What are decision styles: intelligence and personality or more?

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This report is submitted in partial fulfilment of the degree of Master of Psychology (O&HF)

School of Psychology

University of Adelaide

July 2023

Word Count: 7999

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Declaration

This dissertation contains no material which has been accepted for the award of any other degree or diploma in any University, and, to the best of my knowledge, contains no materials previously published except where due reference is made.

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Statement of Contribution

I generated the topic of this project, using an existing dataset (that I had collected as part of a previous research project), and designed the research questions and analyses in discussion with my supervisor. I undertook all analyses and writing of the report with my supervisor providing a sounding-board for the appropriateness of alternative statistical approaches and my interpretations of the results.

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What are decision styles: intelligence and personality or more?

Abstract:

Cognitive biases result in sub-optimal decisions across a range of industries. The ability to predict individual susceptibility to biases would thus be beneficial. Individual differences work, however, has concluded cognitive ability is largely unrelated to this, resulting in a focus on alternative, 'decision style' measures that describe people's preferences for approaching problem solving. This work has also, however, tended to use low validity measures of cognitive ability which may have obscured relationships. In this study, six decision style measures were examined to determine: how they relate to one another; how each relates to psychometrically validated cognitive ability and personality measures; and, finally, how much incremental predictive power they provide over those established traits. Results show decision style measures are only weakly related to one another, are worse predictors of bias susceptibility than cognitive ability and do not provide additional predictive power once cognitive abilities and personality are controlled for.

Keywords: decision making, decision styles, cognitive abilities, personality, cognitive biases, individual differences.

Author Note

This article is intended for submission to Organizational Behavior and Human Decision Processes, which adheres to the *Publication Manual of the APA (6th ed.)* reference style. At present the article has been written to the Master of Psychology (Organisational and Human Factors) Research Report requirements of 6,000-8,000 words but will be edited prior to submission to meet the 30-page, manuscript text limit specified by OBHDP.

What are decision styles: intelligence and personality or more?

Predicting decision making ability and, in particular, susceptibility to decision biases, has been the focus of decades of research since being brought sharply into focus by the 'heuristics and biases' approach of Tversky, Kahneman and colleagues in the 1970s and onward (see, e.g., Gilovich, Griffin, & Kahneman, 2002; Kahneman, Slovic, & Tversky, 1982).

This highlighted discrepancies between people's decisions and rational, economic decision-making theories (see, e.g., von Neumann & Morgenstern, 1953) identifying 'cognitive biases' (Haselton, Nettle, Andrews, & Buss, 2005) where individuals are not consciously motivated to be biased. Sources list twenty+ of these (see, e.g., Bazerman, 2006; Pohl, 2004) and their impact has been demonstrated across multiple domains, from medical decision making (Liaw, Welsh, Copp, & Breyer, 2019; Redelmeier & Shafir, 1995) to real estate (Northcraft & Neale, 1987) to petroleum exploration (Bratvold, Mohus, Petutschnig, & Bickel, 2020). Evidencing the magnitude of the problem, Welsh and colleagues (Welsh, Begg, & Bratvold, 2007) showed a $255 million dollar error in the valuation of a petroleum development project arising from a single bias' effect on initial geological forecasts. Organisations thus have clear motivations to improve decision making through the implementation of better processes or the selection of staff showing less bias susceptibility.

Individual Differences in Decision Making

Cognitive biases research grew from cognitive psychology and, thus, looks to general effects and explanations – explaining commonalities in how people make decisions rather than individual differences (for discussions of this divide in scientific psychology, see: Cronbach, 1957; Deary, 2001).

For example, Prospect Theory (Kahneman & Tversky, 1979) describes *average* tendencies of people faced with deciding between risky and certain options in situations described as losses or gains (i.e., negative or positive 'frames'). Generally, people are risk seeking (selecting the risky option) in negative frames and risk averse (selecting the certain option) in positive frames. Closer examination, however, shows these tendencies do not explain everyone's behaviour. Instead, there are individuals who are risk seeking in positive frames and others who are risk averse in negative frames. That is, as Cronbach (1957) and Deary (2001) argue, to explain people's behaviour requires an understanding of both individual differences and cognitive psychology.

Attempts to predict decision making ability and bias have, however, turned up inconsistent and unexpected results. For example, researchers have attempted to link anchoring bias – the tendency of people to base numerical estimates on any number they have just seen regardless of its relevance (Tversky & Kahneman, 1974) to the Big 5 personality traits (Costa & McCrae, 1992). McElroy and Down (2007) hypothesised openness-to-experience includes a greater willingness to take on outside influences, and found evidence that higher openness resulted in greater susceptibility to anchoring. Eroglu and Croxton's (2010), however, linked anchoring with high conscientiousness and agreeableness. Again, this has face validity, in terms of more conscientious people being more inclined to consider the anchor and thus be affected, or more agreeable people being more willing to go along with it as a suggested answer. The authors also, however, specifically failed to replicate the earlier finding relating to openness. Recent work by Welsh (2021) has added to this confusion, finding no significant relationships between any of the Big 5 traits and anchoring.

Decision styles. Likewise, attempts to link decision making with cognitive ability have often failed – to the extent that Stanovich and West argue intelligence and decision-making ability are largely distinct (Stanovich & West, 1998, 2000, 2008). As a result, much of the focus on individual differences in decision making has turned to 'thinking dispositions', 'cognitive styles' or 'decision styles' (the last of which is used henceforth). These measures straddle the line between personality and cognitive ability, describing people's preferences for how they approach problem solving rather than their ability per se. (Stanovich, West, & Toplak, 2016).

An early example was need for cognition (Cacioppo & Petty, 1982), conceptualised as reflecting a tendency to enjoy rational thinking over a reliance on intuition. More recent work, however, suggests that preference for intuitive thinking may be separate to preference for rationality. That is, a person may consider both or neither a strength rather than high need for cognition always implying low levels of faith in intuitions. As a result, newer measures include separate rational and intuitive scales (e.g., the Rational-Experiential Inventory or the Decision Styles Scale; Epstein, Pacini, Denes-Raj, & Heier, 1996; Hamilton, Shih, & Mohammed, 2016; respectively).

Another measure - need for cognitive closure (Webster & Kruglanski, 1994) - while designed to measure decisiveness and aversion to ambiguity in decision making, is described similarly. That is, reflecting a tendency to find ongoing reasoning around problems uncomfortable and preferring to quickly close out tasks rather than seeking additional information.

This description makes need for cognitive closure seem almost the direct opposite of a third decision style - actively open-minded thinking (Haran, Ritov, & Mellers, 2013). This describes a person's beliefs around whether deliberately maintaining an open mind and reflecting on thoughts before responding to questions or coming to conclusions is a good thing. Conversely, if a person believes changing their mind or being undecided is a sign of weakness, they will score low on this measure.

Inspired by the friction between rational economic decision making and the satisficing approach described by Simon (1957), the brief maximization scale (Nenkov, Morrin, Schwartz, Ward, & Hulland, 2008), distinguishes between individuals who prefer to engage in maximization – conscious consideration and comparison of options – versus satisficing – the selection of the first, satisfactory option. This seems, once again, to draw a distinction between high and low effort problem-solving strategies.

Finally, the cognitive reflection test (Frederick, 2005), is conceptualised as measuring 'cognitive reflection', a person's preference for reflecting on their answers before giving them. People scoring low on this measure tend, instead, to rely on their immediate, intuitive responses.

While these decision styles were designed by different researchers for different purposes, the descriptions given above suggest commonalities. Specifically, all describe strategies or tendencies around problem-solving relating to how much effortful thought a person prefers to put into problem solving. This suggests that the various decision styles may be capturing aspects of the same underlying construct or constructs.

Decision styles and cognitive abilities. Frederick's (2005) paper on the cognitive reflection test, however, highlights a key concern around decision styles. Frederick concluded his 3-item test of logic/maths measures 'cognitive reflection' and this predicted people's decision making better than cognitive ability. Two, related, problems arise from this claim.

Firstly, the cognitive reflection test questions are all mathematical problems. As a result, the measure is confounded with cognitive ability and it is not clear if the cognitive reflection test could distinguish people with high 'cognitive reflection' but low mathematical ability from those with low 'cognitive reflection', as both would get the questions wrong. While variant scoring mechanisms have been suggested to distinguish between wrong and both-wrong-and-intuitive answers (see, e.g., Pennycook, Cheyne, Koehler, & Fugelsang, 2016), Welsh (2022) found these alternate scoring measures correlated at between 0.9 and 0.98, and were largely indistinguishable in terms of relationships with other measures.

This argues against the idea that reflection versus intuition is key to understanding the cognitive reflection test. Instead, mounting evidence from independent analyses points to the cognitive reflection test being a measure of quantitative (numerical) ability (Weller et al., 2013; Welsh, 2022; Welsh, Burns, & Delfabbro, 2013) rather than a separate trait.

This leads to a second, broader, concern. Frederick's paper, along with much of the work by Stanovich, West and others (Stanovich & West, 1998, 2000, 2008; Toplak, West, & Stanovich, 2011) examining relationships between cognitive ability and decision making, uses low validity measures of cognitive ability. For example, while a subset of Frederick's sample was tested using the Wonderlic Personnel Test (Wonderlic, 1973), which yields a measure of general intelligence, the 'intelligence' measure for most participants was their self-reported SAT (US college entry) score. While these correlate highly (r = 0.82) with actual SAT scores (Kuncel, Credé, & Thomas, 2005) and SAT scores are a form of cognitive ability test correlating with other intelligence measures between r = 0.48 and 0.86 (Frey & Detterman, 2004), this still results in an imperfect measure (self-report) of an imperfect measure (SAT) of general ability being used to represent a person's cognitive ability.

This also ignores the structure of cognitive abilities identified by Carroll (1993) and codified in the Cattell-Horn-Carroll model of intelligence (McGrew, 2009), now considered the gold standard in psychometrics. Combining this with the observation that Frederick's (2005) cognitive reflection test seems largely to measure quantitative ability (*Gq* from the Cattell-Horn-Carroll model), the claim that cognitive reflection is a better predictor of decision making than cognitive ability seems based on an unstable foundation. That said, it remains possible that other decision style measures are superior – as the work showing the cognitive reflection test to be a measure of cognitive ability also suggested it was relatively distinct from other decision style measures (Welsh, 2022).

Alternately, though, it remains possible that the development and use of decision styles, in general, has grown out of the continued division between cognitive and individual differences psychology, with researchers from the cognitive side selecting sub-optimal individual differences measures - undermining efforts to predict decision making. Given this, relationships between decision styles and other individual differences need to be examined to provide clarity around whether decision styles measures – beyond the cognitive reflection test - are capturing something unique in terms of decision making ability or if their predictive power is captured in general cognitive ability, *g*, by the 8+ broad abilities of the Cattell-Horn-Carroll model (i.e., fluid ability, Gf; crystallized ability, Gc; long term retrieval, Glr; short term memory, Gsm; etc; see, McGrew, 2009) and/or the Big 5 personality traits (McCrae, Costa, & Martin, 2005), to ensure relationships are not being obscured by poorly chosen measures.

Once the relationships between decision styles, cognitive abilities and personality traits are established, is will be possible to assess the unique contribution of decision styles to predicting specific cognitive biases by partialling out covariance with existing measures. This will determine whether decision styles are, as has been argued, reflective of novel traits distinct from personality and cognitive ability or if their predictive power comes from variance shared with these well-established constructs.

Research Aims

This study seeks to answer three, related, research questions.

Firstly, to determine whether the various decision style measures are related to one another as their descriptions imply. That is, establishing whether they reflect the same or distinct underlying constructs.

Secondly, decision styles will be compared to cognitive ability and personality traits from the Cattell-Horn-Carroll and Big 5 models (respectively) to see the extent to which decision styles capture unique rather than existing traits.

Finally, the unique contribution of decision styles to predicting cognitive biases will be examined, determining the extent to which decision style measures have incremental predictive power once analyses control for covariance with established cognitive ability and personality measures.

Materials and Method

Analyses were undertaken using a dataset collected as part of ARC Linkage Project LP160101460. As a result, the full data collection procedure includes details already reported in the literature (Welsh, 2020a, 2020b, 2021, 2022) and measures not relevant to the analyses herein. Given this, a brief summary is provided here with fuller information on participants and procedure included as Appendix B.

Participants

Participants were 301 university students and members of the general public, recruited via on-campus fliers, Facebook and snowball sampling. Of these, 172 identified as female, 120 male and 9 as non-binary with ages from 18 to 79 (M = 28.8, SD = 12.8). The majority of participants (207) indicated English was their first language and most (234) were university educated. Participants were paid $100 on completion of testing. The study received ethics approval from the Psychology Sub-Committee of the University of Adelaide's Human Research Ethics Committee (Approval No: 18/99).

Procedure

Testing took approximately 5 hours and was conducted over multiple sessions, with participants first indicating willingness to participate through an introductory, online survey incorporating the information sheet and consent form and asking participants to provide their email and demographics.

Participants were then emailed a link to Survey 1, which included: questions assessing the Big 5 personality traits (Costa & McCrae, 2010); decision styles measures including actively open-minded thinking, the Decision Styles Scale (which includes a 'rational' subscale equivalent to Cacioppo & Petty's (1995) Need for Cognition; Hamilton et al., 2016); need for cognitive closure (Webster & Kruglanski, 1994); the brief maximization scale (Nenkov et al., 2008); and a variety of cognitive ability measures..

Following completion of Survey 1, participants were emailed a link to Survey 2. This survey included: a seven-item version of the cognitive reflection test (Frederick, 2005; Thomson & Oppenheimer, 2016); a variety of cognitive ability tests (described in Appendix B) and questions testing for confirmation bias (Nickerson, 1998), framing (Kahneman & Tversky, 1979), outcome bias (Baron & Hershey, 1988) and three forms of overconfidence (Moore & Healy, 2008).

Following Survey 2, participants were invited to one-on-one, in-person testing. This session included additional computerised and paper-and-pencil cognitive ability tests, and testing for a number of biases.

At the end of the in-person testing, a final online survey presented participants with the correct answers to a set of questions from Survey 2, asking them to indicate whether they had answered each correctly, yielding a measure of hindsight bias (Fischhoff & Beyth, 1975). Following completion, participants were prompted to alert the experimenter, thanked for their time and given their gift vouchers.

Measures

Decision styles. Six decision style scales were used: the rational and intuitive scales from the Decision Styles Scale (DS Rational and DS Intuitive; Hamilton et al., 2016), need for cognitive closure (NFCC; Webster & Kruglanski, 1994), actively open-minded thinking (AOT; Haran et al., 2013), brief maximization (Nenkov et al., 2008) and a seven-item version of the cognitive reflection test combining the 3 original questions (Frederick, 2005) with 4 designed to be less mathematical in nature (Thomson & Oppenheimer, 2016). These are listed and described in terms of what they are proposed to measure in Table 1.

As noted above (and explained fully in Welsh, 2022) previous analyses suggest the cognitive reflection test is largely unrelated to the others, instead reflecting cognitive ability. Thus, while included, the key focus is on the remaining five measures.

Cognitive abilities. Twenty measures of cognitive ability were taken across the surveys and in-person testing (see Appendix B for additional details). This included 3 measures for each of six Cattell-Horn-Carroll broad abilities (*Gf*, *Gc*, *Gq*, *Gt*, *Glr* and *Gsm*) which were used to generate factor scores for each broad ability as described in Welsh (2022). Additionally, measures reflecting two additional broad abilities (*Gv* and *Gs*) were included. These eight broad abilities are listed in Table 2, along with their loading on the general cognitive ability factor, *g*. This, higher-order factor was generated by factor analysis in SPSS using PAF with oblimin rotation. The KMO statistic for the factor analysis was .780 and the Bartlett's test of sphericity was significant ($p<.001$), indicating the data were appropriate for factor analysis. Given the established evidence for the Cattell-Horn-Carroll model, a single factor was required, returning an eigenvalue of 3.337 and explaining 41% of the variance in the broad abilities – in the typical range of 40-50% of variance explained by *g* (Mackintosh, 2011). All broad ability factors loaded on *g* at .47 or above, with fluid ability (*Gf*) having the highest loading - as typically seen in the Cattell-Horn-Carroll model (McGrew, 2009).

Personality. The Big 5 personality traits – neuroticism, extraversion, openness-to-experience, agreeableness and conscientiousness - were calculated from participant's responses to NEO-PI3 questions as per McCrae, Costa and Martin (2005). Given the solid psychometric underpinnings of these traits and known relationships between them, no attempt at dimension reduction was undertaken.

Decision Biases. Five cognitive biases were included in analyses: confirmation bias, framing, hindsight bias, outcome bias and overconfidence (measured in three distinct ways as overestimation, overplacement and overprecision).

Confirmation Bias. This was assessed using three illusory correlations questions, presenting a data table and asking the participant whether it supported a proposed relationship. In all cases, the relationship was sensible, leading to an expectation people would believe it did exist and preferentially look for and or weight evidence supporting it - despite the presented data not doing so. Participants indicated how much support they believed the data provided on a 5-point scale from None to Very Strong. These were converted to 0-4 scores and summed across the three questions to give a 0-12 score with higher numbers indicating greater confirmation bias susceptibility. Figure 1 shows a screenshot of one question as seen in the online test, with the relationship between headaches and a new medication being shown. A person looking for confirming evidence would note the largest group of participants falls in the headache+medication cell. However, examination of the full table shows approximately twice as many people report having versus not having headaches, regardless of whether they were taking the medication or placebo. Thus the data do not support the relationship.

Framing. Bias due to framing was assessed using a pair of risky choice questions as per Kahneman and Tversky's Prospect Theory (1979). These asked the participant to imagine that they were at a casino playing a game of chance. The first described a situation in a negative frame, where the participant had lost $1000 and now had to decide on whether to walk away accepting that loss or take a double-or-nothing gamble that could result in them winning their money back or losing another $1000. That is, a certain loss (-$1000) or a 50/50 chance of $0 and a $2000 loss. In the positive frame, the participant was $1000 up after the first round and deciding between walking away and a double-or-nothing gamble that would result in overall winnings of $0 or $2000. Prospect theory argues people in positive frames will be risk averse, taking the certain option while people in negative frame will be risk seeking and more likely to take the gamble. In addition to their selection, participants rated how strongly they preferred that option, on a 4-point scale (No Preference, Weak, Moderate or Strong). This was converted to a 0-3 score and assigned a positive value if their selection aligned with the Prospect Theory prediction (e.g., being risk seeking in the negative frame) or negative value if it disagreed (e.g., being risk seeking in the positive frame). Overall framing susceptibility was the sum of the scores from the two questions, taking values from -6 to 6 with higher scores reflecting more strongly typical framing effects. It should be noted that negative scores are possible, where people do the opposite of what is predicted by Prospect Theory. These should, however, be less common than positive scores.

Hindsight bias. Hindsight bias was calculated from a short online survey at the end of the in-person testing showing participants correct answers to 44 questions they had responded to during Survey 2 and asking them whether they had correctly answered the questions at that earlier time. The measure was the difference between their recalled number of correct responses and their actual number expressed as a percentage. This produces a theoretical range from -100 to +100% with higher scores suggesting greater impact of hindsight bias.

Outcome bias. Outcome bias (Baron & Hershey, 1988) was tested using a set of eight questions asking participants to imagine they were watching a friend gambling and rating the quality of their decisions. The eight decisions represented all combinations of correct and incorrect decision making with good and bad outcomes for two scenarios – one with a certain option that was less valuable than the 50/50 gamble ($100 vs $0/$250) and one with a certain option more valuable than the 50/50 gamble ($100 vs $0/$150). Participants were asked to rate the quality of each decision on a 7-point scale (Terrible, Very Bad, Bad, Neutral, Good, Very Good, Great), translated into a 1-7 score. Outcome bias scores were calculated for each pair of questions with the same set-up that differed in outcome, by subtracting the rating when the outcome was bad from that of the same scenario with a good outcome. This gave a -6 to 6 scale, with higher numbers indicating a stronger effect of the outcome in the predicted direction. These were summed across the four pairs of questions to yield overall outcome bias susceptibility on a -24 to 24 scale. (NB - while negative numbers are possible they were expected to be rare.)

Overconfidence. Overconfidence bias was assessed in the three distinct ways described by Moore and Healy (2008), as: overestimation, where an individual overestimates their performance on some measure; overplacement, where an individual ranks themselves higher within a group than their performance warrants; and overprecision, where an individual is too certain regarding the limits of their knowledge and makes forecasts or estimates ranges that are too narrow and capture the truth less often than they predict. All three of these measures were captured using the set of 20 overprecision questions, as detailed in Welsh (2020b).

Results

Decisions Styles

The first research question asked how and to what extent the various decision style measures are related to one another. To answer this, correlation analyses were run on the six decision style measures, revealing a number of weak to moderate correlations as shown in Table 3.

Looking at Table 3, one sees relationships that are in the expected directions. For example, there are positive relationships between DS Rational, need for cognitive closure, brief maximization and the cognitive reflection test. The pattern, however, reaffirms that decision styles are not linked by a single factor as DS Intuitive, while negatively correlated with DS Rational has a positive relationship with need for cognitive closure. Brief maximization has the strongest relationships with the other measures, correlating at up to .33 with need for cognitive closure and .29 with actively open-minded thinking ($p < .001$ in both cases), while the cognitive reflection test has the lowest, with two non-significant relationships with need for cognitive closure and brief maximization and its strongest the negative relationship with actively open-minded thinking ($r = -0.17$, $p < .01$).

Despite the weak correlations, a factor analysis was run in SPSS using Principal Axis Factoring extraction and Oblimin rotation to shed light on the underlying relationships. Unsurprisingly, given the weak correlations, the KMO statistic was below the traditional 0.6 cut-off at 0.56. The communalities and factor loadings indicated that the cognitive reflection test was an outlier within the group, with only 7.1% of its variance explained by the two factors suggested by Kaiser's rule and examination of the scree plot and loading below 0.3 on both. Given this, the analysis was rerun removing the cognitive reflection test. While this did not increase the KMO statistic, it lifted the communalities for other variables and the overall proportion of variance accounted for by two factors, from 29% (17% and 12%) to 37% (21% and 16%). The variables, communalities and loadings on these factors are shown in Table 4.

Looking at Table 4, one sees that, perhaps unexpectedly, the factors do not align with the rational/intuitive division. Rather, while Factor 2 is centred on DS Intuitive, DS Rational is the other variable that loads here. Factor 1, on the other hand, seems to captures the variables most closely related to the satisficing/maximization divide – that is, whether someone is willing to make a fast decision on incomplete information or inclined to make slower, more considered decisions. Given the high degree of unexplained variance shown by the communalities for DS Rational, need for cognitive closure and actively open-minded thinking in particular, however, these factors can not be regarded as adequately explaining the variables.

Overall, these results suggest the various decision style measures are not closely related to one another. The weak correlations between them and the unconvincing factor analysis suggest that the five scales, while touching on similar ideas, should not be considered as reflecting the same underlying constructs.

Decision Styles and Intelligence

The second research question asked how the decision styles are related to cognitive ability and personality – represented by the eight Cattell-Horn-Carroll broad abilities and Big

5 personality variables. These relationships are examined in the following two sections, starting here with the Pearson correlations between the decision style and cognitive ability measures as shown in Table 5.

Looking at Table 5, one sees the cognitive reflection test correlates significantly with all of the Cattell-Horn-Carroll broad abilities at $r \geq .25$ and most strongly with fluid ability (*Gf*, $r = .63$) and quantitative ability (*Gq*, $r = .47$), strongly supporting previous work suggesting that the cognitive reflection test is an ability measure. The fact that fluid ability (*Gf*) rather than quantitative (*Gq*) is the stronger predictor in this study may reflect the inclusion of the less-mathematical questions from Thomson and Oppenheimer (2016).

The other decision style measures also have significant relationships with Cattell-Horn-Carroll abilities but these tend to be weaker. For example, both DS Rational and DS Intuitive correlate, positively and negatively respectively, with fluid (*Gf*) and quantitative ability (*Gq*) while actively open-minded thinking correlates negatively with six of the eight Cattell-Horn-Carroll measures – all except quantitative ability (*Gq*) and short term memory (*Gsm*). Finally, need for cognitive closure and the brief maximization scale have the fewest and weakest relationships to cognitive abilities, with the former have a weak negative correlation with crystallized ability (*Gc*) and the latter with long term retrieval (*Glr*) and processing speed (*Gs*).

These results suggest the decision style measures (excluding the cognitive reflection test), while significantly correlated with various of the Cattell-Horn-Carroll broad abilities, remain fairly distinct - as evidenced by the relatively small amount of variance in decision styles explained by the correlations with cognitive abilities.

Decision Styles and Personality.

A similar analysis compared the decision style measures to the Big 5 personality traits, with Pearson correlations between these shown in Table 6.

Looking at Table 6, one sees all of the decision style measures other than the cognitive reflection test correlate with multiple personality traits. The cognitive reflection test correlates only with openness-to-experience – which is unsurprising given the known relationship between openness and cognitive ability. By comparison, DS Rational and DS Intuitive both correlate with extraversion, openness and conscientiousness, actively open-minded thinking with extraversion, openness and agreeableness, brief maximization with everything but extraversion, and need for cognitive closure with all five personality traits.

The correlations observed here are also stronger, on average, than those seen between the decision styles and measures of cognitive ability, with a number above .30 and up to -.40 between need for cognitive closure and openness and .41 for the relationship between DS Rational and conscientiousness. Given less shared covariance between personality traits, compared to cognitive abilities, the stronger and more numerous relationships seen here suggest that more of the variance in decision styles is accounted for by personality than cognitive ability. That said, the relationships are still weak to moderate, meaning that significant variance in the decision styles remains unaccounted for in these analyses as well.

Decision Styles and Cognitive Biases

The third research question asked whether the decision style measures would retain predictive power for performance on cognitive bias tasks after controlling any variance shared with the cognitive ability and personality traits. This requires establishing that predictive power first and then recalculating controlling for these covariates.

(NB - rather than controlling for all potential covariates individually, linear regressions were run as described in Appendix C. The regression models' predictions were then saved and partial correlations calculated below controlled for these, predicted, variables accounting for all of the significant predictors identified in each regression.)

Cognitive bias susceptibility scores. Participants' susceptibility to the various cognitive biases is described below, followed by the correlation analyses showing the relationships between these measures and the decision styles as zero-order correlations in Table 7 and partial correlations controlling for the predictive power of the regression models in Table 8.

Confirmation bias. Confirmation bias scores ranged from 0 to 10, with a mean of 3.96 (*SD* = 2.91). This equates to typical responses saying that the data provided a little more than weak support (3/12) for the proposed relationships and demonstrating an overall confirmation bias effect (0/12 would be no support, 6/12 moderate, 9/12 strong and 12/12 very strong). Significance was confirmed using a one-sample t-test, comparing against the expected score of 0 if there were no effect, $t(299) = 23.6$, $p < .001$.

Framing. Participants' framing susceptibility scores ranged from -6 to 6 with a mean of 0.68 (*SD* = 2.11), reflecting a small-medium (Cohen's $d = .32$) tendency towards acting in accordance with Prospect Theory predictions.

Hindsight bias. Participant's hindsight bias scores ranged from -39% up to 57%, with a mean of 3.0% (*SD* = 13.0). That is, on average, people recalled getting 1-2 more questions right out of 44 than they actually did. Some, however, believed they had answered many fewer correctly and others many more.

Outcome bias. Participants' outcome bias scores ranged from -7 to 16, with a mean of 2.0 (*SD* = 3.5). The average rating of decisions in scenarios with bad outcomes was 4.2, just above neutral (4), while a good outcome raised this by half a response category to 4.7 – closer to the 'good' rating of 5 - indicating that the sample, as a whole, displayed outcome bias – as confirmed by a paired sample t-test, $t(598) = 8.9$, $p < .001$.

Overconfidence. Participant scores on the three overconfidence measures revealed significant bias, regardless of which method for defining and measuring it was selected. For example, participants overestimated the number of questions they had gotten right by 5.5%, which a single sample t-test indicated differed significantly from the expected difference of 0% for people with no overconfidence, $t(300) = 3.7$, $p < .001$. They also showed overconfidence in their expected placement within the group, ranking themselves on average 7.9 percentile points higher than they achieved. Again, a single sample t-test confirmed this as significant, $t(300) = 3.8$, $p < .001$. Finally, participant's estimated ranges and forecasts captured the true value on only 31% of occasions, compared to the expected 80%, yielding an average overprecision score of 49%. This was confirmed as significant using a single sample t-test, $t(300) = 17.4$, $p << .001$. (NB - while noticeably larger than the other two measures, this level of overprecision is quite typical as participants find this type of task difficult.)

Correlations between decision styles and cognitive bias measures. Pearson correlations between participants' scores on decision style measures and for each of the seven bias susceptibility measures were calculated and are shown in Table 7. Additional analyses looked at the relationships between the cognitive bias measures and the cognitive ability and personality traits. These are not presented in full for reasons of space but the strongest relationships are detailed in the results below to provide an indication of which traits (decision styles, cognitive abilities or personality) provide the best predictors of each bias.

Looking at Table 7, results show a number of weak to moderate relationships between decision styles and biases. For example, confirmation bias is weakly linked to all of the decision styles measures except DS Rational but its strongest relationships is with the cognitive reflection test (already identified as a cognitive ability measure), $r = -.42$, $p < .001$. The additional analyses supported this, with all eight Cattell-Horn-Carroll broad abilities correlating significantly with confirmation bias. The strongest relationship being $r = -.47$ ($p < .001$) with fluid ability (*Gf*), suggesting higher fluid ability predicts confirmation bias susceptibility better than any of the decision styles. Of the personality traits, only openness-to-experience (with its known links to cognitive ability) correlated with confirmation bias, $r = -.22$, $p <.001$.

Looking at the framing results in Table 7, by comparison, one sees no significant relationships. Additional analyses looking at the cognitive ability and personality traits found only Agreeableness correlated significantly with framing and this result was very weak ($r = -.12$, $p = .041$).

Hindsight bias showed significant correlations with only two decision style measures. Once again, the cognitive reflection test has the strongest relationship, with a correlation of -.40 but the relationship with actively open-minded thinking is also significant, $r = .24$, $p < .001$. Additional analyses indicated that all cognitive ability measures except quantitative ability (*Gq*) were significantly related to hindsight bias, with fluid ability (*Gf*) correlating at -0.50, suggesting people with higher fluid ability scores display less hindsight bias. Two personality traits also showed significant relationships with hindsight bias, with neuroticism and agreeableness both showing weak, negative correlations (r = -.13 and -.15, p < .05 and .01, respectively).

Correlations between outcome bias scores and the decisions styles measures in Table 7 show that both need for cognitive closure and brief maximization have weak, positive, relationships, r = .19 and .13, p < .001 and .05, respectively. That is, higher scores on these decision style measures predict *more* outcome bias. Additional analyses looking at the cognitive ability and personality measures, revealed weak, positive relationships with crystallized ability, *Gc*, long term retrieval, *Glr*, and neuroticism (r = .18, .13 and .15, p < .01, .05 and .01, respectively. This is weakly suggestive of people with better memories and a greater disposition for anxiety being more susceptible to this bias.

Finally, correlations between the overconfidence and decision style measures in Table 7 show only actively open-minded thinking and the cognitive reflection test have (weakly) significant relationships with overestimation and overplacement. Overprecision, meanwhile, correlates significantly with the cognitive reflection test and DS Intuitive. In all cases, the correlations with the cognitive reflection test indicate higher scores on this predict less bias, while higher scores on the other decision style measures predict greater bias. Additional analyses looking at the relationships between overconfidence measures and the cognitive ability and personality traits showed a number of significant relationships with fluid (*Gf*), crystallized (*Gc*), long term retrieval (*Glr*) and processing speed (*Gs*) broad abilities all correlating significantly with all three overconfidence measures, with the strongest relationship being $r = -.35$ ($p < .001$) between *Gf* and overprecision. By contrast, none of the personality traits showed significant relationships with any overconfidence measure.

Overall, the trend observed in the above analyses is that the relationships in Table 7 between bias susceptibility ,measures and the decision styles (excluding the cognitive reflection test) tend to be markedly weaker than those observed between the bias susceptibility measures and the cognitive ability measures.

Partial correlations between decision styles and cognitive bias measures. To test the third research question – the extent to which decision styles would retain predictive power after controlling for cognitive ability and personality covariates - the relationships presented in Table 7 were recalculated controlling for the relationships between decision styles, intelligence and personality measures described in the regression models (see Appendix C). Partial correlations in Table 8 show few of the decision style measures retain any predictive power after controlling for these identified relationships.

Specifically, significant relationships between decision style measures (again, excluding the cognitive reflection test) and confirmation bias, hindsight bias, overestimation, overplacement and overprecision all disappeared when the decision styles relationships with cognitive ability and personality were partialled out.

The only bias for which the decision styles measures retained significant predictive power was outcome bias, which continued to correlate significantly (if weakly) with need for cognitive closure and brief maximization.

Finally, the partial correlation analysis resulted in need for cognitive closure becoming a significant predictor of overestimation bias ($r = .14$, $p < .05$), which may suggest its effect had previously been obscured by other relationships, although the relationship is weak.

Discussion.

The above results are discussed in terms of their implications for the study's three research questions in the sections below, along with caveats around the interpretation before general conclusions are drawn regarding the utility of decision styles measures for predicting individual susceptibility to the decision biases discussed herein.

Relationships amongst Decision Styles.

The first research question asked whether and to what extent the decision style measures are related to one another, reflecting the same underlying trait or traits. The first thing to note, here, is that initial inclusion of the cognitive reflection test in analyses re-confirmed that this measure is distinct from the other decision style measures, with weak correlations and a failure to load on either of the factors extracted from the set of decision styles.

Even with the cognitive reflection test excluded, though, the correlations and factor analysis presented above show only weak relationships between the different decision styles and suggestive evidence of two underlying factors - perhaps capturing aspects of peoples' preference for relying on intuition and their tendency towards making considered decisions. The weakness of these relationships (with correlations no higher than $r = .33$) and lack of convincing support for the factor structure suggests that the five decision styles are quite different from one another and, as a result, should be considered as measuring distinct constructs.

Relationships to other Psychometric Traits.

The second research question – in line with the observation that the descriptions of decision style measures seem to skirt the line between cognitive abilities and personality - asked how these measures are related to the psychometrically supported Cattell-Horn-Carroll broad abilities and Big 5 personality traits.

Results showed the five decision style measures (setting aside the cognitive reflection test) had numerous relationships with cognitive abilities and personality traits; a key observation being that the personality traits tended to be more strongly related to decision styles than were the cognitive abilities.

Exactly which personality traits and cognitive abilities covaried with different decision styles varied somewhat but, taking into account the results in Tables 5 and 6, and the regression analyses in Appendix C, Conscientiousness was perhaps the strongest predictor, having significant correlations and being retained in the regression models all of the decision styles except actively open-minded thinking (Haran et al., 2013). This makes sense when looking at the facets of conscientiousness - Competence, Order, Dutifulness, Achievement Striving, Self-Discipline and Deliberation (Costa & McCrae, 2010). Deliberation, for example, seems similar to the idea of a Rational decision style (Hamilton et al., 2016) and is quite similar to the potential 'Consideration' factor described in the results. Similarly, Achievement Striving could be framed as opposite to the idea of satisficing captured by low scores on the Brief Maximization scale.

Of the other personality measures, Agreeableness was negatively related to three decision styles – need for cognitive closure, actively open-minded thinking and brief maximization – potentially reflecting that the low end of agreeableness captures competitiveness and unwillingness to compromise, which might lead to continued searching for the 'best' outcome rather than settling for passable ones.

Finally, both extraversion and neuroticism were related to two decision style measures, extraversion to DS Rational (negatively) and DS Intuitive (positively) and neuroticism positively to both need for cognitive closure and brief maximization. The first could be interpreted as relating to the confidence often linked to higher extraversion through its facets of Assertiveness and Excitement Seeking, which may make individuals more comfortable with relying on their intuitions – and less for those with lower extraversion. Similarly, the Anxiety facet of neuroticism could be motivating a greater desire to reduce ambiguity (need for cognitive closure) or limit bad outcomes (brief maximization).

All of the decision style regressions other than for need for cognitive closure also had multiple correlations with cognitive abilities and retained contribution from at least one of the cognitive ability measures in its regression model. A key observation is that, other than two positive correlations with DS Rational (and, of course, the cognitive reflection test), the significant relationships between the various cognitive abilities and decision styles were entirely negative. That is, people with higher cognitive ability scores tended to score lower on DS Intuition, need for cognitive closure, actively open-minded thinking and brief maximization. While the reason for this is not clear from the results, it could be theorised these scales might reflect compensatory strategies used by people with lower ability when faced with decision making tasks.

Predictive Power of Decision Styles.

The final research question asked to what extent decision style measures would retain predictive power after controlling for covariance with cognitive ability and personality measures. That is, to what extent these measures capture some unique trait or traits beyond the constructs of intelligence and personality. This is important for answering the question raised at the beginning of this paper: whether the lack of clear relationships between cognitive abilities, personality and decision making ability has resulted from there being a separate trait not captured by these existing tests – such as Stanovich and colleagues' (2016) proposed 'rationality quotient' – or if this failure has resulted from the cognitive/psychometric divide in psychology (Deary, 2001) leading to poor selection of individual differences measures within the cognitively-focussed, decision-making literature.

The results largely support the latter conclusion. The decision style measures had some predictive power when considering the confirmation bias, hindsight bias, outcome bias and overconfidence (but not framing) but these relationships were weaker, in almost every case, than predictors found amongst the cognitive ability and personality measures for the same biases. Further, when other predictors were controlled for, the majority of these correlations disappeared, suggested that they were, initially, mediated by these other traits. Across five biases (and seven bias measures given three types of overconfidence), significant correlations with decision styles remained only for outcome bias (with need for cognitive closure and brief maximization). This has some face validity as both of these scales involve a focus on achieving particular outcomes, potentially making people with high scores on these more sensitive to the quality of the outcome over that of the decision.

However, both relationships are weak (r = .17 and .13, p < .01 and .05 for need for cognitive closure and brief maximisation, respectively), explaining a very small fraction (< 3%) of the variance in the bias score. By comparison fluid ability (*Gf*), correlated with confirmation bias at -.47, hindsight bias at -.50 and overconfidence (overestimation) at -.35.

Overall, results suggest decision styles add little in terms of incremental, predictive power over existing measures of cognitive ability and personality. Rather, they seem to be composite measures capturing aspects of personality and some cognitive abilities. Once these relationships are removed, the decision styles measures are poor predictors of decision-making ability – specifically, herein, the ability to avoid cognitive biases – and, the relationships that exist are in the opposite direction to what would be expected, with 'better' scores on the decision style scales (i.e., those suggestive of greater effort being put into problem solving) predicting more rather than less susceptibility to the biases.

Caveats.

With the exploratory approach undertaken here, come a great many comparisons, resulting in an increased possibility of Type 1 errors. Family-wise corrections, however, are ill-suited to sets of related variables such as cognitive abilities (Derringer, 2018) and, as a result, have not been used herein. While the chance of Type 1 errors is greatly reduced when analysis of a set of variables results in multiple significant relationships, some analyses herein show only a small number or single significant relationship from a number of comparisons. In these cases, the results must be considered less certain. For example, when controlling for the effect of cognitive ability and personality on overestimation (overconfidence), the correlation between need for cognitive closure and overestimation *increased* from .08 to .14, becoming significant at the .05 level. While an argument could be made for this being genuine, with need for cognitive closure linked to overconfidence in previous research (Kaesler, Welsh, & Semmler, 2016), a more cautious interpretation is required given the large number of comparisons, the weakness of the correlation and the fact that this was only observed for one of the three types of overconfidence (which are, themselves, moderately to strongly correlated with $r = .49$ to .81).

A second caveat follows from the weak results observed for the framing bias. While framing was observed in the sample, it was weaker than commonly seen (Kahneman & Tversky, 1979). This may have resulted from the within-subjects design, whereas much of the bias literature uses between-subjects (Kahneman & Tversky, 1996). This makes it more likely participants will recognise the two questions as equivalent and respond in more similar ways across conditions. This concern holds true for all of the biases to some extent, as seeing a number of 'trick' questions can prime participants to be careful in responding, reducing the apparent effect of biases. As a result, the overall strength of biases observed here may be less than would occur in other conditions, which could act to reduce correlations between these and decision styles, cognitive abilities and/or personality traits.

Similarly, it should be noted that testing was long, taking most participants 5 hours in total, and that the online surveys were delivered unproctored. As a result, test conditions will have varied across participants, lessening the reliability of results - on ability tests in particular. Additionally, the long (3 hour), in-person testing session is likely to have resulted in some participants becoming fatigued, again reducing the reliability of results.

Finally, it should be noted that susceptibility to cognitive biases, while an aspect of decision-making ability, does not cover this concept in its entirety. Thus, the results shown herein, examining a subset of well-known cognitive biases, leave open the possibility that the decision style measures might capture aspects of performance on other bias measures or other constructs such as decision competence (Bruine de Bruin, Parker, & Fischhoff, 2007).

Conclusions.

With those caveats in mind, the results still seem to offer clear answers to the research questions being consdiered. Firstly, the decision style measures seem somewhat related to one another, capturing aspects of some common, underlying traits. These relationships, however, are quite weak, potentially because they are being mediated by the decision style measures' shared relationships with cognitive ability and personality traits. This suggests that the decision styles must be considered separately, rather than as alternate measures of the same construct/s.

In answer to the second research question, the decision styles were all shown to be linked to multiple Catell-Horn-Carroll broad abilities and/or Big 5 personality traits, with conscientiousness, in particular, standing out as a common relationship and personality, in general, showing closer links than cognitive abilities. This suggests that the decision style measures are, to a significant extent, capturing aspects of existing rather than unique constructs and that a significant aspect of what they are capturing is the tendency to approach problems in an ordered and careful manner.

Given this, it is unsurprising that analyses aimed at answering the final research question showed little evidence of any incremental power of the decision style measures in predicting people's susceptibility to cognitive biases once cognitive ability and personality traits were controlled for. From 10 significant relationships between decision styles and cognitive biases (see Table 7), only 2 remained after partialling out shared variance (see Table 8) and these correlations were both weak ($r < .2$), indicating very little predictive power. Of additional concern was the observation that scores reflective of greater effort on the decision style scales predicted increased bias susceptibility. This may make sense if these decision styles reflect compensatory strategies attempted by people with lower cognitive ability – that is, if people with lower abilities have learnt that they need to engage in more effortful reasoning when faced with problem-solving tasks. This negative relationship has been observed by some researchers between conscientiousness and fluid ability (see, e.g., Moutafi, Furnham, & Crump, 2006), with people lower in fluid ability consciously engaging in more deliberation and self-discipline, which map onto characteristics of the various decision styles examined herein.

As a result, the study strongly suggests cognitive ability measures are superior predictors of the cognitive biases considered herein, compared to any of the decision style measures. Thus, previous problems in predicting decision-making ability or susceptibility to cognitive biases may have resulted from poor choices of measures rather than a difference between the underlying constructs of intelligence and rationality as others have hypothesised (Stanovich et al., 2016). Given this, future research using established, psychometric measures should increase our ability to predict people's susceptibility to bias and, thus, ability to make good decisions.

References.

Arthur, W., & Day, D. V. (1994). Development of a short form for the Raven Advanced Progressive Matrices Test. *Educational and Psychological measurement, 54*(2), 394-403.

Baddeley, A., Emslie, H., & Nimmo-Smith, I. (1993). The Spot-the-Word test: A robust estimate of verbal intelligence based on lexical decision. *British Journal of Clinical Psychology, 32*(1), 55-65.

Baron, J., & Hershey, J. C. (1988). Outcome bias in decision evaluation. *Journal of Personality and Social Psychology, 54*(4), 569.

Bazerman, M. H. (2006). *Judgement in managerial decision making*. Hoboken, NJ, USA: John Wiley & Sons.

Bennett, G. K., Seashore, H. G., & Wesman, A. G. (1989). *Differential Aptitude Test*. Marrickville, NSW: Psychological Corporation.

Bratvold, R. B., Mohus, E., Petutschnig, D., & Bickel, E. (2020). Production Forecasting: Optimistic and Overconfident—Over and Over Again. *SPE Reservoir Evaluation & Engineering*.

Bruine de Bruin, W., Parker, A. M., & Fischhoff, B. (2007). Individual differences in adult decision-making competence. *Journal of Personality and Social Psychology, 92*(5), 938.

Cacioppo, J. T., & Petty, R. E. (1982). The need for cognition. *Journal of Personality and Social Psychology, 42*(1), 116-131.

Carroll, J. B. (1993). *Human cognitive abilities: a survey of factor-analytic studies*. Cambridge, UK: Cambridge University Press.

Cokely, E. T., Galesic, M., Schulz, E., Ghazal, S., & Garcia-Retamero, R. (2012). Measuring risk literacy: The Berlin numeracy test. *Judgment and Decision Making, 7*(1), 25.

Costa, P. T., & McCrae, R. R. (1992). *NEO PI-R Professional Manual*. Odessa, FL: Psychological Assessment Resources.

Costa, P. T., & McCrae, R. R. (2010). *NEO-PI-3*.

Cronbach, L. J. (1957). The two disciplines of scientific psychology. *American Psychologist, 12*, 671-684.

Deary, I. J. (2001). Human intelligence differences: Towards a combined experimental–differential approach. *Trends in cognitive sciences, 5*(4), 164-170.

Derringer, J. (2018). *A simple correction for non-independent tests*. Champaign, IL.

Epstein, S., Pacini, R., Denes-Raj, V., & Heier, H. (1996). Individual differences in intuitive–experiential and analytical–rational thinking styles. *Journal of Personality and Social Psychology, 71*(2), 390.

Eroglu, C., & Croxton, K. L. (2010). Biases in judgmental adjustments of statistical forecasts: The role of individual differences. *International Journal of Forecasting, 26*(1), 116-133.

Fagerlin, A., Zikmund-Fisher, B. J., Ubel, P. A., Jankovic, A., Derry, H. A., & Smith, D. M. (2007). Measuring numeracy without a math test: Development of the subjective numeracy scale. *Medical Decision Making, 27*(5), 672-680.

Fischhoff, B., & Beyth, R. (1975). I knew it would happen: Remembered probabilities of once—future things. *Organizational Behavior and Human Performance, 13*(1), 1-16.

Frederick, S. (2005). Cognitive reflection and decision making. *Journal of Economic Perspectives, 19*(4), 25-42.

Frey, M. C., & Detterman, D. K. (2004). Scholastic assessment or g? The relationship between the scholastic assessment test and general cognitive ability. *Psychological Science, 15*(6), 373-378.

Gilovich, T., Griffin, D., & Kahneman, D. (Eds.). (2002). *Heuristics and Biases: the Psychology of Intuitive Judgment* (1st ed.). Cambridge, UK: Cambridge Universty Press.

Hakstian, A. R., & Bennet, R. W. (1977). Validity Studies Using the Comprehensive Ability Battery (CAB): 1. Academic Achievement Criteria. *Educational and Psychological measurement, 37*(2), 425-437.

Hamilton, K., Shih, S.-I., & Mohammed, S. (2016). The development and validation of the rational and intuitive decision styles scale. *Journal of Personality Assessment, 98*(5), 523-535.

Haran, U., Ritov, I., & Mellers, B. A. (2013). *The role of actively open-minded thinking in information acquisition, accuracy, and calibration*. ScholarlyCommons, (5-2013).

Haselton, M. G., Nettle, D., Andrews, P. W., & Buss, D. M. (2005). The evolution of cognitive bias

In D. M. Buss (Ed.), *The handbook of evolutionary psychology* (pp. 724-746). Hoboken, NJ, USA: Wiley & Sons.

Kaesler, M., Welsh, M. B., & Semmler, C. (2016). Predicting overprecision in range estimation. . In A. Papafragou, Grodner, D., Mirman, D., & Trueswell, J.C. (Ed.), *Proceedings of the 38th Annual Conference of the Cognitive Science Society*. Austin, TX: Cognitive Science Society.

Kahneman, D., Slovic, P., & Tversky, A. (1982). *Judgement under uncertainty: heuristics and bias*. Cambridge: Cambridge University Press.

Kahneman, D., & Tversky, A. (1979). Prospect Theory: an analysis of decision under risk. *Econometrica, 47*(2), 263-291.

Kahneman, D., & Tversky, A. (1996). On the reality of cognitive illusions. *Psychological Review, 103*(3), 582-591.

Kirby, N., & Nettelbeck, T. (1989). Reaction time and inspection time as measures of intellectual ability. *Personality and Individual Differences, 10*(1), 11-14.

Kuncel, N. R., Credé, M., & Thomas, L. L. (2005). The validity of self-reported grade point averages, class ranks, and test scores: A meta-analysis and review of the literature. *Review of educational research, 75*(1), 63-82.

Liaw, A., Welsh, M., Copp, H., & Breyer, B. (2019). Individual Differences, Expertise and Outcome Bias in Medical Decision Making. In C. Freska, A. Goel, & C. Seifert (Eds.), *Proceedings of the Annual Meeting of the Cognitive Science Society* (Vol. 41, pp. 2140-2146). Austin, TX: Cognitive Science Society.

Mackintosh, N. (2011). *IQ and human intelligence*: Oxford University Press.

McCrae, R. R., Costa, J., Paul T, & Martin, T. A. (2005). The NEO–PI–3: A more readable revised NEO personality inventory. *Journal of Personality Assessment, 84*(3), 261-270.

McElroy, T., & Dowd, K. (2007). Susceptibility to anchoring effects: How openness-to-experience influences responses to anchoring cues. *Judgment and Decision Making, 2*(1), 48.

McGrew, K. S. (2009). CHC theory and the human cognitive abilities project: Standing on the shoulders of the giants of psychometric intelligence research. *Intelligence, 37*(1), 1-10. doi:https://doi.org/10.1016/j.intell.2008.08.004

Moore, D. A., & Healy, P. J. (2008). The trouble with overconfidence. *Psychological Review, 115*(2), 502.

Moutafi, J., Furnham, A., & Crump, J. (2006). What facets of openness and conscientiousness predict fluid intelligence score? *Learning and Individual Differences, 16*(1), 31-42.

Nenkov, G. Y., Morrin, M., Schwartz, B., Ward, A., & Hulland, J. (2008). A short form of the Maximization Scale: Factor structure, reliability and validity studies. *Judgment and Decision Making, 3*(5), 371-388.

Nickerson, R. S. (1998). Confirmation bias: a ubiquitous phenomenon in many guises. *Review of General Psychology, 2*(2), 175-220.

Northcraft, G. B., & Neale, M. A. (1987). Experts, amateurs and real estate: an anchoring-and-adjustment perspective on property pricing decisions. *Organizational Behavior and Human Decision Processes, 39*, 84-97.

Pennycook, G., Cheyne, J. A., Koehler, D. J., & Fugelsang, J. A. (2016). Is the cognitive reflection test a measure of both reflection and intuition? *Behavior Research Methods, 48*(1), 341-348.

Pohl, R. F. (2004). *Cognitive illusions: A handbook on fallacies and biases in thinking, judgement and memory*: Psychology Press.

Preiss, A. K., & Burns, N. R. (2012). Accurately measuring inspection time with computers. *International Journal of Intelligence Science, 2*(4). doi:DOI:10.4236/ijis.2012.24013

Raven, J. C. (1958). *Guide to using the Mill Hill Vocabulary Scale with the Progressive Matrices Scales*: H.K. Lewis & Co.

Redelmeier, D. A., & Shafir, E. (1995). Medical decision making in situations that offer multiple alternatives. *Jama, 273*(4), 302-305.

Schrank, F. A., & Wendling, B. J. (2018). *Woodcock–Johnson IV Tests of Cognitive Abilities Examiner's Manual, Standard and Extended Batteries.* Itasca, IL.: Riverside Publishing.

Simon, H. A. (1957). *Models of man: social and rational*. New York, NY: Wiley.

Stanovich, K. E., & West, R. F. (1998). Individual differences in rational thought. *Journal of Experimental Psychology: General, 127*(2), 161-188.

Stanovich, K. E., & West, R. F. (2000). Individual differences in reasoning: implications for the rationality debate. *Behavioral and Brain Sciences, 23*(645-726).

Stanovich, K. E., & West, R. F. (2008). On the relative independence of thinking biases and cognitive ability. *Journal of Personality and Social Psychology, 94*(4), 672-695.

Stanovich, K. E., West, R. F., & Toplak, M. E. (2016). *The rationality quotient: Toward a test of rational thinking*: MIT press.

Thomson, K. S., & Oppenheimer, D. M. (2016). Investigating an alternate form of the cognitive reflection test. *Judgment and Decision Making, 11*(1), 99.

Toplak, M. E., West, R. F., & Stanovich, K. E. (2011). The Cognitive Reflection Test as a predictor of performance on heuristics-and-biases tasks. *Memory & Cognition, 39*(7), 1275-1289.

Tversky, A., & Kahneman, D. (1973). Availability: a heuristic for judging frequency and probability. *Cognitive Psychology, 5*, 207-232.

Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science, 185*, 1124-1131.

von Neumann, J., & Morgenstern, O. (1953). *Theory of Games and Economic Behavior*. Princeton, New Jersey: Princeton University Press.

Webster, D. M., & Kruglanski, A. W. (1994). Individual differences in need for cognitive closure. *Journal of Personality and Social Psychology, 67*(6), 1049.

Weller, J. A., Dieckmann, N. F., Tusler, M., Mertz, C. K., Burns, W. J., & Peters, E. (2013). Development and Testing of an Abbreviated Numeracy Scale: A Rasch Analysis Approach. *Journal of Behavioral Decision Making, 26*, 198-212. doi:doi: 10.1002/bdm.1751

Welsh, M. B. (2020a). May I Have Your Attention? Testing a Subjective Attention Scale. In S. Denison, M. Mack, Y. Xu, & B. C. Armstrong (Eds.), *Proceedings of the 42nd Annual Conference of the Cognitive Science Society* (pp. 2535-2541): Cognitive Science Society.

Welsh, M. B. (2020b). Overconfident in Hindsight: Memory, Hindsight Bias and Overconfidence. In S. Denison, M. Mack, Y. Xu, & B. C. Armstrong (Eds.), *Proceedings of the 42nd Annual Meeting of the Cognitive Science Society* (pp. 822-828): Cognitive Science Society.

Welsh, M. B. (2021). Does anything predict anchoring bias? In T. Fitch, C. Lamm, H. Leader, & K. Tessmar-Raible (Eds.), *Proceedings of the Annual Meeting of the Cognitive Science Society* (Vol. 43, pp. 3089-3094): Cognitive Science Society.

Welsh, M. B. (2022). What is the CRT? Intelligence, Personality, Decision Style or Attention? In J. Culbertson, A. Perfors, H. Rabagliati, & V. Ramenzoni (Eds.), *Proceedings of the Annual Meeting of the Cognitive Science Society* (Vol. 44, pp. 607-614). Austin, Texas: Cognitive Science Society.

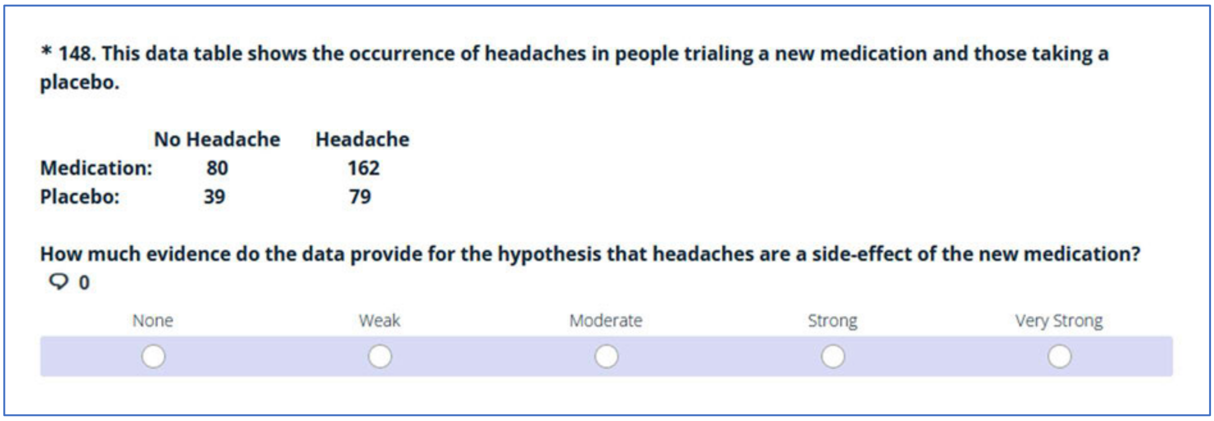
Welsh, M. B., Begg, S. H., & Bratvold, R. B. (2007). SPE 110765: Modeling the economic impact of cognitive biases on oil and gas decisions. *Proceedings of the Society of Petroleum Engineers 83rd Annual Technical Conference and Exhibition*.

Welsh, M. B., Burns, N. R., & Delfabbro, P. H. (2013). The Cognitive Reflection Test: how much more than Numerical Ability? In M. Knauff, M. Pauen, N. Sebanz, & I. Wachsmuth (Eds.), *Proceedings of the 35th Meeting of the Cognitive Science Society* (pp. 1587-1592). Austin, TX: Cognitive Science Society.

Wonderlic, E. F. (1973). *Wonderlic Personnel Test*. Los Angeles: Western Psychological Services.

Figures.

Figure 1. Screenshot of illusory correlation (confirmation bias) question



*** 148. This data table shows the occurrence of headaches in people trialing a new medication and those taking a placebo.**

	No Headache	Headache
Medication:	80	162
Placebo:	39	79

How much evidence do the data provide for the hypothesis that headaches are a side-effect of the new medication?

0

None | Weak | Moderate | Strong | Very Strong

Tables.

Table 1. Decision style scale descriptions.

Scale	Description
Decision Styles Scale - *DS Rational* - *DS Intuitive*	Preference for making decisions using rational, conscious and deliberate reasoning or intuitive approaches using hunches and first impressions - measured on separate scales.
Need for Cognitive Closure - *NFCC*	Preference for decisiveness and reducing uncertainty and ambiguity by quickly ending problem solving tasks.
Actively Open-minded thinking - *AOT*	Value attached to maintaining curiosity, willingness to change one's mind and to engage in continued search for new information.
Brief Maximization Scale - *BM*	Preference for engaging in full consideration of options (maximization) versus selecting first adequate option (satisficing)
Cognitive Reflection Test - *CRT*	Tendency to reflect on responses rather than giving immediately intuitive responses.

Table 2. Catell-Horn-Carroll (CHC) Broad Ability Measures and Loadings on *g*

CHC Broad Ability	Loading on *g*
Gf - Fluid Ability	.738
Gv – Visualisation	.705
Gq – Quantitative Ability	.553
Gt – Decision Speed	-.526
Gc – Crystallized Ability	.498
Glr – Long Term Retrieval	.493
Gs – Processing Speed	.493
Gsm – Short Term Memory	.470

Table 3. Pearson correlations between decision style measures.

	DSR	DSI	NFCC	AOT	BM	CRT
DS Rational	-	-.24***	.16**	.03	.20***	.12*
DS Intuitive		-	.13*	.31***	.06	-.11*
Need for Cog. Closure			-	.13*	.33***	-.03
Act. Open-Minded Thinking				-	.29***	-.17**
Brief Maximization					-	-.10
Cognitive Reflection Test						-

Note: * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$, two-tailed. N= 300-301.

Table 4. Factors loadings (≥ .3) and communalities of decision style measures.

Variable	Communality	Factor 1	Factor 2
Brief Maximization	.500	.706	
Need For Cognitive Closure	.214	.462	
Act. Open-minded Thinking	.235	.391	
DS Intuitive	.692		-.808
DS Rational	.210		.362

Table 5. Pearson correlations between decision styles and cognitive ability measures.

	DS Rational	DS Intuitive	NFCC	AOT	BM	CRT
g	.12*	-.19**	-.08	-.28**	-.09	.59***
Gf	.12*	-.29***	-.08	-.26***	-.07	.63***
Gc	.08	-.10	-.17**	-.28***	-.10	.41***
Gsm	.06	-.11	.07	.00	.05	.25***
Glr	.02	.05	-.10	-.26***	-.19**	.28***
Gq	.17**	-.25***	.03	-.05	.03	.47***
Gt	.04	.09	-.01	-.13*	.03	.26***
Gs	.06	-.14*	-.11	-.23***	-.12*	.30***
Gv	.03	-.06	.04	-.16**	-.07	.43***

Note: * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$, two-tailed. N = 290-301. NFCC, need for cognitive closure; AOT, actively open-minded thinking; BM, brief maximization; CRT, cognitive reflection test; *g*, general ability; *Gf*, fluid; *Gc*, crystallized; *Gsm*, short term memory; *Glr*, long term retrieval; *Gq*, quantitative; *Gt*, decision speed; *Gs*, processing speed; *Gv*, visualisation.

Table 6. Pearson correlations between decision style and Big 5 personality measures.

	DS Rational	DS Intuitive	NFCC	AOT	BM	CRT
Neuroticism	.03	.07	.35***	-.01	.19***	.01
Extraversion	-.13*	.24***	-.11*	.10*	-.01	-.06
Openness	.11*	-.12*	-.40***	-.15*	-.13*	.19***
Agreeableness	.02	-.09	-.21***	-.23***	-.24**	.08
Conscientiousness	.41***	-.15**	.23***	.07	.20***	-.01

Note: * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$, two-tailed. N = 300-301. NFCC, need for cognitive closure; AOT, actively open-minded thinking; BM, brief maximization; CRT, cognitive reflection test.

Table 7. Pearson correlations between bias measures and decision styles.

Cognitive Bias	DS Rational	DS Intuitive	NFCC	AOT	BM	CRT
Confirmation	-.08	.15*	.13*	.18***	.16**	-.42***
Framing	.09	-.05	-.03	.02	-.01	.06
Hindsight	.05	.10	.03	.24***	.05	-.40***
Outcome	.09	.04	.19***	-.03	.13*	.01
Overestimation†	-.05	.08	.08	.17**	.03	-.14*
Overplacement†	-.01	.08	.09	.14*	.06	-.21***
Overprecision†	-.08	.12*	.07	.04	.03	-.29***

Note. † - forms of overconfidence. * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$, two-tailed. N = 294-301. NFCC, need for cognitive closure; AOT, actively open-minded thinking; BM, brief maximization; CRT, cognitive reflection test.

Table 8. Partial correlations between bias measures and decision styles controlling for predictor variables calculated from regression models in Appendix C.

Cognitive Bias	DS Rational	DS Intuitive	NFCC	AOT	BM	CRT
Confirmation	-.06	.00	-.03	.02	.09	-.13*
Framing†	-	-	-	-	-	-
Hindsight	.05	-.01	.02	.07	-.01	-.16**
Outcome	.10	.03	.17**	-.00	.12*	-.08
Overestimation††	.05	.06	.14*	.11	.02	-.08
Overplacement††	-.01	.04	.07	.05	.02	-.07
Overprecision††	-.06	.02	.02	-.09	-.01	-.08

Note. † - partial correlations were not calculated for framing as this bias had no significant relationships in Table 7 and was largely unrelated to cognitive ability and personality. †† - forms of overconfidence. * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$, two-tailed. N = 294-301. NFCC, need for cognitive closure; AOT, actively open-minded thinking; BM, brief maximization; CRT, cognitive reflection test.

Appendix A.

Organisational Behavior and Human Decision Processes Author Information Pack.

See attached document.

Appendix B.

Full Data Collection Procedure from ARC Project LP160101460.

Participants.

Participants were 301 university students and members of the general public, recruited via on-campus fliers, Facebook advertising and snowball sampling. A minimum age of 18 was specified in the advertising materials and underage applicants were excluded. A total of 404 participants responded to the introductory survey (described below) with drop-outs reducing this to 364 by Survey 1, 346 by Survey 2 and 301 by Survey 3, which was conducted at the end of the in-person testing session.

Of the final sample, 172 identified as female, 120 male and 9 as non-binary with their ages ranging from 18 to 79 with a mean of 28.8 (SD = 12.8). The majority of participants (207) indicated English was their first language and the sample as a whole gave 34 counties of origin with the largest sub-groups being: 123 from Australia; 42 from India; 27 from China; and 26 from Singapore. Most (234) participants were university educated, 26 having post-graduate degrees, 101 bachelor degrees (including 38 currently enrolled in post-graduate study) and 107 current university students. Participants were paid $100 on completion of the testing described below. The study received ethics approval from the Psychology Sub-Committee of the University of Adelaide's Human Research Ethics Committee in 2018 (Approval No: 18/99) and data collection was conducted between December 2018 and November 2019.

Procedure.

Introductory survey. Testing was conducted over multiple sessions, with participants first indicating their willingness to participate by filling in an introductory, online survey. This survey incorporated the information sheet and consent form for the project, outlining the purpose of the project and the commitment being asked of participants. It then asked participants to provide a contact email and demographics including their age, gender, level of educational attainment, country of origin and whether English was their first (native) language.

Survey 1 – Personality and decision styles. Following completion of the Introductory survey, participants were emailed a link to Survey 1, which included: questions assessing the Big 5 traits and facets (Costa & McCrae, 2010); decision styles measures including Actively Open-Minded Thinking, the Decision Styles Scale (which includes a 'rational' subscale equivalent to Cacioppo & Petty's (1995) Need for Cognition; Hamilton et al., 2016); Need for Cognitive Closure (Webster & Kruglanski, 1994); the Brief Maximization Scale (Nenkov et al., 2008); measures of subjective attention (for details, see: Welsh, 2020a) and numeracy (included as a marker of *Gq*; Fagerlin et al., 2007); and the Spot-the-Word test as a measure of crystallized ability (Gc; Baddeley, Emslie, & Nimmo-Smith, 1993) (see the Measures section below for additional details). This survey had a completion rate of 96% and took participants an average of 45 minutes to complete.

Survey 2 – Cognitive abilities and cognitive reflection. Following completion of Survey 1, participants were emailed a link to Survey 2. This survey included: two versions of the cognitive reflection test (CRT), the original 3 questions from Frederick (2005) and 4 less mathematical ones from Thompson and Oppenheimer (2016); the Berlin Numeracy Test (BNT, included as a measure of Gq; Cokely, Galesic, Schulz, Ghazal, & Garcia-Retamero, 2012); the Mill-Hill Vocabulary Scale (as a measure of *Gc*; Raven, 1958); the 12-item Ravens matrices (as a measure of *Gf*; Arthur & Day, 1994); and the CAB-I (as a measure of *Gf*; Hakstian & Bennet, 1977). In addition to these predictor variables, this survey included a wide range of questions designed to test for specific, cognitive biases including confirmation bias (Nickerson, 1998), framing (Kahneman & Tversky, 1979), outcome bias (Baron & Hershey, 1988) and three forms of overconfidence (Moore & Healy, 2008). These cognitive bias measures are analysed herein and are described in greater detail in the Measures section below. The survey had a 91% completion rate and took participants approximately 60 minutes to complete.

In-person testing. Following Survey 2, participants were invited into the lab to undertake one-on-one, in-person testing. This session included: tests written in Matlab for memory span (forward and backward, measuring *Gsm*), attention (for details, see, Welsh, 2020a), reaction and inspection time (measuring *Gt*; Preiss & Burns, 2012); paper-and-pencil tests of memory for words and numbers including primacy and recency effects; paper-and-pencil bias testing for availability bias (specifically, due to saliency; Tversky & Kahneman, 1973) and base rate neglect (Tversky & Kahneman, 1974); and computerised, Matlab testing for anchoring bias (for details, see, Welsh, 2021). In addition to these, a computerised Reading Speed and Comprehension Test (*Glr*), the Numerical Abilities Test (measuring Gq; Bennett, Seashore, & Wesman, 1989) and six scales from the Woodcock-Johnson IV (Schrank & Wendling, 2018) – Oral Vocabulary (*Gc*), Numbers Reversed (*Gsm*), Rapid Picture Naming (*Glr*), Retrieval Fluency (*Glr*), Letter-Pattern (*Gs*) and Visualization (*Gv*) - were included to round out the study's cognitive ability measures. At the end of this session, participants also undertook the final survey as described below – delivered online but completed while seated in the room with the experimenter. Including this, participants took between 2 and 3 hours to complete the in-person testing and all participants who attended completed all tasks.

Survey 3 – Hindsight bias. This survey presented participants with the correct answers to 32 questions they had answered in Survey 2 and asked them to indicate whether they believed they had answered each question correctly, allowing a measurement of their degree of hindsight bias (Fischhoff & Beyth, 1975) by comparison with their actual number correct on these sets of questions (for details, see: Welsh, 2020b). Following completion of this survey, participants were prompted to alert the experimenter and were thanked for their time and given their gift vouchers. All participants who attended the in-person testing completed this, final survey, taking an average of 7 minutes.

Measures.

Table B1 shows the individual cognitive ability measures described in the sections above that contributed to the generation of each of the broad ability factors used herein.

Table B1. Cognitive Ability Measures, Broad Abilities and Loadings on *g*

CHC Broad Ability	Loading on *g*	Contributing Measures
Gf - Fluid Ability	.738	12-item Ravens APM
		CAB-I
		WJ-IV Number Series
Gv – Visualisation	.705	WJ-IV Visualisation
Gq – Quantitative Ability	.553	12-item Numerical Aptitude Test
		Berlin Numeracy Test
		Subjective Numeracy Test
Gt – Decision Speed	-.526	Inspection Time
		Simple Reaction Time
		Go-No-Go Reaction Time
Gc – Crystallized Ability	.498	Mill-Hill Vocabulary Scale
		Spot-the-Word
		WJ-IV Oral Vocabulary
Glr – Long Term Retrieval	.493	WJ-IV Rapid Picture Naming
		WJ-IV Retrieval Fluency
		Comprehension
Gs – Processing Speed	.493	WJ-IV Letter-Pattern
Gsm – Short Term Memory	.470	WJ-IV Numbers Reversed
		Memory Span Forward
		Memory Span Backwards

Appendix C

Regression models: Decision Styles, Intelligence and Personality

To calculate how much of the variance in each decision style can be accounted for by the Cattell-Horn-Carroll broad abilities and Big 5 personality traits, linear regressions were run in SPSS using the Forward entry method with a Probability-of-F inclusion criterion of $p \leq .05$ and removal of $p \leq .10$. Table C1 summarises these regression models.

Unsurprisingly, given the correlations observed in the main text, all regression models were significant with the inclusion of multiple predictors. The total adjusted R^2 values varied from a high of .396 for the cognitive reflection test (regressed upon fluid, *Gf*, crystallized, *Gc* and quantitative ability, *Gq*) down to .121 for brief maximization (regressed upon agreeableness, neuroticism, long term retrieval ability (*Glr*) and conscientiousness).

Interpretting these within a psychometric framework, it can be useful to look at the *R* values, reflecting the correlation coefficient between the regression line and the regressed variable. This, for example, indicates a correlation of above 0.6 between the cognitive reflection test and its regression line, which falls in the range one might expect for two alternative measures of the same psychometric trait (for comparison, in this dataset, inspection time and reaction time, both meaures of Gt, correlate at ~.52, similar to the 0.48 observed in Kirby & Nettelbeck, 1989). Similarly, the need for cognitive closure model correlates with the actual variable at close to 0.6, suggesting that the regression model is performing as well as one might expect of an alternative test of the construct.

By comparison, the *R* values for the remaining decision style regression models range from 0.365 (for Brief Maximization) to 0.476 for DS Intuitive. If resulting from alternative tests, relationships of this strength would likely be interpreted as capturing related but potentially distinct constructs. This suggests brief maximization, actively open-minded thinking, DS Rational and DS Intuitive may be distinct enough from both cognitive abilities and personality traits to retain predictive power after these have been controlled or selected for.

Table C1. Linear regression models for decision styles variables.

Decision Style	Predictors	*Adj.* R^2	R	ANOVA results	p
DS Rational	Conscientiousness	.160	.403	$F(1,288) = 55.9$	<.001
	+ Gq (quantitative)	.177	.427	$F(1,287) = 32.0$	<.001
	+ Extraversion	.193	.449	$F(1,286) = 24.1$	<.001
DS Intuitive	Gf (fluid)	.084	.296	$F(1,288) = 27.6$	<.001
	+ Extraversion	.135	.376	$F(1,287) = 23.6$	<.001
	+ Gt (decision speed)	.164	.415	$F(1,286) = 19.9$	<.001
	+ Gq (quantitative)	.185	.443	$F(1,285) = 17.4$	<.001
	+ Conscientiousness	.197	.459	$F(1,284) = 15.2$	<.001
	+ Agreeableness	.211	.476	$F(1,283) = 13.8$	<.001
Need for cognitive closure	Openness	.152	.394	$F(1,288) = 52.9$	<.001
	+ Neuroticism	.301	.553	$F(1,287) = 63.3$	<.001
	+ Conscientiousness	.348	.595	$F(1,286) = 52.4$	<.001
Actively open-minded thinking	Gc (crystallized)	.068	.266	$F(1,288) = 21.9$	<.001
	+ Agreeableness	.099	.325	$F(1,287) = 16.9$	<.001
	+ Gf (fluid)	.128	.370	$F(1,286) = 15.1$	<.001
	+ Glr (long term retrieval)	.138	.388	$F(1,285) = 12.6$	<.001
Brief Maximization	Agreeableness	.054	.238	$F(1,288) = 17.4$	<.001
	+ Neuroticism	.087	.306	$F(1,287) = 14.8$	<.001
	+ Glr (long term retrieval)	.106	.340	$F(1,286) = 12.4$	<.001
	+ Conscientiousness	.121	.365	$F(1,285) = 11.0$	<.001
Cognitive Reflection Test	Gf (fluid)	.344	.588	$F(1,288) = 152.5$	<.001
	+ Gc (crystallized)	.376	.617	$F(1,287) = 88.1$	<.001
	+ Gq (quantitative)	.396	.634	$F(1,286) = 64.0$	<.001