety of functionally equivalent but numerically different choices values in each order ($300 gain versus 50% chance of $2000 gain; $240 gain versus 50% chance of $1600). Finally, for all questions risky option probabilities range from 1%-80%.

Procedure

All participants were individually tested by a single experimenter in a quiet, private room. The experimental session lasted on average approximately 50 minutes. As in Experiment 1, all participants were first provided with an informed consent document and their basic demographic information was recorded. Next, participants were instructed to wear a head-mounted microphone and were seated at a computer facing the wall such that the experimenter and recording equipment were largely out of their view.

Verbal Report Instructions. Verbal report instructions were similar to those described in Experiment 1, except that participants were further trained to provide retrospective verbal reports (described as memory reports; see Appendix D). Again, participants were told that "we are interested in knowing your thoughts as you come up with the answers to the problems in this experiment" and were given other detailed instructions as in Experiment 1. Additionally, participants were subsequently told the following:

> "Sometimes, people have more thoughts, or more complicated thoughts, than they can comfortably say out loud when they are thinking. We want to hear those thoughts as well. To do this, we will sometimes ask you to remember the thoughts you had in the exact order you had them in. This is called a memory report. During a memory report, *never guess* what you might have been thinking about, or what you could have been thinking about. Instead, we want you to say out loud the exact thoughts you are confident that you remember thinking, in order."

The full instructions and practices problems required on average approximately 10 minutes (see Appendix D). Upon successfully completing the required exercises, and based on the judgment of the experimenter, participants were told that they had completed their training and were asked if they had any final questions or concerns before they begin the experiment.

Choices and Individual Differences. Following verbal report training, the experimenter initiated the computer program and remained seated and quiet, behind the participant. Participants then completed a computerized version of the CRT task. Next, the experiment started by describing an example choice designed to familiarize participants with the process. Following the example, the experimenter asked the participant if they understood the instructions and if they had any other questions. Participants were next told that the experiment required that they make 40 similar choices and upon cuing that they provide retrospective reports. Following any final questions, participants began making choices. Each choice option was presented on the screen in either position 'a' (on the top-half of the screen) or position 'b' (around the center of the screen). These options remained on the screen until the participant had made his or her selection. Importantly, each option was presented one at a time from top to bottom such that the first option was always displayed at the top of the screen 2 seconds before the second option appeared. At the bottom of the screen a small box appeared wherein participants were instructed to type their answer (a or b) and press enter when finished. Following participants' answer selection the problem information disappeared and participants were prompted to provide a retrospective report. After all 40 trials had been completed each participant was thanked for his or her participation and was informed that verbal reports were no longer needed. All unnecessary equipment was removed and participants completed the operation span and were debriefed as described in Experiment 1.

Results and Discussion

An alpha level of .05 was used for all statistical tests. Following Brandstatter, Gigerenzer, and Hertwig (2006) a model competition was conducted for each of the 40 choice trial types. This analysis assessed the accuracy and frequency with which each model predicted the majority choices. Binomial analysis indicated that the rational theory of choice predicted majority choices significantly better than chance ($M = .83$, $p < .001$). The predictive reliability of the rational model's accuracy held for both gain ($M = .80$, $p = .01$) and loss problems ($M = .85$, $p < .01$). However, in contrast to previous research, binomial analyses also indicated that the priority heuristic did not perform better than chance ($M = .45$, $p > .5$). A non-parametric test of equal proportions indicated that the rational theory of choice also significantly outperformed the priority heuristic $\chi^2 = 12.17$, $p = .001$, $d = 1.3$. Therefore, as in Experiment 1, the rational model significantly outperformed the priority heuristic at the descriptive level.

Priority Heuristic Model Performance. Because individual differences are hypothesized to influence judgment, planned analyses examined the model prediction accuracy for each participant. Unless otherwise noted, all subsequent analyses compared the model prediction scores averaged across all choices for each individual (i.e. how well did each participant's choices match the model's prediction, averaging across all of the participant's choices) as outlined in Experiment 1. A one sample *t* test indicated that priority heuristic was significantly less accurate in predicting participant choices ($M = .42$, $SD = .09$) as compared to chance, t (79) = -7.40, $p < .001$, $d = .9$. As observed in the more traditional model competitions and in Experiment 1, the priority heuristic performed very poorly. Finally, priority heuristic accuracy was not significantly correlated with either span or CRT ability measures ($p > .20$). These data suggests that the priority heuristic is not always an accurate descriptive model.

In order to better assess the priority heuristic as a process model, planned analyses were conducted to examine predicted differences in reaction time for theoretically identified *one reason* versus *three reason* choice types. A univariate ANOVA on reaction times indicated a significant difference for choice types (one reason, three reason), *F* (1, 3151) = 19.63, *p* < .001, screening only problems accidentally omitted by the participants (e.g. pressing enter twice), wherein, in contrast to previous research, theoretical one reason choices showed longer reaction times (*M* = 13.3sec, *SD* = 9.82sec) as compared to theoretical three reason trials (*M* = 11.79sec, *SD* = 9.16sec). Next, in order to screen for potential outliers, a common screening procedure was used. First, an initial filter based on a visual inspection of reaction time distributions excluded reaction times that were faster than 300ms or slower that 40sec and a standard deviation was calculated for each choice type (one reason, three reasons). All scores that were more than two standard deviations from the mean were then excluded. For priority heuristic choices, the screening resulted in the exclusion of 8.65% of all reaction time data. A univariate ANOVA again indicated a small but highly reliable difference in reaction times, *F* (1, 2921) = 16.17, *p* < .001, *d* = .15. However, in contrast to priority heuristic model predictions, theoretical one reason choices showed significantly longer reaction times (*M* = 10.91 sec, *SD* = 5.28 sec) when compared to three reason choices (*M* = 10.10 sec, *SD* = 5.52 sec). Of note, reaction time may not have been effectively tested in this experiment as people were not aware that reaction time was being collected and were never instructed to make their choices as soon as they had decided.

Finally, to preview information from subsequent protocol analyses, key comparisons (i.e. considering the difference in minimum gains relative to the maximum gain) that were theoretically predicted on 100% of all trials were reported only 19 times on about .5% of all problems. In contrast, more than 4000 other instances of a variety of comparisons were verbalized across all choice problems. This suggests a clear limitation for the priority heuristic account of the majority choice process. More generally, all data provide converging evidence indicating limits for the priority heuristic and suggesting it is not necessarily an accurate process or descriptive model of choice.

Rational Choice Model Performance. Following the procedures for analyses described in the priority heuristic section and Experiment 1, all subsequent analyses compare the model prediction scores of all choices for each individual. A one sample *t* test indicated that the rational theory of choice was reliably more accurate in predicting participant choices (*M* = .72, *SD* = .12) as compared to chance, t (79) = 16.02, $p < .001$, $d = 2.0$. A repeated measures ANOVA also indicated that the rational theory of choice accuracy was dramatically superior to that of the priority heuristic, F (1, 79) = 428.95, $p < .001$, $\eta_p^2 = .84$. These analyses replicate findings from Experiment 1, and are similar to findings observed with the previously presented, more traditional, model competition analyses.

Planned analyses next assessed whether reaction time differed for rational versus non-rational choices. A univariate ANOVA failed to detect a significant difference F (1, 3151) = 3.11, $p > .05$, screening only trails omitted by the participants, wherein rational choices did not reliably differ (*M* = 13.20 sec, *SD* = 9.85 sec) compared to non-rational choices (*M* = 12.53 sec, *SD* = 9.16 sec). Next, the following procedure was used to screen for possible outliers: An initial filter based on a visual inspection of reaction time distributions excluded reaction times that were faster than 300ms or slower that 40sec and a standard deviation was calculated for each choice type (rational, non-rational). All scores that were more than two standard deviations from the mean were then excluded. For rational choices, the screening resulted in the exclusion of 7.66% of all reaction time data. A univariate ANOVA again indicated no reliable difference in reaction times, F (1, 2953) < 1. That is, reaction time for non-rational choices was not reliably different (*M* = 10.80 sec, *SD* = 5.57 sec) from reaction time for rational choices (*M* = 10.94 sec, *SD* = 5.95 sec). Therefore, in contrast to my initial prediction reaction time did not differ as a function of choice type (rational, non-rational). However, a number of factors may have influenced the sensitivity of the test. For example, sensitivity is limited because a high proportion of rational choices (50%) would for some individuals reflect simple chance or guessing processes. As well, because participants were unaware of any need to report their responses promptly other factors such as between subject variability resulting from differences providing partial concurrent verbal reports, reading part of the question aloud, or starting retrospective reports before pressing enter (for any subset of the questions) may obscure effects. To preview, however, reaction time is strongly related to individual differences and to the overall number of considerations verbalized in retrospective protocols. Importantly, these considerations and individuals differences in turn predict rational choices.

<u>Rational Choices and Individual Differences.</u> Planned analyses next examined the relationship between individual difference measures and rational choices. As predicted, CRT was

significantly related to rational choices, *r* (75) = .27, although operation span was not reliably related to rational choices, *r* (75) = .16, *p* <.20. Planned analyses also followed the common procedure for working memory research and split data into top and bottom quartiles (Kane & Engle, 2002). The extreme group span scores were split into the rough bottom (*N* = 21, *M* = 6.86, *Mdn* = 7, range = 2 to 9) and top quartiles (*N* = 18, *M* = 22.7, *Mdn* = 21, range = 17 to 28) such that no participant scores in the range of low or high groups would be excluded. A mixed model ANOVA of risk type (sure, risky) by choice type (gain, loss) by span quartile (low, high) examined rational model predictions (Table 3). ANOVA analysis revealed a main effect of risk type, *F* (1, 36) = 23.56, *p* = .001, η_p^2 = .30 indicating an overall bias toward sure choices (*M* = .83, *SD* = .16) as compared to risky choices (*M* = .66, *SD* = .23) for both gains and losses. As predicted, high and low span participants differed in their overall rational choices, *F* (1, 36) = 7.70, *p* = .01, η_p^2 = .18, such that high span participants made significantly more rational choices (*M* = .79, *SD* = .13) as compared to low span participants (*M* = .70, *SD* = .10), replicating Experiment 1. This difference was qualified by a marginally significant span (low, high) by choice type (gain, loss) interaction, *F* (1, 36) = 3.41, *p* = .07, η_p^2 = .09. A subsequent set of univariate ANOVA analyses indicated that high span participants showed no reliable rational choice asymmetry (*F* < 1) for gains (*M* = .79, *SD* = .13) and losses (*M* = .79, *SD* = .13), whereas low span participants showed a large asymmetry in rational choices, *F* (1, 20) = 6.96, *p* = .02, η_p^2 = .26, for gains (*M* = .73, *SD* = .14) and losses (*M* = .66, *SD* = .09).

Protocol Analysis. All verbal reports were first transcribed verbatim and a random subset of data (5%) was transcribed twice and compared at the item level as an accuracy check. Protocols were next coded according to the scheme detailed in Appendix E. The key codes included the overall frequency and type of considerations, such as verbalized adaptive or general considerations, expected value (EV) calculations, and other or unclear considerations. A randomly selected subset of verbal reports from 10 participants (12.5% of all data) were coded by a second rater and tested for inter-rater reliability. The overall agreement of absolute frequencies of considerations per participant was highly correlated, *r* (9) = .97, *p* < .01. Seven participants were excluded from all subsequent analyses because at least half of their protocols were unrevealing and could not be coded (e.g. I picked A because it was better; B was more appealing). Coded frequencies of considerations and type of consideration were next used to test each of the models of interest.

The frequency of verbalized expected value calculations was summed and correlated with rational choices. As expected, the frequency of verbal reports that included expected value calculations was significantly related to rational choices, r (77) = .26. This relationship appears to be driven primarily by the fact that three (4%) of the individuals used expected value calculations nearly exclusively (range 38 to 40 times across 40 problems) and thus achieved high rationality scores. Of note, expected value was coded so as to err on the side of maximal sensitivity in terms of EV detection. This included coding EV verbalizations as anything that resembled or otherwise included necessary and potential intermediate products of expected value calculations (e.g. well odds are 50/50 and half of option A is less that option B). In spite of this conservative approach, 55% of all participants never verbalized anything consistent with expected value (EV) predictions. Moreover, 90% of all participants expressed fewer than three verbalizations that could be coded as expected value type calculations and instead verbalized other choice aspect comparisons for the vast majority of trials. As well, EV calculations were not significantly related to any of the individual difference variables ($p > .5$). These data provide clear evidence indicating that rational processes do not likely account for individual differences in rational choices. Moreover, they indicate that simple comparisons and processes traditionally considered to be non-rational, under certain conditions, can produce rational choices.

The next set of analyses more directly tested the elaborative adaptive strategy hypothesis. The first analysis examined the relationship between the absolute frequency of (non-EV) choice considerations (e.g. recoding probabilities, considering absolute value, considering maximum differences) and rational choices. As predicted, the number of choice considerations for each person summed over 40 problems was reliably, linearly related to the proportion of rational choices, $\beta = .37$, $t = 3.31$, $p < .001$, $R^2 = .14$. Next, planned analyses excluded the three participants who were identified as using EV nearly exclusively. A new regression was constructed and revealed a strong relationship between number of non-EV considerations and proportion of rational choices, $\beta = .60$, $t = 15.90$, $p < .001$, $R^2 = .36$. Moreover, the number of considerations was also strongly related to mean reaction time per problem for each participant, r (67) = .46, $p < .001$. The finding of a relationship between reaction time and number of coded consideration suggests that individuals who took longer to select a choice likely did so as a result of making more considerations. This also provides converging evidence of protocol reliability as participants who reported more considerations would be expected to require more time to make their final choices.

Next, the relationships between ability measures, rational choices, and number of considerations was assessed. Again the three individuals who were identified as using EV calculations were excluded. As predicted, CRT was significantly related to the number of verbalized considerations, r (67) = .30, as was span, r (67) = .27. A univariate ANOVA further indicated that span quartile groups (low, high) differed in their overall number of considerations F (1, 29) = 4.55, $p < .05$, $\eta_p^2 = .14$. Low spans verbalized significantly fewer considerations (M = 47.56, SD = 14.56) than did high spans (M = 60.80, SD = 20.79). These findings, along with the observed relationship between number of considerations and rational choices, are consistent with the hypothesis that individual differences in elaborative adaptive processes may mediate the relationship between abilities and rational choices.

In order to more directly assess the contributions of different strategies, processes, and abilities, a series of hierarchical linear regression models were constructed and analyzed. The first model used verbalized EV calculations as an independent variable and significantly predicted rational choices, F (1, 69) = 4.628, $p < .05$, $R^2 = .06$. The second model was constructed to predict rational choices with reported EV calculations as the first independent variable and CRT and span as the second set of independent variables. This model was also a significant predictor of rational choices, F (3, 66) = 3.93, $p < .05$, $R^2 = .15$. As expected, the model including CRT and span accounted for unique variance beyond reported EV calculations, F (2, 66) = 3.41, $p < .05$, $R^2_{change} = .09$, and did not mediate the relationship between reported EV calculations and rational choices, $\beta = .26$, $t = 2.29$, $p < .05$. Finally, a third model was constructed to predict rational choices with reported EV calculations as the first independent variable, CRT and span as the second set of independent variables, and verbalized choice considerations as the third independent variable. This model was a reliable and strong predictor of rational choices, F (4, 65) = 7.16, $p < .001$, $R^2 = .31$. Moreover, the number of consideration verbalized accounted for unique variance beyond all other independent variables, $\beta = 46$, $t = 3.8$, $p < .001$, $R^2_{change} = .15$. That is, as predicted by an elaborative adaptive hypothesis, rational choices are uniquely predicted by the number of verbalized choice aspect considerations. Critically, the number of considerations verbalized also fully mediated the rational choice and CRT relationship, $\beta = .14$, $t = 1.4$, $p > .20$, and span relationship, $\beta = .05$, $t < 1$, $p > .20$.

Critically, this provides further clear, converging support for the hypothesis that individual differences in rational choice that are predicted by cognitive ability measures also result from differences in the use of elaborative adaptive processes.

In review, Experiment 2 allowed for a higher fidelity assessment of the exact cognitive processes that were used for judgment under uncertainty. Protocol analysis indicated that about 4% of the sample consistently achieved rational choices through reliance on expected value calculations, although the vast majority of individuals relied on simple considerations. The observed simple considerations are similar to those theoretically predicted by the priority heuristic; however, in sharp contrast to the predictions of the priority heuristic there was consistent evidence suggesting that participants very rarely used any of the exact priority heuristic comparisons (i.e. compare difference in minimum gains relative to maximum gain). Moreover, the priority heuristic proved very poor at predicting majority choices at the individual and item levels (i.e. descriptive modeling). In contrast, the rational theory of choice consistently outperformed both priority heuristic and chance models. In summary, the Experiment 2 results clearly supported the adaptive process framework that serves as a basis for the priority heuristic, but casts doubt on the accuracy or generalizability of the priority heuristic as a descriptive and process model. Instead, the result of Experiment 2 provided considerable converging evidence for the hypothesis that elaborative adaptive processes are mechanisms of rational choices. These mechanisms not only uniquely predicted differences in rational choices they also fully mediated the relationship between rational choices and cognitive abilities. Individuals who make more and more varied considerations are much more likely to make normatively superior, rational judgments under uncertainty.

GENERAL DISCUSSION

What are the sources of superior judgment under uncertainty? In a series of two studies, I tested the hypothesis that individual differences in rational choices, including the cognitive ability and rational choice relationship, result from elaborative adaptive strategies. Specifically, Experiments 1 and 2 demonstrated that normatively superior, rational choices often result from the use of more and more varied simple heuristic comparisons. These experiments provided a variety of converging evidence in support of the elaborative adaptive processes hypothesis, and indicated that the mechanisms of majority choices are similar to those predicted by the priority heuristic. Indeed, there was consistent evidence suggesting that at most a very small portion of either sample used what are traditionally considered rational processes, namely expected value calculations, to achieve rational choices. However, in contrast to previous priority heuristic research and theory, the priority heuristic predictions consistently underperformed other models and were below chance level accuracy. These experiments indicate that participants routinely use a variety of simple heuristic comparisons to make choices and that those individuals who use more elaborative heuristic considerations tend to make more normatively superior, rational choices.

In Experiment 1, a conceptual replication of Frederick's (2005) research, I tested whether the cognitive ability and rational choice relationship was mediated by differences in specific math skills and examined the influence of general conscientiousness and self-control tendencies. The results of Experiment 1 replicated the finding that cognitive abilities, including the otherwise yet to be tested working memory capacity measures, predict rational choices. Indeed, these ability measures were the only reliable predictors of rational choices and were negatively related to choice behavior predicted by prospect theory. The results also revealed that other specific personality or self-control traits were unrelated to both rational choices and cognitive abilities. Perhaps most critically, the results indicated that the mechanisms of rational choices were not rational, expected value calculations. That is, the majority of participants failed at least half of a slot machine math test that was designed to approximate the types of calculations required for accurately executing expected value calculations. Moreover, scores on the math test were also unrelated to rational choices such that even high specific (probability) math ability individuals were no more likely to achieve high rationality scores than low math skill individuals. These results suggest that the rational choices made by high ability individuals, as well as others, are not likely the result of rational processes, a finding further supported by evidence from a series of hierarchical regression models. In these and other ways, the results of Experiment 1 supported the elaborative adaptive strategy hypothesis, although converging evidence was unavailable as concurrent verbal reports proved unrevealing.

Experiment 2 was designed to allow for additional tests of the elaborative adaptive strategy hypothesis. Again, I examined the relationship between participant choices and cognitive abilities; however, a central aim of the experiment was to avoid some of the limitations of Experiment 1. Toward this end, Experiment 2 included a larger better balanced choice set and following extensive pilot testing included the collection and analysis of retrospective verbal reports. Critically, protocol analysis revealed a very strong relationship between the total number of considerations a participant verbalized and his or her overall rationality score. Subsequent hierarchical linear modeling indicated that these considerations predicted a moderate to large amount of unique variance but as well completely mediated the relationship between cognitive abilities and rational choices. That is, after controlling for the number of heuristic considerations verbalized, cognitive abilities no longer reliably predicted differences in rational choices. Furthermore, other converging evidence supports the elaborative adaptive strategy hypothesis such as the fact that ability scores and number of considerations verbalized were positively related to reaction time. As well, protocol analysis revealed that less than four percent of the sample (three participants) regularly calculated expected values and instead the vast majority of participants verbalized simple heuristic comparisons. These results further confirm the elaborative adaptive strategy hypothesis and suggest a number of theoretical implications for individual differences and superior judgment under uncertainty.

Cognitive Abilities, Cognitive Control, and Superior Judgment. As noted, Frederick (2005) and Kahneman (2003) have both suggested that individual differences in choice predicted by cognitive ability measures are likely to reflect differences in deliberative processes that work to correct or alter more automatic intuitions. Similarly, another leading account of cognitive ability differences in judgment under uncertainty draws on the *cognitive styles framework* (Baron 1979; 1985; 1990; Stanovich & West, 1998; 2002). This framework suggests that rational decision-making and generally intelligent thinking often require deliberative, intentional strategies. Baron and others have argued that some of the high abilities advantages evidenced in judgments are related to a cognitive style that emphasizes *reflectiveness* (Baron, 1985; 1990).

This general style is abstract enough to be applied in a variety of situations and thus can act as a basis for non-specific transfer, or general abilities.

The clearest evidence supporting the views of Stanovich and West (2000), and Baron (1985), comes from a battery of cognitive styles included in what is to date the largest analysis of cognitive abilities, heuristic and reasoning (Stanovich and West, 1998; 2000). Specifically, Stanovich and West used a correlational, factor analytic approach in an attempt to clarify contributions of more basic abilities (i.e. biological and computational constraints) and those of cognitive style (e.g. metacognitive processes) across nearly a dozen categories of judgment and reasoning tasks. Stanovich and West's (1998) data provide some support for the notion that cognitive style factors contribute to superior judgment and decision-making yet there are several limitations of their data, perhaps the most noteworthy of which is methodological. That is, the cognitive styles evidence rests on the assumption that the self-report questions that were collected (e.g. it is better to simplify; even if I had a different family my views would be the same; I always put forth my best effort; changing your mind is a sign of weakness) accurately measured the variability associated with differences in metacognitive and strategic mechanisms. While the evidence indicates that the style scales did explain a small amount of unique variance in rational choices, results could not confirm construct validity. Critically, the results of the current set of experiments indicate that Stanovich and West's scales may have missed strategic variation in decision making processes that may have otherwise mediated at least in part the relationship between rational choices and cognitive abilities.

Generally, the evidence from Experiments 1 and 2 are consistent with and supports to some extent Stanovich and West's (1998; 2000), and Baron's (1985), theory. However, one key difference between the reflectiveness concept and my elaborative adaptive strategy hypothesis is that the reflectiveness hypothesis posits that short-term performance is relatively fixed (Stanovich and West, 1998) because many of the key capacities that enable reflectiveness (e.g. speed of processing, working memory) cannot be rapidly changed. In contrast, the result of Experiment 1 and 2 indicate that most choices, including rational choices, may result in from simple considerations. To speculate, these considerations appear simple enough as to be accessible to most participants (i.e. "$5000 is a lot more than $200 and 50/50 is like a coin flip"). That is, when more elaborative processing is used performance may become more rational simply as result of the attenuation of framing effects or otherwise noticing other highly relevant information. Thus performance may be markedly improved despite the fact that basic capacities may remain unchanged. More generally, a growing literature further suggests that strategic process differences can *functionally* alter cognitive dynamics and performance parameters and significantly relate to or cause performance (Cokely, Kelley, & Gilchrist, in press; Cowan, 1988; Cowan, Elliot, Saults, Morey, Mattox, Hismajtullina, & Conway, 2005; Logie, Della Sala, Laiacona, Chalmers, & Wynn, 1996; McNamera & Scott, 2001). In at least some cases, strategic control factors may act together with knowledge, skill, or other theoretical capacity variables to give rise to functionally superior abilities and task performance.

<u>Mechanisms of Cognitive Control.</u> Research has yielded considerable data and theory describing a variety of dual process models and modes of thought (Jacoby & Kelley, 1992; Moskowitz, Skurnik, & Galinsky, 1999; Sloman, 1996). Common to many of these frameworks is the idea that cognition involves multiple, often largely parallel processes such that one mode is principally automatic while the other is subjectively controlled (Kahneman, 2003). The consideration of the interplay of these automatic and controlled processes has proven useful in organizing a number of seemingly contradictory findings in a variety of areas including and beyond the judgment and choice literature (for review see Sloman 1996; but see also Epstein, 1994; Stanovich and West, 2002). To illustrate in the domain of decision making, Kahneman argues that the intuitive *System 1* dynamics are highly similar to those of perceptual processes where automatic, parallel, effortless, sometimes emotional (hot), associative processes rapidly give rise to "impressions." Subsequently, *System 2*, the slow, subjectively controlled, serial system, can monitor the quality of such impressions. System 2 will then perform one of a number of processes such as endorsing, adjusting, or correcting impressions, and in some cases when no impression is formed, may compute a judgment. Kahneman further notes that the primary role of System 2 is the monitoring of System 1.

As noted, both Kahneman (2003) and Frederick (2005) suggest that the relationships between cognitive ability and effective judgment and decision-making stems from differences in strategic metacognitive monitoring and other corrective operations taken by deliberative System 2 (Kahneman, 2003). Indeed, Frederick suggests that individuals who are more cognitively impulsive are less likely to check, or re-check, their immediate automatic impressions and so are subject to biases that others avoid. This application of cognitive control has been characterized in the memory literature as a *late correction* cognitive control mechanism (Jacoby, Kelley, &

McElree,1999). Late correction mechanisms are commonly interpreted as the dominant means of strategic control in social psychological and the judgment and choice literatures (Kahneman, 2003; Jacoby, et al.,1999; Moskowitz, Skurnik, & Galinsky, 1999).

As an alternative and complement to the late correction mechanisms of cognitive control, Jacoby, Kelley, & McElree (1999) introduced the notion of *early selection* cognitive control mechanisms. In early selection, automatic cognitive processes are altered when one strategically makes use of knowledge, goals, context, etc., in order to (tightly) constrain what automatically comes to mind. To borrow the language of Kahneman (2003), we could say that the reasoning System 2 can act to constrain the output of the automatic System before any impressions are yielded. To further illustrate consider a quote from Jacoby, Kelley, and McElree (1999):

"Why doesn't the average person say obscenities when talking to a nun? According to the late-correction approach, the obscenities may well come to mind while speaking to a nun, but are withheld because they are recognized as being socially inappropriate to say. The early-selection view, in contrast, holds that the person is likely to be sufficiently situated in the 'speaking to a nun' context that obscenities never even come to mind. That is, cognitive control can take the context into account and operate to determine what comes to mind, rather than only being called forth to serve as an editor for the contents of consciousness."

Because these early selection processes can constrain the automatic System, the products of that System can be qualitatively altered (Jacoby, et al., 1999, Jacoby, Shimizu, Daniels, & Rhodes, 2005; Koriat, Ma'ayan, & Nussinson, 2005). Individuals who make use of early selection constraints may be likely to directly affect automatic, intuitive processes, in some cases eliminating the need for subsequent corrective actions. Moreover, these and similar dynamics may be related to some of the performance observed in Experiments 1 and 2. Rather than reflecting only differences in late correction mechanisms, the observed differences in rational choices may reflect qualitative differences in one's approach to the task that *functionally* alter and create, at least in part, performance differences (Cokely, Kelley, & Gilchrist, in press; Jacoby, Kelley, & McElree, 1999).

<u>Cognitive Control Heuristics.</u> To further explore the potential role of early selection cognitive control mechanisms, we can consider CRT performance (Frederick, 2005). As demonstrated, individuals who score higher on the so-called cognitive reflection task are more likely to behave in a normatively superior, ration way (Frederick, 2005). However, what is the

exact source of the relationship between CRT and judgments? Frederick (2005) speculates, in the absence of a high-fidelity task analysis, that during the CRT the intuitive System 1 generates a rapid, intuitively appealing answer- an incorrect impression. Frederick further speculates that for nearly all people this answer springs so easily to mind that it is output by individuals who are not cognitively reflective (i.e. individuals who do not do additional monitoring). To extend this view, theoretically, the initial impression may be so fluent that some individuals might be considered to be *captured*, such that controlled processing is bypassed (Jacoby, Bishara, Tessels, & Toth, 2005). Alternatively, or perhaps for some subset of individuals, this situation may also involve an *illusion of simplicity* (Kelley, 1999, Kelley & Lindsay, 1993) such that high levels of initial processing fluency for the perceived answer lead to an underestimation of problem difficulty and thus an acceptance of the intuitive response.

Frederick’s (2005) the theoretical explanations and interpretations of cognitive control in the CRT suggest that accuracy results from a late correction monitoring process. When control is effective, a wrong idea comes to mind, is detected, and then is corrected. However, in the case of the CRT, early selection processes may also play a critical role, particularly if capture is involved. Although speculative, many types of early selection mechanisms might be considered *cognitive control heuristics.* For example, one such heuristic could be a *hyper-fluency heuristic*. This heuristic might operate such that when any idea comes to mind unexpectedly easily (e.g. “this is too easy”), it would serve to cue one to subject thoughts to additional analysis. This cognitive control heuristic might be similar to Whittlesea's (2002) discrepancy attribution ideas. He suggests that there must be a local norm for fluency and when something is too fluent, you look for a reason, and are prompted to make an attribution. Therefore, the attribution could be "I did this wrong, it was too easy." In this way, one critical aspect of the early selection mechanism would be the selection of fluency norms. Individual differences therefore might reflect to some extent the expected difficulty of the CRT problems when one uses a norm of "math problems are difficult aptitude-SAT type questions” versus "I’m just answering a questionnaire in a psychology experiment.” In these cases an early selection mechanism of task orientation and the activation of a cognitive control heuristic may play a significant role in effective task performance. More generally, because fluency is typically associated with and used as a basis to infer accuracy (Kelley & Jacoby, 1996; Goldstein & Gigerenzer, 2002) it is difficult to imagine why in the absence of an early selection mechanism such fluency would trigger any late correction monitoring.

Returning to the consideration of the mechanisms of rational choices, in the current series of experiments there is at least one candidate early selection mechanism that may have contributed to performance. To review, using more adaptive considerations (what's the difference in gains; is the probability likely or unlikely) likely results in more adaptive choices for a number of reasons. First, considering more problem aspects increases the likelihood that one will take into account highly relevant information such as very large differences between maximum values or probabilities. As well, by considering more aspects one may be more likely to attenuate or avoid framing effects. Indeed, other research indicates that when participants are forced to produce additional reasons or when stakes are made higher or presented in more familiar domains framing effects can be altered or eliminated (for review see Levin, Schnieder, & Gaeth, 1998). But what sort of early selection mechanism might push some individuals toward using more thorough considerations?

In the case of higher ability individuals, some participants may generally be individuals who are more likely act carefully and deliberative in many conditions (Baron, 1985). However, in Experiment 2, for example, many other high rationality participants were not necessarily those with high CRT or high working memory span scores. Therefore, a second potential candidate mechanism is the contextual orientation that one generates for evaluating each choice. For example, considering choices in the context of a game (I feel lucky; I'll play it safe; it's not real money anyway) may produce different patterns of elaboration than when one considers gains and losses in terms of real world buying or earning power (I earn more than $50 bucks in one shift; $7000 dollars would cover my entire tuition). Other research has shown that different problem contexts (e.g. stock pick, gamble, grade trade-offs) produce different distributions of strategies for the same individuals (Rettiger & Hastie, 2001; 2003). To test this hypothesis, although protocols were not initially coded to assess this difference in context, some types of considerations that are clearly associated with more real world context can be examined, such as *considering values small or large* (e.g. $300 is a lot of money; I don't even have $7000). Reanalysis of Experiment 2 verbal reports on small or large value considerations indicated that these considerations are significant predictors of rational choices, r (78) = .41, r (78) = .36, respectively. Moreover, the overall frequency of considering values small or large was strongly related to the overall frequency of number of considerations, *r* (78) = .62, and *r* (78) = .68, respectively. Four other considerations were also strongly positively related to the overall number of considerations including comparing the maximum difference, *r* (78) = .84; recoding probability, *r* (78) = .58; considering probability low, *r* (78) = .66; and considering probability high, *r* (78) = .68.

The results of the Experiment 2 protocol reanalysis suggest that considering choices in context of real world purchasing or earning power may have been a particularly effective strategy for the selection of rational choices, or at least an effective component of the an effective choice strategy. In these ways, the subsequent monitoring and elaborative behaviors related to rational choices may reflect the fact that participants use different contextual orientations when approaching and considering choices. To speculate, this difference in early selection cognitive control may have altered participants' automatic impressions and thus the processes that participants were likely to follow. To speculate further, some individuals may commonly use a collection of *cognitive control heuristics* wherein context, goals, choice orientations, and the like, are used to constrain the impressions that are automatically produced by System 1 in order to improve performance in a variety of tasks. More generally, this level of analysis of the interplay of automatic and control processes is consistent with the judgment and choice research agenda set forth by Daniel Kahneman (2003) stating that as a top priority "we must study the determinants of high accessibility, the conditions under which System 2 overrides or corrects System 1, and the rules of these corrective operations." For these reasons, more studies are needed in order to identify the roles and types of cognitive control heuristics and other control operations such as elaboration that allow for superior judgment and decision making. These studies should include a variety of decisions from lay decision making to expert choice. For now what is clear is that individuals who make more rational choices do not necessarily need to use rational processes and instead will in some cases make better decisions by using simple heuristics and elaborative strategies.

Conclusions

We live in a fundamentally uncertain world in which individuals with limited capacities, knowledge, and time are regularly challenged to make decisions. How can people make these choices effectively and efficiently and moreover what are the mechanisms that allow some people to consistently make better judgments under uncertainty? In this paper I have drawn on a strategic cognitive control approach (Cokely, Kelley, & Gilchrist, 2006) to conduct a series of experiments and test an elaborative adaptive strategy hypothesis. Each experiment provided converging data indicating that rational choices are rarely the product of rational processes. Instead, in contrast to models that assume complex multiattribute computations, the evidence suggests that both better decision-making and individual differences in choice may arise from the use of elaborative combinations of simple considerations (Gigerenzer & Shelton, 2001). These findings may have implications for the design of better decision environments and may otherwise serve to inform prescriptive decision making models (Todd & Gigerenzer, 2007). In these ways and others, this process oriented approach to judgment under uncertainty affords a greater understanding of the exact cognitive mechanisms involved in choice, including cognitive control mechanisms, and represents a unique theoretical approach for future investigations of superior decision making.

Table 1

Unique Predictions for Four Critical Trials

	Gain A	Gain B	Loss A	Loss B
Rational Theory	Risk	Risk	Non	Non
Priority Heuristic	Non	Risk	Risk	Non
Prospect Theory	Non	Non	Risk	Risk

Gain A = \$100 for sure or 75% chance of \$200

Gain B = \$100 for sure or 3% chance of \$7000

Loss A = Lose \$100 for sure or 75% chance to lose \$200

Loss B = Lose \$100 for sure or 3% chance to lose \$7000

Table 2

Correlations among Scores and Choices

		1	2	3	4	5	6	7
		CRT	Span	S-Quart.	Math	BF-C	BSCM	Rational
1	CRT	1.00	-0.10	0.24	0.17	0.12	0.01	0.23*
2	Span		1.00	.931**	0.04	0.02	0.01	0.18
3	S-Quart.			1.00	0.08	0.27	-0.03	0.40*
4	Math				1.00	0.02	-0.04	0.16
5	BF-C					1.00	-0.54*	0.04
6	BSCM						1.00	-0.01
7	Rational							1.00

* $p < .05$, ** $p < .01$

Legend:

CRT: Cognitive Reflection Task

Span: Operation Span Task

S-Quart: Operation Span High and Low Quartiles

Math: The Slot Machine Probability Math Task

BF-C: Conscientiousness Score from the Big Five Inventory

BSCM: Brief Self Control Measure

Rational: Overall Proportion of Rational Choices

Table 3

Means for Rational Choice Model Accuracy

	Sure Choices		*Risky Choices*	
	Gains	Losses	Gains	Losses
High Span	0.91	0.81	0.67	0.78
Low Span	0.84	0.76	0.62	0.57

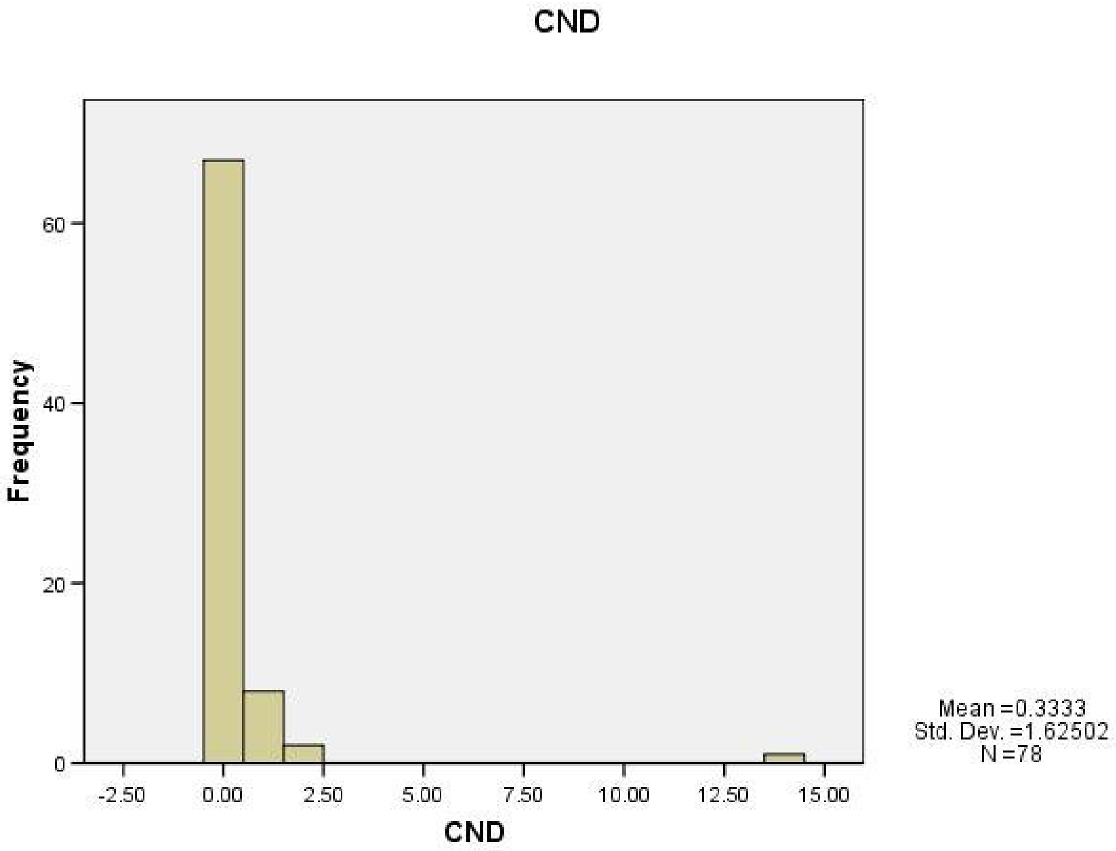


Figure 1: Frequency of Subjects Verbalizing CND

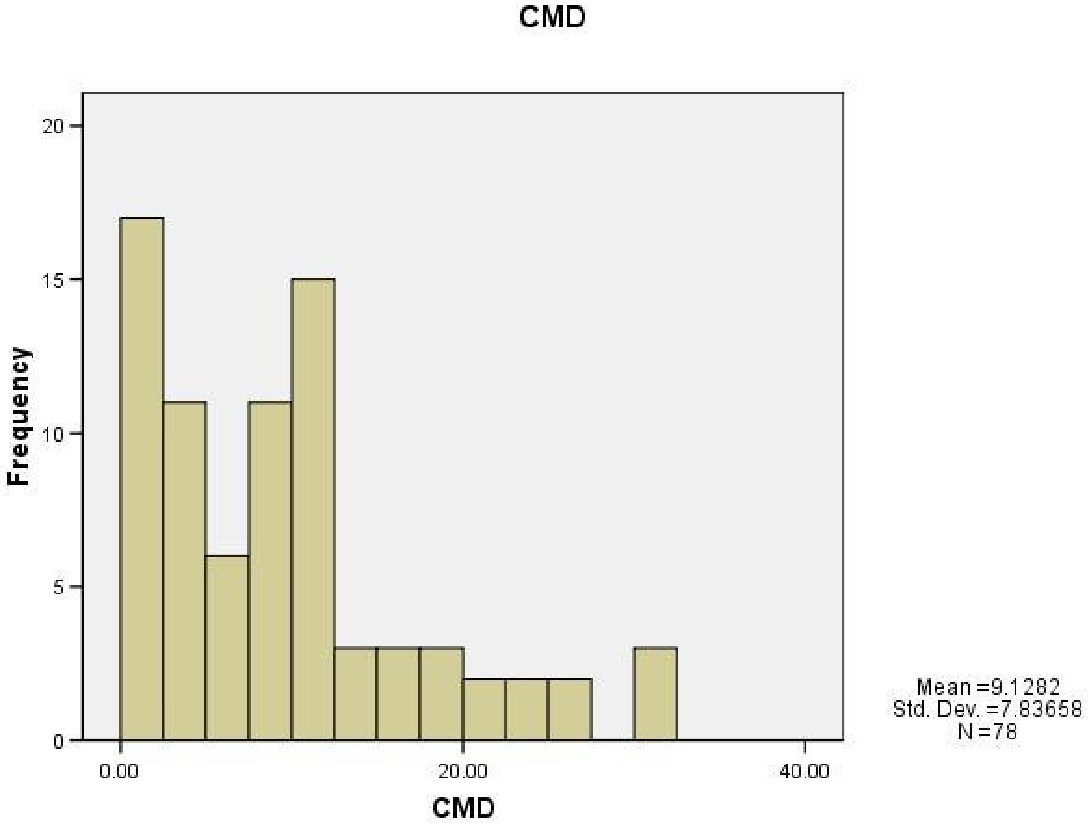


Figure 2: Frequency of Subjects Verbalizing CMD

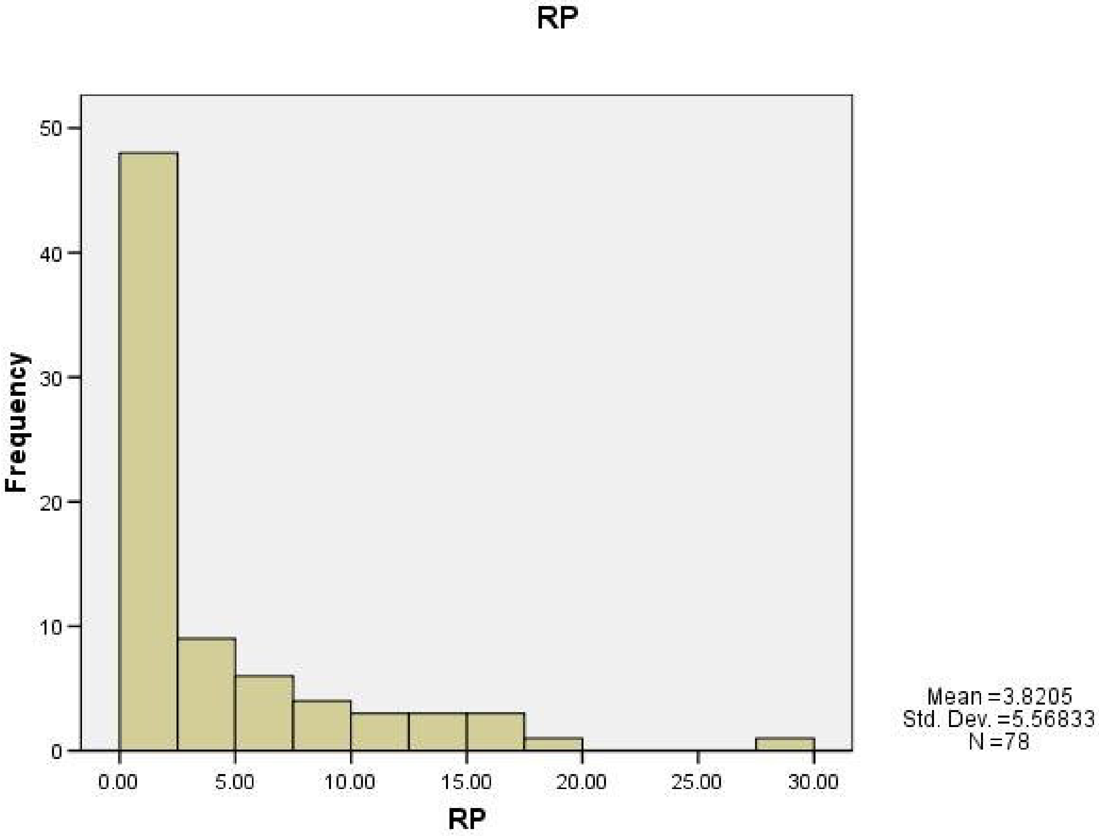


Figure 3: Frequency of Subjects Verbalizing RP

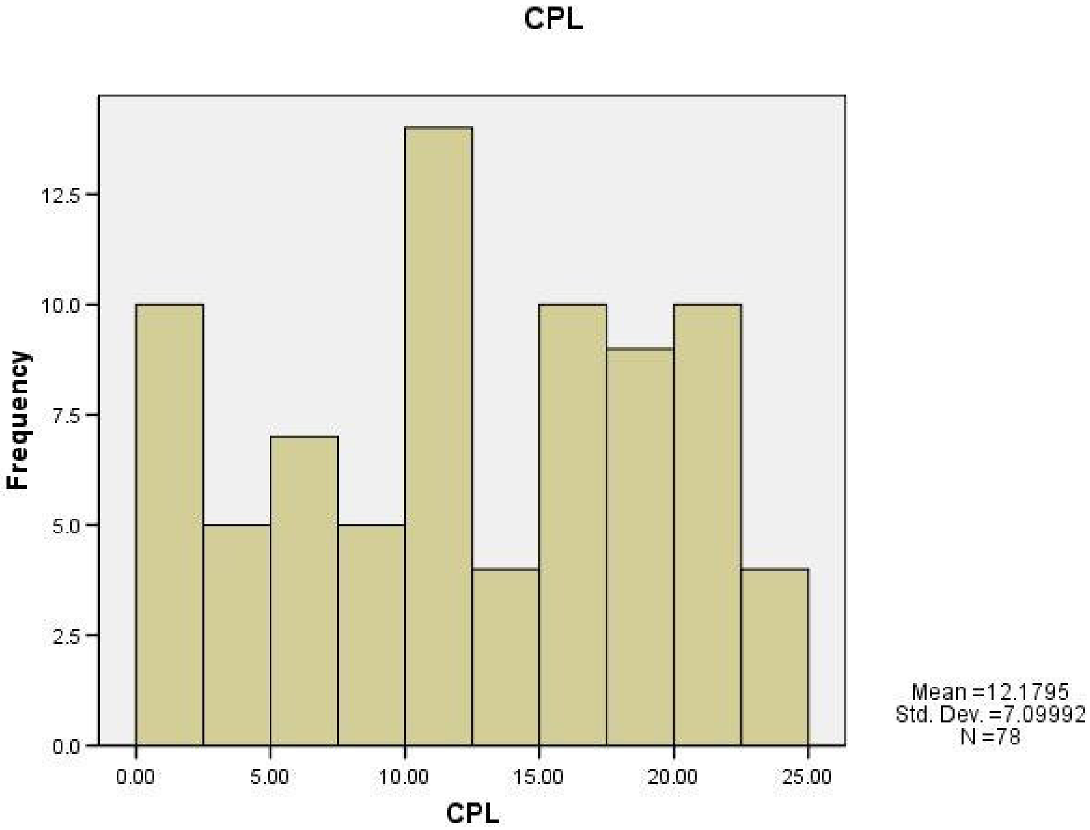


Figure 4: Frequency of Subjects Verbalizing CPL

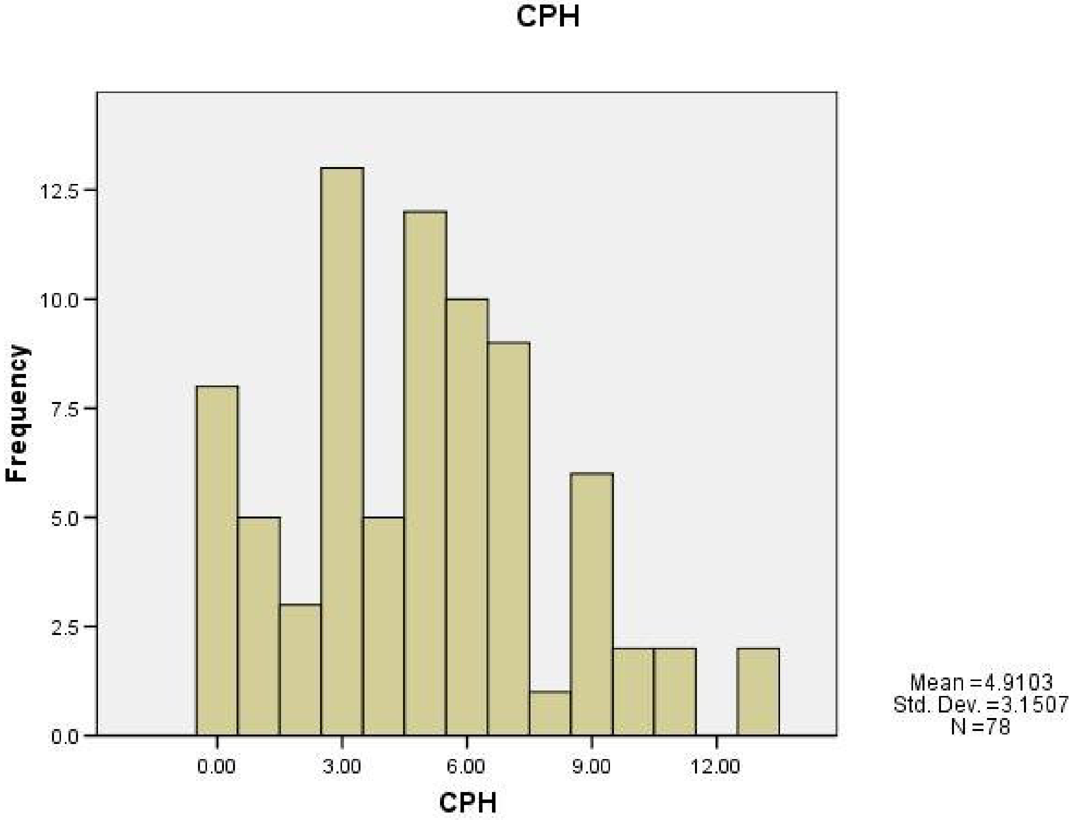


Figure 5: Frequency of Subjects Verbalizing CPH

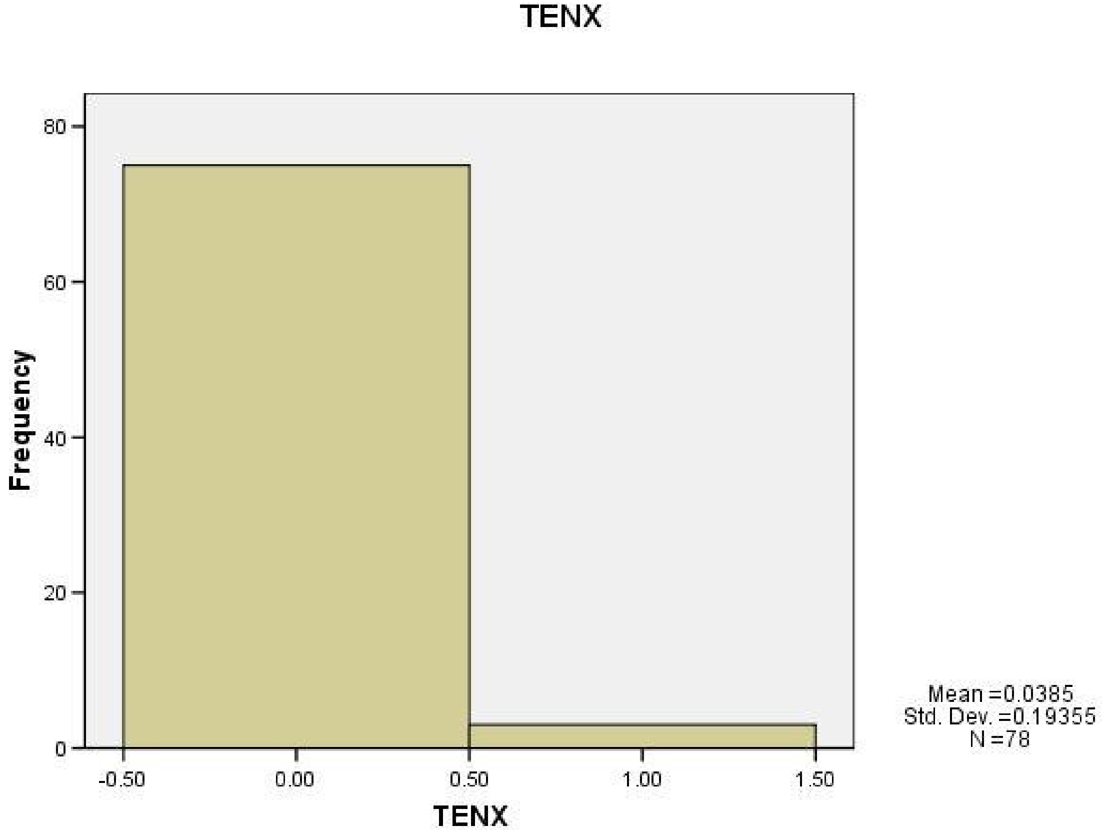


Figure 6: Frequency of Subjects Verbalizing 10X

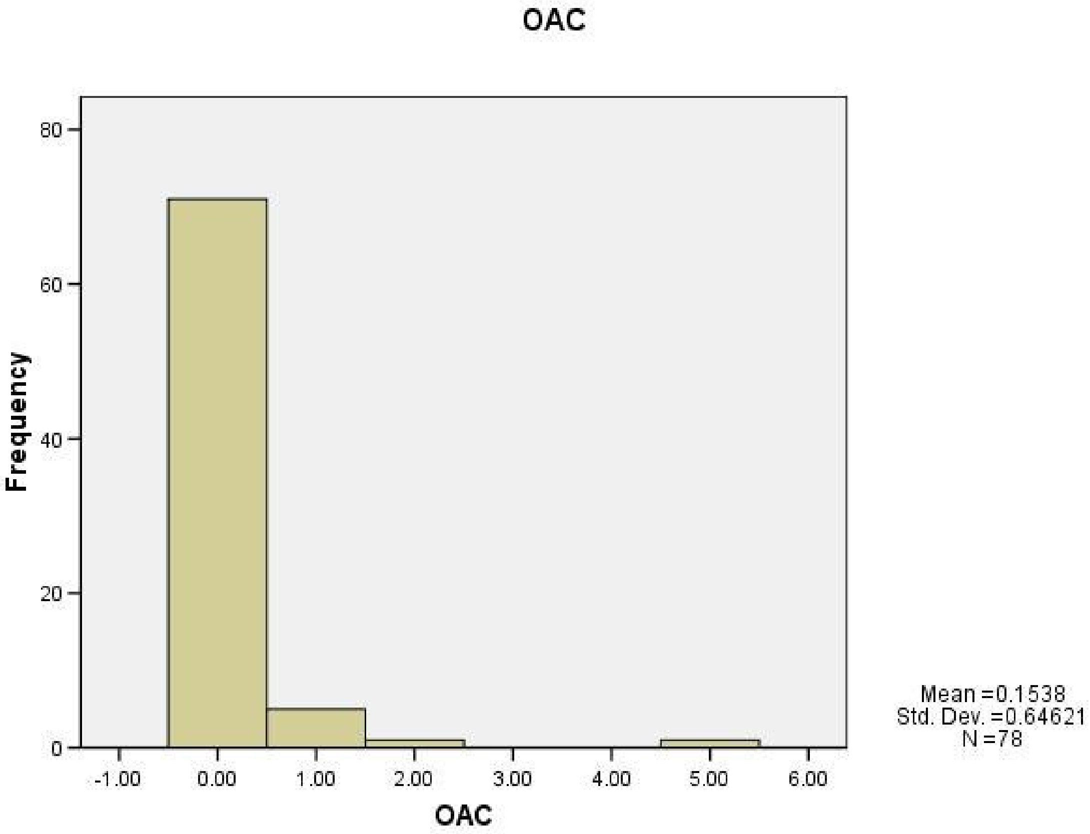


Figure 7: Frequency of Subjects Verbalizing OAC

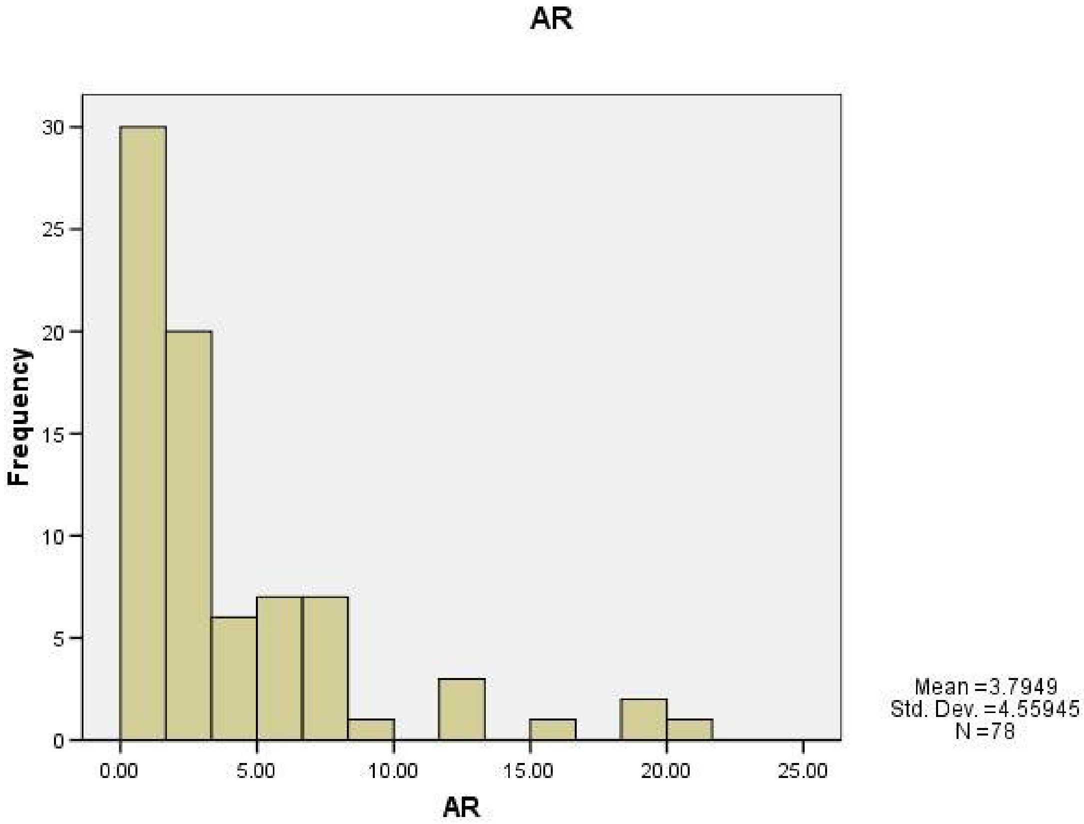


Figure 8: Frequency of Subjects Verbalizing AR

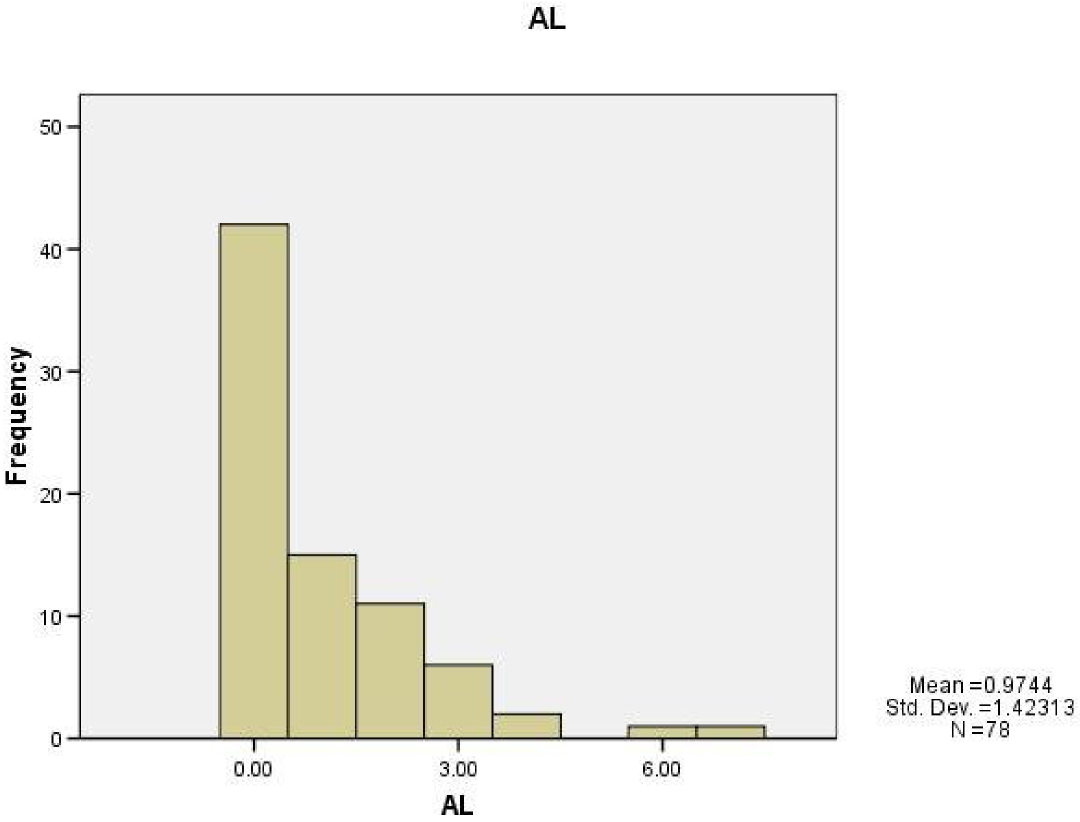


Figure 9: Frequency of Subjects Verbalizing AL

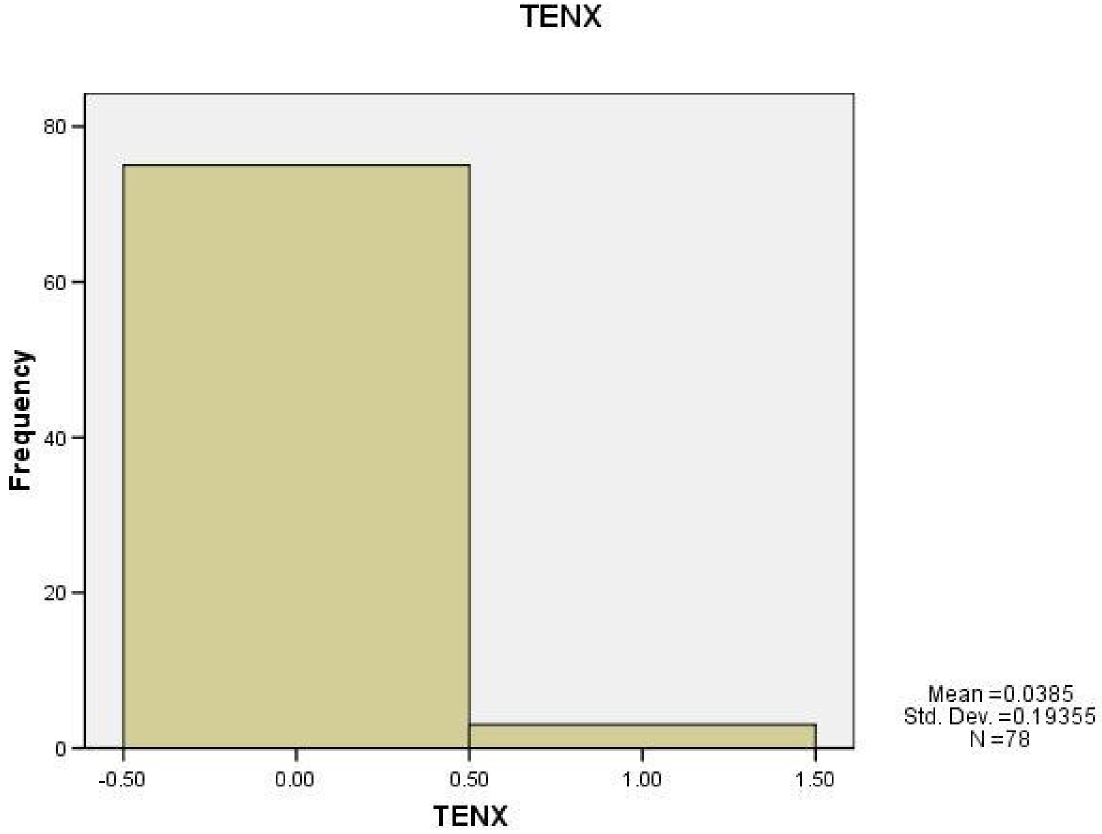


Figure 10: Frequency of Subjects Verbalizing MAX

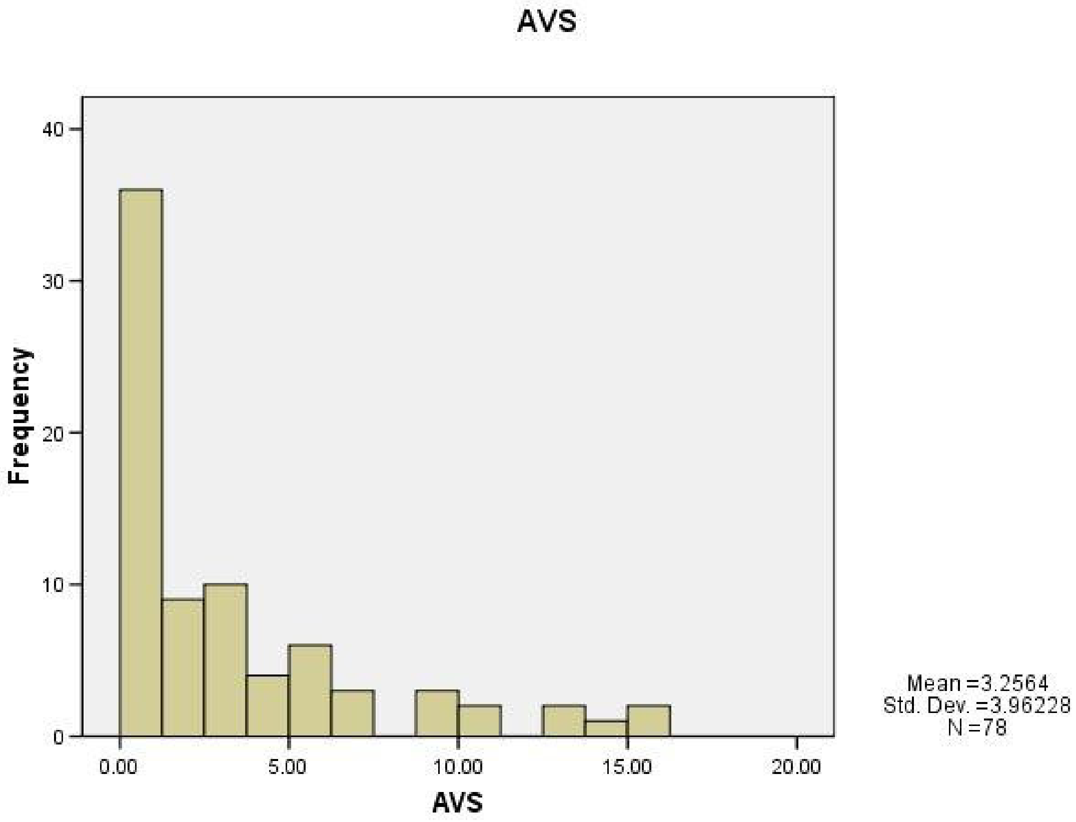


Figure 11: Frequency of Subjects Verbalizing AVS

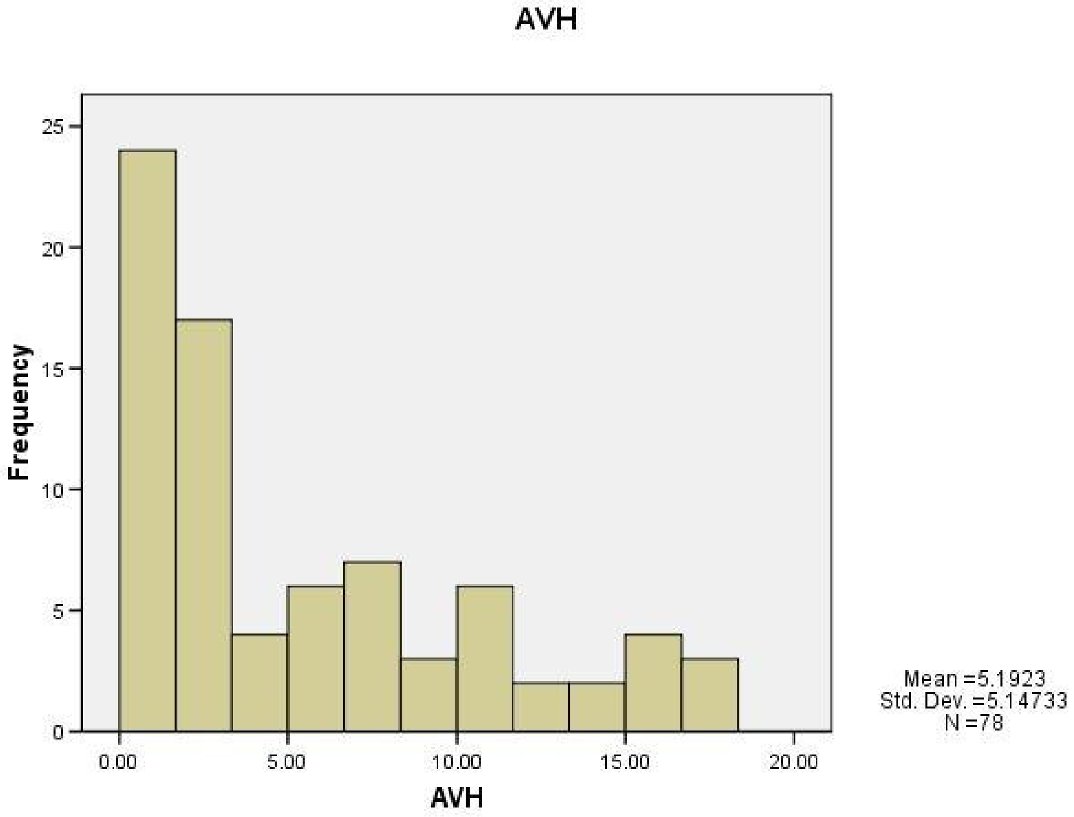


Figure 12: Frequency of Subjects Verbalizing AVH

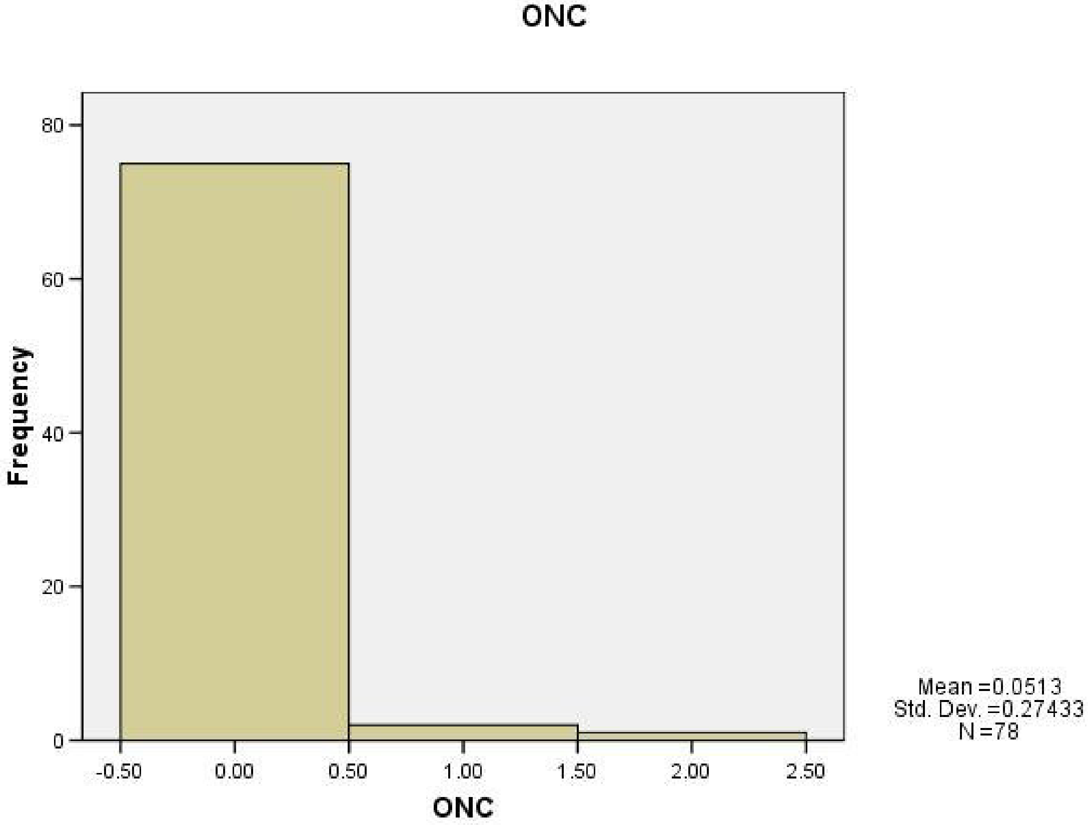


Figure 13: Frequency of Subjects Verbalizing ONC

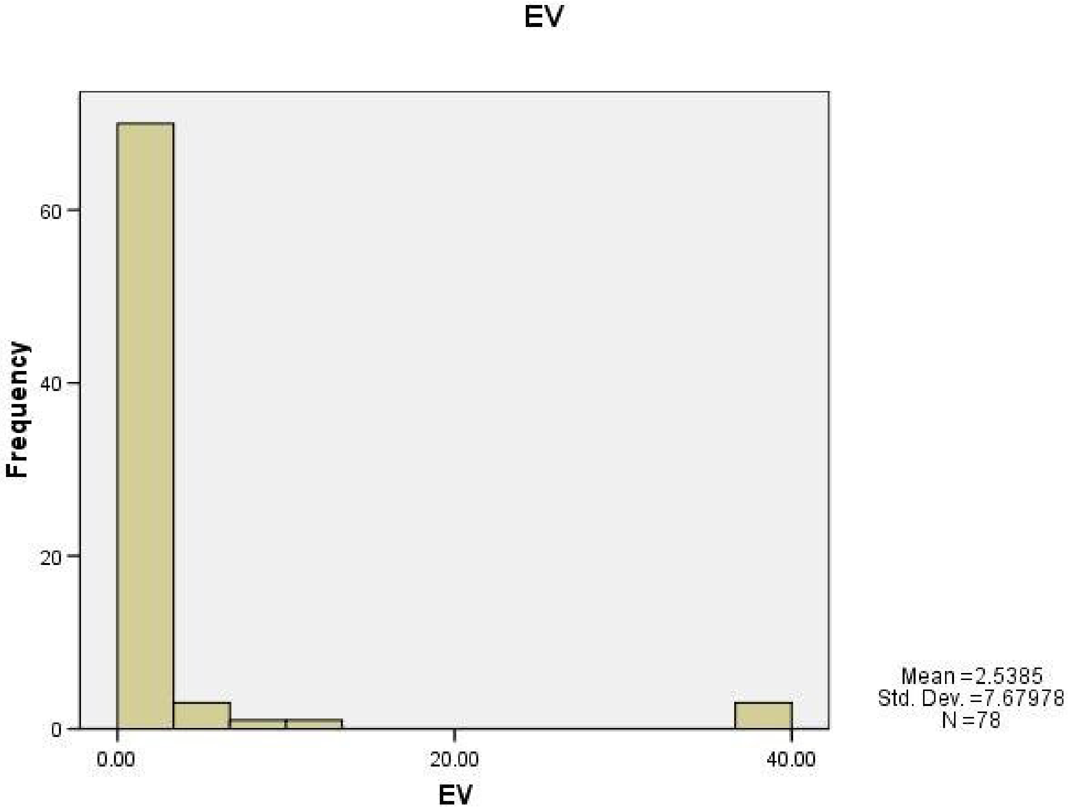


Figure 14: Frequency of Subjects Verbalizing EV

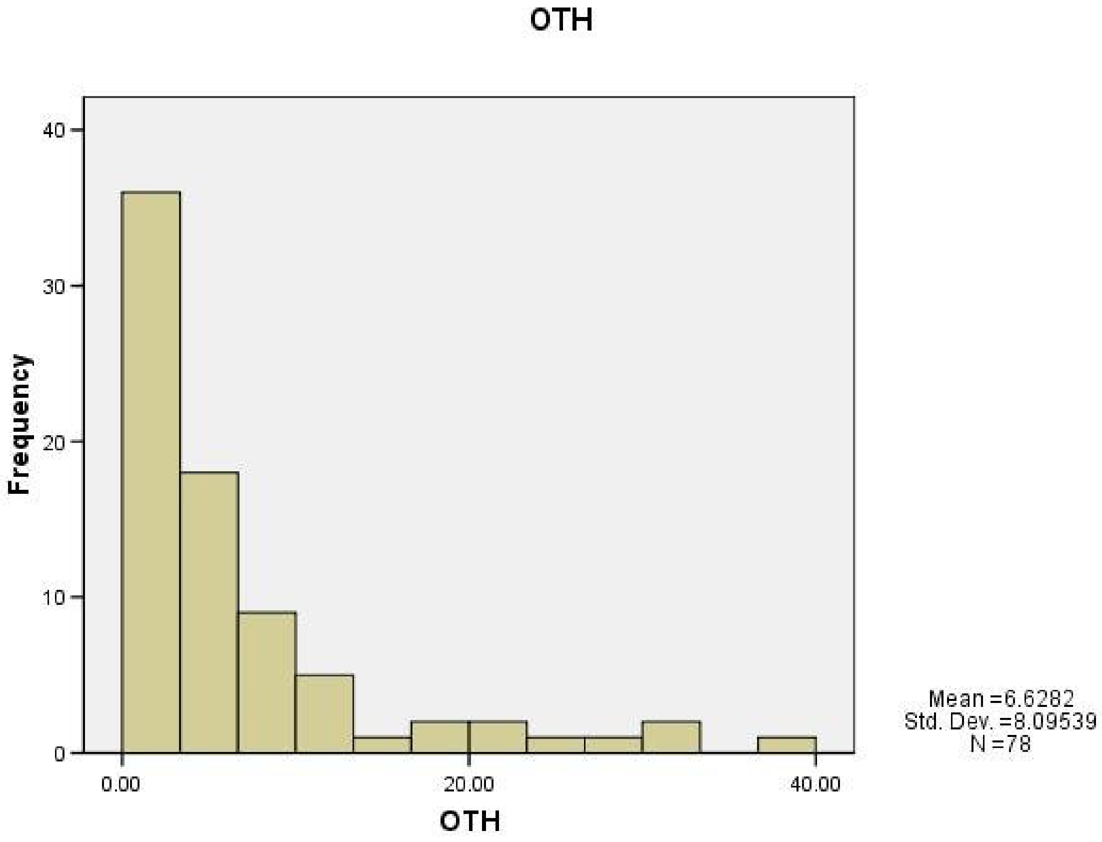
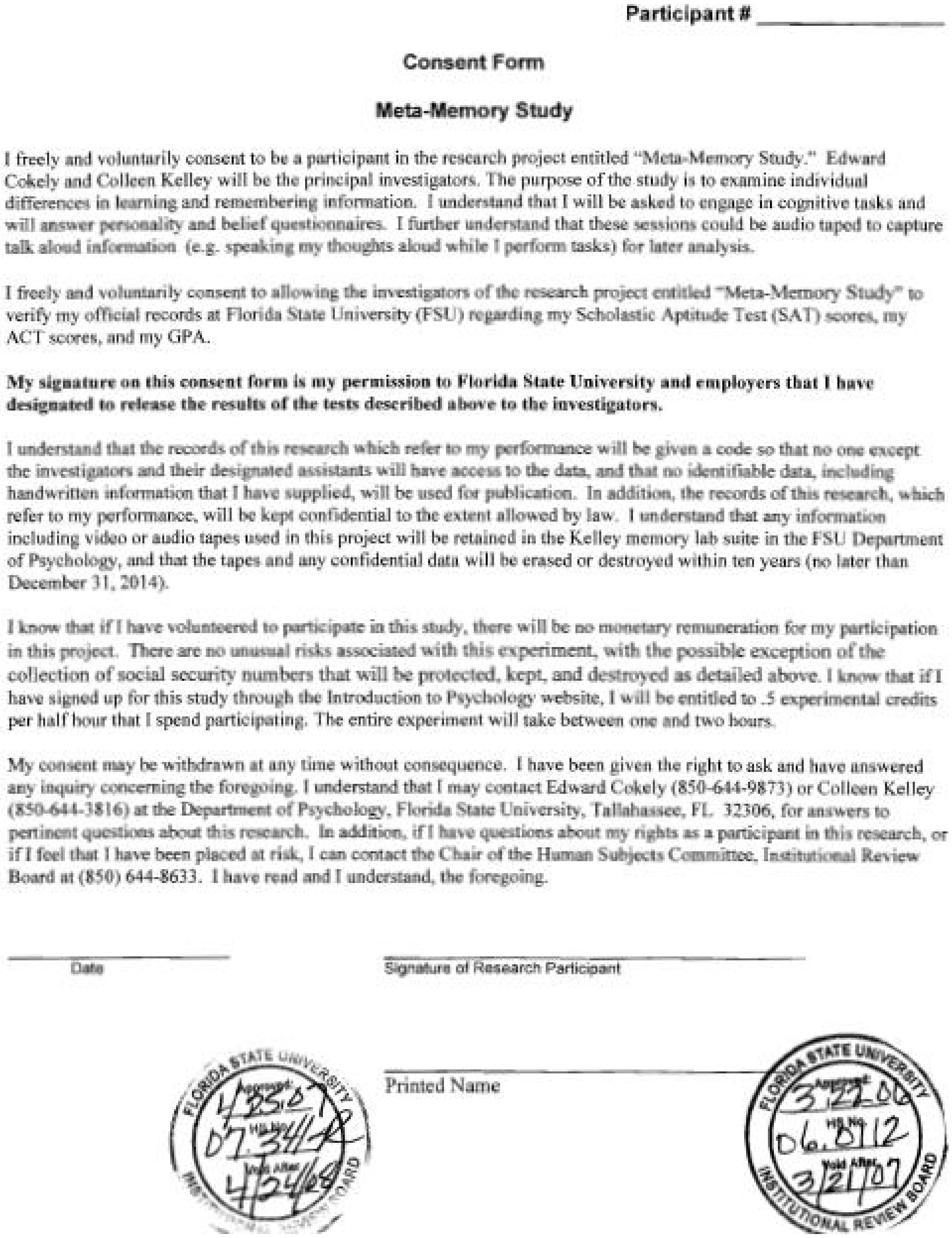


Figure 15: Frequency of Subjects Verbalizing OTH

APPENDIX A: INFORMED CONSENT FORM



Participant # ______________

Consent Form

Meta-Memory Study

I freely and voluntarily consent to be a participant in the research project entitled "Meta-Memory Study." Edward Cokely and Colleen Kelley will be the principal investigators. The purpose of the study is to examine individual differences in learning and remembering information. I understand that I will be asked to engage in cognitive tasks and will answer personality and belief questionnaires. I further understand that these sessions could be audio taped to capture talk aloud information (e.g. speaking my thoughts aloud while I perform tasks) for later analysis.

I freely and voluntarily consent to allowing the investigators of the research project entitled "Meta-Memory Study" to verify my official records at Florida State University (FSU) regarding my Scholastic Aptitude Test (SAT) scores, my ACT scores, and my GPA.

My signature on this consent form is my permission to Florida State University and employers that I have designated to release the results of the tests described above to the investigators.

I understand that the records of this research which refer to my performance will be given a code so that no one except the investigators and their designated assistants will have access to the data, and that no identifiable data, including handwritten information that I have supplied, will be used for publication. In addition, the records of this research, which refer to my performance, will be kept confidential to the extent allowed by law. I understand that any information including video or audio tapes used in this project will be retained in the Kelley memory lab suite in the FSU Department of Psychology, and that the tapes and any confidential data will be erased or destroyed within ten years (no later than December 31, 2014).

I know that if I have volunteered to participate in this study, there will be no monetary remuneration for my participation in this project. There are no unusual risks associated with this experiment, with the possible exception of the collection of social security numbers that will be protected, kept, and destroyed as detailed above. I know that if I have signed up for this study through the Introduction to Psychology website, I will be entitled to .5 experimental credits per half hour that I spend participating. The entire experiment will take between one and two hours.

My consent may be withdrawn at any time without consequence. I have been given the right to ask and have answered any inquiry concerning the foregoing. I understand that I may contact Edward Cokely (850-644-9873) or Colleen Kelley (850-644-3816) at the Department of Psychology, Florida State University, Tallahassee, FL 32306, for answers to pertinent questions about this research. In addition, if I have questions about my rights as a participant in this research, or if I feel that I have been placed at risk, I can contact the Chair of the Human Subjects Committee, Institutional Review Board at (850) 644-8633. I have read and I understand, the foregoing.

______________ Date

______________ Signature of Research Participant

______________ Printed Name

Approved: 4/25/07
HS No. 07.341R
Void After 4/24/08

Approved: 3/22/06
HS No. 06.0812
Void After 3/21/07

APPENDIX B: PROBABILITY MATH SKILLS INSTRUMENT

Read and Think Out Loud

Imagine you are playing different slot machines with different payoff rules
Please try to figure out the expected pay-off for each machine below
Feel free to use the space below for scratch paper but remember to THINK OUT LOUD

Machine A A 75% chance to win $200 ea. play
1 If you played 10 times how much would you expect (___________________________)
2 If you played 7 times how much would you expect (___________________________)

Machine B A 100% chance to win $100 ea. play
3 If you played 5 times how much would you expect (___________________________)

Machine C A 3% chance of winning $2000 ea. play
4 If you played 100 times how much would you expect (___________________________)
5 If you played 50 times how much would you expect (___________________________)

Machine D A 50% chance to win $300 ea. play
6 If you played 7 times how much would you expect (___________________________)

APPENDIX C: CONCURRENT THINK ALOUD INSTRUCTIONS

Verbal Protocol – Concurrent Think Aloud Instructions

Always sit behind or otherwise out of view of the participant-

Be sure recording equipment is unobtrusive (i.e. help them forget you are there)

Read these instructions:

I will start by familiarizing you with the procedure for “thinking out-loud.” We are interested in knowing your thoughts as you come up with the answers to the problems in this experiment. In order to do this, I am going to ask you to think out-loud as you work on some practice questions. What I mean by “think out-loud” is that I want you to say your thoughts out loud from the moment you finish hearing a practice question until you say the final answer. ***Don’t explain or summarize what you say***, it doesn’t even need to make sense. Just think out loud *as if you are alone and speaking to yourself*.

Lets’ start with an easy question:

What is the first letter after A

B is correct. When I asked you “what is the first letter after A,” you might have thought of B, but felt unsure of whether some thought occurred in between. In that case, you’d only say B (like you did). Only report thoughts that you have. Don’t try to report unclear thoughts or thoughts you think you should have had or might have had, just think out loud as if you were alone, as much as you can. And remember- Never summarize your thoughts. Lets consider an example- Please think out loud:

“What is the sixth letter after B?”

Good. The letter “H” rarely immediately comes to mind after hearing the question. People commonly need to go through several steps to find the answer. However, when someone summarizes their thinking, **which we don’t want**, they might say “ I am finding the letter H by counting through the alphabet.” Instead, when people solve this problem by thinking out loud, they usually say a sequence of individual letters, such as A ***B, C, D, E, F, G,*** before they answer H. Remember, you never need to explain your thoughts, just say exactly what you’re thinking “out-loud.”

Ok Lets try another practice question. Are you ready? Think aloud while you generate the answer. How many dot are in this array

(Experimenter- present 27 dot grid)

(Experimenter, give feedback on participant's answer, remind them to avoid explaining or summarizing their answers)

Lets try another grid. Ready?

(Experimenter- present 2 dot grid)

(Experimenter provide feedback). Now lets try a different question.

(Experimenter- present 18 dot grid)

(Experimenter provide feedback). Now lets try a different question.

(Experimenter- ask the participant to describe the difference between thinking out loud and summarizing thoughts)

If need be, the experimenter may administer the following questions for added practice:

- *"How many months begin with the letter J?"*
- *"What is the fifth letter before M?"*
- *"name 5 animals in a zoo"*
- *What is 14 * 9*
- *What is 13 * 4*
- *"Name 3 different team sports"*

One last point before we begin, periodically or if you ever become silent I will remind you to "please keep talking." This is simply part of the procedure to ensure you think out loud as much as you can. Please do not be disturbed and do not worry about any prompting- just continue to think out-loud as if you were alone in the room.

Any questions?

ALTERNATIVE:

If the experiment involves the reporting of imagery (Level 2 or higher)- you may want to use the following warm up- to familiarize the participant with this kind of (difficult) report.

Please count the number of windows in the house you grew up in.

APPENDIX D: RETROSPECTIVE AND CONCURRENT VERBAL REPORT INSTRUCTIONS

Verbal Protocol – <u>Concurrent & Retrospective</u> Think Aloud Instructions

Always sit behind or otherwise out of view of the participant- Be sure recording equipment is unobtrusive. Read these instructions:

I will start by familiarizing you with the procedure for "thinking out-loud." We are interested in knowing your thoughts as you come up with the answers to the problems in this experiment. In order to do this, I am going to ask you to think out-loud as you work on some practice questions. What I mean by "think out-loud" is that I want you to say your thoughts out loud from the moment you finish hearing a practice question until you say the final answer. ***Don't summarize what you say***, in fact, it doesn't even need to make sense. Just think out loud <u>as if you are alone and speaking to yourself</u>.

Lets' start with an easy question:

What is the first letter after A

B is correct. When I asked you "what is the first letter after A," you might have thought of B, but felt unsure of whether some thought occurred in between. In that case, you'd only say B (like you did). Only report thoughts that you have. Don't try to report unclear thoughts or thoughts you think you should have had or might have had, just say your thoughts out loud as if you were alone, as much as you comfortably can. And remember- never summarize your thoughts. Lets try another example- Please think out loud:

"What is the sixth letter after B?"

Good. The letter "H" rarely immediately comes to mind after hearing the question. People commonly need to go through several steps to find the answer. However, when someone summarizes their thinking, **which we don't want**, they might say " I am finding the letter H by counting through the alphabet." Instead, when people solve this problem by thinking out loud, they usually say a sequence of individual letters, such as A ***B, C, D, E, F, G,*** before they answer H. Remember, you never need to summarize your thoughts, just say exactly what you're thinking "out-loud."

Ok, lets try another practice question. Are you ready? Think aloud while you generate the answer. How many dots are in this array.

(Experimenter- present 27 dot grid)

(Experimenter, give feedback on participant's answer, if needed remind them to avoid summarizing their answers)
Lets try another grid. Ready?

(Experimenter- present 2 dot grid)

(Experimenter- ask the participant to describe the difference between thinking out loud and summarizing thoughts)

If need be, the experimenter may administer the following questions for added practice:

- *"How many months begin with the letter J?"*
- *"What is the fifth letter before M?"*
- *"name 5 animals in a zoo"*
- *What is 14 * 9*
- *What is 13 * 4*
- *"Name 3 different team sports"*

PART II: RETROSPECTIVE REPORTS

Great, I think you've got it.

Sometimes, people have more thoughts, or more complicated thoughts, than they can comfortably say out loud when they are thinking. We want to hear those thoughts as well. To do this, we will sometimes ask you to **remember** the thoughts you had in order. This is called a **memory report.** During a memory report, **never guess** what you might have been thinking about, or what you could have been thinking about. Instead, we want you to say out loud all of the exact thoughts you are confident that you remember thinking, in order. Specifically, in this experiment you may remember thoughts that you couldn't think out loud because they happened too fast or were too detailed, etc... In these cases, please report all the thoughts that you remember having, ***in the exact order you had them***.

One more thing, whenever I ask you for a ***memory report***, please start by saying ***"My first thought was"*** For example, if we consider the question *what is the sixth letter after B* you would say "my first thought was A, B,C,D,E,F,G,H" (fill in what they said) Any questions?

Ok, Let's try another question. Remember to think out loud.

What is the fourth letter <u>after</u> N?

After they answer, tell them- Please give a retrospective report starting with **"My first thought was"....** (Experimenter provide feedback)

Let's try another one:

(*Experimenter--Present the 4 dot grid and ask "How many dots are there?"*)

Please give a retrospective report- The first thought I had (they should only say "4")

For the next question, you do not need to think out loud, but I will ask for a retrospective report. Are you ready?

Please count the number of windows in the house you grew up in.

EXTRA PRACTICE TRIALS

Which would you prefer 5 dollars today or 200 dollars tomorrow.
Which city do you think is bigger San Francisco or Marin (pronounced MAR-INN)
Which State do you think is colder Michigan or Georgia
Which would you prefer 1 dollar today or .50 tomorrow
What is the western most state in the United States

APPENDIX E: PROTOCOL ANALYSIS CODING SYSTEM

Code	
	Priority Heuristic Type and other Comparisons
CND	Compare Minimum Differences ($100 v. 0 dollars; 100 is a lot more than 0)
CMD	Compare Maximum Differences (100 v 3000 is 2900; that's much more money)
RP	Recode probability (3% chance is a 97% to lose nothing)
CPL	Consider probability low (20% is low; 5% won't happen)
CPH	Consider probability high (80% is high; 60% will probably happen)
10X	Assess 10% of maximum gain (10% of $7000 gain is like $500)
OAC	Other Adaptive Comparison
AR	Avoid Risks (I don't want to risk it; I want the sure thing)
AL	Avoid Losses (I hate to lose; I don't want to lose anything)
MAX	Max/Min Money (I really want 5000; I try for the biggest gain/smallest loss)
AVS	Consider absolute value low (I can afford to lose $50; $20 bucks is nothing)
AVH	Consider absolute value high ($1000 is a lot to lose; $7000 is so much money)
ONC	Other general-comparison
	Expected Value Calculations
AEV	Attempted to Calculate EV (but can't)
EEV	Estimate EV (that's more than 5% of that)
EV	Calculated EV (calculated)
OTH	Other (I prefer A, B was better)

APPENDIX F: CODED PROTOCOL ANALYSIS SAMPLE

1. A sounds better. My first thought was, uh, 400 dollars certain gain, uh, 70% seems kind of low ***(CPL)*** and 480 isn't that much more ***(CMD)*** so I just immediately went with a.
2. uh, a. my first thought was that 80% for 2000 is pretty high chance ***(CPH)*** compared to only 300 certain gain ***(AVS)*** so.
3. I'll go with b. my first thought was: a 5% chance was really low ***(CPL)*** even though 2000 dollars is high ***(AVH)*** so I went with the certain gain.
4. Uh, I'm gonna go with a. my first thought was that uh, 80% chance of loss is pretty high ***(CPH)*** and it was…the amount for the certain loss was a lot lower ***(CMD)*** so I went with a.
5. Go with a. my first thought was that 20% again is low ***(CPL)*** for the chance of losing, and uh, the amount below it was still significantly high ***(AVH)*** so I went with a.
6. uh, I'll go with b. my first thought was that 5% chance is again really low ***(CPL),*** I figured that probably won't happen so that was my rational answer.
7. I'm gonna go with a. my first thought was that uh, 1% is really low so that probably won't happen ***(CPL)*** so I'd rather take that chance.
8. Go with b. my first thought was that…I can't even remember my first thought right now so I'll go on to the next one ***(OTH)***
9. Okay, my first thought is that 80% of 2000 is way more money than 300 dollars for sure ***(EEV)***
10. Hmm, that won't happen, my first thought is that there is a 99% chance this won't happen ***(RP)*** and 200 is a lot of money ***(AVH)***

APPENDIX G: CHOICE SET FOR EXPERIMENT TWO

	number	certain	risk odds	risky choice
Gains				
	1	50	50%	400
	2	225	50%	375
	3	300	80%	2000
	4	125	30%	900
	5	500	70%	600
	6	275	20%	900
	7	100	3%	7000
	8	50	5%	4000
	9	150	5%	2000
	10	200	1%	3000
	11	40	50%	320
	12	270	50%	450
	13	240	80%	1600
	14	150	30%	1080
	15	400	70%	480
	16	330	20%	1080
	17	80	3%	5600
	18	60	5%	4800
	19	120	5%	1600
	20	240	1%	3600

Losses	number	certain	risk odds	risky choice
	21	50	50%	400
	22	225	50%	375
	23	300	80%	2000
	24	125	30%	900
	25	500	70%	600
	26	275	20%	900
	27	100	3%	7000
	28	50	5%	4000
	29	150	5%	2000
	30	200	1%	3000
	31	40	50%	320
	32	270	50%	450
	33	240	80%	1600
	34	150	30%	1080
	35	400	70%	480
	36	330	20%	1080
	37	80	3%	5600
	38	60	5%	4800
	39	120	5%	1600
	40	240	1%	3600

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BIOGRAPHICAL SKETCH

Edward T. Cokely earned his Bachelor of Arts in Psychology, with concentrations in cognitive and biological psychology, from the California State University, Fresno, in 2001. He earned his Masters of Science in Cognitive Psychology, with concentrations in memory and cognitive modeling, from the Florida State University, in 2003. He has authored or co-authored a number of publications and has presented his work at regional and international conferences. His main research interest is the investigation of cognitive mechanisms involved in superior cognitive performances. Edward is also a dedicated teacher who has won several teaching awards and has taught a variety of psychology lecture and laboratory courses. As well, he has directly mentored 34 independent studies students at FSU and the majority of these students have gone on to advanced graduate or professional training.