Solving problems with an Aha! increases uncertainty tolerance

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Abstract

When people come up with an idea in a sudden insight, they often experience an “Aha! moment”: a feeling of pleasure, and certainty. In real life, an insight is often followed important decisions -i.e., people need to decide what to do with the idea. In this research, we ask how one solves a problem, with an Aha! or with a step-by-step analysis, affects the subsequent decision involving uncertainty. Former research showed how having insight feels rewarding and confident. Thus, we hypothesized that people would favor a monetary payout with more upside but greater uncertainty after solving a problem with an Aha! compared to solving analysis. Participants were asked to solve Compound Remote Associates problems and report whether they solved them with or without insight. After providing the solution to a problem, they had to choose between two bonus options: a *fixed payout* of 25¢, or a *risk payout* with a 50% chance to receive a low (5¢) and 50% chance to receive a high amount (e.g., 45¢). As predicted, among participants who changed their bonus choices throughout the experiment, they were more likely to choose the risk payout (temporarily higher risk preference or uncertainty tolerance) after they solved problems with insight compared to solving with analysis. This carryover effect – the impact of an Aha! moment on the subsequent risk choice – is discussed in terms of its implications in everyday decision making.

Solving problems with an Aha! biases towards risk choice

An *Aha! moment* is mostly seen as the climax of a mental process when a person solves a hard problem with sudden insight. In daily life, insights often precede various decisions, sometimes important ones. People need to decide what to do with the solution, whether to stay the course or embark on a new endeavor. For example, when people come up with an investment idea from an Aha!-like experience, such as "connecting the dots" from a social media narrative (Fox, 2021) accompany a recent asset price surge (e.g., "dogecoin is the next bitcoin", "GameStop is turning around with a non-fungible token platform launch"[1]), are they likely to take on a larger stake than they would have if the idea came from deliberate research and data analysis? Few studies have examined the psychological impact of sudden insight on decision-making. We investigated how one solves the problem, either with an Aha! or with a deliberate, step-by-step analysis, differentially affects the subsequent decision on monetary rewards involving uncertainty.

When people solve a problem with insight, they suddenly become aware of a solution, accompanied by a feeling of surprise and confidence (Salvi, 2022; Sternberg et al., 1995), an *Aha!* moment. Insight seems to rely on the sudden reorganization of a mental representation of a problem (Sternberg et al., 1995), and solvers are not usually aware of how the solution rose to mind. In contrast, when people solve analytically, the processes are more continuous and characterized by awareness of the reasoning steps involved (Metcalfe & Wiebe, 1987). A single problem potentially can be solved with sudden insight or step-by-step analysis (Bowden & Jung-Beeman, 2007; Webb et al., 2016) or a combination of both. Extensive behavioral and

[1] How Dogecoin Is Creating a Frenzy for the Next Big Cryptocurrency—and Why Experts Advise Caution - WSJ," 2021; Can the GameStop NFT Marketplace Help GME Stock Turn Around - Investerplace, 2022.

physiological evidence has shown that solving with insight or analysis can involve different cognitive and neural processes (for review, Kounios & Beeman, 2014).

Most past research on insight has examined what facilitates or inhibits sudden insight, but some recent research provides increasing evidence suggesting an insight experience can itself have a behavioral impact. Insight can make the accompanied item more accessible in a later memory test (Danek et al., 2013; Kizilirmak et al., 2016). Participants are more likely to rate statements as true when they solved anagrams and experienced Aha! moments (Laukkonen et al., 2020, 2022). Insight often invokes positive affect of gratification, confidence, and certainty (Danek & Wiley, 2017; Topolinski & Reber, 2010). Furthermore, evidence tentatively suggests the moment of insight is accompanied by activities in reward processing circuits and the release of dopamine (Boot et al., 2017; Ludmer et al., 2011; Oh et al., 2020; Salvi et al., 2020; Tik et al., 2018). Thus, experiencing insight could alter subsequent behavior, since dopaminergic circuitry is heavily involved in risk-reward decision-making (Schultz, 2010; Stopper et al., 2014). However, little work has directly examined whether having an insight affects the subsequent risk decision.

decision making and uncertainty tolerance

One of the most important building blocks of human decision-making is the choice behavior under risk and uncertainty (Hillson & Murray-Webster, 2017; Tversky & Fox, 1995). In economics, risk preference is a key concept concerning the attitude towards uncertainty, often quantified by variance, of potential monetary payoffs (Chiles & Mcmackin, 1996). A large body of investment theories has been built upon this concept (Fama & French, 2004; Markowitz, 1952). In psychology, risk preference is often thought to capture the propensity to engage in behavior with the potential for loss or harm (Kahneman & Tversky, 1979; Mata et al., 2018). In many contexts, uncertainty and risk are used interchangeably (Frijns et al., 2013; Hillen et al., 2017). Uncertainty tolerance (or risk preference) varies widely across individuals. It is associated with different personality traits (Frey et al., 2017; Zuckerman, 2007), and shaped by the cultural environment (Weber et al., 1999), economic status (McDougal, 1995), gender (Powell & Ansic, 1997), and age (Josef et al., 2016).

Situational factors like affect can modulate choice behavior by influencing the computation of subjective value (Phelps, 2006). Positive affect has been found to induce optimism in estimating favorable probabilities (Nygren et al., 1996) and was associated with increased risk-taking tendencies (Herman et al., 2018) because the preferred outcome is deemed (subjectively) more likely to happen. However, the relationship between affect and risk decision-making is complex and nuanced (Lerner & Keltner, 2000). It depends on one hand on which affective process is engaged, and on the other hand how the risk decision task is framed. For example, a positive mood may make people less likely to gamble due to heightened loss aversion (Juergensen et al., 2018; Nygren et al., 1996).

How can insight modulate uncertainty tolerance?

When a positive affect is elicited by an Aha!, it is accompanied by gratification and confidence. In this case, a choice with higher reward potential can be perceived more favorable than a choice with a fixed outcome. Therefore, we hypothesized that solving problems via insight leads to more risk-taking behavior or reduced uncertainty avoidance. In particular, when presented with a choice with more upside and higher uncertainty versus a relatively lower reward without uncertainty (i.e., neither choice involve explicit loss), participants may prefer the uncertain reward with upside because they become more optimistic in face of uncertainty after having an insight, compared to solving similar problems with analysis.

The modulation of choice behavior can vary from person to person. There is considerable evidence, from both behavioral and neuroimaging analyses, demonstrating gender differences to reward signals and risk choices (Li et al., 2014). For example, males exhibited greater responsiveness to stimulus salience, when the reward is performance linked, in cortical and subcortical areas (Warthen et al., 2020). During win trials of a gambling task, greater ventral striatum BOLD response occurred in men than in women (Curtis, Williams, & Anderson, 2019). Therefore, gender can be one of the factors that affect the trial-to-trial shift of uncertainty tolerance.

The current experiment

We used Compound Remote Associates (CRA), to elicit numerous insights and analytic solutions while maintaining other cognitive processes involved in solving puzzles (Bowden & Jung-Beeman, 2003; Bowden et al., 2005). Like many problems, CRA problems can be solved via insight or analysis, and people can report how they reach the solution. Self-reports for insight or analytic solving processes have been widely used to study neural substrates underlying those strategies (e.g., Becker et al., 2020; Bowden, et al., 2005; Jung-Beeman et al., 2004; Kounios et al., 2006; Laukkonen et al., 2018; Salvi et al., 2015; Salvi et al., 2020; Santarnecchi et al., 2019; Sprugnoli et al., 2017).

The *Aha!* moment elicited by a verbal puzzle is subtle and transient. To examine its potential effect on the uncertainty tolerance on a trial-by-trial basis, we adopted a risk elicitation task using real monetary reward, in the form of a “bonus choice” (e.g, a *fixed payout* of 25¢, versus a *risk payout* with a 50% chance to receive 5¢ and 50% chance to receive 45¢) following each CRA trial. Given the wide range of individual uncertainty tolerance (Frey et al., 2017), it is important to customize the payout amounts so that the choice is sensitive to small shifts in preference. Imagine all participants are presented with the same choices. The more risk-seeking people will always prefer the one with higher reward potential and the risk-averse people will always prefer the one with more certainty, regardless of the moment-to-moment influence of an Aha!. We set each participant's choice around their neutral baseline estimated from a pre-experiment survey, to increase the chance that the subtle effect of solving puzzles with insight might bias participants' choices toward the risk payout. To ensure that the baseline survey properly captures the individual's "indifference level" and that the customization is effective, we only include participants who at least switched their bonus choice at least once during the experiment in our primary analysis. For completeness, we also report a secondary analysis without the exclusion.

Given the possible gender difference in both the baseline preference and risk-reward responses, we included gender as a factor in the analysis. In addition, we explored other potential mediating factors, such as reward responsiveness and impulsivity (see Methods).

In the following experiment, we attempt to validate a novel experimental design and test whether a participant would be more likely to choose the risk payout after solving a problem with insight, compared to solving with analysis.

Experiment 1

Methods

The experiment was reviewed and approved by Northwestern University Institutional Review Board. Total participation time was 20 – 30 minutes.

Participants

All participants were recruited via Amazon's Mechanical Turk (MTurk) platform. Due to the language dependency of the CRA, we used pre-screening to only include American native

English speakers. We also excluded participants if they reported a condition that could affect alertness, mood, or the reward system: depression, ADHD, anxiety, stress, and sleep disorder. A total of 307 people[2] participated in the experiment, of which 259 participants passed the quality check and provided data in all conditions. After excluding participants who did not switch their bonus choices (see Analysis below), we included data from 160 participants (91 females; age 39.7±11.8) in the primary analyses. For completeness, we conducted a secondary analysis of the 259 participants.

Material

Compound Remote Associate (CRA) problems. Participants were asked to solve CRA problems (Bowden & Jung-Beeman, 2003). Participants viewed three stimulus words (e.g., pine, crab, sauce) simultaneously on a computer screen, and attempted to generate a fourth word that completed a compound or common two-word phrase with each of the three words (e.g., solution apple: pineapple, crab apple, and apple sauce). The problem order was randomized for each participant. After participants solved a problem (max 15 s), they pressed a button in response to a prompt to indicate whether they had solved the CRA with insight or with analysis. Insight was described as a solution that "came to mind as a sudden surprise…, it may be difficult to articulate how you reached the solution" and "feeling like an Aha! moment". Analysis was described as one that was "reached gradually, part by part" and "using a strategy such as generating a

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[2] These 307 participants were tested over two phases. After we tested 170 participants (phase I), we found that the total length of the experiment was relatively short (averaged 20 minutes). We then adjusted the number of trials to 60 for the next 137 participants in order to collect more data (phase II). The experiment lasted 30 minutes on average in phase II. We report the combined results below, as the phase, i.e. length of the experiment did not interact with the main results (p=0.82).

compound for one word and testing it with the other words". (Instructions were adapted from Salvi et al., 2016).

Baseline survey. The baseline survey was used to assess an individual's baseline uncertainty tolerance. We adopted a simplified version of the Multiple Price List (Binswanger, 1981). The survey consists of 5 levels. At each level, participants were asked to choose either a fixed payout (25¢) or a risk payout: a 50/50 chance of receiving either a low amount (5¢) or a high amount that varied across 5 levels (i.e., 30, 40, 50, 60, or 70 cents). Participants are expected to choose the fixed payout in level 1. As the amount of the higher payout increased, participants were expected to switch to the risk payout at a certain level, which indicated their uncertainty tolerance. We defined the baseline as the midpoint of the high amount immediately before and after the switch. For example, if a participant chose the fixed amount (25¢) over the 50% chance of either 5¢ or 40¢, but then preferred the 50% chance of either 5¢ or 50¢ over the fixed (25¢), then the baseline was set to 45¢. This meant that the person was about equally likely to choose (or be indifferent to) the fixed 25¢ or a draw from 5¢ and 45¢.

Participants who provided inconsistent responses were excluded from further analyses. A baseline survey response was inconsistent if there was a "backward switch". I.e., one chooses the risk payoff at a lower level, then switches to the fixed payoff at a higher level. Only 1 participant provided an inconsistent response.

Bonus choice. After each CRA problem, participants were asked to choose between a fixed payout (25¢) and a risk payout with a 50% chance to receive a low (5¢) and a 50% chance to receive a high amount (e.g., 45¢). The high amount was set to the *baseline* from the baseline survey and was fixed throughout the experiment for the same participant.

Reward responsiveness. To explore individual factors that potentially mediate the insight effect, we included additional questionnaires. Because insight may act as a neural reward signal, we consider reward responsiveness as a possible factor. Reward responsiveness can be measured by the behavioral inhibition/activation systems scales (BIS/BAS, Carver & White, 1994) that gauge each participant's sensitivity to negative outcomes (behavioral inhibition system, or BIS) and sensitivity to positive outcomes (behavioral activation system, or BAS). BIS/BAS scale is directly related to risk preference (Demaree et al., 2008). The questionnaire has a total of 23 items scored on a 4-point scale.

Impulsivity. The potential moment-to-moment shift of uncertainty tolerance can be characterized by spontaneity, therefore, impulsivity is another factor that can mediate the insight-risk relationship (Herman et al., 2018). The Barratt Impulsiveness Scale (Patton et al., 1995) assessed impulsive personality traits. It includes 30 items describing different forms or degrees of impulsivity scored on a 4-point scale. Total scores were computed by summing across all items for each participant.

Procedure

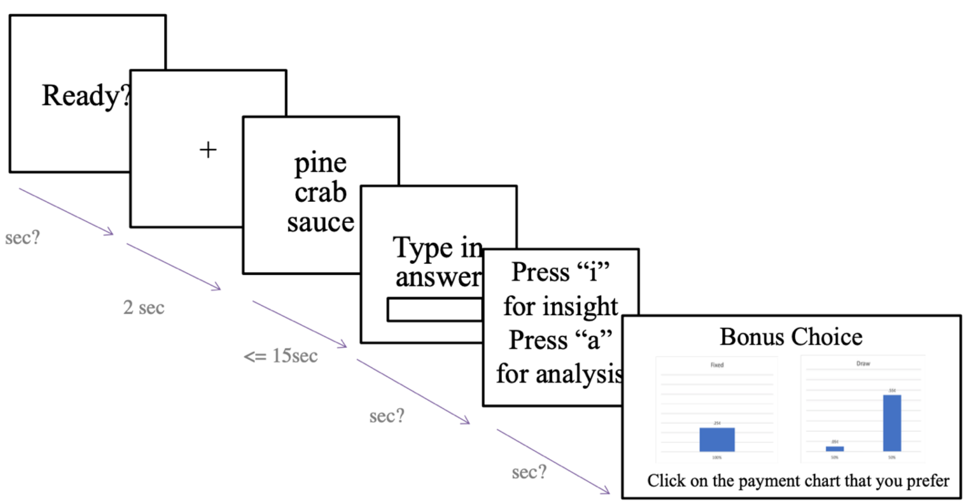
After agreeing to an online consent form, participants completed the risk baseline survey, then instructions and examples for solving the CRA problems and reporting solution types (insight or analysis). Participants had to answer questions correctly to make sure they understood the distinction between these solution types before they started the trials. Participants were informed that a bonus opportunity would appear following each trial, and at the end of the experiment a subset of the bonus choices would be randomly selected and paid out.

Participants were administered 40 ~ 60 CRA problems (depending on the phase, see participant section), with the problem words presented in black text on a white background and displayed in 32 points bold Verdana. The three words were centered horizontally, with one word above, one at, and one below the vertical center of the monitor.

Each trial started with a fixation cross for 2 seconds, followed by the CRA problem for up to 15 seconds; then, if they solved a problem, they saw a prompt to enter the solution, then a prompt to report whether they had solved the problem by insight or by analysis. At the end of each trial, a bonus choice was presented, with a graphical depiction of the options (see Figure 1). The trial would time out after 15 sec if no solution was reported, and the participant was presented with the same bonus opportunity before a new trial (fixation cross of 2 sec) would begin. During the experiment, participants were not given feedback on either the correctness of their responses or the bonus outcome if they chose the risk payout, to prevent possible emotional carryover affecting their subsequent performances.

Figure 1

Trial Procedure



Notes. Trial Procedure for experiment 1: each trial started with participants pressing the space bar. A fixation cross appeared for 2 seconds, followed by the CRA problem for up to 15 seconds; then, if they solved a problem, they saw a prompt to enter the solution, then a prompt to report whether they had solved it with insight or with analysis. At the end of each trial, a bonus choice was presented, with a graphical depiction of a fixed payout and a risk payout.

After trials with CRA problems, the participants were asked to complete the two questionnaires (BIS/BAS and Impulsiveness). At the end of the experiment, they were informed of their total bonus payout, depending on their choices. Each participant was compensated with $3 plus the bonus earned in the session.

Analyses

We analyzed all problems solved in more than 2s since these are thought to accurately reflect both insight and analytic solving (Cranford & Moss, 2012; Salvi et al., 2015). Forty-one participants were excluded for not reporting a correct solution in each solution type, thus yielding insufficient data to analyze. Due to the limitation of the online experiment environment (see Discussion section), we adopted multiple criteria to ensure attention quality. Three participants were excluded because they failed the embedded attention check or provided inconsistent baseline survey responses. Four participants were excluded because fewer than 25% of their attempted solutions were correct (the mean for the remaining participants was 78.8%).

Our primary analyses tested the potential effect of insight upon risk choice by focusing on participants who varied their bonus choices. Despite the customization of bonus choice, some participants may still fixate on one of the bonus payout types throughout the experiment, indicating they were not presented with bonus options that *felt* neutral to them. This can be due to a variety of reasons such as a lack of understanding or inattention to the task. The primary analysis applied a *switch criterion* which excluded ninety-nine participants for choosing the fixed or the risk payouts no more than once. However, results including those ninety-nine participants shows the same pattern (see Appendix S1).

We applied Generalized Linear Mixed-Effect models (GLMM) to test whether the bonus choice is affected by the manner of solving the preceding puzzle as well as by other individual factors on a trial-by-trial basis. The outcome variable is binary: risk, or fixed payout. The fixed effects are gender and the manner of solving, which is a binary variable indicating insight or not insight (i.e., analysis). We included random intercepts and random slopes for participants, since individuals' sensitivities to Aha! experience may vary. We used the glmmTMB package (v 1.1.3) in R (Brooks et al., 2017), and the *p*-values were estimated from the likelihood-ratio tests. To explore the potential impact of traits (reward responsiveness and impulsivity), as well as the gender-insight interaction, we conducted the additional GLMM analysis with a similar setup.

Results

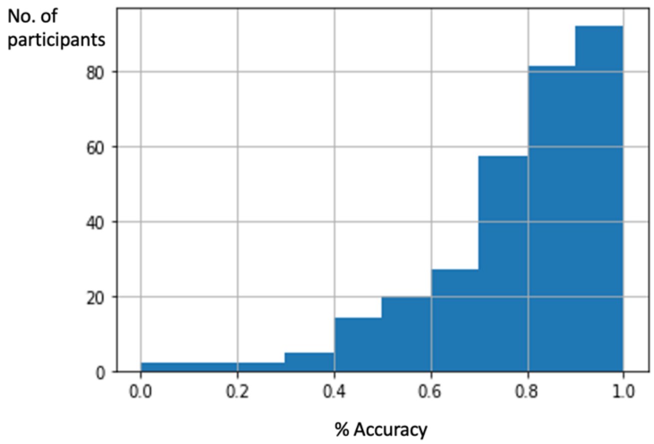
Problem-solving performance

Participants responded to 61.8±1.2% of CRA problems, of which 32.6±1.1% of trials were reported solved with insight and 29.2 ±1.2% with analysis. When participants reported solving with insight, their responses were accurate 81.9±1.5% of the time, reliably more accurate than when they reported solving with analysis, 72.9±1.8%, (t=4.66, p<0.001), consistent with previous work (Salvi et al., 2016). See Fig. 2 for the histogram of the overall accuracy [3].

[3] Given the small number of incorrect answers, we did not include them in the analyses. Incorrect answers may be produced for various reasons, and it is not appropriate to mix them together with correct answers in analyses for our purpose.

Figure 2

Histogram of accuracy



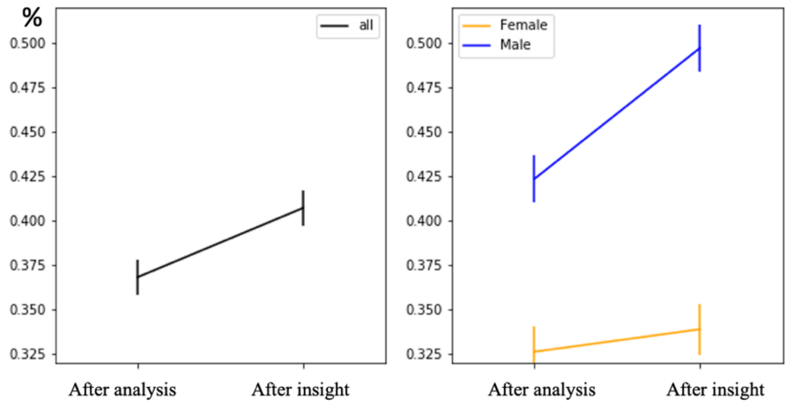
Risk choice after solving

The average baseline preference (the high amount needed so that the risk payout is equally preferable to the fixed payout) was 54.1±0.9¢. Following correct CRA solutions, participants chose the risk payout 38.8±2.5% out of all bonus opportunities. For reference, the percentage of choosing a risk payout after a time-out (no solution) was 38.3±2.5%.

Importantly, participants chose the risk payout on 40.7±2.7% of trials after they solved with insight, versus 36.8±2.7% after trials solved with analysis (Figure 3). GLMM (Table 1) indicates that people were 29% more likely to choose the risk payout after an insight relative to analysis solution (odds ratio = 1.29, $p = 0.052$), although statistical significance is marginally missed. Men were more likely to choose the risk payout than women with a ratio of 2.12 ($p = 0.015$). The insight and the sex effect do not interact. The secondary analyses on 259 participants (not applying the *switch criterion*) showed a similar pattern (S1).

Figure 3

Percentage of choosing risk payout after solving the puzzle



Notes. (left) All participants after exclusion criteria; (right) participants grouped by sex. Error bars represent one standard error.

Table 1

Generalized Linear Mixed-Effects Model (Exp. 1)

Model	risk choice ~ insight + gender +(1 + insight |id)		
Predictors	*Odds Ratios*	*CI*	*p*
(Intercept)	0.32	0.20 – 0.49	**<0.001**
insight [True]	1.29	1.00 – 1.67	0.052
gender [Male]	2.12	1.16 – 3.89	**0.015**
Random Effects			
$\tau_{00\ id}$	3.58		
$\tau_{11\ id.insightTrue}$	0.77		
$\rho_{01\ id}$	-0.37		
ICC	0.50		
N_{id}	160		
Observations	3310		

Notes. ICC: intraclass correlation coefficient; τ_{00} τ_{11}:variance explained by random intercept and random slope, resp.; $\rho_{01\ id}$: correlation between the random intercepts and random slopes.

To explore the potential factors that mediate the insight-risk choice relationship, we included the trait variables (BIS/BAS scores, impulsivity, baseline preference) as fixed effects in a GLMM analysis. None shows a reliable effect on the bonus choices (Appendix S2) or interacted with the manner of solving.

Experiment 2

In experiment 1, with a novel experimental design, we found that there was a tendency for participants to choose the more uncertain bonus payout after solving problems with insight. The high exclusion rate may raise some concerns. Although the *switch criterion* is needed to focus on participants who shifted their bonus choices, we did not expect a large percentage of participants who stuck with the same bonus payout throughout. The resulting high exclusion rate was partially due to the nature of the online experiment environment (see Discussion section). Nonetheless, we attempt to improve the experiment design in Experiment 2 to better isolate the insight effect, as well as to reproduce it.

The overall chance of choosing the risk payout was significantly less than the chance in Exp. 1 (38.3%), even when the bonus was customized to match each individual's neutral level. It suggests that participants overestimated their uncertainty tolerance during the initial baseline survey. We decided to address this limitation in Experiment 2 by making the responses to the baseline survey directly linked to monetary payout.

Additionally, in Experiment 1, a bonus choice was presented in each trial, regardless of the CRA solving outcome. Participants might become insensitive and develop a choice pattern after too many repetitions. In Experiment 2, we only presented the bonus choice after participants responded to a CRA (regardless of correctness), to create a superficial connection between solving a puzzle and the risk choice.

Participants and Methods

317 (126 female, age 38.5±12.0) participants recruited via MTurk passed the pre-screen (same as Exp 1) and completed the experiment, of which 217 participants[4] passed the quality check and provided data in all conditions. Applying the same *switch criteria* as in experiment 1, data from 119 participants (54 females, age 37.7±11.7) remained for the primary analyses. Again, we performed a secondary analysis on the broader set of 217 participants without applying the *switch criterion*.

Each participant completed 40 trials. This experiment used the same procedures and material as experiment 1, except for two differences:

1. Participants were informed that they would receive a payout tied to the baseline survey, in addition to the bonus payout from trials. One of the 5 levels from the survey was randomly selected, and the participants received the payment according to their choice.
2. A bonus choice was only presented if the participant reported a solution to the CRA within 15 seconds (regardless of the correctness). [5]

Results

Similar to Experiment 1, participants provided responses to 67.2±1.5% of all CRAs, reporting to solve 35.9±1.5% of all trials with insight, and solving 31.2±2.9% with analysis. When participants reported solving with insight, their solutions were accurate 79.5±1.8% of the

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[4] Specifically, thirty-six participants were excluded for not reporting a correct solution in each solution type. Fifty-five participants were excluded because they failed the embedded attention check or because they provided inconsistent risk baseline survey responses. Nine participants were excluded because their CRA responses were correct less than 25% of the time.

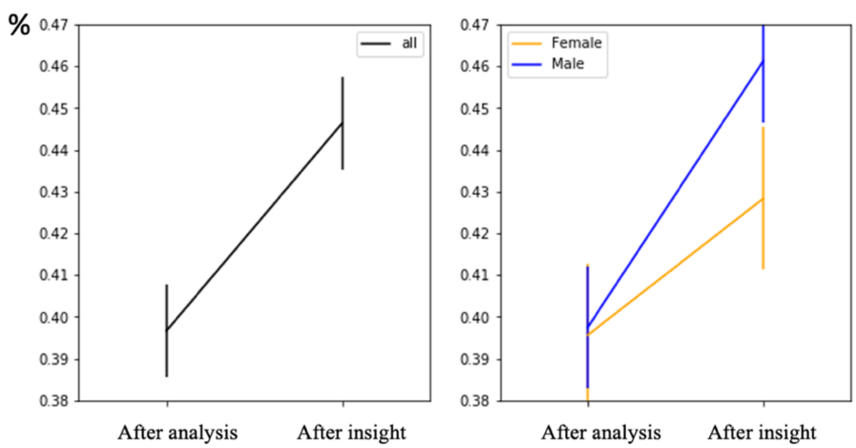
[5] To disincentivize participants providing incorrect solutions just to get bonus, the final payout was tied to the correct solutions. If a participant solved fewer than 5 CRAs, the number of bonuses to be paid out would be equal to the number of the correct solutions. Each bonus choice, however, still had equal chance of being selected by computer.

time, once again reliably more accurate than when they reported solving with analysis, 67.4±2.4% [t=4.74, p<0.001].

The average baseline was 54.1±0.7¢. Importantly, participants chose a risk payout on 44.6±2.8% of trials after they solved with insight, and on 39.7±2.9% of trials solved with analysis (Figure 4), a significant insight effect(Table 2, odds ratio=1.31, p=0.03). There was no sex effect on bonus choice (ratio=1.03, p=0.93), nor did the insight and the sex effect interact. The pattern did not change in the secondary analyses which included the broader 217 participants (not applying the *switch criteria*, Appendix S3), although the p-value for the insight effect was 0.051.

Figure 4

Percentage of choosing risk payout after solving the puzzle



Notes. (left) All participants after exclusion criteria; (right) participants grouped by sex.

Again, we explored the potential factors mediating the insight-risk choice relationship by including the trait variables (BAS scores, impulsivity, baseline preference) as fixed effects in a GLMM. The result (Appendix S4) suggested that impulsiveness increased an individual's chance of choosing a risk payout, and a higher baseline (i.e., higher risk aversion, lower uncertainty tolerance according to the baseline survey) decreased the chance of choosing the risk payout, although we did not observe these effects in Experiment 1. None of the trait variables interacted with the insight effect.

Table 2

Generalized Linear Mixed-Effects Model (Exp. 2)

Model	risk choice ~ insight + gender +(1 + insight |id)		
Predictors	*Odds Ratios*	*CI*	*p*
(Intercept)	0.57	0.37 – 0.88	**0.012**
insight [True]	1.31	1.03 – 1.67	**0.030**
gender [Male]	1.03	0.58 – 1.80	0.930
Random Effects			
$\tau_{00\ \text{id}}$	2.10		
$\tau_{11\ \text{id.insightTrue}}$	0.26		
$\rho_{01\ \text{id}}$	-0.17		
ICC	0.39		
N_{id}	119		
Observations	2259		

Discussion

In two experiments, we investigated whether the manner of solving a verbal problem, with or without insight, affected people's subsequent choices involving monetary reward and uncertainty, a proxy for a real-world investment decision.

When evaluating two bonus payouts, a fixed payout of 25¢, or a risk payout with a 50% chance of receiving 5¢ and a 50% chance of receiving 45¢, a *rational* agent would be indifferent between the two options of equal expected value — such a risk preference is called risk-neutral. Most people prefer certainty when evaluating positive outcomes (PRATT, 1978). Therefore, increasing the high amount in the risk payout (45¢) can make them indifferent to the two payouts. We presented a set of options that varied the high amounts in the risk payout in a survey conducted at the beginning of the experiment. Based on a participant's responses, we calibrated the bonus choice to each individual's indifference (neutral) level.

Participants were presented with this individually calibrated bonus choice after each problem-solving trial (Experiment 1) or after each reported solution (Experiment 2). On a trial-by-trial basis, we found that participants were more likely to choose the risk payout (temporally increased uncertainty tolerance) after solving with insight than after solving with analysis. Across two experiments, we observed consistent effect sizes in terms of odds ratios.

The *Aha!* feeling induced by solving a short verbal problem is small and unlikely to have a long-lasting effect. Nevertheless, we observed a significant trial-by-trial modulation of preference. Like most real-world problems, solving a verbal puzzle can involve both insight and analysis in the intermediate steps. Our results demonstrated a pure carryover effect: the outcomes of the bonus choices were unrelated to the problem solving, but the choices were modulated by the manner of solving immediately preceding the bonus. Few works have directly explored the impact on decision-making after an insight (cf. Laukkonen et al., 2020, 2022). In real life, solving a problem is often followed by courses of action that involve risk/reward evaluation. Our results imply that the processes by which people achieve a solution, besides the solution itself, can bear consequences on the succeeding decision. Consider two investment practices -- one determines the allocation of risky assets by a systematic analysis (risk as analysis), and the other makes spontaneous decisions based on popular narratives on social media (risk as feeling, Loewenstein et al., 2001; Tompkins et al., 2018). The present work implies that when the narrative triggers an *Aha!* feeling, that the investor may take on a riskier position than he or she would have if the conclusion is preceded by systematic analysis.

There can be multiple factors mediating the insight-risk effect. The *Aha!* experience associated with insight is pleasurable and optimistic. Incidental positive emotions have been found to increase uncertainty tolerance among participants (Jiang et al., 2009; Zhao, Gu et al., 2016), consistent with our results. Additionally, insight is putatively associated with neural reward signals, according to neuroimaging research (Ludmer et al., 2011; Oh et al., 2020; Salvi et al., 2021; Subramaniam et al., 2008; Tik et al., 2018). A reward signal in the brain may increase people's sensitivity to positive outcomes. For example, priming an individual with information about past wins increases their risk preference (Ludvig et al., 2015). Finally, the positive affect and the reward signal account may be intricately linked. For example, positive mood has been shown to elevate corticostriatal neural regions implicated in reward processing (Young & Nusslock, 2016). Thus, the within-subject analysis in the current project, together with the previous theoretical accounts, suggests a causal link between the intrinsically rewarding insight and the increase in risk tolerance. Although, without strict manipulation, we cannot rule out the possibility of a latent factor that affects both "insightfulness" and risk decisions on a moment-to-moment basis.

In experiment 1 (but not in exp 2), we also observed a sex effect. Men are more likely to choose the risk payout after solving a problem (whether with insight or analysis) than women, although the interaction between sex and insight is not reliable. Because the bonus payout was customized according to a pre-experiment survey, men and women were expected to be indifferent to the bonus choice even if they may have different baseline preferences (Powell & Ansic, 1997). However, men were more likely to choose the risk payout in Exp 1 when the baseline was extracted from a hypothetical questionnaire. The sex difference disappeared in Exp 2 when the choice in the baseline questionnaire was paid out. Although not the focus of the current study, this observation suggests that men (relative to women) underestimate their uncertainty tolerance (or risk preference) in a hypothetical situation. In other words, men's expressed preference is more sensitive to the actual reward setup.

How insight modulates uncertainty tolerance is likely to vary from person to person. Data from Exp. 2 (but not Exp. 1) suggested that impulsiveness scores increase the chance of choosing the risk payout while baseline preference decrease the chance. However, we did not find factors considered in the current study (sex, BIS/BAS, impulsiveness, baseline preference) mediating the relationship between insight and the risk choice. Future work might explore other potential mediating factors, as well as obtain more robust measurements either by using an in-person protocol or behavioral-based assessments (instead of using questionnaires).

One limitation of the current study is that we exclusively utilized an online participant pool, MTurk. Although studies in psychological and other health science have supported the reliability and validity of data gathered using crowd-sourced samples (Strickland & Stoops, 2019), some studies found that online participants may have lower emotional stability, more self-selection bias (Keith, et al., 2017) and some forms of careless behavior (Brühlmann et al., 2020). Attention checks deployed in this study mitigated these effects, but the experimental conditions could not completely match an in-person, supervised, lab experiment setting. It is unclear how these factors may affect results. Potentially, the relatively high percentage of fixed payout choices observed in our results (60% among those included in our primary analysis, and 66% of participants who did not meet the switch criterion) may signal the lack of trust in an anonymous experimenter.

The limitation of the testing environment can also contribute to the high percentage of participants who predominantly chose one solution type or one bonus option. People may be fixated on the same option for reasons unrelated to our hypothesis: attention, understanding, or trust. We excluded those participants with the switch criterion in the primary analysis to focus on the effect upon preference *change*. However, including the non-switching participants in the analysis does not change the main conclusion (Appendix S1, S3).

Although many studies have investigated the processes and precursors that lead to insight, very few have investigated the consequences of insight. Across two experiments, we found evidence for a carryover effect: participants' bias toward a risk payout after solving with insight versus with analysis. The current project not only explored the psychological impact of *Aha!* moments on decision making but also has direct implications in everyday life, especially in understanding investor behavior.

Open Practice Statement

The datasets generated during the current study and the analysis code are publicly available at https://osf.io/5f4ez/.

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Appendix

Table S1

Generalized Linear Mixed-Effects Model (Exp. 1) without switch exclusion

Model	riskchoice ~ insight + gender +(1 + insight |id)		
Predictors	*Odds Ratios*	*CI*	*p*
(Intercept)	0.14	0.07 – 0.29	**<0.001**
insight [True]	1.29	0.96 – 1.73	0.089
gender [Male]	3.18	1.18 – 8.58	**0.023**
Random Effects			
σ^2	3.29		
$\tau_{00\ id}$	14.63		
$\tau_{11\ id.insightTrue}$	0.90		
$\rho_{01\ id}$	-0.38		
ICC	0.80		
N_{id}	259		
Observations	5561		
Marginal R^2 / Conditional R^2	0.020 / 0.809		

Notes. One participant is dropped because no sex information.

Table S2

GLMM (Exp. 1) with additional trait variables

Model	riskchoice ~ risk_baseline+bas+impulse+ gender+ insight+ (1+insight|id)		
Predictors	*Odds Ratios*	*CI*	*p*
(Intercept)	0.24	0.05 – 1.15	0.074
risk baseline	1.63	0.11 – 23.77	0.720
bas	1.14	0.85 – 1.54	0.374
impulse	1.16	0.87 – 1.56	0.318
gender [Male]	2.25	1.21 – 4.19	**0.011**
insight [True]	1.28	0.99 – 1.66	0.058
Random Effects			
σ^2	3.29		
$\tau_{00\ id}$	3.49		
$\tau_{11\ id.insightTrue}$	0.77		
$\rho_{01\ id}$	-0.35		
ICC	0.50		
N_{id}	160		
Observations	3310		
Marginal R^2 / Conditional R^2	0.029 / 0.514		

Table S3

Generalized Linear Mixed-Effects Model (Exp. 2) without switch exclusion

Model	riskchoice ~ insight + gender +(1 + insight |id)		
Predictors	*Odds Ratios*	*CI*	*p*
(Intercept)	0.46	0.20 – 1.05	0.065
insight [True]	1.32	1.00 –1.74	0.051
gender [Male]	0.40	0.14 – 1.17	0.095
Random Effects			
σ^2	3.29		
$\tau_{00\ id}$	12.07		
$\tau_{11\ id.insightTrue}$	0.27		
$\rho_{01\ id}$	0.30		
ICC	0.80		
N_{id}	217		
Observations	4119		
Marginal R^2 / Conditional R^2	0.013 / 0.799		

Table S4

GLMM (Exp. 2) with additional trait variables

Model	riskchoice ~ risk_baseline+bas+impulse+ gender+ insight+ (1+insight|id)		
Predictors	*Odds Ratios*	*CI*	*p*
(Intercept)	3.11	0.75 – 12.81	0.117
risk baseline	0.04	0.00 – 0.53	**0.013**
bas	0.96	0.73 – 1.27	0.781
impulse	1.31	1.00 – 1.71	**0.047**
gender [Male]	0.97	0.56 – 1.68	0.924
insight [True]	1.32	1.03 – 1.68	**0.028**
Random Effects			
σ^2	3.29		
$\tau_{00\ id}$	1.98		
$\tau_{11\ id.insightTrue}$	0.25		
$\rho_{01\ id}$	-0.24		
ICC	0.37		
N_{id}	119		
Observations	2259		
Marginal R^2 / Conditional R^2	0.037 / 0.392		