THE UNIVERSITY OF QUEENSLAND
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The Phenomenology of Truth:

The Psychological Functions of the Insight Experience

RUBEN E. LAUKKONEN
BSc (Hons)

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Abstract

Nearly all waking moments are accompanied by an endless stream of thoughts and ideas passing rapidly through the mind (James, 1890). Many of these mental events can feel unproductive, arbitrary, or even distracting. But once in a while, an idea appears in the stream that is immediately imbued with a sense of profound importance and value. The central thesis of my work is that this phenomenology—epiphanies, insight experiences, and Eureka moments—serve an important function in human decision-making. I propose that the feelings associated with our ideas are like lights whose brightness guide the incognisant mind in choosing to trust only the best ideas; they help us to intuitively discriminate the diamonds from the rocks, so to speak. This functional view puts insight experiences into a broader context in human cognition than before. By evaluating insight experiences from a higher level of analysis, we are able to make and test novel predictions regarding the ways that spontaneous feelings of insight guide decisions in contexts of uncertainty.

The thesis is divided into two parts. In Part 1—**How** to elicit and detect insight moments—Chapter 1 begins by testing a model of the neuro-cognitive processes commonly believed to elicit insight experiences, known as restructuring or representational change. I then evaluate the efficacy of existing methods for detecting insight experiences in controlled experiments. In the final Chapter of Part 1, I develop and test a novel visceral and embodied measure that captures metacognitions during problem solving as well as the sudden insight experience in real-time. In Part 2—**Why** we have insight experiences—I begin with a theoretical discussion of insight as a heuristic in contexts of uncertainty, where I propose that people rely on insight phenomenology in order to appraise new ideas. In a subsequent empirical Chapter, I describe three experiments that broadly test and affirm the predictions made by the *Eureka Heuristic* model of insight. The results of these experiments show that impulsive feelings of insight—and their intensity—predict the accuracy of responses in contexts of uncertainty, in both problem solving and sensory identification tasks. In the third experiment, I show that when participants are presented with a general knowledge ‘fact’—and an insight experience is artificially elicited at the same time—then the participants are more likely to believe that the claim is true.

Taken together, this thesis makes both a methodological and theoretical contribution. The first half of the thesis focuses on improving existing methods for measuring and detecting insight experiences, and culminates in a new visceral measure of insight. The second half makes a theoretical contribution, proposing a functional role for insight experiences in human decision-making. The implications of the Eureka Heuristic and the empirical results derived from the theory may speak to a range of psychological phenomena, particularly the development of false beliefs. Our empirical findings show that the phenomenology that accompanies ideas is usually a helpful signal—insight experiences tend to accompany correct ideas. However, there are situations where the function of this normally adaptive process may be jeopardised—for example by false information, psychoactive substances, or mental illness—and therefore feelings of insight may not always provide a valid signal. In one such demonstration, we find that feelings of insight can be induced to bias judgments and make a false fact appear true.

Declaration by Author

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

I have clearly stated the contribution of others to my thesis as a whole, including statistical assistance, survey design, data analysis, significant technical procedures, professional editorial advice, financial support and any other original research work used or reported in my thesis. The content of my thesis is the result of work I have carried out since the commencement of my higher degree by research candidature and does not include a substantial part of work that has been submitted to qualify for the award of any other degree or diploma in any university or other tertiary institution. I have clearly stated which parts of my thesis, if any, have been submitted to qualify for another award.

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Publications During Candidature

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Laukkonen, R. E., & Tangen, J. M. (2017). How do we know when our ideas are true? The Aha! experience predicts accurate decisions in contexts of uncertainty where problem solving or retrieval processes are hidden from awareness. *Proceedings of the 58th Annual Meeting of the Psychonomic Society.* Vancouver, Canada.

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Jason Tangen contributed to the conception and design of all studies presented in this thesis, and has made comments on the written work.

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Daniel Ingledew contributed to the design and data collection of one experiment which is discussed in Chapter 3 and Chapter 5 as part of his BSc (Hons) requirement. However, initial conception of the idea, as well as all analyses, interpretations, presentation of results, and written work, are my own.

Research Involving Human or Animal Subjects

Ethical approval in accordance with the Declaration of Helsinki was obtained from an independent review committee for all experiments involving human subjects. The committee and clearance numbers are listed below.

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Part 1 Introduction

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General Discussion

Preface

The thesis is divided into two parts. Part 1 is concerned with the pragmatic and theoretical issues relating to eliciting and detecting insight moments in controlled laboratory experiments. Measuring and evoking insights is in many ways a prerequisite for the empirical and theoretical work that follows. As we will see, the methodological contributions eventually play an important role in the process of testing the predictions made in Part 2.

The thesis begins with an introduction to Part 1, followed by Chapters 2-4. I will then introduce Part 2 separately, which will be followed by Chapters 4 and 5 (see Figure 1). The thesis is expressed as a chronology of ideas, from my (and my collaborator's) earlier work to the most recent. Therefore, hopefully, it will be possible to share in the process of discovery as one reads along.

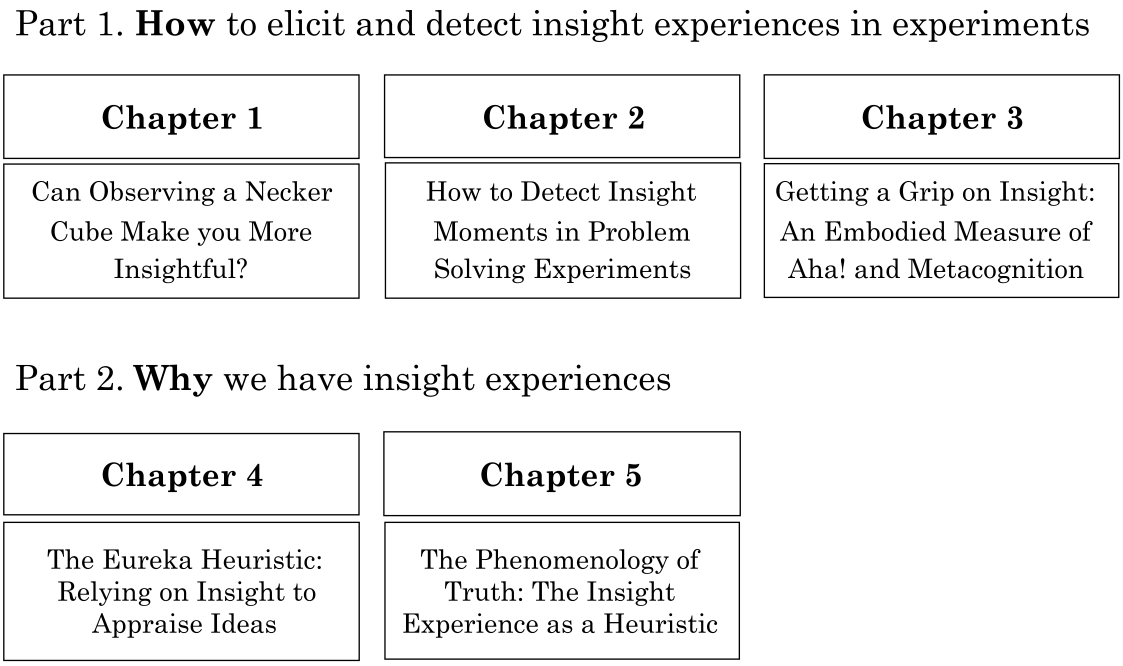


Figure 1. A schematic representation of the thesis. Part 1 includes a general introduction and Chapters 1-3. Part 2 includes a general introduction and Chapters 4 and 5. The thesis is integrated in a final general discussion.

PART 1

How to Elicit and Detect Insight Experiences in Experiments

Introduction

The psychological phenomena that interest humans the most are often deeply and fundamentally subjective; take for example, happiness, love, meaning, or consciousness. The challenge of understanding these phenomena—particularly in pursuing them scientifically—lies in this ephemeral subjectivity. This challenge is extant for the sudden feeling of insight, an enigmatic phenomenon where a solution to a problem appears in the mind of its pursuer as if 'out of nowhere,' immediately filling them with certainty about its truthfulness and value. To overcome these challenges, and therefore to prod insight experiences with the tools of science, we require careful and well-thought-out methods. I begin in Chapter 1 by elucidating one of the key neuro-cognitive processes preceding insight moments, in part so that we can better understand how insight experiences are elicited. In Chapter 2 and 3 I turn my attention to detecting insight moments in the laboratory, because even with the best stimuli it is not possible to guarantee an insight experience, and therefore we need to effectively capture them on a case-by-case basis; a thorny task both methodologically and philosophically.

Eliciting Insight Moments

On the 5th of August in 1949, lightning struck the Southside of Mann Gulch located at the Gates of the Mountains Wilderness of Helena National Forest, in Montana, USA. Wagner Dodge lead a team of 15 smokejumpers who parachuted into a nearby campground on the same day to fight a small and routine fire that was sparked by the lightning. It was the hottest day ever recorded in the state. As the firefighters moved down the gulch towards the fire, Dodge realised that the fire was too hot, and they couldn't get closer than 100ft. As the afternoon progressed, the situation escalated and winds intensified. A short while later, the winds suddenly changed direction, and Dodge—realising the danger they were now facing—instructed his team to drop their heavy equipment and head back up the gulch because the fire was hurtling towards them at a dangerous pace. While making their escape, Dodge realised that the fire—now traveling at 700ft per minute towards them—was too close, and moving too fast. In that moment, Dodge stopped running, and changed his mind. Instead of racing the fire, a task that he realised was futile, he did something "… unprecedented in the history of the US Forest Service" (Weisberg, 2013). In a moment of insight, Dodge lit a match and set fire to the grass in front of him, stepped into the burned area and called for the others to do the same. None listened and two of the remaining 15 men made it to the top of the gulch, the rest were caught by the fire and died. Dodge, with the fire passing around the burned area he was in, was left relatively unscathed and with credit for the discovery of what's now known as an 'escape fire' (Lehrer, 2008).

Dodge's initial plan for escaping the fire was to outrun it and reach safety at the top of the gulf. However, when he saw that this route was not going to be successful (reaching an impasse), he discovered an entirely novel plan. Instead of running, he created an 'escape fire'—a complex solution that draws on considerable expertise and past experience with fighting fires, but is nevertheless completely novel and occurred to him suddenly, 'as if out of nowhere'. In this case, he had no choice but to trust his idea as soon as it occurred to him, his life was literally on the line. The immediate sense of certainty that accompanies an insight like Dodge's seems particularly adaptive, because the stakes are high and a quick decision is paramount. There was no room for self doubt (we discuss this functional value of insight in detail in Part 2). Presumably, the other firefighters also had the skills and the knowledge to arrive at the same solution, and if the solution was described to them, they would have no difficulty in understanding why it worked. If that's the case, why didn't they have the same insight? One hypothesis is that they were overly constrained by their experiences—by how things have been done in the past. Representational Change Theory (Ohlsson, 1984, 2011) suggests that insightful solutions may be rare—and insight problems difficult to solve—because they are counterintuitive in nature and they conflict with past experience. The task of overcoming our initial interpretations, and hence discovering counterintuitive solutions, is exemplified by the process of solving insight problems.

In the interest of understanding how insight experiences can be elicited in the laboratory, consider Wagner Dodge's experience relative to the stimuli used in insight problem-solving experiments. The classic 9-dot problem demands that participants connect nine dots using only four lines, and without lifting their pencils. A very small proportion of participants discover the solution because most start with an initial representation where the lines drawn must stay within the square made up of nine dots (MacGregor, Ormerod, & Chronicle, 2001). Without reinterpreting the problem constraints, literally 'thinking outside the box,' the problem is unsolvable. See below for the solution:

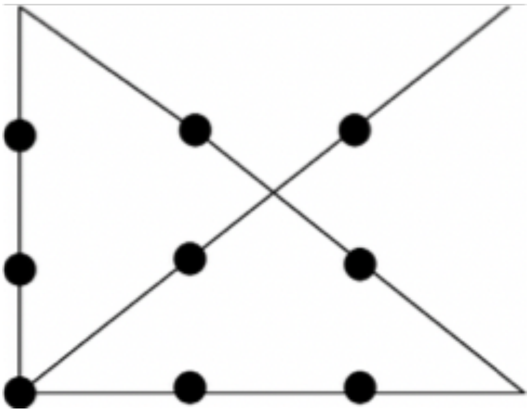


Figure 2. One solution to the 9-dot insight problem.

Now try to answer the following:

1. Our basketball team won a recent match 78-42, but not one man scored as much as a single point. How is this possible?
2. A young boy turned off the lights in his bedroom and managed to get into bed before the room was dark. If the bed is ten feet from the light switch and the light bulb and he used no wires, strings, or other contraptions to turn off the light, how did he do it?

To solve the first problem, the dominant interpretation that needs to be overcome is that the basketball team is made up of male players. Once you see that the players might be female, then the solution tends to be immediately activated, in fact, with the correct representation there is hardly a problem left to solve. In problem two, individuals usually imagine the scenario playing out at night. However, when the problem is reinterpreted to day time, then the room is not dark, no matter how long he takes to get into bed. If, and only if the problem has the correct interpretation can the solution be reached. Since you either have the correct representation, or you don't have it, when it comes to insight problems individuals appear to go from 'zero to hero,' so to speak. And when one arrives at a correct representation "…there is not only the satisfaction of having solved the problem but also the sense of having escaped the tyranny of automaticity" (Gick & Lockhart, 1995, p. 209).

Duncker and Lees (1945) described another powerful way to make apparently 'simple' problems tricky, and as a result revealed an interesting tendency of our cognitive systems, which he termed *functional fixedness*. Functional fixedness occurs when our experiences with particular objects hinders our ability to use the object in a way that's incongruent with its traditional application (Birch & Rabinowitz, 1951; Maier, 1931; Duncker & Lees, 1945). For instance, if we need a paperweight but only have a teapot, we may not notice that a teapot may also function as a paperweight because our past experience with teapots involves brewing tea, and rarely much else. Like the 9-dot problem and the riddles, participants usually solve the functional fixedness problems suddenly and seemingly 'out of nowhere' once they overcome the constraints imposed by the past (Knoblich, Ohlsson, Haider, & Rhenius, 1999). If the correct interpretation of these problems is arrived at immediately, then they tend to be trivially easy to solve, hence it is the conflict between the interpretations that makes them difficult. According to Representational Change Theory (Ohlsson, 2011), functional fixedness represents one example of a more general principle where past experience can lead us astray in situations that are counterintuitive—i.e., contain elements that require an interpretation that is contrary to our past experiences.

Overview of Experiments

Restructuring and representational change theory provide a framework for at least one cognitive process that may lead to sudden insight moments, and therefore also contribute a formula for eliciting insights in the laboratory: if the problem tends to be misleading regarding the correct interpretation, then discovering the new interpretation may lead to an insight moment (Duncker & Lees, 1945; Maier, 1990; Ohlsson, 1984). Here we also have the starting point for Chapter 1. In my first experiment, I explore whether there might be some domain general ability to change one's representations or assumptions (and therefore to achieve the alluring moment of insight). I do this by comparing participants in their ability to switch perspectives in bistable images (examples provided shortly) to their ability to solve insight problems. These analyses aim to answer the question: does switching perspectives in a visual domain predict ones ability to switch perspectives in a conceptual domain? In a second experiment—Drawing on Conflict Monitoring Theory (Botvinick, Cohen, & Carter, 2004)—I formulated the following prediction: Simply observing a visually bistable stimulus (a Necker cube) will prepare participants to better solve conceptual insight problems and therefore trigger more insight moments.

These first two experiments were largely successful and we found support for our predictions. We published the paper in *Consciousness and Cognition* in February 2017. This first Chapter is somewhat 'stand alone,' because it is the only Chapter in which I focus on the specific cognitive processes occurring *prior* to the insight experience.

There was also a secondary goal to Experiment 2. While designing the experiment, I was beginning to discover limitations to the existing methods of *measuring* insight. Creating circumstances where representational changes occur was not sufficient to always elicit an insight moment, and there are many other types of problems—most notably the compound remote associate (Bowden & Jung-Beeman, 2003)—that also elicits insight moments, albeit through a different mechanism (e.g., complex associative processes, Mednick, 1962). There appeared to be many different factors determining whether or not an insight experience would occur, and even the best problems seemed to elicit insights only half of the time (Bowden & Jung-Beeman, 2007; Webb et al., 2016). Therefore, in order to understand insight, it was not sufficient to simply study a specific kind of problem—insights had to be detected on a case-by-case basis. As part of our study we were—for the first time in the literature—measuring insight moments using two of the most popular methods simultaneously: Self-report and feelings-of-warmth. Therefore, we could use the data from Experiment 2 to test for convergent validity between the two methods. In previous work it was always presumed that the two were capturing the same phenomenon, but we had reason to believe otherwise.

Detecting Insight Moments

Chapter 2 begins with a first principles assessment of the assumptions involved with measuring insight experiences, including a test of convergence between popular methods. There are currently two predominant tools for detecting insights, which are self report and feelings of warmth (Metcalfe & Wiebe, 1987; Bowden & Jung-Beeman, 2007). One method relies on an individual's ability to metacognitively monitor their own phenomenology as they approach the solution, whereas the other relies on the individual to retrospectively report on their experience. Both have considerable strengths and weaknesses that we carefully detail in the Chapter. In essence, we argued that self reported insights were capturing the feeling of Aha!, whereas the feelings of warmth measure was simply measuring the unexpectedness of the solution. From our point of view, there wasn't much evidence that unexpected solutions always provoked feelings of insight, and there was reason to believe that solutions which seem predictable, may still lead to feelings of Aha!. By representing the problem in a contingency matrix, we were able to evaluate the specific cases in which the two measures agreed, and where they tended to disagree. For example, if a participant showed a metacognitive pattern where the solution looked predictable, it seemed to have no bearing on whether an Aha! experience was reported, which is clearly problematic (it turns out there's a straight forward reason for this finding, discussed in Chapter 2). We concluded that the self report measure was preferable, but that new methods were sorely needed. We published the paper in *Frontiers in Psychology in March* 2018.

What was really needed was a tool that could achieve the best of both worlds—one that measured metacognitions during problem solving as well as the phenomenology of the experience, without interfering with the primary task. With some good fortune, we happened on a paper that measured feelings of hunger using a dynamometer, which is a highly sensitive measure of grip strength (Creswell, Layette, Schooler, Wright, & Pacilio, 2016). The authors found that the dynamometer was a better predictor of eating behavior than the participant's self reports, and they implicated both the embodied nature of the measure and diminished verbal overshadowing to explain this effect. A major limitation of the existing warmth measure of insight is its insensitivity to subtle changes in metacognitions over time, as well as interruptions to problem solving. The dynamometer had the potential to overcome these limitations. The tool also seemed to be well placed to capture the Aha! experience—we instructed participants to give the device a full-strength squeeze as soon as they experienced ‘Aha!’, causing a sudden spike in their rating. The dynamometer therefore had the potential to capture metacognitions during problem solving as well as the sudden insight experience in real-time. As we will see in the following Chapters—and particularly in Part 2—the fact of capturing ‘Aha!’ experiences in-the-moment is a particularly valuable extension to existing methods.

Chapter 1

Can observing a Necker cube make you more insightful?

Preface

This Chapter is reproduced from a published article in *Consciousness and Cognition*. The majority of the work is my own, with Jason Tangen contributing 10% to the experimental design and 10% to the writing of the publication.

Laukkonen, R., & Tangen, J. M. (2017). Can observing a Necker cube make you more insightful? *Consciousness and Cognition, 48,* 198-211. doi: 10.1016/j.concog. 2016.11.011

Abstract

It is a compelling idea that an image as simple as a Necker cube, or a duck-rabbit illusion, can reveal something about a person's creativity. Surprisingly, there are now multiple examples showing that people who are better at discovering 'hidden' images in a picture, are also better at solving some creative problems. Although this idea goes back at least a century, little is known about how these two tasks—that seem so different on the surface—are related to each other. At least some forms of creativity (and indeed scientific discoveries) may require that we change our perspectives in order to discover a novel solution to a problem. It's possible that such problems involve a similar cognitive process, and perhaps the same cognitive capacities, as switching perspectives in an ambiguous image. We begin by replicating previous work, and also show metacognitive similarities between the sudden appearance of hidden images in consciousness, and the sudden appearance of solutions to verbal insight problems. We then show that simply observing a Necker cube can improve subsequent creative problem-solving and lead to more self-reported insights. We speculate that these results may in part be explained by Conflict Monitoring Theory.

Introduction

In a 1973 short film, Take the World from Another Point of View, Richard Feynman was asked by esteemed astronomer, Sir Fred Hoyle: "Have you had a moment when, in a complicated problem, where quite suddenly the thing comes into your head and you are almost sure that you have got to be right?" Feynman agreed enthusiastically, and replied, "For example, I worked out the theory of helium once and suddenly saw everything. I had been struggling and struggling for two years and suddenly saw everything." Commenting further on the moment of revelation, Feynman says, "And then afterwards, you wonder why was I so stupid that I didn't see this?" As we will soon see, this exchange between Feynman and Hoyle captures several now well documented features of the insight experience.

On one end of a problem-solving spectrum, there are problems that we solve, or things we learn, where progress is gradual, moving step by step to a solution. Problems solved in this analytic way are characterized by linearity and predictable solutions; from beginning to end, progress is smooth. On the other end of the spectrum we have solutions to problems that are sudden, unexpected, and accompanied by an 'Aha!' moment. These occasions—and Feynman discovering the theory of helium is one example—we may call insights, eureka moments, or revelations. And once an experience like this occurs, the solution seems obviously correct, and like Feynman, we are left to wonder how we were "so stupid" just a moment before. Curiously, the problem of understanding how and why insights occur, and predicting their appearances, has made considerable progress through our understanding of a far simpler stimulus, a bistable image.

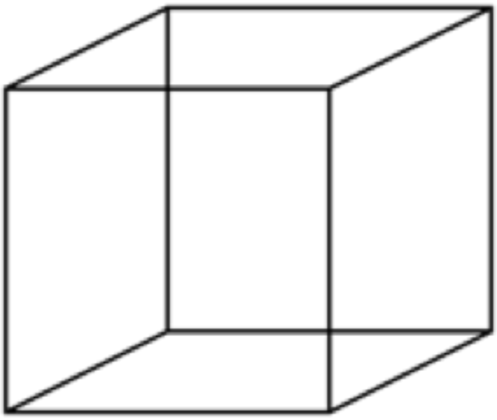


Figure 1. A Necker cube that can, with sustained attention, alternate between two mutually exclusive interpretations: A cube facing down and left, or a cube facing up and right (Necker, 1832).

If you identified both perspectives in Figure 1, chances are that you experienced a small 'Aha!' moment when the image suddenly appeared quite differently than just a moment before. Here we will begin by describing at least three reasons that we believe bistable images, like the Necker cube, have become so intimately linked to the insight experience in previous research (e.g., Maier, 1931; Schooler, McLeod, Brooks, & Melcher, 1993; Schooler & Melcher, 1995; Schooler, Fallshrore, & Fiore, 1995, Sternberg & Davidson, 1995; Wiseman, Watt, Gilhooly & Georgiou, 2011; Doherty & Mair, 2012; Ohlsson, 1984, 2011).

Reason 1: *Phenomenology*. The 'Aha!' experience of solving a bistable image and experiencing an insight is the simplest and perhaps most intuitive reason that the relationship has become so popular. We can see first-hand that the way a "hidden" image appears in consciousness has similar phenomenological characteristics to a sudden insight (Schooler & Melcher, 1995; Metcalfe & Wiebe, 1986). Reason 2: *Representational Change*. Bistable images and some (but perhaps not all) insight experiences are preceded by a change in representation, or interpretation of problem elements or assumptions (Schooler & Melcher, 1995; Ohlsson, 1984, 2011). When some part of the problem is re-interpreted, or a new perspective is found, then the solution may be immediately obvious, and therefore the insightful solution appears suddenly and unexpectedly. We do not usually have conscious access to our interpretations or awareness of when they change, so all that is experienced is a sudden recognition of a solution that was previously unknown (Ohlsson, 1984, 2011). Reason 3: *Performance Correlations*. Evidence has also accumulated suggesting that the relationship between bistable images and insight may be more than a simple analogy. That is, the ability to change perspectives in ambiguous images appears to be associated with our ability to solve creative problems (Schooler & Melcher, 1995; Wiseman et al., 2011; Doherty & Mair, 2012; Jarosz, Colflesh, & Wiley., 2012; O'Brien, Harris, & Higgs, 2013).

Taken together, bistable images and insights feel the same, they may be solved through the same cognitive process of changing perspectives, and successfully reinterpreting an ambiguous image predicts success in creative problems that often lead to insights. It is this third reason—i.e., the empirical relationship between ambiguous images and creative problems—that is particularly not well understood, and as far as we know, there is currently no evidence of a mechanism, cognitive, neuroscientific, or otherwise. To this end, in Experiment 1, we begin by replicating and extending on previous work by testing the association between perceptual switching in ambiguous images and solving insight problems using both accuracy and metacognitive measures. In Experiment 2, we test whether observing the alternations in a Necker cube can trigger cognitive processes that improve subsequent insight problem-solving.

Summary of Previous Research

In the first and most popular experiment of its kind, Schooler and Melcher (1995) demonstrated that recognising out-of-focus images was correlated with performance on traditional insight problems. Recognising blurry images was a better predictor of success with insight problems than analytic problem-solving, remote associate tests, vocabulary, need for cognition, and more. In more recent work, Wiseman et al. (2011) found that self-reported creativity and performance on an alternative uses task correlated with self-reported ease of reversal for one ambiguous figure (the duck-rabbit illusion). Doherty and Mair (2012) found a similar pattern of results, where reversals in three ambiguous figures correlated with performance on a pattern meanings test. Two separate studies also found that insight problems and reversals in ambiguous images were positively influenced by alcohol intoxication, whereas non-insight problems were not (O'Brien et al., 2013; Jarosz et al., 2012). Taken together, the existing research points to a relationship between re-interpreting perceptual stimuli (e.g., blurry or ambiguous images) and re-interpreting conceptual stimuli (e.g., solving insight problems: Doherty & Mair, 2012; Riquelme, 2002; Schooler & Melcher, 1995; Wiseman et al., 2011). However, there are reasons to begin with a conceptual replication and extension using a well-known metacognitive measure of insight.

Experiment 1

Previous research has not tested for the presence or absence of an insight experience, so it is unclear whether the relationship between insight problems and ambiguous images has anything to do with insight *per se*. If ambiguous images and insight problems are related because they both rely on the same cognitive process of representational change (or shifting perspectives), then we would expect similar metacognitions. In order to measure metacognitive patterns and whether an insight has occurred during problem-solving, a popular method is Metcalfe's (1986) feelings-of-warmth (or simply 'warmth') measure. The warmth measure requires participants to make frequent estimates during problem-solving about how close they are to solving the problem from cold (far) to hot (close). We expect that ambiguous images and insight problems are solved more suddenly and unexpectedly (i.e., moving from a cold state to a solution state) compared to analytic problems, where solutions are more likely to follow from gradually increasing warmth ratings. There is evidence that the warmth measure can reliably signal insights and distinguish between traditional insight and non-insight problems (Metcalfe, 1986; Metcalfe & Wiebe, 1987).

Previous work also relied on a small number of ambiguous images, and occasionally did not include a control condition (Doherty & Mair, 2012; Wiseman et al., 2011). The study conducted by Schooler and Melcher (1995) used blurry instead of ambiguous images, which may not have involved representational change in the way we conceptualize it here. To address these issues, Experiment 1 includes a control condition (an analytic problem-solving task), as well as multiple ambiguous images and insight problems, which have been chosen specifically because there are at least two possible representations to each stimulus. If, under these constraints, we find a positive association between ambiguous images and insight problems, and similar metacognitive patterns, then—combined with the work described above—we ought to take seriously the idea that changing interpretations in ambiguous images is related to, and predictive of, changing interpretations in problem-solving, and perhaps creativity.

Experiment 1 Method

Fifty-one undergraduate students from The University of Queensland participated for course credit (mean age = 20.3; *SD* = 4.9). All of the participants (17 males and 34 females) experienced the same three conditions: ten traditional insight problems, ten analytic problems, and ten ambiguous images. All insight and analytic problems were restricted to verbal problems in order to minimise extraneous differences between the conditions. Insight problems were obtained from either Schooler et al. (1993), Weisberg (1996), or online sources. An a priori 'Taxonomy for Identifying Insight Problems' as outlined in Weisberg (1995) was used to ensure that each insight problem required a re-interpretation of the problem elements. Analytic problems were similarly obtained, but chosen because solutions did not require participants to reinterpret the problem elements.

All video instructions for this experiment were pre-recorded to ensure that each participant received the same information. The experiment was constructed and presented using LiveCode (an open-source programming tool) and conducted in quiet rooms with no more than four participants per session using desktop computers. Each participant began by answering basic demographic questions, and indicated whether their first language was English or not. We suspected that if English was not a participant's first language, difficulties may arise because insight problems required that participants re-interpret specific English words in multiple ways, but no significant differences were identified, so the variable was removed from any further analysis. In the instructions, although participants were not explicitly told about the presence of distinct insight and non-insight problems, they were provided with an example of both in order to prevent any differential practice effects. Participants were also provided with an example of an ambiguous image trial and were shown the two possible interpretations. In the experiment, a correct response for an ambiguous image trial was recorded if both images in the picture were successfully identified within the time limit.

Participants were then told that while they were solving the problems, a warmth rating scale would appear on the right hand side of the screen every fifteen seconds with a tone. When the warmth rating appeared, they were told to indicate how close they were to solving the problem from 1 (cold / far), to 10 (hot / close). For ambiguous image trials, participants were told to indicate how close they were to discovering the second interpretation of the image. When the warmth rating appeared, the response field was disabled and unresponsive to mouse clicks, and participants were shown how to make a rating from one to ten in order to continue working on the problem. They were asked to make a rating as quickly as possible when the rating bar appeared, and were provided with a demonstration of the entire process. Participants were told to finish entering their response and to not change their rating after they had solved the problem (to ensure clarity, they were reminded of these instructions again before beginning the experiment). They were told that each problem would appear for two minutes and then disappear. After the instructions were completed and any questions answered, the experiment began and the stimuli were presented in random order.

Experiment 1 Results

Accuracy and Correlations

One of our primary interests was the relationship between the accuracy of the bistable image problems and the insight problems. As in the previous insight demonstrations, we found that participants who correctly identified two images in the bistable image problems (*M* = 68%) also correctly solved more insight problems (M = 43.7%, *r* = .39, *n* = 51, *p* = .012). We found a smaller, but significant correlation between analytic problem-solving (M = 41.6%) and ambiguous images (*r* = .32, *n* = 51, *p* = .003), as well as a correlation between solving insight and analytic problems (*r* = . 48, *n* = 51, *p* < .001). The correlation between analytic problems and ambiguous images was larger than that found in previous research (Schooler & Melcher, 1995), and larger than we expected to find. We elaborate on this relationship further in the discussion of Experiment 1.

Accuracy and Correlations

In order to identify the metacognitive pattern preceding solutions, differential warmth ratings were calculated by subtracting each participant's last warmth rating from their first warmth rating for each problem. Negative numbers were converted to positive, so that a higher differential warmth rating indicates a larger increment in warmth preceding a correct answer, and a lower number indicates a smaller increment (i.e., less of a gradual process toward solving the problem). For example, an average score of zero indicates that a participant's warmth ratings were not at all predictive of correct answers, and higher numbers indicate more gradual warmth ratings prior to correct solutions. Each participant was assigned an average incremental warmth rating for each condition for comparison (see Figure 2, A).

Incremental ratings were then used to identify insight problems and bistable image trials that were solved in a way that resembled insight (i.e., suddenly, without any incremental ratings prior to solution). This is considered the most conservative method, as a participant must experience no progress towards the solution before the solution appears (Metcalfe, 1986). The same method was used to identify analytic problems that were solved incrementally (i.e., greater than zero differential warmth ratings preceding solution). Once identified, each participant received an average score for insight and analytic solutions for each of the conditions (see Figure 2, B).

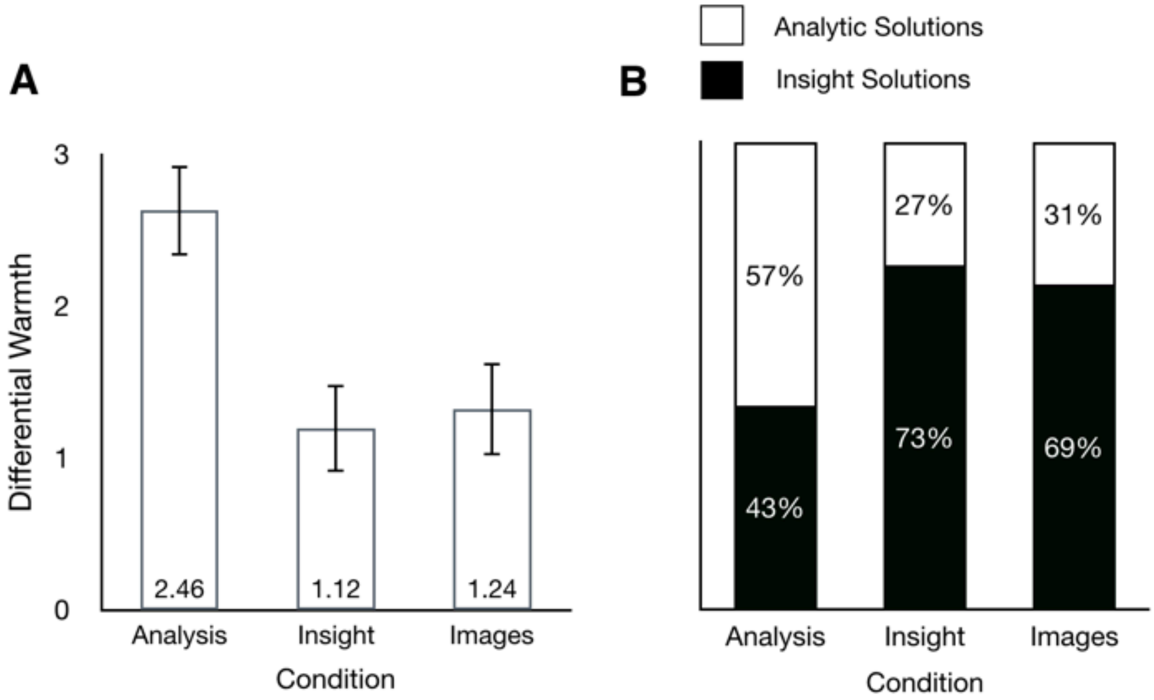


Figure 2. A (left): Differential warmth ratings by condition (error bars represent the standard error of the mean). B (right): Proportion of insight and analytic solutions by condition.

Experiment 1 Discussion

Consistent with previous insight demonstrations (Schooler & Melcher, 1995; Ohlsson, 1984, 2011; Wiseman et al., 2011), participants who were better able to identify two alternative perspectives in ambiguous images (i.e., reinterpret the stimulus) were also more likely to solve insight problems. We also found a positive, although perhaps smaller, relationship between ambiguous images and analytic problem-solving. Previous research has shown that some common factors (e.g., vocabulary) are positively associated with performance in all three conditions—insight, analytic, and image problems (Schooler & Melcher, 1995). Therefore, correlations between each of the conditions were not necessarily surprising. However, the relationship between ambiguous images and analytic problems was larger than found in previous research (Schooler & Melcher, 1995). There are two possible explanations. It may simply be that this experiment was not sensitive enough to identify major differences between the conditions, or, it is possible that there is nothing unique about the relationship between ambiguous images and creative problem-solving, and instead, the ability to switch perspectives in ambiguous images is associated with problem-solving generally. We cannot draw a firm conclusion either way, although previous work suggests that the latter conclusion is unlikely. Nevertheless, the accuracy results were in the expected direction, and our primary aim for Experiment 1 was to measure whether the metacognitions observed in the ambiguous images and insight problems were similar to each other, and different from analytic problems.

The metacognitive data support the possibility that there is something unique about the cognitions involved in reinterpreting ambiguous images and solving insight problems. Extending on previous research, we found that insight problems and ambiguous images are solved more suddenly compared to analytic problems. This result suggests that progress on an analytic problem occurs consciously, in the sense that participants are aware of the steps required in the problem and how they are progressing along those steps. For insight problems and ambiguous images, however, the alternative interpretation—and hence the solution—seems to occur to participants spontaneously and unconsciously (most of the time). Therefore, it is also unlikely that the underlying ability is the same in the analytic problems as in insight problems and ambiguous images, since the underlying cognitions appear to be different (i.e., conscious versus unconscious). Considering the results reported here in combination with previous work, we decided to continue with a second experiment and investigate the possibility that a Necker cube would trigger the neuro-cognitive mechanisms required for insight problem-solving, and thereby improve performance.

Experiment 2

The finding that conflict leads to activation of the anterior cingulate cortex has become one of the most replicated findings in cognitive neuroscience (Botvinick et al., 2004; Weissman, Giesbrecht, Song, Mangun, & Woldorff, 2003). According to Conflict Monitoring Theory, the anterior cingulate cortex functions as a conflict detection centre, which upon detecting conflict, triggers cognitive control mechanisms required to overcome the conflict (Botvinick et al., 2001). The Stroop task, Erikson Flanker Task, and the Simon Task, are classic examples where task difficulty, reaction time, and anterior cingulate activation increases with stimuli that induce conflict compared to non-conflicting versions of the same stimuli (Botvinick et al., 2001; Simon & Wolf, 1963). For example, in Stroop trials (Stroop, 1935) where a word such as blue, is coloured in red, naming the colour of the word takes longer than if the word blue was also coloured blue. The conflict or mismatch induced by the word is responsible for the increased difficulty of the task. Kounios et al. (2006) and Subramaniam et al., (2009) hypothesised that conflict monitoring and cognitive control processes are important for insight because they allow individuals to detect competing options other than the prepotent response. Kounios and Beeman (2014) proposed that if the anterior cingulate cortex is sufficiently active before problem-solving, then the participant is better prepared to detect non-dominant—perhaps creative—solutions. This is indeed the very difficulty with traditional insight problems. Insight problems are specifically designed so that the problem is initially represented (interpreted) incorrectly, and therefore to solve the problem, a different, conflicting (non-dominant) interpretation must be discovered. Cognitive control processes and the anterior cingulate cortex are also believed to be important for monitoring competing responses (Van Veen, Cohen, Botvinick, Stenger, & Carter, 2001; MacDonald, Cohen, Stenger, & Carter, 2000), and for shifting attention (Davis, 2005; Dreisbach & Goschke, 2004), which may be other potential mechanisms involved in solving insight problems.

The Necker cube as well as the ambiguous images used in Experiment 1, are visually bistable stimuli that, due to their two competing interpretations, reliably induce conflict (for a review, see Toppino & Long, 2005; Kornmeier & Bach, 2005). Therefore, it seems that the re-interpretation process in both insight problems and ambiguous images benefit—indeed may require—the Conflict Monitoring System as described by Botvinick et al., (2001). It is possible then that the relationships thus far observed in the literature between bistable or ambiguous stimuli and creative problem-solving are partly accounted for by the role that the Conflict Monitoring System plays in switching between competing representations. In support of this hypothesis, there is evidence that activation of the anterior cingulate cortex prior to problem-solving is associated with more insight solutions than analytic solutions (Kounios & Beeman, 2006; Kounios & Beeman., 2014; Subramaniam et al., 2009). Creativity, by definition perhaps, requires a movement from the old to the new. Switching from the old to the new requires that we overcome habitual, prepotent responses driven by past experience. The Conflict Monitoring System may therefore not only partially account for the relationship between insight and ambiguous images, but may play a larger role in creativity than previously thought.

How do we test this hypothesis? It is well known that a conflicting stimulus, which is preceded by another conflicting stimulus of the same category is likely to be solved faster and more often than conflicting stimuli preceded by non-conflicting stimuli (Botvinick et al., 2001; Botvinick et al., 2004; Kan et al., 2013). According to Conflict Monitoring Theory, this finding—namely the Gratton Effect (Gratton, Coles, & Donchin, 1992)—occurs because conflict in the preceding trial triggers cognitive control, and therefore the participant has control mechanisms prepared for the subsequent trial. Recent evidence suggests that conflict adaptation effects and therefore the Conflict Monitoring System may be domain general. Kan et al., (2013) showed across three experiments that conflict experienced in one task (e.g., a Necker cube) predicted better performance in overcoming conflict in another task (e.g., Stroop tasks or ambiguous sentences) that followed.

In Experiment 2, we test the possibility that a Necker cube can improve subsequent insight problem-solving. Broadly replicating the design of Kan et al., (2013), we presented participants with either a Necker cube (conflict condition) or an alternating cube (no conflict condition) followed by an insight problem. Our conservative hypothesis was that a Necker cube will elicit some shared cognitive processes which will improve subsequent insight problem-solving. Our more specific, but also more speculative hypothesis, is that experiencing conflict with the Necker cube would elicit conflict monitoring and cognitive control mechanisms, which would lead to better performance in the subsequent insight problem. If our hypotheses are supported, then it is possible that Conflict Monitoring Theory, and individual differences in conflict monitoring and cognitive control, can at least partially account for the relationship between insight problems and bistable images. At a bare minimum, there are likely to be shared cognitive mechanisms (cognitive control or otherwise). Recent evidence also suggests that engaged cognitive control mechanisms (i.e., preparatory activation in the anterior cingulate cortex) is associated with more self-reported insights (Subramaniam et al., 2009). Therefore, we also expected that participants presented with conflicting Necker cubes would report more insights and less analytic solutions overall than participants presented with normal alternating cubes.

Experiment 2 Method

Eighty undergraduate students (32 males and 48 females) from The University of Queensland participated in exchange for course credit (mean age = 20.1, *SD* = 5.1). Unless indicated otherwise, Experiment 2 was procedurally the same as Experiment 1. Participants were presented with 20 insight problems, preceded by either a Necker cube (conflict condition), or an alternating cube (no conflict condition) for 90 seconds. In order to make the two conditions as similar as possible (aside from the conflict), the cube in the no conflict condition alternated between the two possible percepts of the

Necker cube (as in Fig. 3) at the average rate that reversals tend to be experienced in the Necker cube (i.e., approximately 27 times in 90 seconds; Kan et al., 2013). In both the conflict and no conflict conditions, participants were instructed to indicate by pressing a key whenever they experienced a reversal in the cube, and were told not to try and change perspectives in either condition, but to observe the images passively. On the left arrow key, a picture of an unambiguous cube pointing left and down was attached, and on the right arrow key, a picture of an unambiguous cube pointing right and up was attached (see Figure 3). This methodology allows participants to indicate which percept they were currently experiencing by pressing one of the cubes, and each button press indicated a reversal. The insight problems were obtained and presented as in Experiment 1, but participants were provided with only one minute to solve the problem to increase the potential impact of the conflict adaptation from the preceding trial. The insight problems were randomised across the conflict and no conflict conditions.

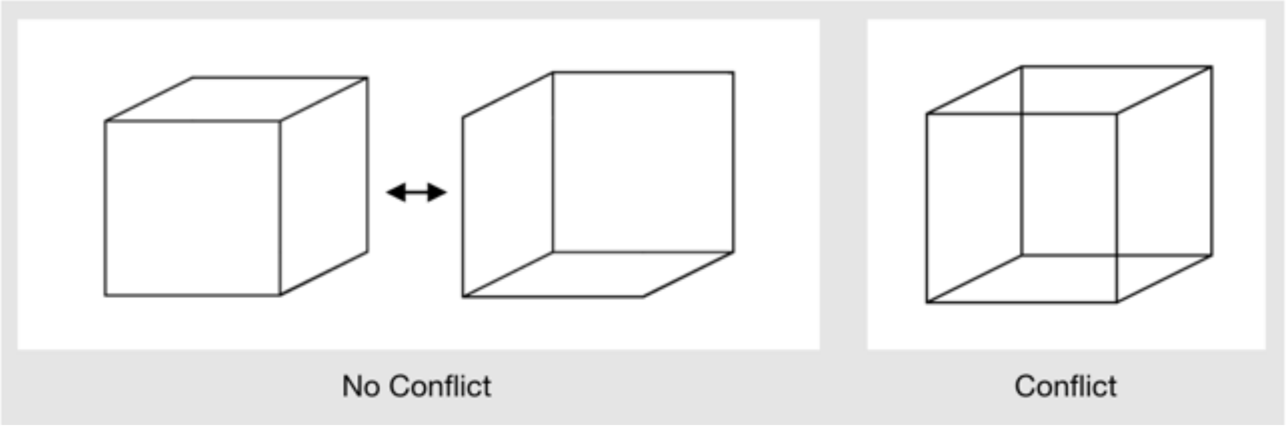


Figure 3. Left: The two alternating cubes presented intermittently every 2.7 seconds for 90 seconds (no conflict condition). Right: Necker cube also presented for 90 seconds (conflict condition).

In order to measure metacognitions and experiences of insight, we used the warmth measure as in Experiment 1, but we also adapted a self-report measure of insight from Bowden and Jung-Beeman (2007). The self-report measure is an alternative to Metcalfe's (1986) warmth rating, and was commonly used in the research reviewed for Experiment 2. Therefore, for consistency with previous research (e.g., Kounios et al., 2006, Kounios & Beeman, et al., 2014, and Subramaniam et al., 2009), and to increase sensitivity in identifying insights, we also included the self-report measure of insight. After each insight problem, participants indicated whether they experienced an insight by providing a rating of 1 (no), 2 (other), or 3 (yes). The important features of an insight were described in detail in the instructions. Participants were instructed to indicate 2 (other) if they simply guessed or did not know the answer, experienced neither insight nor no insight, or if they were unsure. Self-reports of insight compared to no insight or analytic solutions have been associated with different neural activation (e.g., Bowden & Jung-Beeman, 2003; Kounios et al., 2006; Jung-Beeman et al., 2004), different eye-movements (Salvi et al., 2015), differences in accuracy (Salvi et al., 2016), and more. The self-report measure provides several potential advantages to Metcalfe's (1986) warmth measure, however these are discussed elsewhere (see Bowden & Jung-Beeman, 2007). In this experiment, we used both the warmth and self-report measures, and reported them separately. Here, we are specifically interested in how these two measures capture differences in insight problem-solving performance and metacognitions as a result of conflict induction. Because of the shorter presentation times, participants were asked to make warmth ratings more often than in Experiment 1, in this case every ten seconds. Otherwise, the warmth measure was consistent with Experiment 1. After providing an insight rating, participants were asked whether the problem they solved was familiar or not, and any familiar problems were removed from further analysis.

Experiment 2 Results

Accuracy and Reaction Time

Participants experienced approximately equivalent reversals when observing conflicting Necker cubes (*M* = 28.2, *SD* = 26.4) and alternating cubes (*M* = 26.1, *SD* = 4), although variability in the Necker cube condition was substantially higher, which is consistent with previous research showing individual differences in reversal rates for Necker cubes (e.g., Kan et al., 2013; Shannon et al., 2011). When participants were presented with a Necker cube, and then an insight problem (conflict condition), they solved an average of 4.24 of 10 insight problems (*SD* = 1.87). When they were first presented with an alternating cube, and then an insight problem (no conflict condition), they solved an average of 3.76 of 10 insight problems (*SD* = 1.82). A paired t-test (one-tailed) showed that participants solved significantly more insight problems in the conflict condition compared to the no conflict condition $t(79) = 1.86$, $p = .034$ (see Figure 4). Therefore, the results suggest that observing a Necker cube increased the likelihood that the subsequent insight problem would be solved correctly.

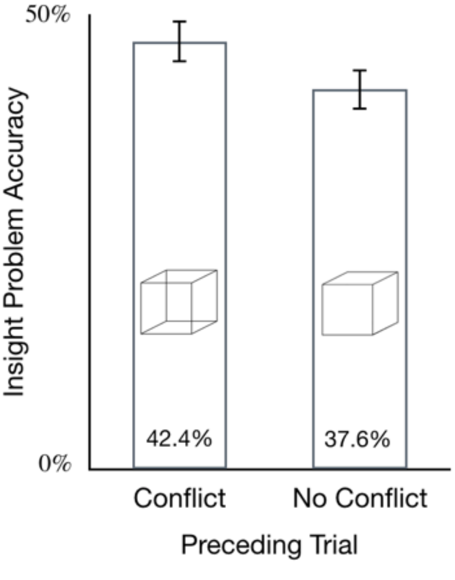


Figure 4. Average insight problems solved by condition (Conflict trials are insight problems preceded by a Necker cube, whereas No Conflict trials are insight problems preceded by an alternating cube). Error bars represent the standard error of the mean.

As in Kan et al. (2013), reaction times between the conflict and no conflict conditions were not significantly different. It is possible that the time constraints in the conditions meant that participants were answering the problems faster than they would naturally, making subtle reaction time differences between the two conditions difficult to detect. As in Kan et al., (2013), we also performed a median split of participants into two groups made up of those who experienced more reversals of the Necker cube in one group (high conflict), and those who experienced less reversals in the other group (low conflict). A one-way ANOVA revealed no significant differences between the two groups in solving insight problems ($p = .17$), and no correlation was found between reversals in the Necker cube and performance ($r = .02$, $p = .82$) or reaction time ($r = .08$, $p = .32$).

Metacognitions

There are two ways to partition metacognitions in this experiment: they can be localised to correct responses only, or it is possible to explore how participants respond metacognitively to all problems, whether solved correctly or incorrectly across the two conditions. In order to make specific comparisons between metacognitions in the conflict condition and the no conflict condition, we combined the responses into two variables for each analysis. For instance, to compare insights, we created two variables, either problems solved through insight or problems solved through non-insight (i.e., collapsing over analytic and other solutions). As illustrated in Figure 7 (A) below, when all responses are analysed, we receive a picture of how participants arrived at solutions to the problem, regardless of whether the solution they found was correct or not. Using a McNemar's test on all responses, we found that when participants solved insight problems preceded by conflict (i.e., a Necker cube), they were significantly more likely to report insights compared to solving insight problems preceded by no conflict (i.e., alternating cubes, $p = .017$). Insight problems preceded by conflict were also associated with fewer reports of analytic solutions than the no conflict condition ($p < .001$), but no difference was found in reports of 'other' solutions. Also illustrated in Figure 5 (B) below, when only correct responses are analysed, a McNemar's test revealed fewer analytic solutions, and more 'other' solutions if the problem was preceded by conflict compared to no conflict (*p* = .003 and *p* = .006, respectively), but there was no difference in the number of insights reported in the two conditions. This may suggest that although participants reported experiencing more insights following Necker cubes (as hypothesised), these insights were not necessarily accurate.

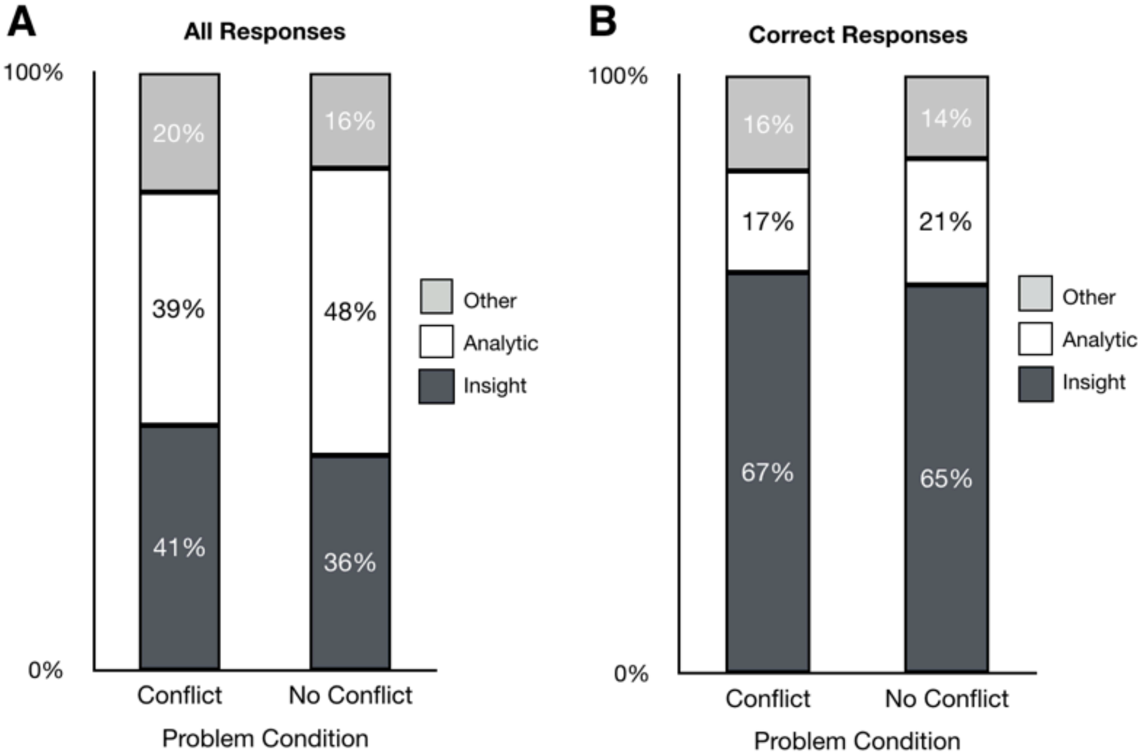


Figure 5. Average insight problems solved by condition (Conflict trials are insight problems preceded by a Necker cube, whereas No Conflict trials are insight problems preceded by an alternating cube). Error bars represent the standard error of the mean.

Initially, the differential warmth data for correct responses were surprising. We found that the total warmth ratings appeared larger in the conflict (*M* = .35) compared to the no conflict (*M* = .31) condition. However, in Experiment 2 we were less interested in the metacognitive patterns (since they ought to be approximately the same across insight problems), but more interested in the number of insights participants experienced. Therefore, as in Experiment 1, the warmth ratings were partitioned into analytic solutions (differential warmth rating greater than zero) and insight solutions (differential warmth ratings of zero or less). The results show a marginally significant difference between insight problems preceded by a Necker cube (conflict condition, *M* = 3.80) and insight problems preceded by alternating cubes (*M* = 3.43), $t(79) = 1.58$, $p = .059$, potentially suggesting more sudden solutions when the problem was preceded by a conflicting Necker cube. Warmth measures are less sensitive than the self-report measure because problems that are solved very quickly cannot be analysed, which may account for the marginal effect. There was also a moderate to strong correlation between the amount of self-reported insights and insights recorded based on the warmth data ($r = .61$, $n = 51$, $p < .001$).

General Discussion

While discussing scientific revelations with Fred Hoyle, Richard Feynman expressed a burning curiosity to find the conditions that lead to the kind of breakthrough insights he’s had in the past. He goes on to say, “Some man suggested I think about it once because if I could only figure out the formula for what condition to be in to get good ideas, I’d be much more efficient and more happy.” One of the implications of this study may be that situations which induce conflict, or conflict experienced during the problem-solving process, may be an important precedent of an insight moment. Once a conflict is experienced between our current interpretations or assumptions and another competing interpretation or assumption, then there is an opportunity to engage control, and step aside from the existing rut to a novel perspective, which if we are lucky, is a vantage point from which we can discover the solution: ‘Aha!’.

Experiment 1 demonstrated a familiar pattern whereby someone who was better at 'solving' or re-interpreting a visual stimulus was also better at solving an insight problem. At this stage there is substantial evidence for the positive relationship between ambiguous or bistable images and insight problems (Maier, 1931; Schooler & Melcher, 1995; Sternberg & Davidson, 1995; Wiseman et al., 2011; Doherty & Mair, 2012; Ohlsson, 1983; 2011). We also found similar metacognitive patterns: both ambiguous figures and insight problems lead to more sudden and unexpected solutions than analytic problems. Our results further indicated that switching perspectives in an ambiguous image may also relate to analytic problem-solving more strongly than previously thought. However, we have assumed—based on previous research and our metacognitive data—that this effect is not equivalent to the relationship between ambiguous images and insight problem-solving. Pending further research, this should be considered a possible caveat to our interpretation of the results that follow. Previous research on the neural correlates of insight indirectly implicate the Conflict Monitoring System as a potential mechanism for resolving conflict in both ambiguous images and insight problems (Botvinick et al., 2001; Kan et al., 2013; Subramaniam et al., 2009; Kounios & Jung-Beeman, 2009). Experiment 2 aimed to explore this hypothesis by examining whether it is possible to elicit conflict adaptation in insight problems using a bistable image. As predicted by Conflict Monitoring Theory, in Experiment 2, we found that insight problems were more likely to be solved accurately when they were preceded by a Necker cube, as opposed to two alternating cubes. This result suggests that when the Conflict Monitoring System is engaged through exposure to conflict in the Necker cube, then the associated control mechanisms assist participants in resolving subsequent representational conflict in an insight problem (Kan et al., 2013).

Overall, the metacognitive results of Experiment 2 were also in the expected direction and consistent with previous research showing that experiencing conflict—presumably activating the functions of the anterior cingulate cortex—will lead to more subsequent insights during problem-solving (Kounios et al., 2006; Subramaniam et al., 2009). Overall, participants reported more insights and fewer analytic solutions when preceded by a Necker cube compared to the no conflict control. When analysing the correct responses only, the same results did not entirely emerge, although the direction was the same. It may be that the insights participants indicated experiencing following Necker cubes were not necessarily accurate insights. Nevertheless, even in the ‘correct responses’ subset, the Necker cube condition did encourage fewer analytic solutions and more ‘middle-ground’ solutions, appearing to shift participants in the expected direction (i.e., towards more insight-like solutions).

In order to formalise the proposed role of conflict monitoring with regard to ambiguous images and insight problems, Fig. 6 illustrates a basic schematic representation of the Conflict Monitoring System as a moderating factor in the successful switching from one interpretation to another conflicting interpretation. The model is general enough to capture how the Conflict Monitoring System relates to two tasks as seemingly disparate as insight problems and ambiguous images. It is likely, however, that as the context of the insight becomes increasingly complex (e.g., conflicting interpretations of Feynman’s theory of helium), then domain specific knowledge and experience will be considerably more predictive of insights relative to an engaged Conflict Monitoring System. Nevertheless, if the domain specific information and experiences are exhausted, engaging in active comparisons of one’s assumptions or interpretations, or indeed engaging in an unrelated but conflict inducing task, may be the missing ingredient for an insight moment.

There is some evidence that deliberately comparing conflicting assumptions on a problem will help with solving it. Patrick et al. (2015), demonstrated a marked improvement (between 24% and 40%) in insight problem-solving when participants were instructed to check for inconsistencies between their interpretations of parts of the problem and the problem’s specification. Naturally, this technique increases the chances of the participant discovering the correct interpretation simply by virtue of exploring other hypotheses. However, the moderation model in Figure 6 suggests that in some cases it may be enough to simply engage the system (i.e., the Conflict Monitoring System) in order to boost the likelihood of switching interpretations and experiencing an insight, which may partly explain the effectiveness of this technique.

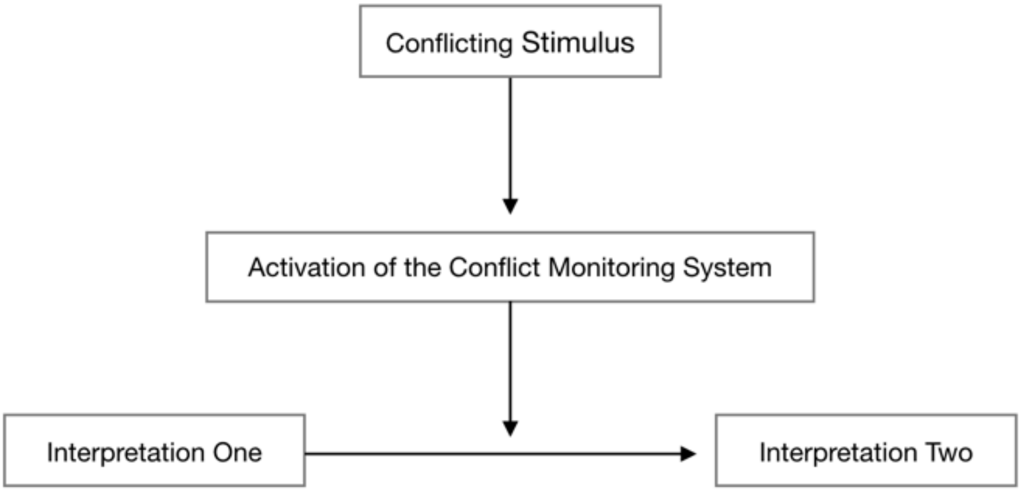


Figure 6. A proposed moderation model in which the Conflict Monitoring System moderates the likelihood of switching between two interpretations of an insight problem or bistable image. The Conflict Monitoring System can be engaged both by task-relevant or task-irrelevant conflicting stimuli.

There are some considerations for interpreting the results of this study. In Experiment 2, we have not included an analytic problem-solving task. It is perhaps important to test whether conflict can improve problem-solving more generally, although this is highly unlikely to be the case given previous research showing that conflict adaption does not improve accuracy with stimuli that do not also have conflict present (Kan et al., 2013; Botvinick et al., 2004). Conceptualising insight problems as situations of representational conflict is also potentially problematic. We assume that there is conflict occurring below awareness between the initially adopted incorrect (dominant) interpretation, and the correct one, and perhaps on the surface the kind of conflict in an insight problem appears different to the kind of conflict experienced in a Stroop task. However, even in the case of the Stroop task, the conflict between the word and the colour does not occur consciously. A participant does not need to read the word “red” in their mind’s eye, then notice that the word is in fact blue, before deciding to resolve the conflict between the word and the colour. This conflict resolution process occurs below awareness, therefore, it is not a stretch to suggest that a conflict between possible interpretations of an insight problem may also occur below awareness. It is also possible that there is something about the Necker cube, which is unrelated to conflict, that improves subsequent insight problem-solving. However, we believe the hypothesis that a Necker cube can improve subsequent insight problem-solving is sufficiently counterintuitive that the Conflict Monitoring System is the best candidate mechanism at this time. It is also possible that cognitive control elicited by the Necker cube improves insight problem-solving in some way unrelated to the Conflict Monitoring System, but we do not have a competing hypothesis. If cognitive control processes are responsible, it is still unknown precisely how this is aiding in the insight problem-solving process. For example, it may be that cognitive control assists specifically with switching between competing representations, or it may be that cognitive control simply deactivates fixedness on the initial, dominant interpretation (or indeed both). Another possibility, as proposed by Kounios et al. (2006), is that activation of the anterior cingulate cortex is responsible for suppressing irrelevant thoughts such as daydreaming, however, there is some evidence that daydreaming may indeed improve insight problem-solving (e.g., Zedelius & Schooler, 2015).

We do not know how well the effects from Experiment 2 generalize. For example, does observing a Necker cube also improve performance in remote associate problems? To better understand the role of the anterior cingulate cortex, an fMRI study would be informative. For example, if observing a Necker cube does not activate the anterior cingulate cortex, but still improves insight problem-solving, then perhaps this brain region is not as important as we think. On the other hand, if observing a Necker cube improves insight problem-solving only when the anterior cingulate cortex is activated, then this would support the role of the Conflict Monitoring System in both tasks. Purely for the purposes of increasing the number of insights, it may also be interesting to simply identify tasks which most effectively activate the anterior cingulate cortex, and explore the extent to which these tasks promote subsequent insights.

Over a century ago, Jastrow proposed that the duck-rabbit illusion can be used to measure creativity (Jastrow, 1900). We continue to find support for Jastrow's bold claim, and propose that—at least conceptually—the conflict we experience between two interpretations of an image is similar to the conflict we experience between two perspectives in a verbal insight problem. In order to switch perspectives in both tasks (i.e., overcome the conflict), we may be engaging the same cognitive processes and capacities. Indeed, we find that observing a Necker cube can improve insight problem-solving and may lead to more experiences of insight, perhaps because the Necker cube engages the capacities necessary for insight to occur. Future work is necessary to determine the precise mechanism, although the Conflict Monitoring System is one candidate. We also find general support for Schooler and Melcher (1995) who proposed shared cognitive processes between switching representations of ambiguous images and insight problems, and for Subramaniam et al., (2009), who suggested that cognitive control mechanisms "…could be an important component of what insight researchers variously term cognitive restructuring and flexibility or 'breaking set' and 'overcoming functional fixedness'."

Chapter 2

How to detect insight moments in problem solving experiments

Preface

This Chapter is reproduced from a published article in *Frontiers in Psychology*. The majority of the work is my own, with Jason Tangen contributing 10% to the experimental design and 10% to the writing of the publication.

Laukkonen, R., & Tangen, J. M. (2018). How to Detect Insight Moments in Problem Solving Experiments. *Frontiers in Psychology, 9,* 282. doi: 10.3389/fpsyg.2018.00282

In this Chapter we are seeing the beginning of a shift in the direction of my research. Although it's worthwhile to study the cognitive processes that precede insight—or indeed improve our understanding of how particular problems are solved—it seemed to me that there were more foundational questions to address. Questions like, what really is an insight? Is it an experience or a cognitive process? Is it just a pattern in problem solving? Is it an emotion? If it's all of these things, are the elements dissociable, and which elements should be weighted most highly? The answers to these questions provide the axioms for research on insight. We ought to know what we are trying to detect before we develop means to detect it. Empirically, this Chapter compares existing methods of detecting insight for convergent validity. Theoretically, this Chapter aims to refine our understanding of insight by testing whether cognitive process conceptions of insight (sudden and unexpected solutions) map onto the phenomenological components of insight (the Aha! experience).

Abstract

Arguably, it is not possible to study insight moments during problem solving without being able to accurately detect when they occur (Bowden & Jung-Beeman, 2007). Despite over a century of research on the insight moment, there is surprisingly little consensus on the best way to measure them in real-time experiments. There have also been no attempts to evaluate whether the different ways of measuring insight converge. Indeed, if it turns out that the popular measures of insight *diverge*, then this may indicate that researchers who have used one method may have been measuring a different phenomenon to those who have used another method. We compare the strengths and weaknesses of the two most commonly cited ways of measuring insight: The feelings-of-warmth measure adapted from Metcalfe and Wiebe (1987), and the self-report measure adapted from Bowden and Jung-Beeman (2007). We find little empirical agreement between the two measures, and conclude that the self-report measure of Aha! is superior both methodologically and theoretically, and provides a better representation of what is commonly regarded as insight. We go on to describe and recommend a novel visceral measure of insight using a dynamometer as described in Creswell et al., (2016).

Introduction

Insight is a multifaceted construct, and is better understood as an umbrella term for more objective features such as: the suddenness and unexpectedness of a solution, a non-linearity in the problem solving process, and the phenomenology of an Aha! experience. A solution to a problem can be anywhere from purely insight (sudden and unexpected), to entirely analytic. When a problem is solved analytically, one proceeds through the problem step-by-step, while consciously aware of their progress towards a solution. Attempts have been made to understand insight as a *feature* of certain types of creative problems that elicit insights (e.g., Weisberg, 1996; Gilhooly & Murphy, 2005), but many researchers have shown that even so-called insight problems are often solved without insight, and can be solved through a variety of strategies (Fleck & Weisberg, 2013; Weisberg, 2013; Klein & Jarosz, 2011; Danek et al., 2014). Indeed, the very definition of an insight problem has often been based purely on the fact that previous research has used them. We agree with Danek et al., (2014) who point out that although it is well documented that some problems are more likely to be solved by insight than others, insight problems *per se* do not exist (Bowden & Jung-Beeman, 2007, were also clear in making this distinction). Therefore, a critical challenge for insight researchers is to identify when—case by case—an individual experiences an insight moment. The most popular methods are self-report, and the feelings-of-warmth (warmth) measure developed by Metcalfe (1986) and Metcalfe and Wiebe (1987). We begin by considering the conceptual strengths and weaknesses of the two measures, then evaluate them experimentally for convergent validity. In the discussion, we also consider methodological strengths and weaknesses that were discovered during the experiment, and provide advice about the general usability and conceptual merit of each measure.

The Warmth Measure

During verbal problem solving Metcalfe (1986) asked participants to write down a number between 0 and 10 every 10 s (15 s in experiment two), where 0 is cold (far away from the solution) and 10 is hot, or certain that they had the solution. If a problem-solver exhibits gradual increases in warmth before solving the problem, then they were ostensibly aware of their progress on the problem and therefore the solution was found gradually, or step-by-step. If the problem-solver exhibits a sudden transition from a cold state to a solution, then it appears that the problem was solved through a more sudden and unexpected insight. One year later, Metcalfe and Wiebe (1987) showed that problems that had been previously categorized as insight problems showed more sudden transitions from cold states to solution states, whereas the previously categorized multi-step problems showed gradual warmth ratings preceding the solution. This contribution has had a long-standing impact on insight research and provided some of the first objective evidences that problem solving can occur in a way that resembles the insight construct. It is rare to find research on insight that does not refer to these findings, and variations of the measure are often used (e.g., Chu, 2009; Chein et al., 2010; Cushen & Wiley, 2012; Hedne et al., 2016). Notably, Cushen and Wiley (2012) used perceived importance to solution ratings in order to track changes in problem representation and found similar evidence of insight and non-insight patterns in solution discovery.

The Self Report Measure

Asking participants to indicate, case by case, whether a problem was solved with an insight moment (i.e., suddenly, unexpectedly, and accompanied by an Aha! experience), or analytically (i.e., gradually, strategically, and step-by-step) is the most common method in recent research. In some cases a rating scale is used (e.g., Bowden & Jung-Beeman, 2003), and in other cases a retrospective forced choice paradigm (e.g., Jung-Beeman et al., 2004). Some recent research has also measured different features of the Aha! phenomenology on separate scales, which is beginning to provide a more nuanced view of the (often variable) insight experience (Danek et al., 2014; Webb et al., 2016).

Predictions

Clearly the ideal situation is to use both the warmth and the self-report measure, and only label insights as those that are corroborated by both (as recommended by Chu & Macgregor, 2011). However, there are reasons why this solution may not be appropriate. In particular, insights can occur—at least theoretically—even when the warmth measure indicates gradual progress on the problem, as long as that progress is not related to the content of the insight (more on this in discussion). The self-report measure can also detect the emotional Aha! experience, but the warmth measure can not. If the two measures are not in agreement about whether an insight occurred, at least most of the time, then using the two measures together to identify insights is not going to be productive, since many true insights would go undetected. In further support of a likely divergence between the measures, Hedne, Norman, and Metcalfe (2016) found no differences in warmth ratings between self-reported insight and non-insight solutions in the case of magic tricks. Magic tricks are a relatively new way to elicit insights (Danek et al., 2014), so we should hesitate to generalize this result to the more commonplace stimuli used in insight research—i.e., classical insight problems. If the two measures do not agree, it is also appropriate to discuss which measure is likely to capture what we regard as insight, and which measure is likely to be capturing something else. We don’t have a specific prediction about the degree of convergence, but given our discussion so far, it is quite possible that the two measures do not often agree. We stress that we are not comparing them empirically to find out which measure is better, only to test agreement. Arguments about the merits of each measure must be made on conceptual grounds, since there is no ground truth. We will aim to provide such a perspective in the discussion.

Method

Design

The participants were eighty undergraduate students (32 males and 48 females) from The University of Queensland who participated in exchange for course credit (mean age = 20.1, *SD* = 5.1). Each participant was presented with 20 verbal insight problems. We collected the insight problems from either Schooler, Ohlsson, and Brooks (1993), Weisberg (1996), or online sources. We used Weisberg's (1996) *a priori* 'Taxonomy for Identifying Insight Problems,' which ensures that the problem involves restructuring (a re-interpretation of the problem elements, Ohlsson, 1984), and therefore is likely to elicit an insight. We used LiveCode (an open-source programming tool) to create the experiment and presented it to participants on desktop computers. The dependent variables of interest were the self-report insight measure and the feelings-of-warmth measure of insight.

The Warmth Measure

We calculated differential warmth in a similar way to Metcalfe & Wiebe (1987) and Hedne et al., (2016). Differential warmth is calculated by finding the difference between the first warmth rating and the last warmth rating prior to a solution. In order to be faithful to the definition of insight as a 'sudden solution,' we determined that an insight had occurred when there is no perceived progress on the problem before the solution, as recommended by Kounios and Beeman (2014). Whereas Metcalfe and Wiebe's (1987) participants provided a final warmth rating that indicated that they were certain they found the solution, our participants were instructed to provide warmth ratings only before they reached the solution, and the solution itself acted as the final rating. The benefit of using differential warmth in this way, is that only two warmth ratings are required for a problem solution to be categorised as insight or non-insight, whereas the version used by Metcalfe and Wiebe (1987) required a minimum of three. Many problems are solved faster than 30 seconds (three warmth ratings at ten second intervals), which means that substantial data are lost. For example, in Metcalfe and Wiebe (1987), out of 73 subjects, only 39 provided usable data. There is no foreseeable reason why our changes would result in different outcomes than the original formulation of the warmth measure and that used in Hedne et al., (2016).

The Self Report Measure

We used a self-report measure of insight as recommended by Bowden and Jung-Beeman (2007). After providing a solution to a problem, participants are asked to indicate whether they experienced an insight moment by providing a rating of 1 (no), 2 (other), or 3 (yes). The 2 (other) option is for participants who guessed, experienced neither insight nor non-insight, were unsure, or did not know the answer.

Procedure

The research questions described in this article were assessed as part of another experiment reported elsewhere (Laukkonen & Tangen, 2017). Each participant began by watching pre-recorded instructions, and were provided with examples of insight problems. They were told that throughout problem solving, a warmth scale would appear on the right hand side of the screen every ten seconds, at which point they would need to indicate how close they felt they were to solving the problem from 1 (cold / far) to 10 (hot / close). When the warmth bar appeared, the screen was locked so that participants had to immediately make a rating before continuing on the problem. The warmth bar was presented alongside a tone and participants were told not to change their rating once they had solved the problem, and to submit their response as soon as they reached the solution. The warmth bar would no longer appear once the participant started typing their answer. Participants had one minute to complete each problem, which was presented in the centre of the screen in large font, with a text box below it for typing the answer. Once a solution was provided, they completed the self-report measure of insight, and indicated whether the problem was familiar. If the problem was familiar, it was removed from further analysis.

Results

Out of a possible 631 correctly solved insight problems, participants provided two or more warmth ratings in 180 cases. We did not include problems that were left unsolved or solved incorrectly, because omission errors and guesses were likely to add too much noise to the analysis. Initially we found a moderate to strong positive correlation between the total number of self-reported insights (M = 5.28, SD = 2.74) and the total number of warmth insights (M = 4.85, SD = 2.7) for each participant (r = .61, n = 51, p < .001). This indicates that self-reported insights and sudden warmth ratings are occurring approximately at the same rate, but it does not tell us whether the same problems were categorised as insight. To this end, we ran another Pearson's correlation analysis across problems case by case (i.e., at the level of the question rather than at the level of participant averages). This analysis showed no significant correlation between the two measures of insight (r = .08, n = 182, p = .235). To provide a more nuanced perspective on the low correlation, a contingency matrix of the data is presented in Table 1. The contingency matrix indicates that when a sudden solution occurred according to warmth ratings, then there was a 75% chance that an insight was also self-reported by participants (i.e., 25% above chance). On the other hand, if no sudden solution was observed according to the warmth measure, then there was a 50% chance that an insight would nevertheless be self-reported.

Table 1. A contingency matrix representing the four possible ways that the two measures of insight can converge or diverge.

	Self-report insight	**Self-report no insight**
Warmth insight	A 75.6%	B 24.4%
Warmth no insight	C 50.8%	D 49.2%

For example, Cell A represents the proportion of warmth insights where participants also reported experiencing an insight. Cell C represents the proportion of warmth non-insights where participants still report experiencing an insight.

Discussion

Our results indicate that agreement between the two most popular measures of insight is low or non-existent. This finding corresponds with Hedne et al. (2016) who found that warmth ratings did not differ for self-reported insights and non-insight solutions when exposed to magic tricks. A closer look at the data using a contingency matrix indicates that the primary source of divergence occurs because gradual warmth ratings have no implication on whether or not an insight is self-reported by the participants. We now consider which measure—self-report or warmth ratings—may be the better option for detecting insight moments.

Aside from the fact that there are difficulties in analysing and comparing warmth data (see Weisberg, 1992 for a commentary on this point), there are also theoretical limitations to using warmth ratings to measure insight. One problem is that a gradual warmth pattern does not necessarily mean that an insight did not occur. A participant can of course make subjective progress on a problem, and therefore provide increasing warmth ratings, but then have a sudden insight that they were using the incorrect strategy followed by a solution to the problem. If this unexpected shift occurs, then the warmth ratings appear gradual and the solution predictable, when in fact it was sudden and unpredictable. There is no a priori reason why an insight must occur without the feeling of progress, as long as that feeling of progress is illusory or unrelated to the content of the sudden and unexpected solution. We find strong support for this perspective in our data, where participants are just as likely to report insight moments despite gradual warmth patterns.

Insights are in essence a subjective phenomenon—feelings such as pleasure, certainty, relief, drive, and surprise, are key dimensions of the insight experience that cannot be captured by warmth ratings (Danek & Wiley, 2017). Experiencing an Aha! moment is becoming increasingly the core feature of both definitions and measures of insight among researchers in the area (Bowden & Jung-Beeman, 2007; Danek & Wiley, 2017; Kounios &Beeman, 2014; Webb et al., 2016). This also means that, in a hierarchy of measures, the self-report measure of insight will take precedence. If self-reported insights consistently contradict warmth measures, then we would be forced to conclude that the warm measure is not capturing insights. Of course, if the subjective rating of insight fails to map onto anything objective, then it may not be a useful or interesting construct. Fortunately, we now know that self-reported insights map onto different eye-movements (Salvi et al., 2015), different cognitive strategies (Kounios et al., 2008), different neural activity (Bowden & Jung-Beeman, 2003; Jung-Beeman et al., 2004; Kounios et al., 2006, 2008; Subramaniam et al., 2009), differences in accuracy (Hedne et al., 2016; Salvi et al., 2016; Webb et al., 2016), and greater positive affect (Subramaniam et al., 2009). This clear mapping onto objective measures for the self-reported insights is not matched by the warmth measure, perhaps partly because it is impractical for neural investigations (Bowden & Jung-Beeman, 2007).

One issue pertaining to self-reported Aha! moments is the way that they are described to participants prior to experiments, which may in turn impact which phenomenology the participant classifies as insight. In the literature there are notable inconsistencies, for example Cushen and Wiley (2012) focused on just two dimensions, surprise and suddenness (see also Davidson, 1995 and Bowden, 1997), whereas more recent work characterises insight based on multiple dimensions that often include affective features such as pleasure, certainty, and relief (e.g., Jung-Beeman et al., 2004; Webb et al., 2016; Danek & Wiley, 2017). Danek and Wiley (2017) recently compared experimentally the extent to which different dimensions used in previous research predict participants global Aha! ratings, thus providing a more objective mapping of the insight phenomenology. It is likely that empirically mapping the subjective Aha! experience—as in Danek and Wiley (2017)—will eventually mitigate inconsistencies and ensure more representative descriptions of insight.

A Visceral Alternative

According to Creswell et al. (2016), “visceral states call for visceral measures.” The authors proposed that the feeling of hunger, like many other non-verbal experiences, is difficult to put into words. It is also known that verbalization can be disruptive to both task performance and subsequent memory (e.g., Schooler & Engstler-Schooler, 1990; Schooler, 2002, 2011; Brown et al., 2014). To solve this problem, the authors tested whether handgrip pressure over time—as measured by a dynamometer—could be used as a visceral, non-verbal alternative to the commonly used self-report measures of hunger. They found that the visceral measure was a better predictor of subsequent eating behavior than the self-report scale, and was sensitive to a well established food cue exposure paradigm. We propose that the insight experience is also visceral in nature, and may therefore be better captured by a visceral measure that does not interfere with the primary task. To illustrate, a participant can be instructed to begin problem solving with their hand resting on the dynamometer without squeezing, and then be asked to increase grip strength as they make progress on the problem, where a stronger squeeze is equivalent to a higher warmth rating, and a full strength squeeze indicates that an Aha! moment occurred. If the participant solved the problem, but did not experience an Aha! moment, then they can simply release their grip, indicating that the solution was found without the insight phenomenology. With these simple instructions, the dynamometer can provide continuous ratings of progress on a problem (feelings-of-warmth), and can show clearly when an Aha! moment occurs—a light squeeze followed by the sudden onset of a full strength squeeze.

Conclusion

We believe the feelings-of-warmth measure captures only a fraction of the insight solutions that can occur during problem solving, and since the warmth measure does not show agreement with the self-report measure, it may fail to capture some crucial features of the insight experience—namely the Aha! moment. The warmth measure remains an innovative and objective measure of progress during problem solving. We recommend that warmth ratings be used to measure perceived progress on a problem, but that concluding that an insight has or has not occurred without other converging evidence is likely premature. Given the strengths of the self-report measure described as well as the relative ease with which it is administered, it is likely that self-report will continue to be the most popular method for detecting insight moments, and justifiably so. As a promising alternative, we propose that the dynamometer as employed by Creswell et al. (2016) can achieve the best of both worlds by providing an embodied continuous measurement of progress on the problem while also capturing the sudden and ineffable moment of insight.

The New Statistics

The reader will notice a change in statistical reporting from the previous chapters to those that follow, particularly Chapter 3. Chapter 1 and 2 rely on traditional null hypothesis testing (NHT), and therefore report the full gamut of statistics that are recommended in most psychology textbooks. However, as most readers will know, NHT is receiving severe and growing criticism. P-values are often misinterpreted, they produce arbitrary dichotomies, ignore the size of an effect and therefore its meaningfulness, and are extremely volatile when the sample is not sufficiently powered. Geoff Cumming (2004) provides a summary of these arguments, and also an alternative that does not require any new statistical training, known as *estimation statistics*. According to this new approach, it is recommended that one reports (and particularly interprets) effect sizes and confidence intervals, while also emphasising the importance of prespecification and ideally preregistration, and the value of figures that illustrate confidence intervals. Focusing on effect sizes and confidence intervals circumvent the dichotomous thinking involved with NHT (among a host of other issues discussed at length in Cumming, 2004), and have recently been shown to lead to better statistical inferences in readers (Coulson, Healey, Fidler, & Cumming, 2010). Chapter 3 therefore reports only estimation statistics, and all experiments in the following chapters are preregistered and fully prespecified on the Open Science Framework.

Chapter 3

Getting a grip on insight: An embodied measure of Aha! and metacognition during problem solving

Preface

This Chapter is preregistered and fully prespecified on the Open Science Framework: https://osf.io/p6gqe, and is currently under review for publication. The majority of the work is my own, with Daniel Ingledew contributing 20% to the experimental design and 100% to data collection. Jason Tangen contributed 20% to the experimental design and 10% to the writing.

Laukkonen, R., Ingledew, D., Tangen, J. (2018). Getting a grip on insight: An embodied measure of Aha! and metacognition during problem solving. *Manuscript under review*. doi: 10.17605/OSF.IO/FYHWB

Abstract

A challenge unique to psychology is objectively capturing ephemeral subjective states during controlled experiments. Large bodies of literature use metacognitive probes and self-reports in order to measure states of knowing, perceived progress, as well as the onset of phenomenologies such as surprise or insight. Here we evaluate the usefulness of a visceral measure—the dynamometer—in a problem solving context to detect feelings of progress and insight experiences. The continuous measure of hand grip strength provides multiple data points per second and effectively captures the onset of insight experiences in real-time, and maps onto other measures showing convergent validity. Our results highlight the importance of viewing metacognitions during problem solving and insight moments as dissociable events that show different behavioral outcomes. We also found evidence that the participants were embodying the intensity of the insight experience, despite not being instructed to do so. The dynamometer may be a useful tool in any context where metacognitions are monitored continuously, and is particularly well suited for research in problem solving and insight.

Introduction

Translating feelings into words is a demanding and fallible process. The challenge snowballs as the task increases in complexity and the phenomenological states are faster and more unpredictable where more demand is placed on the individual to simultaneously complete the task and make her metacognitions known. The problem is exacerbated further because the mere act of verbalizing can be sufficient to disrupt performance and memory (Brown, Brandimonte, Wickham, Bosco, & Schooler, 2014; Schooler, Ohlsson, & Brooks, 1993; Schooler & Engstler-Schooler, 1990). In one such example, Schooler et al., (1993) found that verbalizing strategies interfered with insight problem solving across four experiments. They argued that the verbalization was disrupting non-reportable processes relevant to finding a solution. Verbalizing may also reduce the quality of subjective reports by disrupting the ability to access states of feeling by distracting individuals from their present phenomenology (Schooler, Ariely, & Loewenstein, 2003; Lieberman et al., 2007).

Researchers have made efforts to measure metacognitive progress and insight experiences in problem solving for nearly half a century, relying primarily on self-reports, feelings-of-knowing, and feelings-of-warmth (Metcalfe, 1986; Metcalfe & Wiebe, 1987; Bowden & Jung-Beeman, 2007; Hedne, Norman, & Metcalfe, 2016; Laukkonen & Tangen, 2017). Laukkonen and Tangen (2018) recently critiqued existing measures of perceived problem solving progress and insight experiences, proposing a visceral alternative in the dynamometer—a continuous measure of hand grip strength. Creswell, Layette, Schooler, Wright, and Pacilio (2016) used the handheld dynamometer for measuring hunger because they argued that the device's non-verbal nature makes it less subject to the limitations of language and less likely to interfere with other task demands. The authors found that the dynamometer was a better predictor of actual eating behavior than verbal reports. They also observed 'verbal overshadowing'; if participants verbalised hunger *and* used the dynamometer, the dynamometer was no longer predictive of eating behavior. Creswell et al. (2016) argue that the participants were "losing touch" of their feelings due to the concurrent verbalising, potentially explaining why the dynamometer was a better predictor than self-reports. It may be that the problem solving domain—and particularly research on the subjective insight experience—could likewise benefit from a more visceral measure. Below we briefly review some of the key limitations of existing measures of insight and problem solving and describe how the dynamometer might be a productive alternative.

Feelings of Warmth

The classical way to measure feelings of progress and insight moments is feelings-of-knowing or feelings-of-warmth (Metcalfe, 1986; Metcalfe & Wiebe, 1987). The measure assumes that humans can have some metacognitive sense of how they're progressing during problem solving. The authors chose 'warmth' as an intuitive spectrum of progress, where cold indicates that the participant is far away from the solution and hot indicates that they feel close to the solution. While solving the problem, a participant can be occasionally prompted to make a warmth rating. Perceived progress on the problem can then be estimated by warmth ratings over time. Sudden and unexpected solutions—i.e., insight moments—can also be inferred. If a participant feels that they're not making any progress and then a solution appears, it must have occurred to her 'suddenly and unexpectedly' (for example, shifting from a cold state to a solution state in a matter of seconds). Metcalfe and Wiebe (1987) compiled problems that had previously been used to elicit insights (termed insight problems) and another set that was previously categorised as multi-step problems. The expectation was that so-called insight problems would elicit more sudden transitions from cold states to solution states than the multi-step problems that ought to show more gradual warmth ratings preceding the solution. The authors found support for their hypothesis, and recommended that insight "…be defined in terms of the antecedent phenomenology that may be monitored by metacognitive assessments by the subject." Although the warmth measure was an important contribution and one of the first objective demonstrations of the insight phenomenon, there are limitations both practically and theoretically (Laukkonen & Tangen, 2018).

First, insight moments have many affective qualities including pleasure, relief, a sense of certainty, and surprise (Gick & Lockhart, 1995; Danek & Wiley, 2017; Webb, Little, & Cropper, 2016). This ‘Aha! Experience’ is not captured by the warmth patterns. Second, gradual warmth patterns do not preclude the presence of an insight experience because progress on a problem can be illusory. A participant can feel like they’re making progress on a problem and then experience a sudden and unexpected solution to the problem, so long as the perceived progress was unrelated to the final solution. Laukkonen and Tangen (2018) found that sudden transitions in warmth ratings were more likely to be self-reported as insight moments, as one would expect. However, when participants reported gradual warmth ratings, then there was a 50% chance that a participant would nevertheless report experiencing an insight moment, suggesting that gradual warmth ratings have no bearing on whether or not an insight moment occurred. This pattern of results may indicate that the warmth measure is only capturing insights when participants are stuck, but not when they’re working on a problem from the wrong perspective (Ohlsson, 1984). Laukkonen and Tangen (2018) also found that the overall convergence between self-reports of insight and those indicated by warmth ratings was low, suggesting that the subjective experience of participants in retrospect does not consistently reflect participants’ real-time warmth ratings.

A few methodological difficulties with the warmth measure are also worth mentioning. In previous research, participants provide no more than one data point every ten or fifteen seconds (Chein et al., 2010; Metcalfe & Wiebe, 1987; Laukkonen & Tangen, 2017), which is problematic because insights are sudden and immediate, so even ten seconds provides a meaningful window to experience progress on a problem. Put differently, a ‘sudden’ warmth pattern cannot rule out that a participant spent the preceding ten seconds aware that they were about to find the solution. Many problems can also be solved very quickly, and without at least two ratings it is not possible to infer what progress (if any) was experienced, meaning that several data points are unusable.

Self Report

Aside from the warmth measure, the most popular contemporary measure of insight is self-report, mostly because it's easier to administer, it captures the affective qualities of the insight experience, and it's more amenable to neuroimaging (Bowden & Jung-Beeman, 2007). One weakness of the self-report measure is that it's retrospective. In a typical experiment, a participant solves a problem, and once they provide a solution, are asked whether or not an insight occurred. Inevitably, the participant has an opportunity to reflect before answering, which could reduce the validity of the report due to a lapse in attention, poor memory, or other decision biases. Retrospective self-reports are particularly problematic for experiments interested in comparing insight phenomenology to other behavioral or metacognitive outcomes. For instance, a recent finding is that when insight moments occur—particularly with creative problems—the solution is more likely to be correct than cases where no insight occurred (Danek et al., 2014; Danek & Wiley, 2017; Hedne, Norman, & Metcalfe, 2016; Salvi, Bricolo, Kounios, Bowden, & Beeman, 2016; Webb et al., 2016). With retrospective self-reports, however, participants may simply be choosing to report insight experiences in cases where they are more confident in their answers, rather than reporting on their subjective experience. In other words, a real-time measure of insight experiences means less risk of interference from secondary metacognitions. An ideal measure would capture perceived progress continuously without interfering with the task, and capture the sudden onset of a solution, as well as the Aha! experience in real-time. To this end, the dynamometer is a promising candidate.

The Experiment

In the following experiment, we instruct participants to report how close they are to a solution by gently squeezing a dynamometer, where a stronger squeeze represents greater perceived progress. They are also instructed to give the dynamometer a full strength squeeze if they find the solution and experience an Aha! moment, or to release their grip if they reach the solution without an Aha! moment.

The dynamometer has the potential to prevent verbal overshadowing effects, capture real-time insight experiences, and provide a continuous measure of problem-solving progress. All of the following hypotheses were preregistered on the Open Science Framework (OSF: https://osf.io/p6gqe).

Our first aim is to demonstrate that the dynamometer is able to distinguish between different problem types in line with previous work. We expect that analytic multi-step problems elicit more gradual warmth ratings where participants are better able to predict solutions to problems. On the other hand, we expect that classical insight problems and remote associates—which tend to involve unconscious associative processing and elicit insight moments (Hattori, Sloman, & Orita, 2013)—would show more sudden transitions from cold states to solution states indicating more unexpected solutions (Metcalfe & Wiebe, 1987). Similarly, we expected that analytic problems would elicit the fewest insight experiences, followed by compound remote associates, and insight problems would elicit the most. We expect that self-reported insight moments will have a moderate to strong correlation with spikes in the dynamometer (i.e., full strength squeezes), and show the same pattern of results across the problem types. We also expect that both self-reported Aha! moments and the dynamometer spikes will predict more accurate solutions and higher confidence in the solution (Salvi et al., 2016; Webb et al., 2016; Danek & Wiley, 2017; Hedne et al., 2016). More detailed predictions can be found in the preregistration.

Method

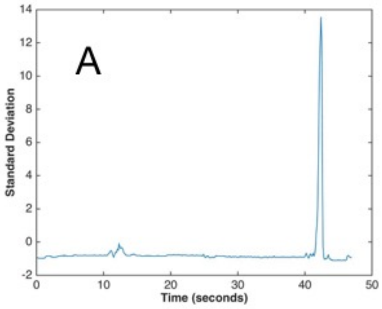
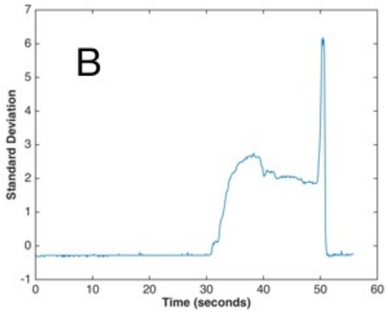
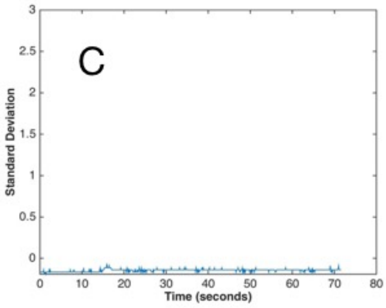
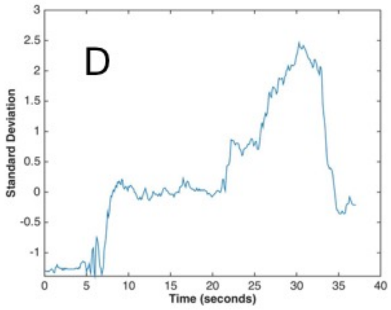
Design and Materials

Sixty participants were tested in exchange for course credit at The University of Queensland, which is a sufficient sample to detect medium effect sizes observed in similar research (e.g., Salvi et al., 2016). Some of the problems involved language cues or cultural references so participation was restricted to native English speakers. All participants were presented with the same thirty problems encompassing 10 insight problems, 10 analytic problems, and 10 compound remote associates (CRA). The problems were printed on 30 individual cards and presented to participants randomly, one-by-one. They were given a maximum of 90 seconds to attempt each problem. All materials, the experimental program, and finer details for replication can be accessed on the OSF. The dynamometer was the same model used by Creswell et al., (2016), developed by Vernier. The device records grip strength 10 times per second and displays the data graphically as a function of time and Newtons (N) of pressure. The device has an accuracy of ±0.6 N and an operating range between 0 and 600 N. The data are recorded on a computer using Logger Lite 1.9.1, and the ratings were recorded using the free open source program LiveCode Community 7.0.6 on another computer. Participants were asked to report whether an Aha! moment occurred (yes or no), and if yes, how intense the experience was on a 12-point scale where 1 is mild and 12 is intense. They also reported confidence in the solution on a 12-point scale where 1 is 'not at all confident' and 12 is "very confident." Participants also completed the Mindful Attention Awareness Scale (Brown & Ryan, 2003), the results of which will be reported elsewhere.

Procedure

All participants were provided with the same written instructions prior to the experiment including a description of the Aha! experience (see OSF for the script). Each participant was given examples of the different problems and was then shown how to use the dynamometer to express how close they felt to the solution. They were told that a loose grip on the dynamometer indicates that they feel far from solving the problem, and a tighter grip indicates that they feel closer to solving it. If a solution to the problem appears in mind accompanied by an Aha! experience, they were told to briefly squeeze the device as hard as possible. If no Aha! moment occurred when they discovered the solution, they were told to simply release their grip on the device. Participants practiced using the device and were shown how changes in grip strength translate to the output graph, and to simulate a full strength squeeze (i.e., an Aha! moment). Problems were then presented to each participant in a random order while they used the dynamometer to indicate their feelings of closeness. After a solution was found, they were asked—in a counterbalanced order—whether an Aha! moment occurred, the intensity of the Aha! moment (if one did occur), and how confident they were in the solution. A contingency matrix representing the four possible combinations of perceived problem solving progress and insight experiences is illustrated in Table 1.

Table 1. Four possible combinations of perceived problem solving progress and insight that can be detected by the dynamometer.

	No Perceived Progress	**Perceived Progress**
Insight		
No Insight		

Note. Traditional warmth measures only detect patterns A and D, where patterns B and C would be misclassified as non-insight or insight, respectively. Spikes greater than 6 standard deviations above the mean are classified as insight moments.

Results

Descriptives and Preprocessing

Since no participants were removed, we received a total of 1800 responses to problems (60 participants and 30 problems per participant), alongside dynamometer patterns. A total of 1278 of the data points were used for analysis because participants rated 13 of the problems as familiar, and participants failed to provide an answer before timing out in 509 cases. The dynamometer data were standardised in order to detect spikes (i.e., full strength squeezes representing insight moments). Informed by a visual analysis of all trials by three independent raters (α = .96), we chose 6 SD above the mean as an appropriate cut off to capture spikes during problem solving. In the preregistration, we planned to use differential warmth (i.e., the difference between the first warmth rating and the last warmth rating) to measure perceived progress. However, we decided against this method because the dynamometer spikes recorded at the end of some trials would directly bias the analysis. Instead, the independent raters also coded the dynamometer patterns according to the size of the slope prior to solution or spike. They blindly rated the slope of every dynamometer pattern as 0 (no slope), 1 (some slope), or 2 (steep slope), again showing high inter-rater reliability, α = .88. The three ratings for each graph were averaged so that each trial had a single slope value ranging from 0 to 2. Since there is no generally accepted objective criterion for evaluating progress prior to solution (particularly with the dynamometer), we see the above method as the safest first pass. Data are available in the preregistration for further analysis. The hypotheses remained the same.

Insight Moments

We began by evaluating self-reported insights and dynamometer spikes using Pearson's correlation coefficient, and found that spikes greater than 6 SD above the mean predicted self reported insight experiences (R^2 = .399). Next we compared the degree of insights reported by the two methods across the different problem conditions. Figure 1 illustrates the incidence of self-reported insight moments, insight intensity, and dynamometer spikes for analytic, insight, and CRA problems. The figure shows that the pattern of insight moments is similar for self-report (top) and for the dynamometer spikes (bottom). Both methods found that analytic problems elicit the fewest insight moments, followed by insight problems, and then CRA problems, providing evidence of convergent validity between the dynamometer and self-reported insights across the problem types. Effect sizes are as follows for self-reported insight moments: Analytic problems showed more insight experiences than CRA problems, $d = 1.57$. CRA problems showed more insight moments than insight problems, $d = .663$. And insight problems showed more insight moments than analytic problems, $d = .926$. For the Dynamometer spikes, there were more spikes for analytic than CRA problems, $d = .9$, more spikes for CRA than insight, $d = .664$, and more for insight than analytic problems, $d = .316$.

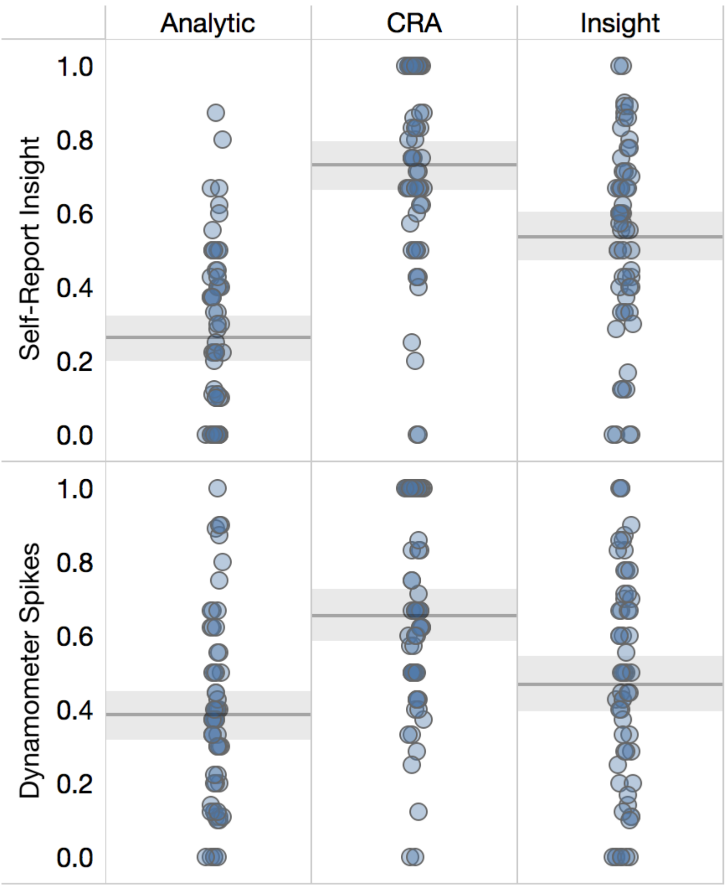


Figure 1. Proportion of self-reported insights for three problem types (top), and the proportion of trials containing spikes greater than 6 SD above the mean (bottom), also for the three problem types. Blue circles represent individual participants and darker shading represents a greater density of participants. Error bars represent 95% confidence intervals.

Insight Moments and Accuracy

Next, we compared the extent to which self-reported insights and dynamometer spikes predicted performance. As in previous research, we found that self-reported insight experiences predicted greater confidence, d = 1.87, and more accurate responses overall, d = 1.64. The dynamometer spikes showed the same pattern of results for both confidence, d = 1.62, and accuracy, d = 1.21, with similarly large effect sizes. The results indicate further convergent validity. Next, we compared the insight-accuracy relationship separately across the three problem types. We found that the relationship between insight and accuracy was only positive for the insight, *d* = 1.2 and CRA problems, *d* = 1.9, but not analytic problems, *d* = 0. The correlation between self-reported insights and accuracy for the three problem types is illustrated in Figure 2 below. The figure shows an interaction where insight experiences show a small but negative correlation with accuracy for analytic problems, and a positive correlation with accuracy for insight and CRA problems.

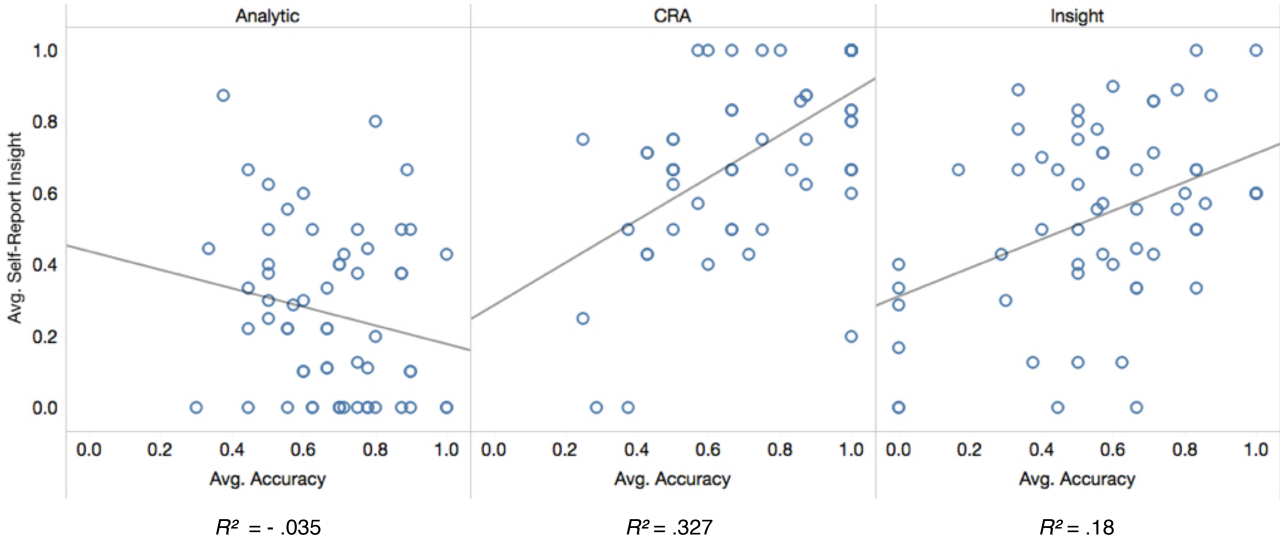


Figure 2. Correlation plots for mean accuracy and self-reported insights for the three problem types, from left to right: Analytic problems, CRA problems, and Insight problems.

With regard to the insight and accuracy relationship, the dynamometer again showed the same pattern of results. Spikes showed more accurate responses with medium to large effects sizes for insight (*d* = .6) and CRA (*d* = .95) problems, but a much smaller effect size for analytic problems (*d* = .1). It appears that wherever insights are concerned, self-reports and objective spikes in the dynamometer readings confer similar results. It is particularly promising that the insight-accuracy relationship was demonstrated without the limitations of self-report, by using a real-time objective measure.

Dynamometer Ratings

Previous research suggests that participants ought to be less able to predict solutions that appear in mind for insight problems and CRAs, whereas solutions to analytic problems follow from more gradual warmth patterns. The size of the dynamometer slope preceding solutions was evaluated for the three problem types. The pattern of results—illustrated in Figure 3—shows that analytic problems had a larger slope (i.e., greater perceived progress prior to solution) than CRA problems ($d = .687$) and insight problems ($d = .464$). Insight problems also showed greater perceived progress than CRA problems ($d = .455$). The results are in line with Metcalfe and Wiebe (1987), and underscore the different problem solving processes—at least with regard to metacognitions—associated with the different problem types. Compared to CRAs, it's likely that the insight problems conferred greater perceived progress because they are essentially verbal riddles. Hence, participants may have reported perceived progress simply while reading the problem.

Figure 3. Average slope size by problem type. A greater slope in the dynamometer pattern indicates that the participant experienced more metacognitive progress towards solution (collapsing over correct and incorrect solutions). Solutions to analytic problems tended to follow from greater perceived progress compared to insight and CRA problems. Shading represents 95% confidence intervals.

Exploratory Analyses

We also conducted some exploratory analyses on the relationship between average perceived progress and problem solving accuracy. Metcalfe and Wiebe (1987) found that perceived progress (feelings of warmth) was predictive of correct solutions for analytic problems, but not insight problems. We decided to explore this possibility in our data and conducted correlations between slope size and accuracy for the three problem types. We expected that slope size would predict accuracy for analytic problems, but not insight and CRA problems. The results are illustrated in Figure 4.

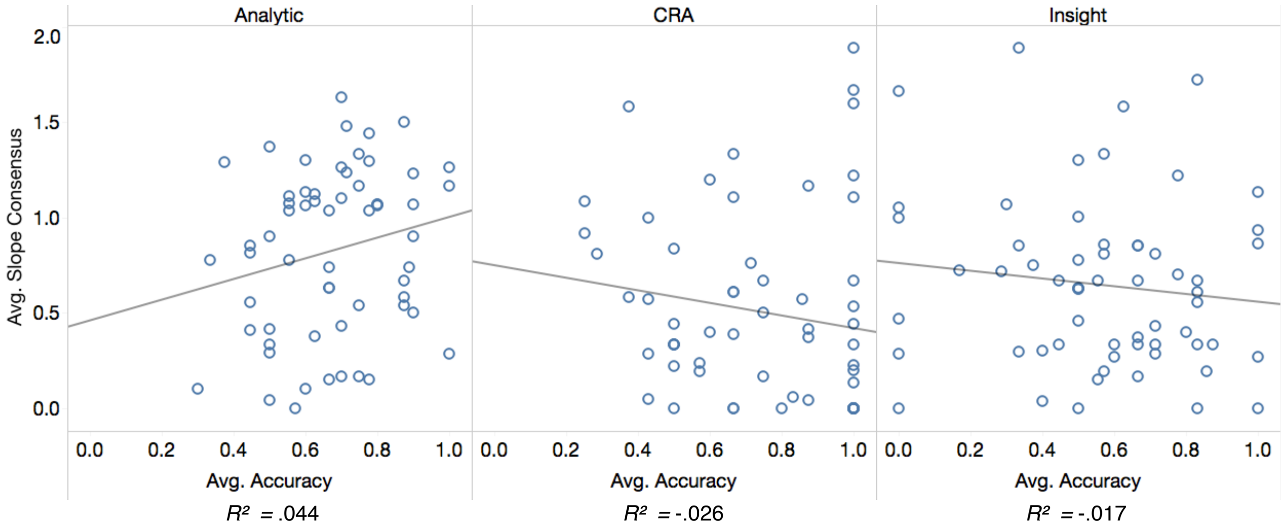


Figure 4. Correlations between slope size and accuracy for the three problem types, from left to right: Analytic problems, CRA problems, and Insight problems.

The data indicate that the correlations between the size of the slope and accuracy are generally weak. It appears that greater perceived progress is marginally predictive of solutions for analytic problems, and is marginally negative for the CRA and insight problems. Given the embodied nature of the dynamometer measure, we considered the possibility that the participants naturally squeezed the dynamometer harder when more intense insight experiences occurred. We therefore correlated the maximum dynamometer score with the self-reported intensity of the experience (R^2 = .141). The positive correlation indicates that when participants reported an insight moment, they naturally squeezed the dynamometer more tightly when the insight was more intense. This prompted us to also evaluate whether the maximum score also predicted how accurate the insight moment was. We were surprised to find that it did (R^2 = .029) although the variance explained was minimal. The results provide some preliminary evidence that the strength of the squeeze during an insight experience—independent of instruction—predicted the accuracy of the solution.

Discussion

In this study, we tested a novel method for measuring perceived problem solving progress and detecting insight experiences, in real-time, using a dynamometer. We compared the device to existing measures of insight and investigated patterns under different problem conditions. In all cases we found evidence of convergent validity. When the dynamometer showed a 'spike' pattern indicative of insight, participants tended to also report that they experienced an insight moment. The dynamometer also mirrored the pattern of results expected for different problem types, where solutions to analytic or multistep problems tended to be metacognitively predictable, and solutions to insight problems and CRAs were subjectively more sudden and unpredictable. To the best of our knowledge, this is the first demonstration that CRA problems tend to be solved in a metacognitively sudden manner analogous to insight problems, and it is the first to support the pivotal results of Metcalfe and Wiebe (1987) using a novel medium.

We found that both spikes in the dynamometer and self reported insight experiences predicted substantially more accurate responses and greater confidence in solutions, specifically for the creative problems. This insight-accuracy relationship is in line with previous work, but includes an important extension (Salvi, Bricolo, Kounios, Bowden, & Beeman, 2016; Webb et al., 2016; Danek & Wiley, 2017; Hedne, Norman, & Metcalfe, 2016). The dynamometer captures the phenomenology of insight in real-time, which makes it more probable that the participants are reporting on their feelings at the moment of solution, as opposed to relying on other secondary metacognitions, such as confidence (Laukkonen & Tangen, 2018). The results indicate that the feelings that arise at the moment of solution are sufficient to predict an accurate response, presumably without any deliberate reflection.

The data also highlight a compelling interaction regarding the metacognitions that predict solutions for different problems. The insight experience predicted accurate responses for CRA and insight problems, while showing a negative correlation for the analytic problems. On the other hand, perceived problem solving progress—or feelings of warmth—showed the opposite pattern of results: greater perceived progress predicted accurate solutions for analytic problems, but trended in the opposite direction for insight and CRA problems. Taken together, the results indicate that where insight phenomenology is predictive of accurate responses, feelings of progress are not. And vice versa, where feelings of progress are predictive of accuracy, insight moments are not. There is potentially a straightforward explanation for this result. Analytic problems usually require that an individual strategically and consciously solve a problem, often demanding greater working memory than insight problems (Webb & Gilhooly, 2018). On the other hand, the important processes for solving insight and CRA problems often occur implicitly in the form of restructuring or complex associative processing (Ohlsson, 1984; Bowden, 1997). It therefore makes sense that perceived progress is not predictive if much of the important processes are hidden from awareness—it's very hard to tell how one is progressing if the problem is being solved below awareness. Conversely, the phenomenology of insight has no informational value if the problem is solved consciously and analytically (Laukkonen, et al., 2018).

There are also multiple practical and conceptual advantages to using a dynamometer to capture insight moments, particularly if one is also interested in measuring perceived progress, or 'feelings of warmth.' First, the dynamometer is continuous and substantially more sensitive than existing measures. Second, the device can be used without significantly impairing task performance, and may help to mitigate verbal overshadowing effects (Brown et al., 2014; Creswell et al., 2016; Schooler & Engstler-Schooler, 1990). Third, when a traditional warmth measure is used, substantial data (up to 70% of trials, Laukkonen & Tangen, 2018) are unusable because participants often solve the problem too quickly. With the dynamometer, no trials were removed. Fourth, the dynamometer can capture novel interactions between experiences of insight and preceding metacognitions (see Table 1).

The opportunity to capture different interactions between perceived progress and insight also affords a paradigm for answering novel questions. For example, what are the consequences or processes involved with insights that follow from gradual warmth patterns relative to insights that follow from sudden warmth patterns? One possibility is that gradual warmth patterns leading to insight are examples of problem restructuring, or representational change (Ohlsson, 1984, 2011). A participant perceives herself as making progress on a problem using the incorrect problem solving representation—and therefore provides gradual warmth ratings—before suddenly arriving at the correct representation and discovering the solution in an insight moment. Such cases may have unique cognitive or behavioral consequences relative to insight solutions that follow from an impasse (i.e., a more sudden warmth pattern).

We also found some evidence indicating that participants were genuinely communicating their phenomenology at the moment of solution. The participants naturally squeezed the dynamometer harder for more intense insights despite not being instructed to do so. It may be that elements of the Aha! experience are unconsciously embodied by using a visceral measure, which may be one reason that the dynamometer was a better predictor of eating behavior than self-report in Creswell et al., (2016). By instructing participants to embody the intensity of the insight experience through the dynamometer in future research, it may be possible to evaluate whether the dynamometer can outperform self-report in predicting problem solving performance.

One divergence from previous research is worth mentioning. We found that, compared to traditional insight problems, CRA problems elicited more insights and had a larger effect size for the insight-accuracy relationship. This finding is contrary to Webb et al., (2017) who found the opposite result. Individual problems vary in their tendency to elicit insights (Webb, Little, & Cropper, 2017), therefore the result is likely due to the specific problems chosen in the different experiments. When compared to existing normative data, it appears we specifically chose CRA problems that were more effective at eliciting insights than usual (Webb et al., 2017).

It is worthwhile to consider possible challenges or limitations in using the dynamometer. First, while we provided participants with a short practice session using the dynamometer, in some cases participants said that they forgot to squeeze the device. The quality of the data will certainly improve if participants are provided with more practice. While our impression is that the dynamometer does not substantially interfere with the primary task, it is inevitable that it divides attention to some degree. A comparison between problem solving performance in a condition with the dynamometer, and without, may be productive. It's likely that dual-task effects will also be attenuated with further practice using the tool, as the task becomes more automatic. There is also room to improve the statistical methods used to capture insight experiences and perceived progress in the dynamometer. One alternative method for detecting spikes is acceleration, i.e., the rate of change over time. By using a moving average window, dynamometer ratings can be evaluated according to changes in acceleration at any point in the trial, which in turn could be used to infer an insight experience. Since acceleration is a measure of the speed of increase rather than the magnitude of the increase, the method navigates any issues regarding the strength of the participant's grip. With regard to perceived progress, methods used to analyse task-evoked pupil dilation—another highly sensitive continuous measure—could be co-opted for the dynamometer (e.g., Beatty, 1982; Laukkonen & Tangen, 2012).

Conclusion

The dynamometer can be used as a continuous measure of perceived problem solving progress that captures insight experiences in real-time. Aside from being more detailed and objective than existing measures, the dynamometer may also help to answer important theoretical questions regarding the underlying processes of insight experiences. In particular, the device is useful for detecting interactions between insight and preceding metacognitions, and demonstrates an important dissociation between the two. In addition, our results show a strong positive relationship between real-time insight phenomenology and accurate problem solving in CRA and insight problems, without relying on self-report. It was also promising that the dynamometer captured features of the insight experience that the participants were not instructed to communicate, namely the intensity of the phenomenology. We see this study as an initial proof of concept in the problem solving domain, but feel confident that the dynamometer is amenable to research in other domains where task relevant metacognitions are of interest.

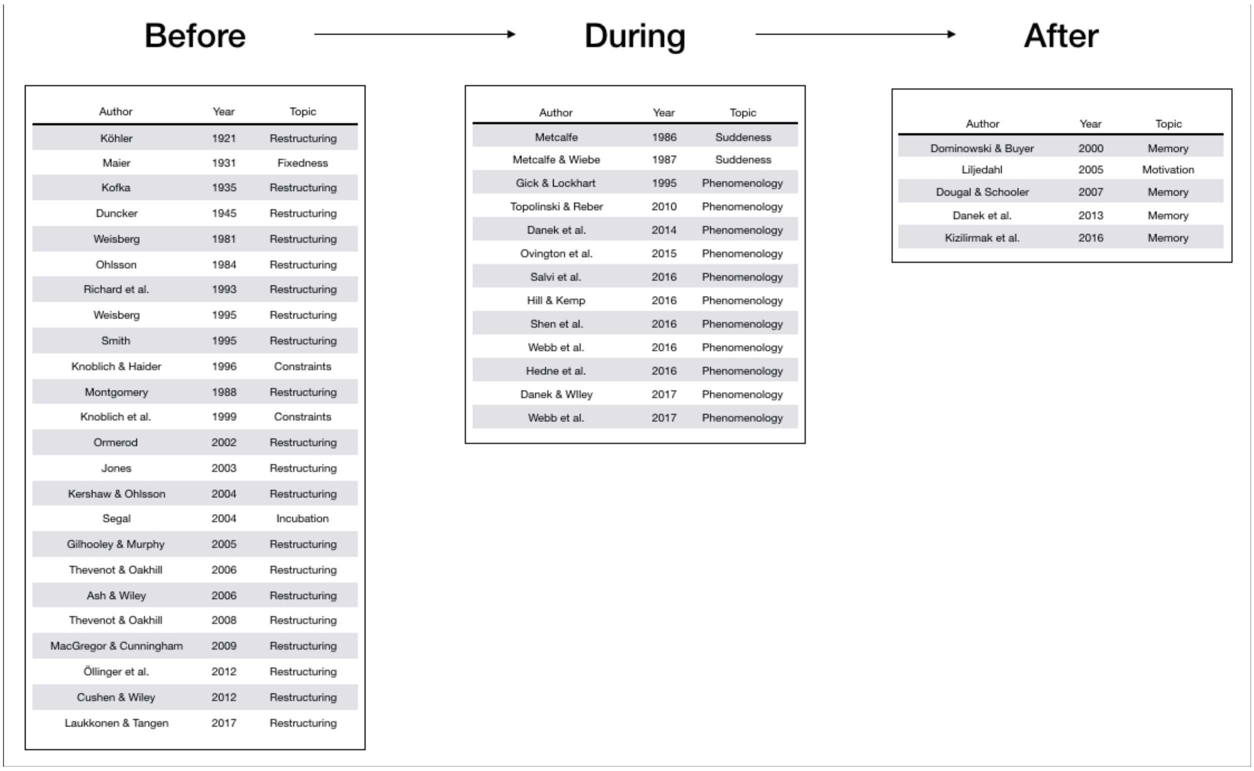
PART 2

Why We Have Insight Experiences

Preface

The focus of each Chapter in this thesis can also be understood in the context of the temporal unfolding of insight. First, there are the cognitive processes that occur *before* insight, which was the focus of Chapter 1. Second, there is the feeling that occurs *during* insight, the measurement of which was discussed in Chapter 2 and 3. Third, there are the behaviours and cognitions that occur *after* an insight experience. Although Part 2 of this thesis draws on research from all three temporal aspects of insight, the empirical contributions particularly relate to this third—and least studied—component. Table 1 below provides an approximate representation of the research that maps onto the different temporal stages of the insight experience. The before column could not be entirely represented (as it would eventually require a separate page), but the during and after columns include all relevant papers that I could find through a google scholar search, as well as inspecting the reference lists of multiple review papers. Clearly, the cognitions that precede insight have historically received the most attention, and there has been a surge of research on the feeling of insight in the last decade. On the other hand, there are only a few papers investigating the effects on cognition or behaviour that follow from insight experiences, and nearly all of them pertain to memory. It's worthwhile noting that experiments looking at problem solving accuracy associated with insight are included in the 'during' column because technically this is a correlation rather than an outcome following insight. Moreover, by attending to all three temporal components, we may begin to see a bigger picture regarding the function of the insight experience.

Table 1. The temporal unfolding of insight and research therein. Papers are categorised based on the focal topic, or the target of the experiments.



Before

Author	Year	Topic
Köhler	1921	Restructuring
Maier	1931	Fixedness
Kofka	1935	Restructuring
Duncker	1945	Restructuring
Weisberg	1981	Restructuring
Ohlsson	1984	Restructuring
Richard et al.	1993	Restructuring
Weisberg	1995	Restructuring
Smith	1995	Restructuring
Knoblich & Haider	1996	Constraints
Montgomery	1988	Restructuring
Knoblich et al.	1999	Constraints
Ormerod	2002	Restructuring
Jones	2003	Restructuring
Kershaw & Ohlsson	2004	Restructuring
Segal	2004	Incubation
Gilhooley & Murphy	2005	Restructuring
Thevenot & Oakhill	2006	Restructuring
Ash & Wiley	2006	Restructuring
Thevenot & Oakhill	2008	Restructuring
MacGregor & Cunningham	2009	Restructuring
Öllinger et al.	2012	Restructuring
Cushen & Wiley	2012	Restructuring
Laukkonen & Tangen	2017	Restructuring

During

Author	Year	Topic
Metcalfe	1986	Suddeness
Metcalfe & Wiebe	1987	Suddeness
Gick & Lockhart	1995	Phenomenology
Topolinski & Reber	2010	Phenomenology
Danek et al.	2014	Phenomenology
Ovington et al.	2015	Phenomenology
Salvi et al.	2016	Phenomenology
Hill & Kemp	2016	Phenomenology
Shen et al.	2016	Phenomenology
Webb et al.	2016	Phenomenology
Hedne et al.	2016	Phenomenology
Danek & WIley	2017	Phenomenology
Webb et al.	2017	Phenomenology

After

Author	Year	Topic
Dominowski & Buyer	2000	Memory
Liljedahl	2005	Motivation
Dougal & Schooler	2007	Memory
Danek et al.	2013	Memory
Kizilirmak et al.	2016	Memory

Introduction

Most aspects of human biology and psychology serve an important adaptive function, and for many features that function is plain to see. Why do we have memory? So that we can learn from the past to improve the future (Suddendorf & Corballis, 2007). Why do we have attention? So that we can focus on the important information (Posner & Petersen, 1990). Why do we have pain and fear? So that we can avoid things that might cause us harm (Broom, 2001). Regarding the more general role of feelings, a number of theoretical accounts have been proposed to answer such 'why' questions (Damasio, 1996; Slovic et al., 2007; Schwarz, 2011). According to feelings-as-information theory, our phenomenology carries important information that helps us to efficiently navigate the world, and even to reason appropriately (Schwarz, 2011). Hunger, for instance, carries information about the organism's nutritional requirements. More subtle feelings like fluency and familiarity also have robust effects on decision-making (Hertwig, Herzog, Schooler, & Reimer, 2008). Fluency—or ease of processing—can be manipulated to persuade participants that a claim is true (Reber & Schwarz, 1999), simply by increasing the contrast between the background and the foreground of typed words, or by adding photographs alongside the claim (Newman et al., 2012). Induced familiarity can trigger false memories (Westerman & Greene, 1996), and reduce the perceived risk of food additives (Song & Schwarz, 2009), and the list goes on (see Loewenstein, Weber, Hsee, & Welch, 2001 for a review of the effects of feeling on decision-making). Despite the evidence that feelings often drive decisions—and over a century of research on the feeling of insight—there has been very little work discussing the potential informational value of insight experiences or its impact in decision-making contexts, and no experimental work (to the best of our knowledge). Filling this lacuna is one aim of the following Chapters.

How might insight experiences impact judgments and decisions? To begin with, it's important to see insight not as the sudden discovery of a correct solution, but instead as a sudden *feeling* that one has discovered a correct solution. In Chapter 1, I outlined some of the compelling analogies between sudden changes in visual perception and the unexpected shifts in understanding that can also occur in problem solving (Laukkonen & Tangen, 2017). This link between vision and insight seems to go even further back than the Gestalt psychologists, in fact it is evident within the etymology of the term: a compound of *in-* and *sight* (Webster, 1913). In-sight is connected to the idea or experience of 'seeing into,' or 'inner sight'. Visual experience has the quality of being direct, and even infallible, akin to knowing the 'truth of the matter'. Insight is ostensibly less concerned with opinion and more concerned with direct perception. Perhaps this is one reason that insight became synonymous with a particular and productive problem solving process, a conception where false insights were technically not possible (Danek & Wiley, 2017). Classical views of insight such as Restructuring (Wertheimer, 1925; Duncker 1945) and Representational Change Theory (Ohlsson, 1984) were essentially mechanisms through which correct solutions were discovered, and hence insight was akin to a direct perception of a true point of view—or a "good Gestalt" (Danek & Wiley, 2017). However, one of the first things one learns as a psychology student is that there is no such thing as direct perception, there is only inferential perception (Ross & Ward, 1995). Optical illusions and cognitive biases illustrate this fact well (Tversky & Kahneman, 1975). What we think of as insight or 'seeing into' is also necessarily an inference that is limited by our biology, our experiences, our assumptions, and our knowledge—no matter how persuasive the phenomenology of the 'seeing'. In other words, insight is not a sudden direct perception of the solution, it is the *sense* of a sudden direct perception of the solution. Understanding insight experiences as inferential is foundational to a functional view of insight.

What then, is the proposed function of the insight experience? We suggest that The role of insight phenomenology is perhaps best understood in the context of heuristics and biases (Tversky & Kahneman, 1975; Whittlesea & Williams, 2001; Slovic et al., 2007; Gigerenzer & Gaissmaier, 2011). In many life situations, it's not practical to analytically review the reasons for and against a new idea or a novel solution to a problem, particularly if it requires immediate action. Therefore, the insight experience may act as a shortcut—a gut feeling—about the quality of an idea that appears in mind, so that quick decisions can be made (recall Wagner Dodge's life-saving insight during the wild fires of Helena National Forest). From the heuristic perspective, insight moments are placed in a much broader decision-making context, where it is a source of information that is relied upon in situations of metacognitive uncertainty to make fast and frugal decisions (Goldstein & Gigerenzer, 2002). Metacognitive uncertainty arises in problem solving because the reasoning that underlies a solution is often not explicitly available. For example, insight experiences can be subliminally primed, and participants are often unable to report—or indeed confabulate—the source of the solution (Maier, 1931; Landrum, 1990; Bowden, 1997; Hattori, Sloman, & Orita, 2013). Insight moments also appear unexpectedly, sometimes while engaged in another task, indicating that implicit processes generated the solution (Ovington et al., 2015; Snyder et al., 2004). The opacity of problem solving processes can make it difficult to evaluate a new solution, and in such cases the feeling of insight is a much more efficient way to appraise a new idea that appears in consciousness (Goldstein & Gigerenzer, 2002). We discuss this view in detail in the following Chapter (Chapter 4).

There are two central empirical claims that arise out of Chapter 4 and the above conjecture. The first is that the feeling of insight has informational value of some sort, in a similar vein as familiarity or fluency, and ultimately sensations like fear and hunger (Schwarz, 2011). One way to test this claim, is to evaluate the extent to which insight experiences predict the accuracy of the solutions that they accompany. As we've already seen in Chapter 3, the positive relationship between insight and accuracy appears to be fairly robust at least in creative problem solving (Salvi et al., 2016; Webb et al., 2016; Danek & Wiley, 2017; Hedne, Norman, & Metcalfe, 2016). In Chapter 5, we discuss some of the limitations of this work, and how the dynamometer may be a valuable tool for assessing whether feelings of insight are genuinely predicting the accuracy of responses (and not some other third factor such as confidence). We were also not satisfied by the fact that the positive relationship between insight and accuracy was only observed in toy laboratory problems. Therefore, we decided to conduct an experiment using high fidelity stimuli that are more representative of the kinds of tasks people encounter in everyday life. By capturing insight experiences in real-time using the dynamometer, and by evaluating the insight and accuracy relationship in a more typical context, we felt that we could be confident about our conclusions regarding the informational value of insight.

The second empirical claim is that the insight experience impacts decision-making. At least hypothetically, feelings of insight could predict accurate responses—and therefore appear to have informational value—but not influence behaviour in any meaningful way. Such a scenario would be surprising given what we know about the role of feeling in decision-making (Loewenstein et al., 2001; Slovic et al., 2007; Schwarz, 2011), but it is an empirical question nevertheless. To address this claim, we devised an experiment where we artificially elicited feelings of insight at the same time as presenting participants with 'facts' that were either true or false. We expected that, since insight experiences evoke a sense of confidence about a problem solving solution, they might also evoke a sense of confidence about an unrelated fact. Specifically, we predicted that facts that are accompanied by an artificially induced insight would be judged as more true than facts not accompanied by the insight. The details of this experiment are discussed in Experiment 3 of Chapter 5.

Chapter 4

The Eureka Heuristic: Relying on insight to appraise the quality of ideas

Preface

This Chapter integrates the ideas and literature that form the basis for the empirical investigations that follow. In the paper, I intentionally focus on reviewing a breadth of research that I see as relevant to the new ideas, in order to avoid an enormous and overly mechanical literature review. Unfortunately, the trade-off is that there is a less extensive discussion of previous theory on insight. This more succinct version of the Eureka Heuristic was partly in response to reviewers who recommended that it be made shorter. A strength of the paper is that it nevertheless results in specific testable predictions, and a number of exciting paths for future work.

The majority of the work is my own. Jason Tangen and Jonathan Schooler jointly contributed approximately 15% to the written work.

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Abstract

Perhaps it is no accident that "Eureka" moments accompany some of humanity's most important discoveries in science, medicine, and art. Here we describe an account where insight experiences play an adaptive role, by aiding humans to choose the right solution to a problem. Experiments reveal that feelings of insight—without any conscious verification or deliberation—predict confidence and accurate solutions to problems. There is also evidence that humans self interpret their Aha! experiences. One possibility is that humans use insight phenomenology heuristically in order to appraise new ideas that appear in consciousness. This functional view of insight speaks to a number of open questions in the literature: Why do insight experiences occur in certain contexts but not others? Why do insight experiences predict confidence and objective performance in some contexts but not others? Why are some insights more intense than others? What leads to false insights? We also propose the *insight fallacy* to describe situations where a person incorrectly concludes that a solution or idea must be true solely based on the fact that it was accompanied by an insight experience.

Introduction

In 2012, while waiting to go to a concert, mathematician Yitang Zhang discovered the solution to the twin prime problem. He said that he "…immediately knew that it would work," and then it took several months to verify his solution (Nisbett, 2015). The mathematician Jacques Hadamard said that, "on being very abruptly awakened by an external noise, a solution long searched for appeared to me at once without the slightest instant of reflection on my part." The Nobel laureate Roger Kornberg tells a more cautionary tale. When asked about his Eureka moments, he responded, "there haven't been very many, so it's really easy to answer that question. There have been a lot of false Eureka moments. There have been so many times when I thought, 'oh of course, it all comes together, now I understand.' …and of course it was wrong."

Each of the above scientists arrived at a sudden and unexpected solution to a problem, and they all felt an immediate sense of certainty about the quality of their idea— regardless of its eventual veracity. This same insight experience is regularly observed in the laboratory albeit on a smaller scale. Participants are more confident about solutions that are accompanied by insight or 'Aha!' experiences (Danek et al., 2014; Danek & Wiley, 2017; Webb et al., 2016), and insight experiences can strike suddenly and unexpectedly (Metcalfe & Wiebe, 1987), even while engaged in another task (Ovington et al., 2015; Snyder, Mitchell, & Ellwood, 2004). The unexpectedness of insight solutions also indicates that it was a product of processing that occurred below awareness. Implicit processing—however momentary—preceding insight solutions is also corroborated by numerous experiments.

Maier (1931) famously found that participants suddenly discovered a solution to his 'two-string' problem shortly after he provided a hint that the participants claimed not to notice (an effect replicated by, Landrum, 1990). Bowden (1997) found that subliminally priming the solution to an anagram led to more reported insight experiences, without participants knowing that they were being primed. Hattori, Sloman, and Orita (2013) also found that subliminal primes improved insight problem solving across three experiments, in some cases leading to a fivefold improvement.

Since the problem solving process—and therefore the reasoning that underlies the solution—is not directly available for introspection, what is the source of such an immediate sense of certainty? We propose that the sudden insight phenomenology plays a functional role as an intuition about the quality of an idea. The processing that precedes an insight solution may draw on a vast and complex network of information, experiences, and beliefs that are difficult and inefficient to consciously appraise. Time pressures also discourage deliberate evaluation. When a solution ultimately emerges, one may not have the luxury of weighing up its components before acting. Therefore it is often less important to know 'why you know,' and is abundantly more efficient to use feeling to signal that a viable solution has been found (Goldstein & Gigerenzer, 2002). It is plausible that the feeling of insight serves as a signal that a promising solution has been discovered through unconscious processes, and that humans rely on insight as a fast and frugal substitute for an effortful and time-consuming review of the evidence. In this paper, we describe how this view of insight experiences is consistent with the evidence, and affords many novel directions for future research.

As a substitute for analytic processing, the insight experience certainly appears to be functional: solutions accompanied by insight experiences are more likely to be correct than non-insight solutions (Danek et al., 2014; Danek & Wiley, 2017; Hedne et al., 2016; Salvi et al., 2016; Webb, Little, & Cropper; 2016). In one of the original demonstrations of this effect, Salvi et al. (2016) presented participants with a range of different problems across four experiments, including compound remote associates, rebus puzzles, anagrams, and visually degraded images. Across all four experiments and each of the problem types, solutions associated with insight experiences tended to be correct more often than those not accompanied by insight. The same basic result is replicated in at least five studies with large effect sizes (Danek et al., 2014; Danek & Wiley, 2017; Hedne et al., 2016; Salvi et al., 2016; Webb, Little, & Cropper; 2016). How can insight phenomenology predict accurate solutions to problems?

Part of the answer to the above question may be found in models where feelings and bodily sensations are presumed to carry informational value based on learned associations and past experiences. Such theories include, the somatic marker hypothesis (Damasio et al., 1994), feelings-as-information theory (Schwarz, 2011), the affect heuristic (Slovic et al., 2007), and possibly others. From the point of view of feelings-as-information theory and the somatic marker hypothesis, the insight experience may be seen as a marker that carries information about the quality of a new solution appearing in mind. If insight phenomenology has informational value then it ought to be associated with more accurate solutions on average. However, what information is the insight experience drawing on?

It is common knowledge that an expert can have intuitive expertise about their domain, for example the next best move on a chess board (Ericsson & Charness, 1994; Kahneman, 2015). Since humans often do not have direct access to their own problem solving processes, it's plausible that they also have intuitions regarding their own ideas. Expert intuitions are often fast and feel automatic, and so too an intuition about the quality of an idea might occur immediately as the idea 'pops into mind'. Thus in the same way that the chess expert draws on her expertise to make a move—often without any conscious effort—the problem solver can evaluate a solution automatically based on her own expertise regarding the problem domain. This cognitive process explains the positive relationship between insight and veracity. As long as a person's experiences are reliable, the greater the consistency between the solution and what is known, the more likely the solution is correct. An accuracy advantage for insight would also be constrained to situations where some unconscious processing is involved. If there is no unconscious processing, then there is no intuition to be had. Likewise, if a novice has no experiences in a domain, then her intuitions will be of little use. A schematic of the *Eureka Heuristic* model is provided in Figure 1.

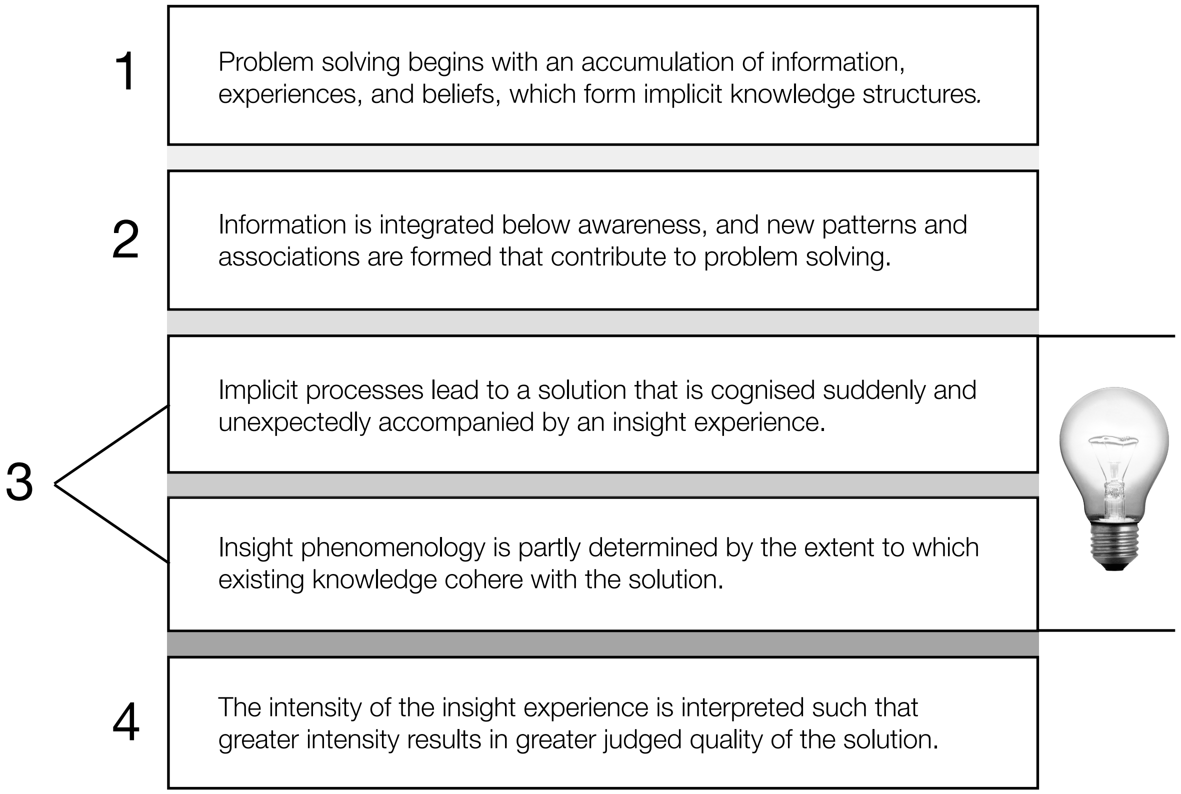

Figure 1. The four steps in the Eureka Heuristic view of the insight experience.

The heuristic view also helps to explain why insight experiences can range from being barely noticeable to intense, and why they can occur in a such a wide variety of circumstances. Mathematicians such as Henry Poincaré and Yitang Zhang, as well as physicists Albert Einstein and Richard Feynman, report intense Eureka experiences that resulted in, as Poincaré put it, "immediate certainty." Their considerable expertise, which was developed over decades of study and practice resonated loudly with the sudden solution. On the other hand, in problems devised for lab-based experiments where one has minimal relevant experience, smaller insights tend to occur. Although less common, it also happens that one can have an insight experience where the contents of the solution are untrue (Danek & Wiley, 2017). If a person's knowledge or understanding is impoverished, then false insights are likely to arise. On the other hand, if one's memory, conceptual structures, and assimilated knowledge are based on decades of quality experience and clear and replicable evidence (and a healthy state of mind), then the Eureka moment *may* signal a breakthrough discovery. Having the appropriate knowledge can be seen as a necessary but not sufficient condition, a point illustrated by Roger Kornberg's series of false insights.

We begin by describing the phenomenology of insight in the context of problem solving and briefly discuss Topolinski & Reber's (2010) fluency account. We then outline the connection to self-interpretation, and discuss why it is useful to view the insight experience within the context of heuristics and biases. We also consider potential trade-offs involved with the Eureka heuristic, and describe the *insight fallacy* as any situation where one concludes that an idea is correct solely on the grounds that it was accompanied by insight phenomenology. In the final section, we discuss how the Eureka heuristic model may contribute to a number of long-standing debates in the insight problem solving literature, and provide a framework for understanding recent empirical findings. Given the breadth of research discussed, it is inevitable that some of the richness of each area is lost. We see that part of the value of this contribution is in describing overlapping literatures that are otherwise isolated, so as to provide novel perspective on an elusive phenomenon.

The Feeling of Insight

Recent definitions of insight emphasize the phenomenology that accompanies some sudden solutions such as pleasure, relief, drive, surprise, and in particular a sense of immediate obviousness of a solution (Danek & Wiley, 2017; Webb et al., 2016). Although the insight experience is more common under certain circumstances—particularly in creative problems that involve unconscious processing or representational change—it is not strictly problem-specific, nor is it ever guaranteed (Webb et al., 2016). Thus, over time, it has become common practice to measure when insight occurs on a case-by-case basis, and also to use a single set of problems to investigate both insight and non-insight solutions classified according to self-report (Bowden & Jung-Beeman, 2007). Given this state of affairs, it's surprising that theoretical contributions regarding the phenomenology of insight are rare. This lack of theory has become problematic recently because the phenomenology is increasingly used to define insight, and self-reported insights are used as dependent measures (Bowden & Jung-Beeman, 2007; Kounios & Beeman, 2014).

To the best of our knowledge, the fluency account of insight is currently the only published explanation of the insight phenomenology, and appears to be gaining popularity (Topolinski & Reber, 2010). According to Topolinski and Reber (2010), when an unexpected solution appears in mind during an Aha! moment, a problem that was once difficult or confusing is suddenly resolved and processed fluently, leading to positive affect and judged truth. Studies find that manipulating fluency creates a sense of cognitive ease, pleasure, and confidence (Topolinski & Strack, 2009; Winkielman & Cacioppo, 2001). For example, statements that are presented with high figure-ground contrast (e.g., black letters with a white background) are more likely to be judged as true compared to low contrast statements (Reber & Schwarz, 1999). Repeated exposure makes a stimulus more pleasurable (Reber, Winkielman, & Schwarz, 1998), and solutions presented more 'suddenly' following an anagram (50ms versus 150ms) are more likely to be judged as correct (Schwarz, Newman, & Leach, 2016). The authors argue that since suddenness, pleasure, and judged truth are dimensions of insight, then fluency is likely to be the driving force behind the experience of insight (Topolinski & Reber, 2010).

It's important to consider what the fluency description of insight affords us, which wasn't previously known. It is known, for example, that the insight experience is associated with greater confidence or presumed accuracy of a solution that appears in mind, but it is *not* known why or how. According to Topolinski and Reber (2010), it is due to the experience of fluency that is inherent to the insight phenomenology, which has previously been shown to predict judged truth. However, this raises the question, *why* does fluency led to increased confidence or judged truth? With regard to the open questions extant in the insight literature, we risk simply passing the buck from the feeling of insight to the feeling of fluency. Moreover, the fluency account does not speak directly to any of the questions outlined at the beginning of this paper (e.g., why do insight experiences predict objective performance in some contexts but not others? Why are some insights more intense than others? What leads to false insights?). Fluency does make promising predictions about situations that might elicit *illusions* of insight, for example by artificially increasing the fluency at the moment of solution. But it seems improbable that the myriad of false insights humans have—

especially those associated with complex belief systems—are driven by incidental states of fluency.

There are also quintessential elements of the insight experience not accounted for by fluency. According to participants' own reports, relief is a key feature of the insight phenomenology not connected to fluency (Danek & Wiley, 2017). Another dimension is drive, or inspiration, which accompanies some insight experiences (Danek & Wiley, 2017). Archimedes was said to be so stimulated and inspired that he ran naked through the streets shouting "Eureka!", pointing to the archetypal role of inspiration and the 'rush of insight' that accompanies the insight experience (Gick & Lockhart, 1995). Fluency also cannot easily explain why an insight can be barely noticeable in some cases, and phenomenally large in others. Andrew Wiles describes his discovery of the solution to Fermat's last theorem in 1994 as follows:

> "At the beginning of September I was sitting here at this desk when suddenly, totally unexpectedly, I had this incredible revelation. It was the most important moment of my working life. Nothing I ever do again will... I'm sorry."

Andrew Wiles fights back tears throughout the video, and in the end turns away from the camera because recounting the experience evokes a powerful emotional response. There is an apparent incongruity between the sheer emotional weight of some insight moments and the effects we observe (or would expect) from changes in fluency.

Our overall impression is that fluency is a parsimonious description of certain features of insight phenomenology. However, fluency does not fully account for the dimensions or the intensity of the insight experience. It is also quite clear that many key questions with regard to the behavioral consequences of the insight experience remain unanswered. It may also be that pigeonholing insight experiences as another instance of fluency may inadvertently lead to omitting the nuance of insight, and therefore to overlooking the unique role that it plays in decision-making.

Self Interpretation

In this section, we begin to unpack the studies that provide the scaffolding for the Eureka heuristic. One assumption of our account is that self interpretation is a basic feature of human cognition, one that is very likely exploited in the case of insight experiences. People often fail to introspect correctly regarding their mental processes or the true causes that underlie their behavior and attitudes, and regularly confabulate instead (Brasil-Neto et al., 1992; Johansson et al., 2004; Schooler, 2002; Wegner & Wheatley, 1999; Wegner, 2002). This is not to say that introspection is always incorrect, but that so-called introspections even when they are accurate, are in fact post-hoc interpretations based on implicit causal theories and an evaluation of contextual and sensory information. There are dozens of experiments that find a mismatch between self-reported causes of behavior (and underlying cognitive processes) and the actual causes triggered by various manipulations (see Nisbett & Schachter, 1966; Latane & Darley, 1970 for famous examples, Nisbett & Wilson, 1977 and Caruthers, 2009 for reviews, and for more recent work see Dougal & Schooler, 2007, Johansson et al., 2004; Johansson et al., 2005; Johansson et al., 2006; Whittlesea & Williams, 1998).

The classic research conducted by Maier (1931) provides an illustrative and relevant example. Maier (1931) set up an insight problem using two ropes hanging from the ceiling. The ropes each had different objects attached at the bottom, such as pliers, or clamps. The task was to attach the two ropes, but it was physically impossible to reach one rope while holding the other. When participants were close to giving up, Maier would haphazardly set one of the ropes in motion. Shortly thereafter participants tended to 'suddenly' discover the solution: they tied an object to the rope, set it in motion, quickly grabbed the other rope and then caught the swinging object and tied the ropes together. When probed about the source of the solution, individuals confabulated that it simply 'dawned on them,' or that it was 'the next obvious thing to try' (for a replication, see Landrum, 1990).

Misattributions of phenomenology highlight how people interpret their feelings, despite the fact that the source of those feelings is unknown. In one such study, Dougal and Schooler (2007) presented participants with 60 words to memorize, and then provided a set of anagrams to solve followed by a recognition judgment regarding the solution of the anagram. They found that the anagrams that were solved were more likely to be recognised compared to the anagrams that were not, suggesting that something about solving the anagram was leading to an 'illusion of prior experience.' In five more experiments, Dougal and Schooler (2007) replicate their basic finding and argue that participants seem to fall prey to 'discovery misattribution': The Aha! experience of solving an anagram leads to a false inference of remembering, where participants incorrectly interpret their insight as a signal that a word is familiar. Not only is this study a further example of self-interpretation, the authors specifically show an effect of self-interpretation with regard to the insight experience.

In a series of similar experiments conducted by Whittlesea and colleagues (1990, 1998, 2000), they suggest that the feeling of surprise—a dimension of the insight experience—can also confound memory judgments, where pseudohomophones of real words (e.g., frog spelled *phrawg*) are more likely to be reported as old (recognised as previously seen) than words spelled correctly and non-words. The surprise experienced as a consequence of an unfamiliar letter-string, which sounds like a real word may have led to a misattribution of phenomenology so that participants felt that the word was previously seen (Whittlesea & Williams, 2001).

Based on these data, we may conclude that the insight experience and some of its dimensions are self-interpreted in ways that lead to incorrect judgments in certain contexts (Dougal & Schooler, 2007; Whittlesea & Williams, 2001). We see no reason to believe that insight phenomenology is self-interpreted in these contexts, but not in the context where they most commonly occur: problem solving. It would be particularly surprising given that problem solving is precisely where the self-interpretation of insight experiences would be functional, given that they predict objective performance (Salvi et al., 2016). It may be that existing self-interpretation effects with regard to insight are a consequence of an otherwise functional signal that leads to bias in certain artificial circumstances.

Studies such as Maier (1930) show that individuals can fail to explain how they arrived at an insight solution. If people are self interpreting their insight moments, then an additional prediction is that they may also fail to explain *why* an insight solution is correct. In many cases where self interpretation and confabulation occurs, people believe that they are genuinely introspecting (Carruthers, 2009). Hence, when a sudden insight occurs, even if it is possible to provide a narrative about why the solution is correct, it too may be a matter of post-hoc theorising and self interpretation. One prediction is that it ought to be possible to have an insight experience and provide an accurate solution, but also provide an inaccurate description about why that solution is correct. Insight phenomenology may in some cases be more trustworthy than one's own deliberate rationalising (Gigerenzer & Gaissmaier, 2011).

The Eureka Heuristic

In this section, we aim to describe how the insight experience is best understood as a heuristic, and why this view is a plausible interpretation of existing data. The heuristics and biases approach has had an enormous impact on decision-making research over the past 40 years (Simon, 1956; 1982; Tversky & Kahneman, 1973, 1975; Gigerenzer & Gaissmaier, 2011). The majority of this progress in understanding how humans make decisions comes from a deceptively simple idea that there are shortcuts to navigating a complex world. Stereotyping is a familiar example where humans categorise people and objects according to the sum of their experiences with them. Due to the inherent fact that humans have limited exposure to the members of any category—and limited cognitive capacities—they are forced to generalize from the small subset that they have been exposed to. They rely on a small subset (stereotype) to make predictions about new instances, which is an adaptive mental shortcut because it *usually* works (Bodenhausen, 1993).

For the purposes of considering the insight experience within this framework, the affect heuristic affords a particularly useful analogy. Slovic et al., (2007) pointed out that, "Although analysis is certainly important in some decision-making circumstances, reliance on affect and emotion is a quicker, easier, and more efficient way to navigate in a complex, uncertain, and sometimes dangerous world.” Consistent with this view, Damasio et al., (1994) studied patients who suffered brain damage in ventromedial frontal cortices, which resulted in a specific impairment in the ability to “feel.” Counterintuitively, the patients experienced a marked failure to make rational decisions and to reason appropriately, despite appearing to have all their other reasoning faculties intact. Slovic et al., (2007) suggest that affective cues are based on impressions developed through experience, where some object or event has been associated with positive or negative affect in the past. In a new uncertain situation, a person can draw on her impressions or experiences of similar situations by consulting her affective responses as a heuristic. Studies show that affect has widespread influence on judgments and decisions even in abstract domains that seem on the surface purely analytical, including risk judgments (Fischhoff et al., 1978), gambling and probability judgments (Loewenstein et al., 2001), and a range of preference evaluations (Anderson, 1981; Mellers et al., 1992; Winkielman, Zajonc, & Schwarz., 1997).

One obvious similarity between the affect heuristic and the Eureka heuristic is that they both involve an interpretation of phenomenology to guide decisions (see also feelings-as-information theory, Schwarz, 2011). A crucial difference lies in the underlying mechanisms. Slovic et al., (2007) proposed that the affective response to a stimulus or situation draws on an “affect pool” that contains previous, related experiences and representations tagged as either emotionally positive or negative. When in a familiar situation, a person can draw on the affect pool by reacting to the affect they currently experience to help guide decision-making. The Eureka heuristic may function in a similar way—where the affect heuristic draws on an “affect pool,” the Eureka heuristic draws on a “knowledge pool.” When a solution is found, and existing knowledge about the problem and relevant associations cohere with the new solution, then an insight moment signals that one’s complex, implicit knowledge structures are consistent with the current solution. Another way to conceptualize this difference is that intuitions and affective cues occur to inform us about *events in the world*, whereas the insight experience occurs to inform us about *events in our minds* (see Figure 2). The same mechanisms that drive our intuitions about the world may therefore also drive our insight experiences.

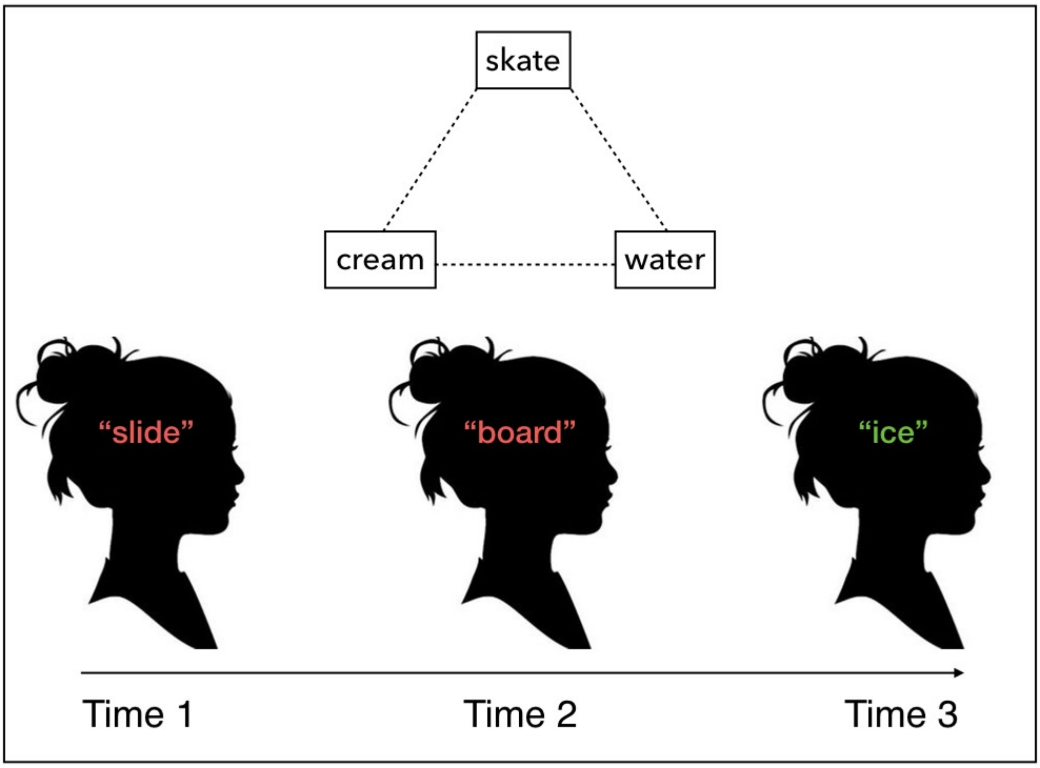

Figure 2. The participant is presented with some problem (e.g., a compound remote associate). Two solutions come to mind: "slide" at Time 1, and "board" at Time 2, but neither solution is compatible with all three words. At Time 3, the word "ice" appears in mind along with an insight experience, so they infer that no further processing is required and reports the solution.

If insight moments are used as an ecologically rational heuristic akin to recognition, or affect (Gigerenzer & Gaissmaier, 2011; Schooler & Hertwig, 2005; Slovic et al., 2007), then this account ought to predict problem solving accuracy and subjective confidence in the solution. The data are clear on both fronts. Across a range of problems, solutions that are accompanied by the insight experience are more likely to be accurate than solutions that are not, and insight moments predict confidence—despite no deliberate verification or introspection by the problem solver (Danek et al., 2014; Danek & Wiley, 2017; Hedne et al., 2016; Metcalfe & Wiebe, 1987; Salvi et al., 2016; Webb, Little, & Cropper, 2016). Importantly, the relationship between insight and accuracy varies depending on the problem type.

A multiplication problem like 46 x 83 is rarely solved unconsciously through associative processing or restructuring, so one is unlikely to experience an insight moment. This is likely why, for classic analytical problems, there are fewer insight moments, and the correlation between insight and accuracy is negligible or non-existent (Danek & Wiley, 2017; Webb et al., 2016). The more the problem is amenable to a linear, conscious strategy, the more easily one can articulate the basis for the solution, and there is little use for informative phenomenology. Consistent with this view, in a comparison of the think aloud protocols leading up to successful solutions of problems associated with insight versus non-insight solutions, Schooler and Melcher (1995) found that numerous elements (e.g., arguments, re-reads) predicted analytic problem solutions, but very few predicted insight solutions. Metcalfe and Wiebe (1987) also showed that feelings of progress on a problem predict solutions for analytic but not insight problems. If the solution to a problem is simply the final step on a staircase then there's no need for informative phenomenology to know you've reached your destination. Whereas, if some parts of problem solving occur below awareness, then the 'how' or 'why' of the solution may not be directly accessible. It is as if you've landed on a new floor with no memory of how you got there. In such cases, the phenomenology of insight is helpful for informing you that—despite not knowing how you arrived at the new location—you're on the right floor.

The above conception can explain why insight moments are problem-general rather than problem-specific, and why certain kinds of problems elicit more insight moments than others. The more likely the problem is to draw on implicit knowledge structures and processing below awareness, the more likely it is to be accompanied by an insight moment. As long as this principle is met, then there are potentially myriad cognitions that can precede an insight, which is why an idea for a new painting, a line of poetry, a way to resolve a dispute, or a solution to an engineering problem, can all appear in mind in a sudden moment of insight. We stress this point because, if true, it is a crucial step in our understanding of insight in general: There is no single problem solving process that leads to insight—the experience may not be a consequence of a specific set of cognitions that take place in solving the problem. Instead, the experience of insight may be a signal that the work done behind the scenes has reached a conclusion that is likely to work given what is known. It is a kind of inference about the validity of the idea rather than a consequence of arriving at a solution. We now consider a trade off where the Eureka heuristic can lead to a persuasive but false sense that a true solution has been found.

The Insight Fallacy

The mathematician and Nobel laureate John Nash was asked why he believed that he was being recruited by aliens to save the world. His response powerfully illustrates the recursive danger of the Eureka heuristic. He said that: "…the ideas I had about supernatural beings came to me the same way that my mathematical ideas did. So I took them seriously" (Nasar, 1998). Here, John Nash may have committed what we term the insight fallacy. He has concluded that an idea is true solely because it occurred to him with certain phenomenology, in this case the same phenomenology as his previous mathematical discoveries. One of the benefits in defining heuristics and understanding the shortcuts we use is that we may also uncover the circumstances where they fall short. For example, the availability heuristic can be led astray by sampling biases, and anchoring and adjustment heuristics can be affected by incidental and irrelevant information (Tversky & Kahneman, 1973; 1975). What, if any, are the trade offs that occur as a consequence of using insight phenomenology to appraise the quality of our ideas?

Fear is an adaptive signal of a dangerous or challenging situation, but is also sometimes unwarranted or irrational, and in severe cases, debilitating. We know that often fear ought to be overcome, for example, so that we can fly in a plane, swim in the ocean, or speak in public. The same is not so obvious for feelings that accompany our ideas when they arise—our insight moments. The insight moment, like fear, may be a helpful signal that perhaps we've discovered something important (Laukkonen et al., 2018). However, if there is overwhelming contradictory evidence, or one is suffering from mental illness (John Nash was diagnosed with schizophrenia in 1959), then it is likely that no matter how intense our revelation, the contents of our idea will remain untrue. Just as a person might experience a profound fear of elevators, the intensity of the fear does not make the elevator dangerous. Likewise, if one is suffering from delusions, or they have been misled with false information, then no matter how explosive the insight moment, the idea is no more likely to be correct. It is hard to predict how widespread the impact is, but consider how many contradictory ideas there are in the world and how many of the ideas that we hold most dearly were—at least subjectively—our own insights. One conclusion from this line of thinking is that we ought to be aware that the phenomenology accompanying our ideas is predictive, but also highly fallible (Danek & Wiley, 2017). Danek and Wiley (2017) found that 37% of incorrect solutions to magic tricks were reported as insight moments. The proportion of false insights in everyday life may be different—since magic tricks are a domain of negligible experience for most people—but even a fraction of 37% is alarmingly prevalent.

Since false insights do occur, then to commit the insight fallacy is to conclude that an idea is true simply because the solution was accompanied by an insight experience. Hedne et al. (2016) showed that when an insight moment occurs, subjects are less likely to accept an alternative solution to the problem, and are more likely to stick with solutions that are similar to their insight. It may be that insight solutions are particularly hard to revise since the underlying process is opaque, because it is impossible to argue against reasoning that is unknown to the problem solver. The Eureka heuristic is certainly functional, but when an error does occur, the consequences can be dire. Not only are insight moments potentially incorrigible, they also promote inspiration, and provide a drive towards action (Danek & Wiley, 2017). Relative to an incorrect-but-analytic solution to a problem, when a false insight occurs, it may be more difficult to change the person's mind and to prevent them from behaving as if the solution were true.

One important implication of the insight fallacy is that humans ought to be aware that the feeling of insight is fallible and that in certain situations, it is advantageous to actively doubt light bulb moments and search for support beyond phenomenology. There are many promising avenues of research here, which are discussed further in the final section below. We propose that an important question for future research is, "what are the variables that lead to *accurate* insight moments?", in order to compliment the more popular extant question of, "what are the variables that lead to *more* insight moments?".

It may also be that some domains of knowledge are particularly prone to false insights. The validity of the insight experience—if it is cuing a consistency with existing knowledge structures—is in direct relationship with the quality of those knowledge structures and thus the information that underlies them. Depending on unique life experiences and exposure to different cultural myths and the sheer abundance of the (often contradictory) information available, it is not surprising that there are revelations of almost every imaginable sort. Where knowledge structures are either biased or untrue, then the insight moment may in fact serve to further reinforce and motivate false beliefs. In the case of complex belief systems of cults, certain conspiracy theories, or superstitious beliefs, one can be an 'expert' in a domain where the knowledge structures that fuel intense Eureka moments are fictitious to begin with. Here, the phenomenology that accompanies new ideas may be altogether unreliable and act only to recursively increase the persistence of these worldviews (see Figure 3).

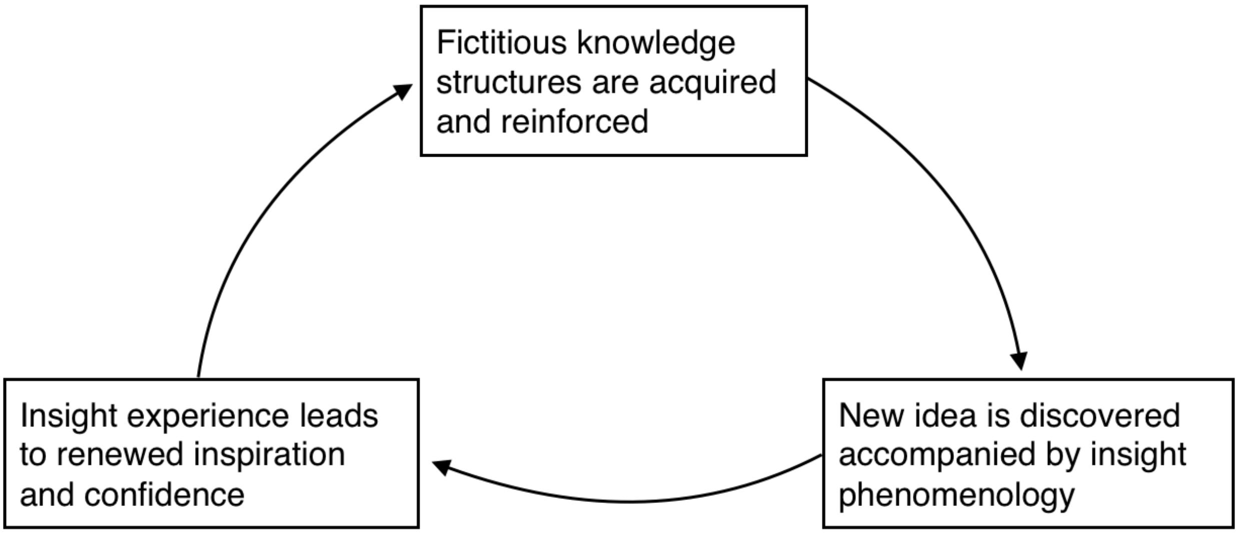

Figure 3. The recursive nature of insight in the formation of complex beliefs.

Discussion

The word Eureka originates in Ancient Greece from the word εὕρηκα (heúrēka), and before that from heuriskein, which means “I find.” Heuriskein is also the ancient origin of the word *heuristic*, which refers to shortcuts that help humans to solve problems. The shared origin of the two words *Eureka* and *heuristic* may point to a forgotten wisdom about the nature of the insight experience, that humans use the feeling of Eureka as a heuristic to evaluate the quality of their own ideas.

There is evidence that insight phenomenology plays an adaptive role in decision-making and problem solving, and we have proposed what that role may be. The heuristic view requires a restructuring of the way we think about insight moments, as a result of a specific problem solving process, to an appraisal of an idea or solution. Human experience is filled with rich phenomenology, bodily sensations, and emotions, that guide our decisions and help us to intuitively navigate complexity and uncertainty. It would be at odds with the greater body of psychological research if the ability to feel was important in most other domains of judgment and decision making, but not with regard to our own ideas and solutions to problems (Kahneman & Beatty, 1973; Kahneman, 2011; Slovic et al., 2007; Schwarz, 2011).

Since much of complex, associative, problem solving occurs below awareness, it is perhaps unnecessary—and certainly inefficient—to review all of the reasoning and information underlying every idea that comes to mind. Therefore, when it comes to solving problems, knowing ‘why we know’ is not as important as simply ‘knowing that we know,’ especially when time is of the essence. To this end, insight phenomenology may serve as a fast and frugal means of signalling support for a solution, employed heuristically during states of metacognitive uncertainty.

The Eureka heuristic helps us understand recent data, and speaks to a number of long-standing debates in the literature. First, the Eureka heuristic can explain why insight moments occur in such a wide array of problems. Any problem can lead to an insight moment provided that some crucial steps in the solution process occurred below awareness. Traditional insight problems, remote associate problems, matchstick arithmetic, anagrams, magic tricks, and likely many others, reliably lead to insight moments in laboratories because they are easily amenable to unconscious processing. Second, the intensity of the insight experience is determined by the extent to which existing knowledge is consistent with the new solution. Third, false insights occur when an idea is consistent with one's knowledge, but inconsistent with facts (Danek & Wiley, 2017). And lastly, the strong insight accuracy relationship is constrained to problems that involve unconscious processing because it is precisely in these domains where the insight experience contains information above and beyond one's deliberate reasoning.

One foreseeable criticism of the Eureka heuristic are cases of restructuring or representational change (Ohlsson, 1984). Insight problems used in the laboratory often lead to an incorrect interpretation, which leads to a mental state where prior knowledge is at odds with the solution. Consider the following example:

> *Mr. Hardy was washing windows on a high-rise office building when he slipped and fell off a sixty-foot ladder onto the concrete sidewalk below. Incredibly, he did not injure himself in any way. How is this possible?*

Most people initially assume that Mr. Hardy is standing at the top of the ladder, despite the fact that the problem does not declare it. The problem solver is now constrained by what they believe they know based upon an implicit interpretation. The problem can trigger an insight solution only when the problem is implicitly restructured and the problem solver realises that Mr. Hardy is on the bottom of the ladder (Ohlsson, 1984). Then one might ask: How is it possible that insight signals consistency with prior knowledge, since prior knowledge was the very barrier to solving the problem?

While existing knowledge is initially at odds with the true solution, it is precisely when the unconscious restructuring occurs that the problem solvers knowledge suddenly *becomes* consistent with the solution. With the incorrect representation of the problem, no insight moment occurs because no solution feels coherent with one's implicit interpretation. However, when one's assumptions change —i.e., the state of one's implicit knowledge and beliefs change—then an insight moment occurs as the solution is suddenly consistent with what one knows about the problem.

There is, however, a dark side to the Eureka heuristic. There is evidence that insight moments are difficult to revise (Hedne et al., 2016), and are more easily recalled (Danek et al., 2013). The insight moment may be highly functional most of the time, but when it signals a false solution, then the implications are profound. The individual may be left with a powerful sense of certainty, and also the drive and inspiration to act according to an incorrect solution. In ill-defined domains, where one has very little experience, or domains that are fictional by nature—insight moments may simply provide a kind of recursive illusion of progress. In such circumstances, the insight moment may reinforce solutions and ideas that are false, and in some cases inspire further work in the wrong problem space.

Future Directions

In the spirit of heuristics and biases, one particularly promising direction for empirical work will be in identifying the key variables that predict the accuracy of insight moments, thereby identifying potential biases arising from the Eureka heuristic. Many studies have aimed to measure and manipulate the ability to solve insight problems, or increase the incidence of insight experiences (e.g., Jarosz, Colflesh, & Wiley, 2012; Ostafin & Kassman, 2012; Steidle & Werth, 2013; Thomas & Lleras, 2009; Weller et al., 2011). However, increasing the incidence of insights overall may also lead to more false insights. In the context of everyday life, false insights may be at least as unhelpful as accurate insights are helpful.

Another key prediction is that, since people may rely on phenomenology rather than deliberate reasoning to evaluate the quality of an idea, then verbalising the reasoning behind an insight solution may lead to confabulation. For example, it is conceivable that a problem may be correctly solved in an insight experience, but because the true reasoning behind the insight is implicit, then the explicit reasoning may turn out to be false. Just as humans may have mistaken interpretations about the reasons for their behaviour, they may have mistaken interpretations about the reasons for their own ideas and solutions to problems. Another possibility is that insight phenomenology may be employed to induce ‘truth misattribution,’ in a similar fashion to discovery misattribution (Dougal & Schooler, 2007). For instance, if an insight experience can be made to occur at the same time as an unrelated proposition (e.g., "lithium is the lightest of all metals," Reber & Unkelbach, 2010), then the insight experience may be falsely attributed to—or confused with—the truth of the proposition. More broadly, a bias towards perceived veracity could be induced in any circumstance where insights occur together with the stimulus.

Other interesting questions arise in the realm of individual differences. Those who score high on the 'need for cognition,' for instance, may adopt a more conservative criterion and therefore experience fewer false insights, whereas those with a low score may adopt a more liberal criterion (Cacioppo & Petty, 1982). Another relevant individual difference variable is Alexithymia, which is characterised by difficulties in accessing and verbalizing emotions and other bodily sensations (Sifneos, 1973). It's possible that those scoring high on scales of Alexithymia will show a diminished insight accuracy effect due to an inability to consciously access feelings of insight, resulting in a failure to benefit from the informational value of insight. Some intoxicants or psychoactive substances may also jeopardise how informative insight experiences are, and thereby influence the rate of false insights. Finally, it may turn out that particular cognitive dysfunctions are strong predictors of false insight experiences. If this turns out to be true, then it may also be possible to use the incidence of false insights during problem solving tasks as a diagnostic tool.

Concluding remarks. A functional, heuristic view of insight experiences is likely to help move the field in many new and productive directions. In particular, questions regarding the behavioral consequences of insight—or biases associated with judgments that rely on insight—become more pertinent than questions regarding problem solving processes, which have held centre stage for the past century. We are optimistic that the Eureka heuristic account of insight fits the existing data, provides an explanation regarding the functional aspects of insight phenomenology, and can explain why that phenomenology has predictive power. This account also helps to explain why insight moments occur across a range of different problems, and illuminates the pitfalls of relying on phenomenology to guide problem solving in some circumstances.

Chapter 5

The phenomenology of truth: The insight experience as a heuristic in contexts of uncertainty

Preface

The experiments in this Chapter were all preregistered and fully prespecified on the Open Science Framework, and the preregistrations can be accessed using the following links: Experiment 1: https://osf.io/p6gqe/, Experiment 2: https://osf.io/xte35/, and Experiment 3: https://osf.io/up98z/. This Chapter is currently under review for publication. Experiment 1 is the same experiment described in Chapter 3, but here we focus on the predictions made in our Eureka Heuristic model, rather than on the methodological contribution. The methodological and theoretical contributions of the dynamometer were separate streams of research that could fortunately be addressed in the one experiment.

The majority of the work is my own. For Experiment 1, Daniel Ingledew contributed 20% to the experimental design and 100% to data collection, and Jason Tangen contributed 20% to the design. For Experiment 2, Hilary Grimmer contributed 60% to the data collection and Jason Tangen contributed 20% to the design. For Experiment 3, Benjamin Kaveladze contributed 50% to data collection, and Jonathan Schooler 30% to the design of the experiment. Jason Tangen contributed 10% to the writing.

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Abstract

Some ideas that we have feel mundane, but others are imbued with a sense of profundity. Here we tested the possibility that humans rely on feelings of insight in order to appraise their own ideas, the source of which is often hidden from conscious view. We began by investigating the recent finding that insight experiences predict objective problem solving performance. In Experiment 1, we measured insight experiences in real-time using a dynamometer, and found that impulsive feelings of insight (and their intensity) are strong predictors of accurate solutions to problems that typically involve implicit processing. In Experiment 2, we found that this insight-accuracy effect is also robust in a sensory identification task reminiscent of everyday life. In a third experiment, we presented participants with general knowledge 'facts' while eliciting insight experiences at the same time using anagrams. Participants reported greater perceived truth for facts accompanied by solved anagrams and particularly those that elicited insight experiences, even if the facts were false. Taken together, the results suggest that insight phenomenology usually contains useful information about the veracity of a solution, and that humans use this feeling heuristically to appraise new ideas. However, so-called Aha! moments can be overgeneralised, and bias truth judgments regarding a temporally coincident but otherwise irrelevant fact. We conclude by discussing potential side effects of relying on phenomenology to evaluate ideas, including false beliefs and dangerous ideologies.

Introduction

John Nash, a mathematician and Nobel laureate, was asked why he believed that he was being recruited by aliens to save the world. He responded, "…the ideas I had about supernatural beings came to me the same way that my mathematical ideas did. So I took them seriously" (Nasar, 1998). Although Nash was diagnosed with Schizophrenia in 1959, the example exposes a basic human conundrum. In everyday life humans need to discern the difference between a true and useful idea and a false one, and sometimes must do so quickly in order to respond in conversation, give advice, or solve a problem under pressure. How is the validity of a new idea evaluated, especially when time is of the essence? Perhaps the metacognitive process described by Nash is correct, and humans turn to the phenomenology that accompanies their ideas —their 'Aha!' moments.

Ideas that are called 'insights' are defined by suddenness (Metcalfe & Wiebe, 1987), and an immediate sense that the idea is correct or valuable despite its unexpected appearance in mind (Gick & Lockhart, 1995; Danek & Wiley, 2016; Kounios & Beeman, 2014). Recent empirical work suggests that the feeling of veracity that accompanies insights is justified, because when participants report an Aha! experience—the subjective feeling of insight—then the solution they provide tends to be correct (Danek et al., 2014; Salvi, Bricolo, Kounios, Bowden, & Beeman, 2016; Webb et al., 2016; Danek & Wiley, 2017; Hedne, Norman, & Metcalfe, 2016). For example, Salvi et al., (2016) presented participants with four different problems to solve: compound remote associates, anagrams, rebus puzzles, and degraded images. For each of the problems, when participants self-reported a feeling of Aha! they were more likely to provide a correct response (nearly twice as likely in some cases). This insight-accuracy effect appears to be robust across a number of laboratory problems, and effect sizes are consistently large (Webb et al., 2016; Danek & Wiley, 2017; Hedne, et al., 2016).

There is currently no generally accepted explanation for why the feeling of insight should predict accurate solutions to problems, but there are theoretical frameworks within which the result is not so surprising. According to Feelings-as-

Information Theory (Schwarz, 2011), subjective experiences in the forms of emotions, bodily sensations, and metacognitive experiences are sources of information that humans regularly rely on to make judgments and decisions (see also the Somatic Marker Hypothesis, Bechara, Damasio, & Damasio, 2000; and the Affect Heuristic, Slovic, Finucane, Peters, & MacGregor, 2007). Obvious examples include hunger, fear, pleasure, and tiredness, which signal something about the organism's internal state, or an automatic appraisal of some external phenomenon. The role of feeling in guiding decision-making has been demonstrated in far-reaching domains including risk judgments (Fischhoff et al., 1978), stock market investments (Hirshleifer & Shumway, 2003; Alter & Oppenheimer, 2006), gambling and probability judgments (Loewenstein et al., 2001), truth and memory judgments (Reber & Schwarz, 1999; Schwarz, Sanna, Skurnik, & Yoon, 2007; Dougal & Schooler, 2007), and jury decision-making (Semmler & Brewer, 2002). It is feasible that the Aha! experience—like the many other feelings and sensations that guide decision-making in productive ways—is a source of information for the problem solver. Moreover, if the feeling of insight carries information about the veracity of a new solution—as it subjectively purports to—then it would not be surprising that it predicts accurate solutions.

How might Aha! moments carry information about the veracity of a new idea? When a scientist, an inventor, or an artist has a new idea, they may be drawing on a vast repository of knowledge and expertise. Therefore, one possibility is that the insight experience signals that the new idea is highly coherent with the individuals existing knowledge and experiences. It's well known that experts can automatically and intuitively bring their expertise to bear in their domain, often without explicitly knowing why their intuitions are correct (Ericsson & Charness, 1994; Kahneman, 2015). New ideas may be evaluated through a similar mechanism, the only difference being that the idea occurs 'in the head' for the problem solver, whereas the stimulus is 'in the world' for the expert. Therefore, when a solution to a problem appears in mind, the problem solver can use the Aha! experience as a heuristic shortcut—a quick appraisal of whether the idea is consistent with what they know—instead of engaging in a slow and effortful evaluation. So long as the person's existing knowledge is valid, then the Aha! experience will likely signal a correct solution.

In the following experiments, we begin by evaluating the boundary conditions of the insight-accuracy relationship in Experiments 1 and 2. In Experiment 3, we test the insight-as-information hypothesis—or the 'Eureka Heuristic' as we have previously called it (Laukkonen et al., 2018)—by attempting to bias truth judgments with artificially elicited Aha! moments.

Brief Summary of the Experiments

Experiment 1 extends on previous work by measuring insight experiences closer to real-time, and then comparing the phenomenology to problem solving accuracy. Previous work has relied almost exclusively on self-report, which is somewhat problematic because participants inevitably have time to reflect on the quality of the solution. Therefore, the positive relationship between self-reported insights and accuracy could simply be due to the relationship between confidence and accuracy, rather than the impulsive feeling of Aha!. In other words, confidence in the solution may be a third variable that accounts for the relationship because it is associated with both insight and accuracy. By capturing the insight experience in the moment, we may be more secure in believing that the sudden insight feeling is sufficient to predict accuracy, rather than any deliberate reflection about the validity of the solution occurring after the fact.

Experiment 2 investigates the generalisability of the insight and accuracy relationship by evaluating it in the context of multisensory identification of songs, smells, and faces. Insights occur in many different contexts outside of toy problems in the laboratory, including visual bistable illusions (Maier, 1931; Schooler, McCleod, Brooks, & Melcher, 1993; Schooler & Melcher, 1995; Laukkonen & Tangen, 2017). However, regarding the insight-accuracy relationship there are no demonstrations outside of toy laboratory problems or relatively uncommon visual stimuli. Sensory identification tasks, for instance identifying a familiar aroma in a restaurant, or recalling the name of a song playing on the radio, are much more representative of the kind of tasks people encounter in everyday life. Therefore, in Experiment 2 we present participants with familiar sensory stimuli for identification—songs, aromas, and faces—and we evaluate whether feelings of Aha! predict the accuracy of the recollection.

Experiment 3 is based on a specific prediction that arises from the theory described above (originally proposed in Laukkonen, et al., 2018). If people are interpreting their insight experiences as a signal about the veracity of a solution, then presumably artificially induced insight experiences can bias subsequent judgments. Similar effects have been found using feelings of surprise (Whittlesea & Williams, 2001), fluency (Reber, & Schwarz, 1999), familiarity (Whittlesea, Jacoby, & Girard, 1990), and more. To test this prediction, we borrow a paradigm used by Dougal and Schooler (2007), and present participants with anagrams to solve at the same time as presenting them with general knowledge claims. For example, we show participants the claim: '*ithlium* is the lightest of all metals,' where the scrambled word is 'lithium' (Reber & Unkelbach, 2010). Participants need to solve the scrambled word before the proposition is complete, and then they rate the extent to which they believe that the proposition is true. We expect that successfully solving the anagram will induce an insight experience that would be *misattributed* to the proposition, such that trials accompanied by insight are given higher truth ratings.

Experiment 1 Introduction

In Experiment 1 we measured insight moments using a dynamometer, which is a highly sensitive measure of hand grip strength. The dynamometer may be particularly well suited for measuring visceral states, and has been shown to outperform self-report in predicting objective eating behavior from states of hunger (Creswell et al., 2016). With this device, participants can communicate perceived problem solving progress and also the sudden onset of an insight moment when it happens, very close to real-time (Laukkonen & Tangen, 2018), mitigating the concern that participants are reflecting on confidence and making a judgment that isn't primarily phenomenological. A positive association between dynamometer insights and objective performance would lend further support to the idea that insight phenomenology contains useful information regarding the quality of the solution. Since intuitions often draw on memories and experiences that may not be consciously accessible, we predicted that the positive relationship between insight and accuracy is greater for creative problems that tend to involve unconscious and associative processing, compared to analytic problems that invoke a more deliberate approach (Kounios & Jung-Beeman, 2014; Schooler & Melcher, 1995). We expect greater confidence for solutions that are accompanied by insight experiences and that the more intense the insight moment, the more likely it is to be correct. A detailed evaluation of the dynamometer as a novel measure of metacognitions during problem solving will be discussed in a separate paper. Here we focus on the dynamometer's contribution as a real-time measure of insight in order to investigate the insight-accuracy relationship.

Experiment 1 Method

Design and Materials

This experiment was approved by The University of Queensland Human Research Ethics Committee (UQHREC), clearance number: 17-PSYCH-141-4-AH, and conducted in accordance with the Declaration of Helsinki. The experiment was an entirely within-subjects design. We tested participants on three types of problems retrieved from previous research: 10 insight problems, 10 analytic problems, and 10 compound remote associates (CRA, Bowden & Jung-Beeman, 2003). To measure grip strength we used an electronic Hand Dynamometer made by Vernier, the same model used by Creswell and colleagues (2016). The device has an accuracy of ±0.6 N and an operational range of 0-600 N. The dynamometer was connected via USB cable to a computer that collects continuous handgrip data (10 data points per second) and displays the data graphically in terms of grip strength as a function of time. The dependent variables were the pattern of handgrip data from the dynamometer (recorded from the beginning of each problem to when it was solved), along with dynamometer 'spikes'—a full strength squeeze—during problem solving defined as greater than 6SD above the trial mean. Other dependent variables were accuracy, confidence measured from 1 ('not at all confident') to 12 ('very confident'), Aha experience (yes or no), and intensity of the Aha! experience from 1 ('mild') to 12 ('intense'). All materials and software can be found on the OSF: https://osf.io/wau7h/.

Participants and Procedure

The participants were 60 undergraduate psychology students from The University of Queensland (pre-specified on OSF), which is more than sufficient for a medium to strong effect size (Salvi et al., 2016). Participation was restricted to native English speakers because some problems involved language cues as well as cultural references. Participation was voluntary and in exchange for course credit. Participants were provided with written instructions and we intentionally did not mention confidence in our description of the insight experience (the transcript can be found on OSF: https://osf.io/p6gqe/). Participants were told to grip the dynamometer in their dominant hand and squeeze the device according to how close they were to solving the problem. They did this until they arrived at a solution, at which point they gave the device a full-strength squeeze if an Aha! occurred. If no Aha! moment was experienced at the moment of solution, then they simply relaxed their grip (see Figure 1 for two example problem solving patterns). Participants were shown the output graph while practicing with the dynamometer so that they could see how actions were depicted on the graph.

The 30 problems were printed on 30 individual cards, and were presented one-by-one in random order. Participants verbalised their solution to each problem, and were given 90 seconds to find the solution. After each response, participants were asked a set of metacognitive questions regarding insight, insight intensity, and confidence. Finally, they were asked whether or not the problem was familiar. The order of the Aha! moment and confidence questions were counterbalanced.

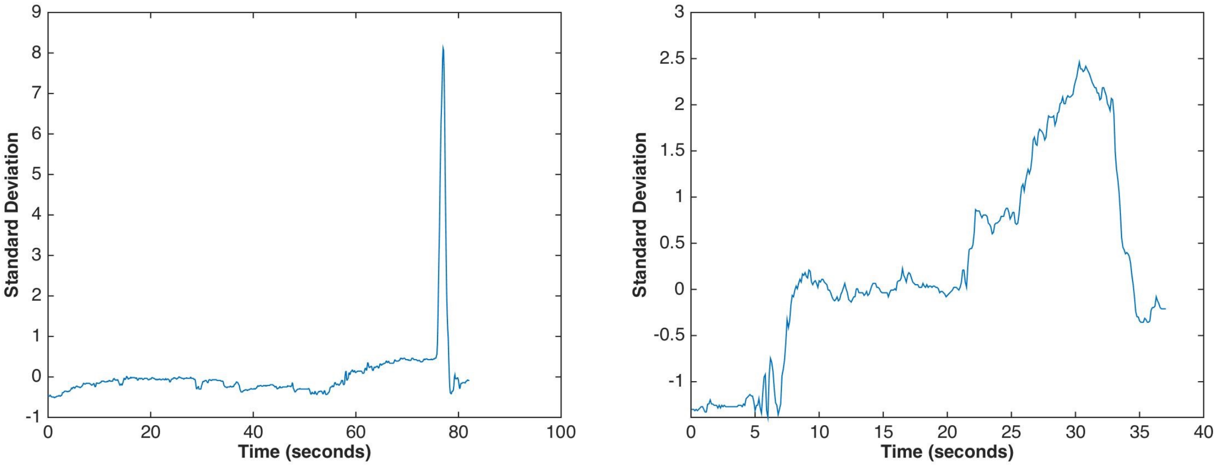


Figure 1. Left: Example of an insight moment as captured by a sudden full strength squeeze of the dynamometer resulting in a force (N) greater than 6SD above the trial mean. Right: An example of a solution without an insight moment, represented by a sudden decrease in grip strength at solution.

Experiment 1 Results

Preprocessing and Descriptives

Of the original 1800 cases (60 participants x 30 problem tasks), 1278 were used for analysis. There were 13 cases where participants were familiar with the problem and 509 cases where participants failed to give an answer within the 90 seconds. Each participant received an average score for each of the metacognitive measures. The dynamometer data for each trial was converted to *z* scores so that outliers (i.e., full strength squeezes of the dynamometer) could be detected on a trial-by-trial basis. Based on a visual analysis detecting spikes across all trials by three independent raters (α = .96), we found that 6 SD above the mean was sufficient to detect a full strength squeeze of the dynamometer.

We found a positive correlation between self-reported Aha! experiences and spikes in the dynamometer (r = .632, p < .001). In line with previous research, there was an effect of problem type on the number of Aha! experiences elicited, F(2,118) = 76.4, p < .001, ηp^2 = .564, where CRAs elicited the most Aha! moments (M = .73, SEM = .03), followed by insight problems (M = .54, SEM = .03, p > .001), and analytic problems elicited the fewest Aha! experiences (M = .26, SEM = .03, p > .001). The pattern was the same for the dynamometer, where analytic problems elicited the fewest spikes (M = .38, SEM = .04), followed by insight problems (M = .47, SEM = .04), and CRAs, which elicited the most spikes (M = .66, SEM = .04), F(2,118) = 28.2, p < .001, ηp^2 = .324 (all differences were p > .05). This pattern of findings is broadly in line with previous research where creative problems elicit more Aha! experiences than analytic problems (Webb et al., 2016; Danek et al., 2014; Salvi et al., 2016).

Insight Predicts Accuracy and Confidence

We evaluated the effect of Aha! experiences on confidence and accuracy (see Figure 2). In line with previous research, Aha! experiences predicted more accurate solutions to problems, t(58) = 12.6, p < .001, d = 1.64, and greater confidence in the solution t(58) = 14.4, p < .001, d = 1.87. Extending on previous research, the impulsive squeeze of the dynamometer also predicted more accurate responses, t(57) = 9.22, p < .001, d = 1.21, and predicted greater subsequent confidence, t(58) = 12.4, p < .001, d = 1.62. The key finding is that the phenomenology at the very moment of solution—as indicated by a full-strength squeeze of the dynamometer—is sufficient to predict more accurate responses collapsing across three different problem solving domains.

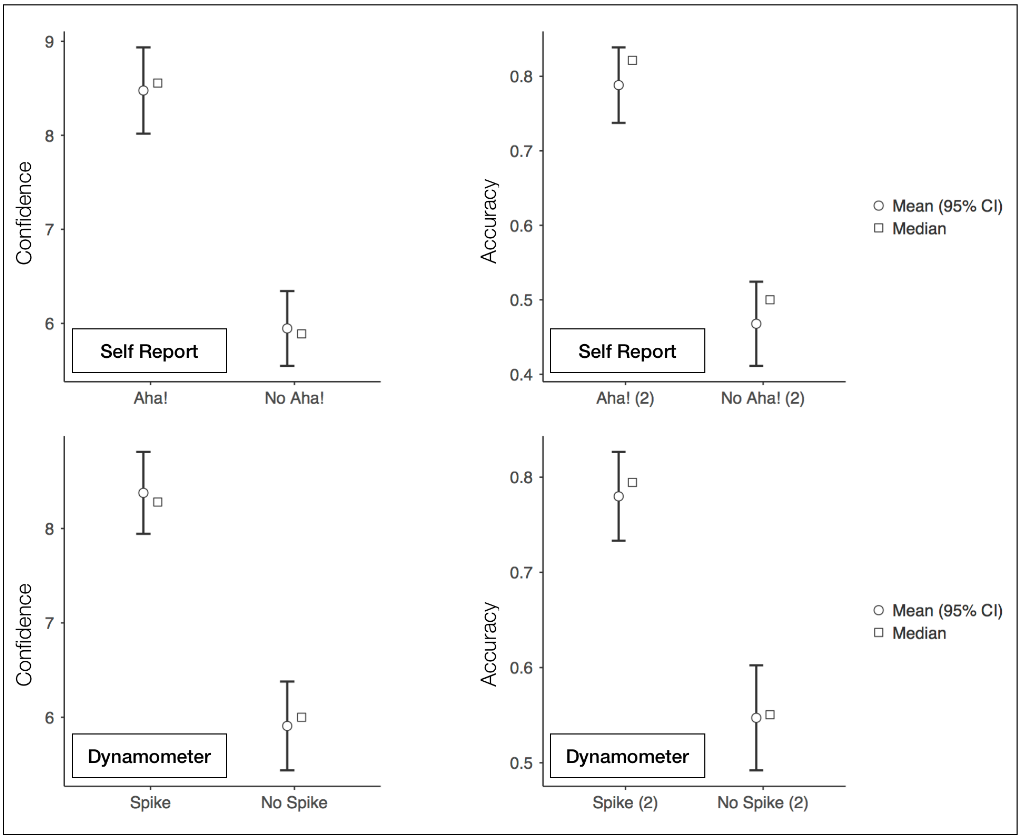


Figure 2. Top left: Solutions accompanied by Aha! or no Aha! and subsequent ratings of confidence. Top right: Solutions accompanied by Aha! or no Aha! and subsequent accuracy. Bottom left: Solutions accompanied by a spike in the dynamometer or no spike and subsequent ratings of confidence. Bottom right: Solutions accompanied by a spike in the dynamometer or no spike subsequent accuracy of the solution. Error bars represent 95% Confidence Intervals.

Insight Predicts Accuracy in Creative Problems, but not Analytic Problems

We predicted that different problem types would impact the degree to which the Aha! phenomenology predicts accurate responses. If the problem is best solved by thinking about it strategically—as in analytic problems—then there is little use for phenomenology, because the reasoning that underlies the solution is already known. We assessed the relationship between self-reported Aha! moments and solution accuracy at each level of problem type using a repeated measures ANOVA, *F*(5,115) =

19.7, $p < .001$, $\eta p^2 = .461$. As predicted, a Tukey post hoc test indicated that Aha! moments are only predictive of accuracy for insight problems ($d = .1.2$, $p = .002$) and CRAs ($d = 1.9$, $p < .001$), but not analytic problems ($p = .99$, *ns*).

The same test—a repeated measure ANOVA—was carried out for the dynamometer spikes at problem type, which also indicated a main effect, $F(5,215) = 17$, $p < .001$, $\eta p^2 = .283$. Post hoc comparisons revealed the same pattern of results as self report, where dynamometer spikes predicted accurate responses only for insight ($d = .6$, $p < .001$) and CRA ($d = .95$, $p < .001$) problems, but not analytic problems ($p = .99$). The findings are illustrated in Figure 3 below.

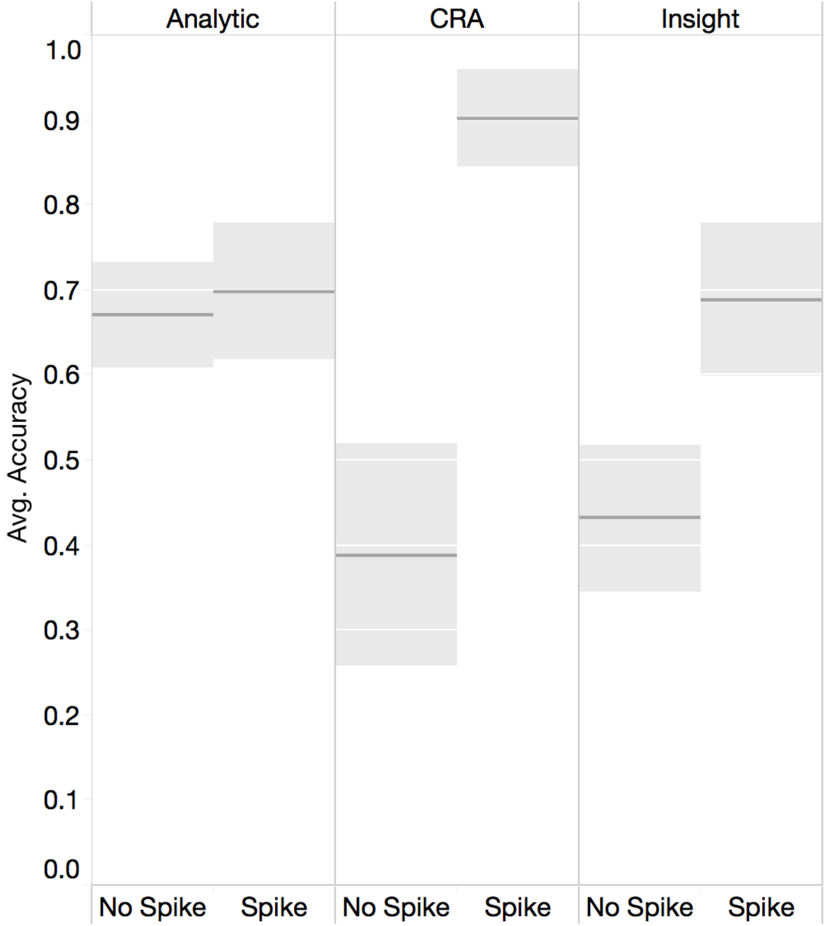


Figure 3. Accuracy by problem type (Analytic, CRA, Insight) for solutions that showed a sudden spike in the dynamometer greater than 6SD above the mean, compared to no spike. The shaded areas represent 95% Confidence Intervals.

Insight Intensity Predicts Accuracy and Confidence

Finally, we predicted that when an Aha! moment occurs, the more intense the reported phenomenology is, the greater the subsequent confidence and accuracy (on a case-by-case basis). The data showed that more intense Aha! experiences were associated with more accurate solutions ($r = .277$, $p < .001$), and greater confidence ($r = .458$, $p < .001$). These results indicate that, not only does the Aha! phenomenology predict objective performance, the intensity of the experience carries additional predictive information beyond the mere presence or absence of the phenomenology.

Exploratory Analyses

We decided to explore a few possibilities we hadn't considered prior to the experiment. The first possibility was that the maximum dynamometer rating from each trial could also be used to predict various phenomena such as insight, accuracy, and the intensity of insight experiences. We found that the maximum full strength squeeze in a trial predicted insight experiences well ($r = .5$, $p < .001$). We also found that the strength of the squeeze predicted accuracy for creative problems (insight and CRA, $r = 0.341$, $p < .001$), but not analytic problems ($r = -.020$). This result most likely occurred because higher scores would naturally be associated with 'spikes' (i.e., dynamometer insights). Interestingly, where insight moments were reported, the strength of the squeeze also predicted the intensity of the experience ($r = .375$, $p < .001$). This result is surprising because we *did not* instruct participants to squeeze harder based on intensity, and yet they appeared to do so naturally. We were then prompted to evaluate whether the strength of the squeeze—where a spike was detected—predicted accuracy. The data indicate that the strength of the participants' squeeze when they experienced an insight predicted whether the solution would be correct for creative problems ($r = .167$, $p < .001$). These results—although exploratory—point to the fact that the intensity of the insight experience was perhaps unintentionally embodied through the dynamometer.

Experiment 1 Discussion

The first experiment addressed the possibility that the relationship between insight phenomenology and accurate problem solving was merely an artefact of self report, where confidence is the primary force that results in the positive insight-accuracy relationship observed in previous research. We found that an 'in the moment' measurement of the insight experience using a dynamometer shows the same pattern of results as previous work, where feelings of insight predict objective performance for problems that involve unconscious or associative processing (i.e., metacognitive uncertainty about problem solving processes). We also found that the intensity of the insight predicted solution accuracy, and that this intensity was captured by the dynamometer.

Experiment 2 Introduction

In Brown's (1991) classic review of the tip-of-the-tongue (TOT) phenomenon, he describes the 'pop-up' experience that many people report after having the quintessential TOT experience, where the solution (in this case the target word) appears "spontaneously," "pops into awareness," often following some "incubation time" and accompanied by "no doubt." Compared to typical descriptions of insight, the TOT experience appears to be very similar, if not precisely the same thing. In Experiment 2, we tested the possibility that Aha! phenomenology positively predicts confidence and accurate decisions in a multisensory identification task, aiming to demonstrate that insight predicts accuracy in a context that is more reminiscent of everyday life. All hypotheses were preregistered on the OSF: https://osf.io/xte35/. We predicted that participants would report experiencing Aha! moments in a multisensory identification task, and that these Aha! moments—as well as their intensity—would predict greater confidence and more accurate identifications specifically when the participants experienced some uncertainty about the identity of the stimulus.

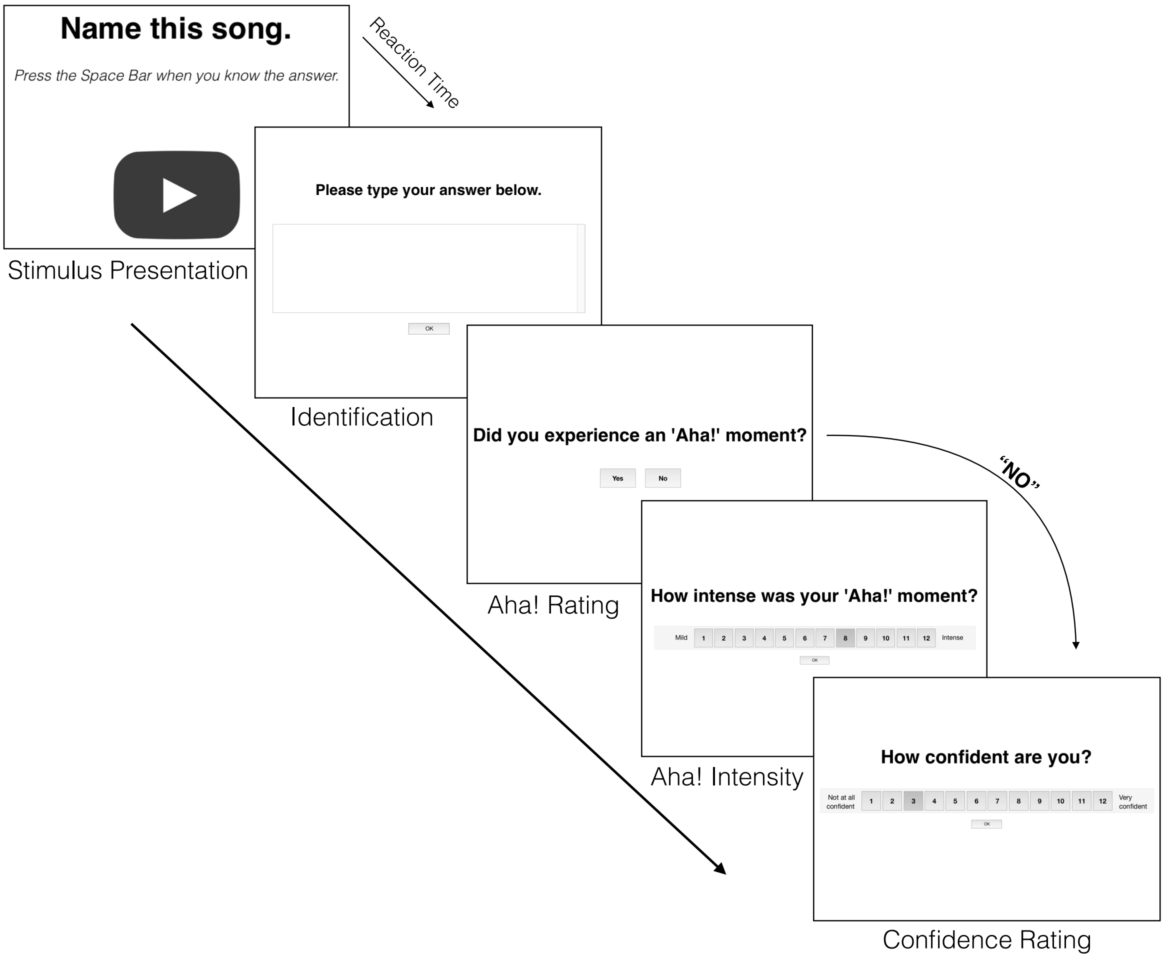
Experiment 2 Method

Design and Materials

This experiment was approved by UQHREC, clearance number: 2014007677, in accordance with the Declaration of Helsinki. In most ways the design of Experiment 2 was the same as Experiment 1, the main difference was the stimuli that were used. All stimuli, software, and further details on preprocessing and pilot testing can be found on the OSF. Because of the fast reaction times and the nature of the stimuli used in the multisensory task, we used self-report to detect Aha! moments, rather than the dynamometer. In Experiment 2, sensory modality was the independent variable, corresponding to 1: The olfactory sense (20 glass vials containing chemical derivatives of common smells), 2: The auditory sense (20 random 5 second segments of popular songs), and 3: The visual sense (20 famous faces). We conducted pilot testing to test the stimuli in order to ensure that participants were familiar with and able to identify them. As in Experiment 1, the dependent variables were accuracy, Aha!, and Aha! intensity measured on the same scales. The order of metacognitive judgments were counter-balanced. A final exploratory measure included was the Five Facet Mindfulness Questionnaire (Baer et al., 2006), but no meaningful interactions were found so this measure is not discussed further in the results.

Participants and Procedure

We collected data from 80 undergraduate students (prespecified on the OSF) from The University of Queensland, who participated in exchange for course credit. To ensure that the stimuli were familiar, we tested native English speakers only. Participants began by watching video instructions for the respective sensory modality. Again, we did not mention confidence in our description of the Aha! phenomenology (see OSF for the script). The order of the three modalities was counterbalanced. In the auditory condition, participants pressed a play button whenever they wanted to hear the song segment again. In the face condition, the photo simply remained on screen. In the olfactory condition, participants were blindfolded and presented with a glass vial containing a chemical derivative, which they could smell repeatedly. When the participant identified the stimulus, they (or the experimenter in the olfactory condition) pressed the space bar and typed the solution. There was no time limit but if they failed to recognise the stimulus they were encouraged to move on to the next question. Participants made their metacognitive judgments after each solution. The phases of the experiment in the song condition are illustrated in Figure 4.



Name this song.

Press the Space Bar when you know the answer.

Please type your answer below.

Did you experience an 'Aha!' moment?

How intense was your 'Aha!' moment?

How confident are you?

Figure 4. Phases of the experiment for the song condition from beginning to end for one trial. Each condition included 20 trials and no time limits.

Experiment 2 Results

Preprocessing and Descriptives

Heuristics are commonly used in times of uncertainty, particularly in probabilistic judgments, where information is limited and where a definite solution or answer is not available (Tversky & Kahneman, 1975; Gigerenzer & Goldstein, 1996; Gigerenzer & Gaissmaier, 2011). Therefore, in order to invoke heuristic decision-making it's important that the problem solver experiences uncertainty. We decided that uncertainty in this context can be approximated by the amount of time it takes a participant to respond. There is also evidence that immediate responses may be impulsively labeled as insight (Cranford & Moss, 2012). It's difficult to pinpoint the exact amount of hesitation to constitute (un)certainty, so we ran three participants through the experiment, and asked them to simply indicate if they liked the song, face, or aroma (yes or no), which should approximate a fairly rapid "certain" response. The results of this initial pilot test revealed that people took an average of 6.077 seconds (range 1.882 to 8.220 seconds) to provide a likability score for songs, 1.168 seconds (range .472 to 5.683 seconds) for faces, and 5.283 seconds (range 3.408 to 9.640 seconds) for aromas. On the basis of these results, we decided that one SD above each mean (rounded up to the second) would suffice as a conservative estimate of uncertainty. We removed trials where participants responded with 'I don't know' (1,204 trials) leaving 2,165 trials for analysis. We found that faces elicited Aha! experiences 60% of the time, songs 65%, and smells 58% of the time. The intensity of the Aha! experience was also fairly similar across the conditions, with an average intensity of 3.32 for faces, 4.02 for songs and 3.28 for smells. The olfactory condition was the most difficult, where participants answered correctly 28% of the time, compared to 87% for faces and 75% for songs.

Insight Predicts Accuracy and Confidence during Uncertainty

We began by comparing identification accuracy for solutions with or without Aha! experiences, at the two different time periods representing certainty and uncertainty (illustrated in Figure 5). As expected, there was no difference between Aha! (*M* = .91, *SD* = .14) and no Aha! trials (*M* = .91, *SD* = .14) for immediate or 'certain' responses, since people were almost always correct if they immediately knew the answer, *t*(67) = .06, *p* = .951. For responses with slower reaction times—or some period of uncertainty—Aha! experiences predicted more accurate identifications (*M* = .73, *SD* = .11) compared to identifications without Aha! experiences (*M* = .60, *SD* = .23), *t*(79) = 4.52, *p* < .001, *d* = .505. The same analyses were conducted to evaluate confidence as a function of Aha! experiences. As predicted, solutions with Aha! experiences lead to greater confidence (*M* = 8.72, *SD* = 1.18) compared to solutions without them (*M* = 6.42, *SD* = 2.24), *t*(79) = 9.22, *p* < .001, *d* = 1.03. The results indicate that, just as in problem solving tasks, the Aha! experience predicts more accurate responses and greater confidence in a multisensory identification task (collapsing over the different sensory conditions).

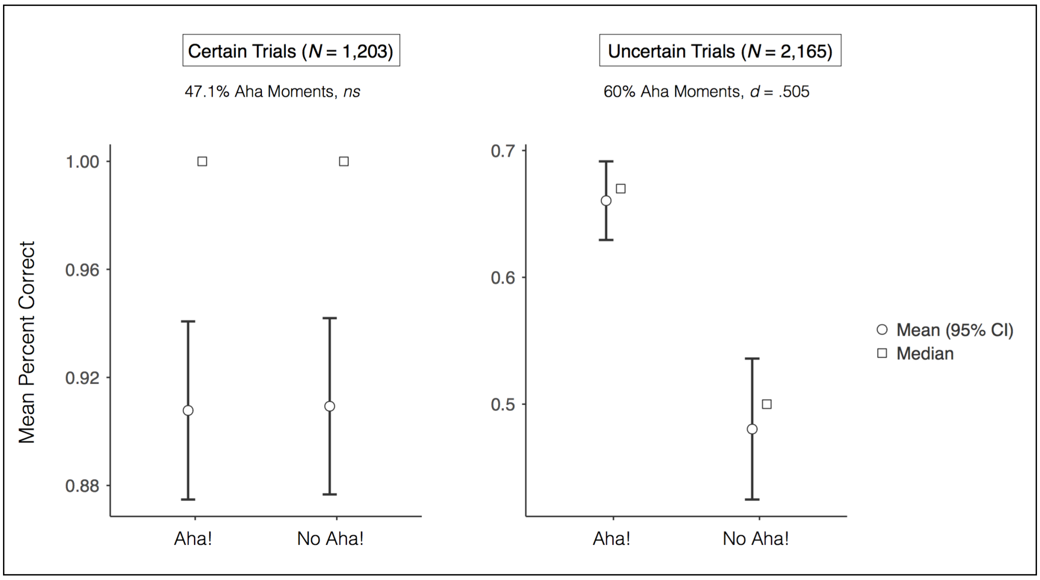


Figure 5. Proportion correct as a function of solutions with and without Aha! experiences, for quick reaction times (left), and slower reaction times approximating uncertainty (right). Error bars represent 95% Confidence Intervals.

Next, we evaluated the correlations between the intensity of the Aha! experience, accuracy of the solutions, and confidence. Notably, the intensity of the Aha! experience positively predicted accurate identifications ($r = .151$, $p < .001$) and confidence ($r = .342$, $p < .001$). Here too, the results mirror those found in classic problem solving tasks. We then compared the predictive power of the Aha! experience across the different sensory modalities. A repeated-measures ANOVA revealed a main effect of sensory condition, $F(5) = 72.7$, $p < .001$, $\eta p^2 = .556$. Tukey's post-hoc tests indicated that Aha! experiences predicted more accurate identifications in every condition, with the strongest effect size observed in the olfactory condition (illustrated in Figure 6).

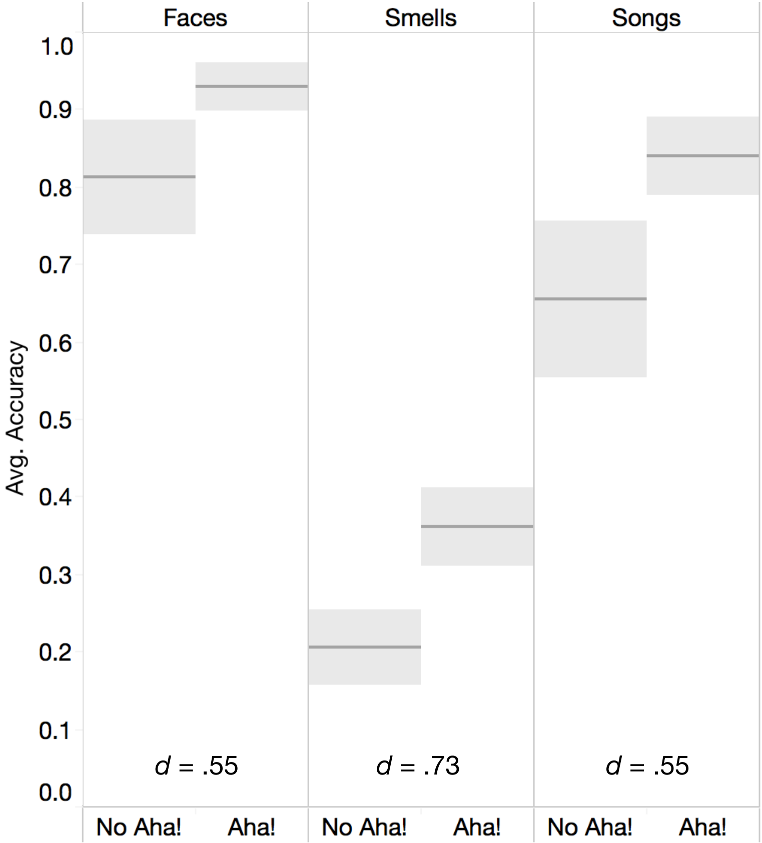


Figure 6. Percent correct as a function of solutions with and without Aha! experiences for faces, songs, and smells. Shaded area represents the 95% Confidence Interval, and effect sizes are Cohen's *d*.

Experiment 2 Discussion

In everyday life, we rely on sensory information to infer the identity of an object, a person, a sound, or an aroma, and therefore frequently make identifications of the sort we tested in Experiment 2. In this context, we found that participants regularly report Aha! experiences, and we recorded 608 cases of strong insight phenomenology that accompanied the identification (between 6 and 12 on a scale where 1 is mild and 12 is intense). Crucially, the insight-accuracy effect appears to be robust beyond toy laboratory problems. As in previous work, the insight phenomenology, and its intensity, also positively predicted confidence and objective performance, specifically when the participants experienced some uncertainty about the stimulus identity. The effect was consistent across faces, songs, and aromas.

Experiment 3 Introduction

According to the Eureka Heuristic view (Laukkonen et al., 2018), people interpret their metacognitive feelings of insight in a way that influences their beliefs about the veracity of new ideas. The first two experiments described above strengthen the finding that impulsive feelings of insight predict the accuracy of solutions in various contexts where there is metacognitive uncertainty. However, they do not directly test whether Aha! moments are interpreted in a way that influences judgments. To test this possibility, in Experiment 3, we aimed to elicit feelings of insight in order to influence judgments in a context that should be unrelated to the phenomenology. Our reasoning was that, if participants interpret their feelings of insight as a marker of truth, then it ought to be possible to bias truth judgments about claims by eliciting a concomitant Aha! experience.

To this end, we presented participants with general knowledge facts, but scrambled one of the key words. For example, we showed participants claims such as: '*ithlium* is the lightest of all metals,' where the scrambled word is '*lithium*'. Participants first solved the scrambled word and then rated the extent to which they believed that the proposition is true. They then reported on whether or not they experienced an Aha! moment when solving the anagram. We expected that solving anagrams would elicit feelings of insight that influence the perceived truth of the fact. These hypotheses are broadly consistent with findings that people interpret their own phenomenology (Schachter & Singer, 1962; Nisbett & Wilson, 1977, Whittlesea & Williams, 1998; Schooler, 2001; Johansson et al., 2004; Carruthers, 2009; Schwarz, 2011), and rely on gut feelings and hunches to make truth attributions (Zajonc, 1968; Reber & Schwarz, 1999; Weaver, Garcia, Schwarz, & Miller, 2007; Schwarz & Newman, 2017).

The paradigm for this experiment is adapted from Dougal and Schooler (2007). In their study comprising six experiments, the authors presented participants with a list of words to memorize. The participants then solved anagrams where half of the scrambled words were previously presented for memorising, and half were not. When participants successfully solved the anagram, they were more likely to believe that they had also seen the word before, even if they had not. They accounted for this finding by positing a "discovery misattribution" process akin to the "Eureka Heuristic" whereby individuals "rely on the distinct nature of the phenomenology of the discovery experience to make inferences about their state of knowledge" (Dougal and Schooler, 2007, p591). In other words, Dougal and Schooler (2007) suggest that the feeling occasioned by solving the anagram lead to the false sense of memory. The following experiment is similar, but includes several extensions. First, solving anagrams is expected to influence the participants' interpretation of an entire proposition, rather than simply the word that was unscrambled. Second, the judgment we aim to influence is perceived truth, rather than memory, which we see as particularly relevant because the Aha! experience is known to evoke a sense of certainty (Webb et al., 2016). Third, we measured whether or not participants experienced Aha! moments on a trial-by-trial basis, so that we could specifically analyse the extent to which insight experiences influenced truth judgments.

Dougal and Schooler (2007) was itself an extension of the Revelation Effect (Watkins & Peynircioglu, 1990). The Revelation Effect (RE) is a robust phenomenon where an initially disguised item is "revealed" to a participant, which can lead them to believe that they have seen the word before. The RE can be occasioned by a variety of different disguise paradigms, including word scrambling, distortion, rotation, transposing, arithmetic tasks, and more (Watkins & Peynircioglu, 1990; Westerman & Greene, 1996). The RE is an influential demonstration that memory is malleable, and that the phenomenological content of the present is important for informing judgments about the past. Bernstein, Whittlesea, and Loftus (2002) conducted a particularly relevant instantiation of the RE in the context of world knowledge. In one experiment, they presented participants with general knowledge facts and a true or false judgment. Half of the items were presented with an anagram, and half without, similar to our design. Crucially, the participants used an algorithm such as {2, 1, 6, 3, 5, 4, 7} so that they could always successfully find the solution to the anagram (any failed attempts were removed from analyses). They found that in the trials with the anagram, participants were more likely to rate the proposition as true, for both true and false facts. Although the RE paradigm is similar on the surface to Dougal and Schooler (2007) and our experiment, there are some important distinctions.

In Dougal and Schooler (2007), all participants experience 'revelation': an anagram followed by the revealed solution. The crucial question in Dougal and Schooler (2007)—and in our experiment—is whether or not the participant successfully solved the anagram themselves, and how this influences subsequent judgments. In Bernstein et al., (2002), they only analyse trials that are solved. Thus, RE experiments don't evaluate whether or not the *solving experience*—or Aha! moments—have an impact on truth judgments. In the rare cases where authors have compared solved versus unsolved items, they find no difference in the memory effects, possibly owing to the presence of the algorithm (Bernstein et al., 2002). Put simply, the main difference is that our experiment is concerned with the solving experience occasioned by the anagram, whereas previous work on RE is focused on the mere presence of another task.

Although our primary interest was comparing truth judgments within-participants for solved and unsolved anagrams (with and without Aha!), we also included a between subjects variable so that we could investigate baseline truth judgments without the anagram. If we find a baseline difference between the presence of the anagram and no anagram, this is equivalent to finding the Revelation Effect. We also included a condition where the key word—the same word that was scrambled in the anagram condition—was presented after a short delay. Solving an anagram inevitably leads to a delayed presentation of the key word that completes the proposition, and we wanted to ensure that the delayed presentation (which may itself elicit a miniature Aha! moment) was not accounting for any effects we observe.

We hypothesised that participants will rate propositions as more likely to be true if they successfully solved the anagram. We also expected that solved anagrams accompanied by Aha! moments would lead to higher truth judgments than solved anagrams without Aha!. We expected that participants in the anagram condition would rate propositions as more likely to be true on average than participants in the no anagram condition, which would be evidence of the RE. After data collection we added two hypotheses to the preregistration (prior to doing the analysis), because we realised there might be an interaction between solved and unsolved anagrams in the between condition. We predicted that, if analysis is constrained to anagrams that are solved more often, then we ought to find higher truth judgments in the anagram condition. On the other hand, we expected no difference between conditions for anagrams that were solved less often. If anagrams are not being successfully solved, then there are presumably no Aha! experiences to increase the truth judgments. This analysis also permitted us to evaluate whether the mere presence of the anagram was sufficient (as in RE), or whether solving the anagram was necessary.

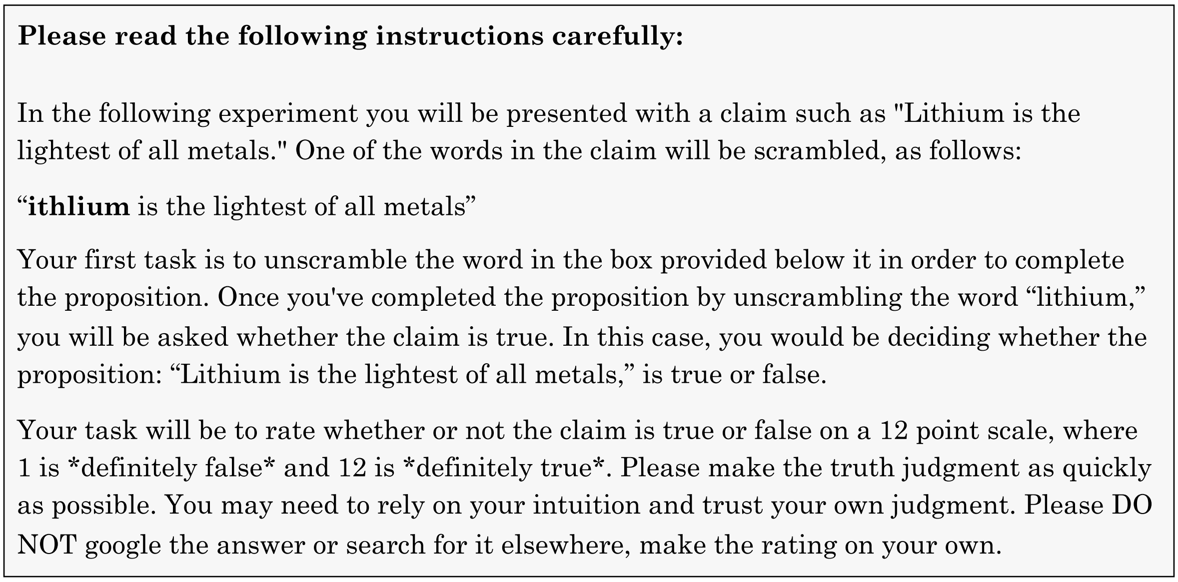
Experiment 3 Method

Design & Materials

This experiment was approved by the University of California, Santa Barbara, Human Subjects Committee, clearance number: 81-18-0543, in accordance with the Declaration of Helsinki. The experiment had three within participant variables: 2 (Proposition: true or false) x 2 (Problem: solved or unsolved) x 2 (Aha! Experience: yes or no), and one between subjects factor (Anagram: present, absent, and absent with delay). The dependent measure of interest was truth judgments on a 12 point scale ranging from 1 (definitely false), to 12 (definitely true). All participants were presented with the same 26 propositions (13 true and 13 false) and those in the anagram condition were also presented with 26 anagrams derived from the propositions (materials can be found on the OSF: https://osf.io/up98z/). In the delay condition, the missing word in the proposition was presented with a 15 second delay in order to mimic the anagram condition as closely as possible.

Participants and Procedure

Based on Dougal and Schooler (2007), we determined that 300 participants (100 in each condition) would provide sufficient power (.8) to detect an effect size of .4, which they observed in Experiment 1. Participants were recruited using Amazon Mechanical Turk. All participants were provided with written instructions, and randomly assigned to either the anagram, no anagram, or delay condition. Instructions provided to participants in the anagram condition are illustrated in Figure 7 below.



Please read the following instructions carefully:

In the following experiment you will be presented with a claim such as "Lithium is the lightest of all metals." One of the words in the claim will be scrambled, as follows:

"**ithlium** is the lightest of all metals"

Your first task is to unscramble the word in the box provided below it in order to complete the proposition. Once you've completed the proposition by unscrambling the word "lithium," you will be asked whether the claim is true. In this case, you would be deciding whether the proposition: "Lithium is the lightest of all metals," is true or false.

Your task will be to rate whether or not the claim is true or false on a 12 point scale, where 1 is *definitely false* and 12 is *definitely true*. Please make the truth judgment as quickly as possible. You may need to rely on your intuition and trust your own judgment. Please DO NOT google the answer or search for it elsewhere, make the rating on your own.

Figure 7. Instructions provided to participants in the Anagram condition. The instructions were similar in the other conditions except that we removed any mention of the anagram.

Each trial proceeded as follows. The participants were first presented with the incomplete proposition, for example: “There are more than 100,000 craters on the…”. Below the incomplete proposition participants were presented with an anagram that completes the claim, in this case they see the word “*nomo*” (moon). When the anagram is resolved participants see the completed proposition as: “There are more than 100,000 craters on the moon.” If the anagram was not solved within 20 seconds then the solution, “moon”, was presented. Participants then made a truth judgment about the claim, after either solving it themselves or having the solution presented to them. Finally, on a new screen, participants reported whether they experienced an Aha! moment (yes or no). The transcript for our description of the Aha! moment didn’t deviate from previous work in any important ways, and can be found in the preregistration: https://osf.io/up98z/.

In the No Anagram condition, participants were simply presented with the completed proposition: “There are more than 100,000 craters on the moon.” They then made a truth judgment about it, and then, for consistency, also reported on their Aha! experience. The delay condition was the same, except that participants were presented with the key word after 15 seconds, which was approximately the same time it took to solve the anagrams. For example, they were shown the claim, “There are more than 100,000 craters on the …”, then after 15 seconds, they were presented with the completed proposition “There are more than 100,000 craters on the moon.” At the end of each condition participants reported their demographic information and completed three manipulation checks.

Decision Rules

All decision rules were prespecified on the OSF. Participants were asked, “did you find the answers to any of the questions online or elsewhere?”. If the answer was yes, they were removed. Participants were asked if they experienced any Aha! moments. If the answer was ‘I don’t know,’ or ‘No,’ the participant was removed. Participants were asked, “Is English the language you are most comfortable using?”. If the answer was no, the participant was removed. An anagram was classified as solved if a correct solution was entered within the 20 second time limit. A correct solution was coded if the unscrambled word completed the proposition, and minor misspellings were accepted. Any participant who failed to complete the full experiment was removed. Any participants who failed to solve more than 80% of the anagrams were removed. Any participants providing more than 80% consistent truth judgments (e.g., always indicating that propositions are false) were removed. Any participants who provided more than 90% consistent Aha! experiences (e.g., always saying they experienced an Aha! moment) were also removed.

Experiment 3 Results

Descriptives

After applying our decision rules, 268 of the 300 participants were included in the analyses. Anagrams were successfully solved 53% of the time (*SD* = .17). Unsurprisingly, participants provided higher truth ratings for true claims (*M* = 6.92, *SD* = 1.39), and lower ratings for false claims (*M* = 5.9, *SD* = 1.44), and the difference was meaningful, $t(267) = 13.8$, $p < .001$, $d = .84$. The anagrams were correctly solved 60% of the time and elicited insights 39% of the time, and consistent with previous work (Salvi et al., 2016), we found that anagrams accompanied by insight were more likely to be correctly solved (*M* = .71, *SD* = .3) compared to anagrams not accompanied by insight (*M* = .5, *SD* = .56), $t(67) = 3.94$, $p < .001$, $d = .48$. The following analyses deviate slightly from the preregistration. We couldn't run the between- and within-subjects factors together (as planned) because the within-subjects factors are only present in the anagram condition, and not the others. Therefore, we ran separate analyses for the within-subjects factors, and then an ANOVA to evaluate the between-subjects manipulation.

Truth Judgments In the Within-Subjects Anagram Condition

We predicted that when a participant successfully solves an anagram, rather than being presented the solution, they will be more likely to believe that the associated proposition is true. We also predicted that Aha! moments occasioned by solving the anagram would increase truth judgments. The results are illustrated in Figure 8. As predicted, solved anagrams resulted in higher truth ratings than unsolved anagrams, $t(68) = 5.06$, $p < .001$, $d = .609$. Moreover, if participants reported experiencing an Aha! moment when solving the anagram, they provided higher truth ratings than on trials without Aha!, $t(68) = 5.23$, $p < .001$, $d = .629$.

We also explored whether Aha! moments resulted in higher truth judgments specifically for anagrams that were solved. We found that they did—solved anagrams accompanied by Aha! resulted in higher truth ratings ($M = 7.2$, $SD = 1.94$) than solved anagrams without Aha! ($M = 6.31$, $SD = 1.87$), $t(64) = 2.59$, $p < .006$, $d = .321$.

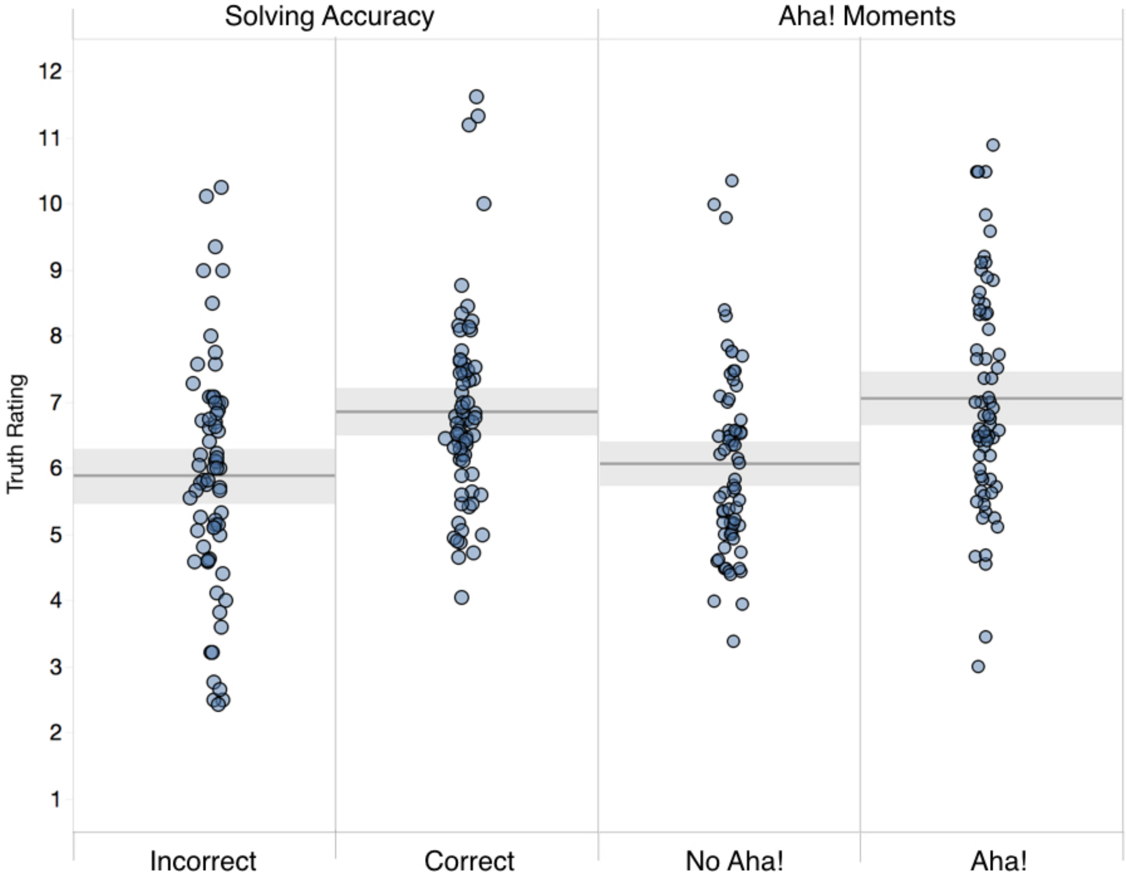


Figure 8. Left: Truth judgments as a function of incorrectly and correctly solved anagrams. Right: Truth judgments as a function of the presence or absence of Aha! moments. Shaded areas represent 95% confidence intervals.

It's possible that solving anagrams has a differential effect on truth judgments for propositions that are true versus false. To test this possibility, we subjected the data to a repeated measures ANOVA, $F(3) = 14.5$, $p < .001$, $\eta p^2 = .178$. Planned comparisons indicate that solving anagrams had a significant effect on truth judgments both when the claim was true, $t(201) = 4.642$, $p < .001$, and when the claim was false, $t(201) = 2.699$, $p = .008$. The results are illustrated in Figure 9 below.

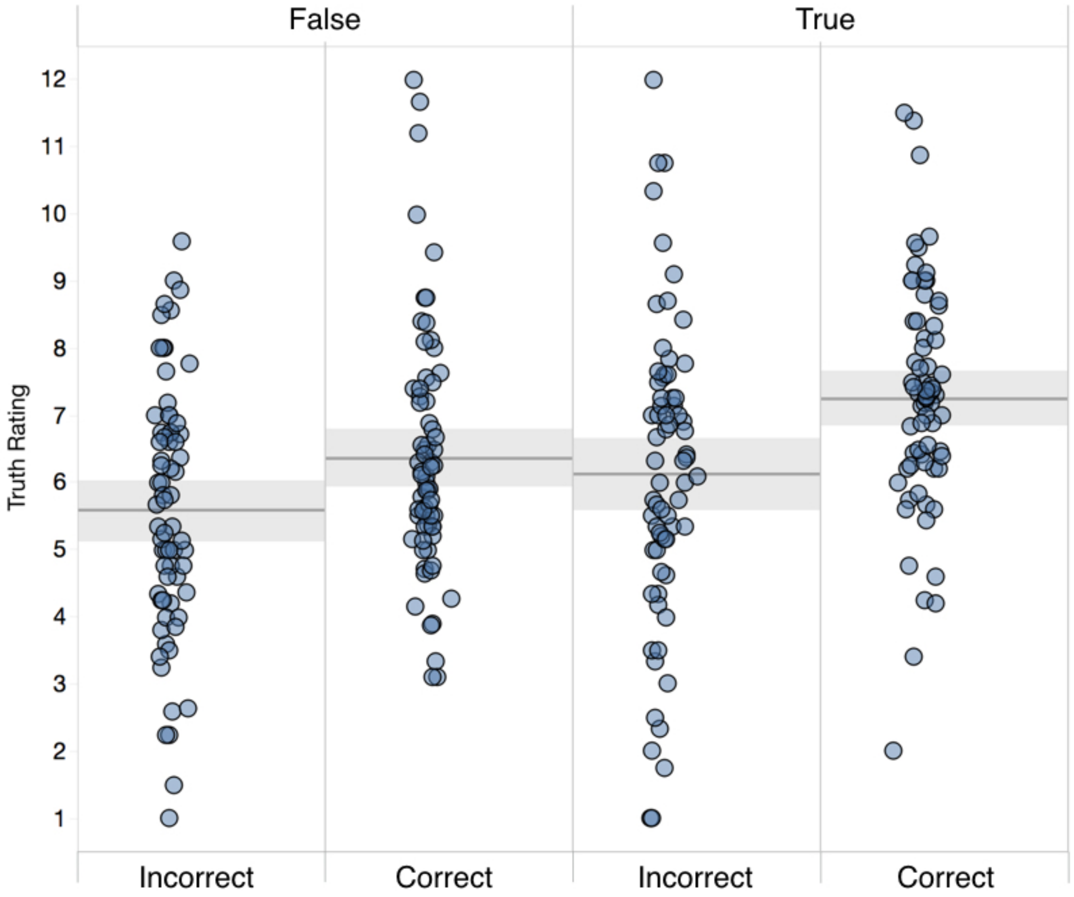


Figure 9. Left: Truth judgments for false claims as a function of correctly and incorrectly solved anagrams. Right: Truth judgments for true claims as a function of correctly and incorrectly solved anagrams. Shaded areas represent 95% confidence intervals.

Truth Judgments in the Between-Subjects Conditions

We first evaluated whether there was an overall difference in truth judgments in the three conditions: Anagram, No Anagram, and Delay. The ANOVA produced a marginal effect, $F(2) = 2.7$ $p < .069$, but none of the post hoc comparisons were significant. Therefore, the presence of the anagram—including both solved and unsolved trials—did not have an overall influence on truth judgments, and neither did presenting the key word after a delay. This result indicates that we did not find evidence of revelation.

We then conducted the same analysis for anagrams that were solved more than 70% of the time, and then again for anagrams that were solved less than 30% of the time. For anagrams that tended to be successfully solved, the main effect of condition was marginal, $F(2) = 2.8$, $p = .062$. Planned comparisons showed a difference between the Anagram condition and the Delay condition, $t(265) = 2.234$, $p < .026$, and a marginal difference between the Anagram condition and the No Anagram condition, $t(265) = 1.955$, $p < .052$. The direction of these effects were such that the Anagram condition lead to the highest truth ratings ($M = 7.025$, $SD = 1.5$) relative to the Delay ($M = 6.51$, $SD = 1.5$) and the the No Anagram condition ($M = 6.57$, $SD = 1.51$). On the other hand, for anagrams that tended not to be solved (less than 30% of the time), we found no difference between the conditions, $F(2) = 1.02$, $p = .363$.

Taken together, we found that the mere presence of the anagram is not sufficient to increase truth judgments between-subjects, instead—as in the within-subjects effects—it's necessary that the participants successfully solve the anagram themselves in order for it to influence truth judgments. In other words, we don't find evidence that revealing the solution to the participant is sufficient (as in RE experiments), but instead it is important that the participant independently discovers the solution (as found in Dougal & Schooler, 2007).

Experiment 3 Discussion

In Experiment 3, we tested whether solving an anagram and eliciting Aha! moments influenced truth judgments about a claim that was presented concomitantly. We reasoned that if people use their insight phenomenology heuristically, then they should provide higher truth judgments overall when an Aha! experience occurs, because they misattribute the phenomenology to the general knowledge claim. Our results were in line with the predictions. When a key word in a proposition was scrambled, and the participants successfully unscrambled the word, then they provided higher truth ratings compared to when they failed to solve the anagram. This result is similar to Dougal and Schooler (2007), who found that solving anagrams influenced memory judgments in an old-new paradigm. In our case, solving the anagram influenced *truth* judgments regarding an entire proposition. We also evaluated whether Aha! moments triggered by the anagram were influencing truth judgments above and beyond simply solving the anagram. Here we found that solved anagrams that elicited Aha! lead to higher truth judgments than solved anagrams that did not trigger Aha!. We interpret these results as follows: solving anagrams is leading to feelings of insight, which is being misattributed to the proposition, such that the general knowledge claim appears more true. The impact of solving anagrams on truth judgments was found for both true and false claims.

The between participants effects were less clear-cut. We initially expected an overall increase in truth judgments for the condition with the anagrams compared to the controls, in line with previous work on RE (Watkins & Peynircioglu, 1990; Westerman & Greene, 1996; Bernstein et al., 2002), but we found no difference. From the perspective of Aha! misattribution, this result is not surprising. If approximately half of the anagrams were solved, and less than half of those anagrams elicited Aha! moments, then an overall increase in truth judgments would be unlikely. The impact on truth judgments ought to be present exclusively for anagrams that are solved. To investigate this possibility, we conducted the same comparison specifically for anagrams that were solved more than 70% of the time. Here we found a difference, such that the anagram condition lead to the highest truth ratings overall. However, for anagrams that tended not to be solved (less than 30% of the time), there was no difference between the conditions. This result further indicates that the independent discovery of the solution by the participants, and the subsequent Aha! experiences, are the key elements for influencing truth judgments.

General Discussion

These experiments sought to consolidate previous work investigating the relationship between feelings of insight and the accuracy of problem solving solutions, and to test whether insight experiences are interpreted as a signal of truth (Danek et al., 2014; Salvi et al., 2016; Webb et al., 2016; Danek & Wiley, 2017; Hedne et al., 2016; Laukkonen et al., 2018). Experiment 1 indicated that when participants report feelings of insight immediately as they appear, those feelings positively predict the accuracy of the solution they then provide, specifically in problems involving implicit processing. This finding, which employed a dynamometer, provides less opportunity for metacognitive reflection than the self-report methods used in previous work. Experiment 2 investigated the relationship between insight and accurate problem solving in a context outside of toy laboratory problems, and showed that the feeling of Aha! also predicted accurate solutions in a sensory identification task reminiscent of everyday life. Experiment 3 tested whether truth judgments can be biased by eliciting an Aha! moment. The results show that successfully solving an anagram at the same time as reading a general knowledge claim resulted in higher truth ratings. We also found that the highest truth ratings were provided when solving the anagram elicited an Aha! moment, indicating that participants were being biased by their feelings of insight to believe that the claim was true.

Does insight phenomenology really carry information about the quality or veracity of an idea? An alternative explanation is that there is something concomitant to the Aha! experience—a confound of some kind—that predicts both the presence of Aha! and more accurate problem solving solutions. We considered that confidence is one such candidate. However, capturing the insight experience very close to real-time —before the participants had a chance to reflect on the quality of the solution— seemed not to diminish its predictive power. We also found that the participants' natural tendency to squeeze the dynamometer harder when more intense insight experiences occurred, predicted the accuracy of the solution above and beyond the presence of insight (despite the fact that participants were not instructed to squeeze harder for more intense insights). Therefore, the intensity of the insight experience— as captured by both self-report and the dynamometer—may provide further information about the veracity of the solution to the conscious mind. It would make sense that solutions that are less likely to be correct elicit smaller Aha! moments, and solutions that are more likely to be correct elicit more intense insight experiences. The data therefore seem to generally support the notion that the feeling of insight is indeed the key element in predicting correct responses, and therefore can be said to 'carry information' about the quality of a new solution that appears in mind, at least in contexts of metacognitive uncertainty (Schwarz, 2011).

One question is whether the Aha! experience carries information about the veracity or quality of an idea (Schwarz, 2011), another question is whether people interpret—in an automatic and largely unconscious way—their Aha! experiences as a signal that a good solution or idea has been discovered. The results of Experiment 3 point to the affirmative: Aha! moments can be misattributed to a different context that is temporally coincident to the feeling (similar to Dougal & Schooler, 2007; and as predicted in Laukkonen, Schooler, & Tangen, 2018). The results from these three experiments, and previous work, seem to place the insight experience comfortably among other heuristics that people use to make quick decisions under uncertainty (Gigerenzer & Gaissmaier, 2011). Just as people turn to availability or representativeness (Kahneman & Tversky, 1973; Tversky & Kahneman, 1973), they too may turn to their insight experiences as a shortcut in place of a lengthy and effortful review of the evidence (Laukkonen et al., 2018).

In Light of Revelation Effects

Some further discussion of Experiment 3 in the context of Revelation Effects is warranted. Dozens of experiments have found that disguising a word before revealing it makes it more likely to be 'remembered' even if the word is being presented for the first time (Peynircioglu & Watkins, 1988; Watkins & Peynircioglu, 1990; Westerman & Greene; 1998; Westerman & Green, 1998). Dougal and Schooler (2007) made a key extension to these REs, by observing that participants who independently solved an anagram, were more likely to report that the word was old, compared to participants who failed to solve the anagram (over and above 'revelation'). Dougal and Schooler (2007) summarise their contribution as follows:

> "…effects of solving cannot be characterised as a form of revelation, because in this paradigm, both the solved and the unsolved items are "revealed" in the sense that their identities are initially obscured and later exposed. Because revelation is held constant for the solved and the unsolved items, it seems that revelation per se cannot be the source of the effect."

In Experiment 3, we made a similar extension to Bernstein et al., (2002), who showed that obscuring words as anagrams could increase the perceived truth of associated claims. Bernstein et al., (2002) made sure that participants solved the anagram by providing them with an algorithm to do so (and removed any that were not solved). Instead, we allowed participants to either fail at solving the anagram or to independently solve it themselves (as in Dougal & Schooler, 2007). In so doing, in our experiment we found that the key ingredient for influencing truth judgments was that the participants independently solved the anagram, and that they experienced an Aha! moment. When we included unsolved anagrams (where the solution was revealed but not independently discovered), we failed to find an overall increase in truth judgments. In other words, we failed to find evidence of revelation—it was not sufficient to present participants with an anagram, and then the solution to that anagram, to influence their truth judgments.

One major difference between our study and Bernstein et al. (2002) is the presence of an algorithm. The algorithm permits the participant to gradually reveal the solution of the anagram, rather than 'discover' the solution in a more sudden and complete way that is reminiscent of insight. In Experiment 6 of Dougal and Schooler (2007), they found that the solving effect on memory judgments is attenuated by the presence of an algorithm. In a similar fashion, our results may indicate that the RE is attenuated by the *absence* of an algorithm, and/or perhaps the presence of unsolved (but revealed) anagrams (at least in the context of truth judgments). One fruitful investigation for future research is to compare solving experiences, and their associated truth ratings, when solving anagrams with and without the presence of an algorithm (which is a question that we are currently addressing: https://osf.io/qkx9p/).

In Light of Fluency Effects

Our results—again particularly those of Experiment 3—are relevant to recent discussions regarding the role of fluency in the Aha! experience. Topolinski and Reber (2010) described fluency as the "glue between its [the Aha! moment's] experiential features." At least some of the elements of insight phenomenology do seem reminiscent of fluency, such as cognitive ease and pleasure. Fluency also appears to impact truth judgments (Newman et al., 2012; Newman et al., 2014). Could a sudden increase in processing fluency account for our results? In Experiment 3, all participants were presented the solution to the anagram, and therefore fluent (i.e., smooth and easy) processing of the previously obscured word ought to be experienced regardless of solving success. Nevertheless, we found that the solutions that were independently discovered lead to higher truth judgments than simply revealing the solution. One possibility then, is that independently discovering the solution leads to greater fluency than the unsolved but revealed anagrams, and that solved anagrams that elicited Aha! moments lead to the strongest sense of fluency of all. We can't exclude this possibility, but it is unclear why a revealed solution would result in less ease of processing than a discovered solution, and why some discovered solutions are processed still more fluently than others. For now, it seems more parsimonious to assume that the Aha! experience—which the participants can easily report and therefore can be empirically tested—is the driving factor. The immediate sense of obviousness that accompanies insight experiences seems to be a particularly important phenomenological component for influencing truth judgments, which appears different to the phenomenology of 'easy processing'.

A more general question is whether feelings of insight and feelings of fluency are dissociable. The Cognitive Reflection Test (CRT) is known for its ability to elicit an initially fluent response that is incorrect, which needs to be overcome in order to find the correct solution (Frederick, 2005). Here is one example: "A bat and a ball cost \$1.10 in total. The bat costs \$1.00 more than the ball. How much does the ball cost?" The fluent answer is 10 cents, but the correct answer is 5 cents (if the answer was 10 cents, then the bat would be only 95 cents more than the ball). One prediction for future research is that, while fluent responses may result in incorrect solutions to CRT problems, insights on the other hand, will be associated with correct responses. If this is the case, then feelings of insight cannot easily be reduced to fluency, since fluency may be the very experience that needs to be ignored so that an insight may occur. This pattern is also described in theories of Representational Change (Ohlsson, 1984) and classic insight problem solving, where the initial interpretation of the problem—i.e., the fluent interpretation—needs to be restructured in order to discover the true solution and experience insight.

Summary and Future Directions

There is a certain mystery about an idea that suddenly strikes the conscious mind, as if totally complete and true. Research has substantially progressed our understanding of the kinds of problem solving processes that precede sudden solutions, and the best way to elicit insight experiences (Maier, 1931; Schooler & Melcher, 1995; Sternberg & Davidson, 1995; Ohlsson, 1984, 2011; Öllinger & Knoblich, 2009; Laukkonen & Tangen, 2016). A less explored level of analysis is the role of insight in judgment and decision-making. We propose that humans interpret their feelings of Aha! heuristically as a signal regarding the quality of a new idea. The results of Experiment 1 and 2 (and previous research on the insight-accuracy relationship) indicate that feelings of insight, and their intensity, can carry useful information about the validity of a solution (Danek et al., 2014; Salvi et al., 2016; Webb et al., 2016; Danek & Wiley, 2017; Hedne et al., 2016; Schwarz, 2011). Experiment 3 indicates that people interpret these feelings as a signal that a correct solution has been found, which is a functional behaviour assuming that the insight experience has genuine informational value to the problem solver. Experiment 3 also indicates that this interpretive process can be overgeneralised, such that the insight experience may be misattributed to another stimulus if it is presented concomitantly.

The fact that insight experiences can be used to bias truth judgments opens many avenues for future research. What other decisions can foreseeably be influenced by the presence of an artificially elicited insight experience? For one, the same methodology could be used to bias judgments specifically about problem solving solutions. If candidate solutions to creative problems are presented as anagrams, then solved anagrams that elicit insight experiences are likely to be judged as better solutions to the problem (compared to both unsolved anagrams and solved anagrams without Aha!). Another possibility is that insight experiences could influence opinion change. For example, the statement “happiness is a matter of *erpecpivtes,*” could be made to seem more believable if the scrambled word “*perspective”* is solved and elicits an Aha! moment. Other ways of artificially eliciting insights are also of interest; CRA problems or rebus puzzles could foreseeably be used to elicit insights in different contexts. How far can Aha! misattribution generalize? Could Aha! moments elicited while reading a news article lead to an overgeneralised sense of truth about its contents? A disconcerting possibility, but a possibility nonetheless.

In some instances, it is clearly disadvantageous to rely on phenomenology to decide whether an idea is true or not. For example, if one is suffering from a psychotic episode or mental illness (as in the case study of John Nash), or one has been exposed to false information, then the intensity of the insight may have no predictive power at all, and may instead promote false beliefs and perhaps in some cases perpetuate dangerous ideologies. Experiment 3 also highlights the concern of overgeneralising feelings of insight. Presentations, news articles, advertising, and other media, may seek to exploit experiences of insight as a tool of persuasion, and may already unwittingly do so. Therefore, while it is useful to know that phenomenology carries information that can be used adaptively, it is perhaps even more productive to know that the process can be jeopardised, and that a sudden feeling of certainty does not have a one-to-one relationship with objectivity.

Context

The initial idea that inspired this series of experiments arose from the simple question: What is the function of the insight experience? We discuss the details of our view of insight experiences as a heuristic in more detail in another paper (Laukkonen, et al., 2018). We are generally curious about how humans evaluate their own ideas. Given that there are manifold thoughts appearing in mind at any given moment, it is interesting to know why some thoughts and ideas are dismissed as meaningless distractions while others are grasped as significant or profound.

General Discussion

Looking back on life, the moments that stood out to me as psychologically important, perhaps even transformative, were all marked by a series of insight experiences that were usually precipitated by a conflict between my beliefs and a stream of new information or experiences. When such a conflict occurs, at first only small parts of the old worldview give way, like a cliff face that is slowly battered by waves. Then a cave begins to form in the wall—in the old belief structures—and the cliff is held together by nothing more than a few pillars of rock around a growing cavern. Eventually the pillars become too thin and all at once, the whole thing comes crashing down. An entirely new vantage point is discovered. From this new perspective, many discoveries can be made, and the insights can seem inexhaustible. As time flows on, new belief structure emerge, now somewhat more stable but still never impenetrable. The ocean is too vast—new cracks always form and new shores are discovered, and new insights emerge once again.

It was true to my experience that new perspectives were an important ingredient for insight moments, and it appears to be so in laboratory experiments as well. So-called bistable images, discussed primarily in Chapter 1, illustrate this fact well. The same visual information viewed through a different lens can elicit a surprising discovery that—once seen—seemed to have been there all along. The sheer obviousness of the new image can hardly be overstated, yet it was entirely ‘not there’ just a moment before. The same experience occurs in the mind’s-eye when we solve tricky problems or when we become overly constrained by our past experiences, and fail to realise that everyday objects can be used to do something they have not done before (Maier, 1931). What we see in the big events of our lives—when worldviews change and new discoveries are made—we also see on a smaller scale, when a series of dots transforms into a Dalmatian dog (see Figure 1 below), or when we finally remember the name of a familiar song on the radio.

Figure 1. A number of black blots that appear without any particular structure until a few key words, like 'dog' or 'Dalmatian' are read or heard, at which point the figure can appear to suddenly reveal a dog walking while sniffing the ground.

In the beginning I was so fascinated by the aptness of the analogy between visual restructuring and insight that I designed the experiments detailed in Chapter 1 to see if there was something more to the metaphor. There was no obvious reason why changing perspectives in a visual domain would have anything to do with solving conceptual creative problems, if one didn't have some sense for why they were similar. Since both involve a kind of restructuring of assumptions (Ohlsson, 1984), then it could be that some people possess the skill of 'restructuring' to a greater degree than others, and that restructuring in one domain might predict restructuring in another. There was already some research pointing in this direction, so it seemed worth pursuing further (Doherty & Mair, 2012; Jarosz, Colflesh, & Wiley, 2012; O'Brien et al., 2013; Schooler & Melcher, 1995; Wiseman et al., 2011). In Chapter 1, we first replicated previous work showing a fairly compelling positive correlation between participants' ability to discover two images in one picture, and their ability to solve creative problems that also involve restructuring (Schooler & Melcher, 1995). We also found that the metacognitions participants were reporting during these problems were similar—both lead to sudden ‘insight-like’ solutions relative to analytic problems that don’t tend to involve restructuring. Drawing on the cognitive neuroscience of insight (Kounios & Beeman, 2014) and Conflict Monitoring Theory (Botvinick et al., 2001), we then hypothesised that both creative problem solving and restructuring visual images may draw on the common resource of cognitive control, which implicates the anterior cingulate cortex (where activation is observed during conflict and when solving insight problems, Kounios & Beeman, 2014). Given conflict adaptation effects observed with other stimuli—where presenting one conflicting stimulus makes another similar stimulus easier to process—we hypothesised that observing a bistable image could make it easier to solve insight problems that were presented subsequently. Put simply, we expected that looking at a Necker cube would put participants in the right ‘state’ for solving insight problems and experiencing more insights. We were excited to find that it worked.

I have some regret that I didn’t pursue the findings in Chapter 1 further, and have intentions to do so in the future. More fundamental questions regarding insight were emerging and so took precedence: our understanding of insight is at least partly contingent on our methods, so if we really wanted to make progress we ought to be sure that our tools were suitable. I began to think carefully about what methods were being used, which eventually culminated in a paper, and Chapter 2 of this thesis. In our paper, we compared empirically the two popular methods for detecting insight moments, and found that they often diverged—where the warmth measure indicated no insight, people still often self-reported insight experiences, and vice versa. To us, this wasn’t all that surprising because we already had good theoretical reasons for why they might come to different conclusions. On the one hand, the warmth measure of insight taps into the metacognitive experience of the participant during problem solving up until they reach a solution (Metcalfe & Wiebe, 1987). On the other hand, the self-report measure captures the extent to which participants experience an ‘Aha!’ moment, with all its unique phenomenology (Bowden & Jung-Beeman, 2007). There is no reason that a sudden solution is necessarily one that fills you with certainty and pleasure, and it’s quite possible that a solution that looks like it was analytic can induce a sense of Aha!. For example, it’s possible to make progress on a problem, only to realise that the progress has been an illusion, and at the same moment discover the right way of looking. One discovers that one has been barking up the wrong tree, so to speak. In the case of insight problems, the participant has failed to restructure the problem and continues to believe the incorrect representation is productive, and therefore reports that they are making gradual progress. Then, suddenly their perspective may change, and the solution is discovered. Indeed, our results suggest that gradual warmth ratings seemed to have no bearing on whether an insight experience was self-reported. The key here—for triggering an insight—is that the new solution is subjectively sudden *relative* to the perceived progress occurring prior. A predictable (analytic) solving experience occurs when the solution is the logical conclusion to the perceived progress leading to that point. In other words, our view (and data) suggest that impasse in problems involving restructuring is not necessary for an insight experience, only a misunderstanding (i.e., a misrepresentation).

As a response to the limitations of existing methods, at the end of Chapter 2 we proposed a new tool for detecting metacognitions during problem solving (akin to a highly sensitive version of the warmth measure), that might also capture the insight experience in real-time. We suggested that the dynamometer—a highly sensitive measure of grip-strength—might be particularly valuable in the context of insight because of its embodied nature, and so it might be better able to represent its visceral elements than existing verbal measures (Creswell et al., 2016; Bowden & Jung-Beeman, 2007). We found some evidence of this in Chapter 3, when participants naturally—i.e., without instruction—embodied the intensity of their Aha! experiences (and this natural embodiment mapped onto the accuracy of the solution they provided). There are also numerous methodological advantages to the dynamometer. For one, it is able to capture interactions between the metacognitions that lead to insight and also the phenomenology of the experience, combinations of which may involve unique cognitive processes and have unique behavioural outcomes. It is also far more sensitive to variation in warmth (on the y-axis) and minute changes over time (on the x-axis). Compared to the traditional warmth measure—which captures one data point every 15 seconds or so (Metcalfe & Wiebe, 1987)—the dynamometer captures 10 data points per second. A lot can happen in 15 seconds, especially considering many creative problems can be solved in less than that (Bowden & Jung-

Beeman, 2003). Finally, the dynamometer can capture insight experiences in real-time, which we think is valuable for reasons discussed shortly.

As my attention shifted to measuring insights, and therefore to insight phenomenology, I started to wonder why such feelings occur at all. Why should we get a rush of pleasure or any sense of Aha!? One would think that the value of a new solution would simply be transparent to the mind that discovered it. There is however much about the mind that is hidden from conscious view. Experts have intuitions that they can't articulate, or the source of which they can't access (Kahneman, 2015). In such cases—like the expert chess player who 'knows' the best move without any deliberation (Ericsson & Charness, 1994)—the mind may release only subtle clues to consciousness about the gamut of processing occurring below. I began to consider whether a similar process might be occurring in the context of problem solving. Just like the expert chess player can get an immediate sense for the next best move, the scientist, inventor, or artist can have an insight experience that instills them with an immediate sense that they've found the 'next best idea' (Gick & Lockhart, 1995; Nisbett, 2015). In general, the conscious access we have to cognitive processes is strikingly limited (Nisbett & Wilson, 1977). In the case of problem solving, subliminal primes can evoke solutions without one's awareness (Maier, 1931; Bowden, 1997), and solutions to problems can appear in mind unexpectedly even if the conscious mind's ruminations are from the problem being inadvertently solved (Ovington et al., 2015). In the absence of conscious access to complex problem solving processes occurring below awareness, informative feelings may provide a productive heuristic alternative. For the same reasons that a chess player's intuitions make them much more efficient players, our feelings about our ideas may make us much more efficient creators and problem solvers.

The reasoning above is also consistent with much present theorising on the broader role of feeling in cognition and decision-making (Damasio et al., 1994; Slovic et al., 2007; Schwarz, 2011). According to these models—which are well supported by empirical findings—judgments and decisions are guided by feelings that can carry important information, and provide valuable cues about the best course of action (particularly in situations of uncertainty, Slovic et al., 2007). I couldn't—given this background—see why the insight experience would be different, and the more I learned, the more reason I had to believe that it too served an important function (rather than being purely epiphenomenal, or simply a reaction to having found a solution, as has been proposed, Klein & Jarosz, 2011). In Chapter 4, we attempted to elaborate what that function might be, and proposed the Eureka Heuristic as a model for understanding the role of insight experiences in decision-making. In the Eureka Heuristic, we drew on evidence from a diverse literature, including traditional views on insight problem solving (Ohlsson, 1984; Maier, 1931), heuristics and biases (Tversky & Kahneman, 1975; Gigerenzer & Gaissmaier, 2011), self interpretation and introspection (Nisbett & Wilson, 1977; Johansson et al., 2006), and the cognitive science of feelings and affect (Damasio, 1996; Slovic et al., 2007; Schwarz et al., 2016). We suggested that, the feeling of insight that accompanies some ideas, is a signal that people rely on as a shortcut for a lengthy and deliberate evaluation of the idea. The value of insight is in providing a fast and frugal appraisal of a new solution so that a quick decision can be made, which is valuable in many circumstances in everyday life (and critical in others, like the Mann Gulch Fire). We also made a number of novel predictions, expecting that—like other heuristics—the Eureka Heuristic may lead to predictable biases. We discussed the 'insight fallacy,' where a solution is believed to be true purely because it was accompanied by an insight experience, and the potential risks of false beliefs and dangerous ideologies therein. We also hypothesised that the insight experience could be misattributed to bias judgments, much in the same way as fluency or familiarity (Alter & Oppenheimer, 2006).

In the final Chapter (Chapter 5), we aimed to narrow in on some of the core assumptions of the Eureka Heuristic in order to test them empirically. In Experiment 1, we put aside our work on the dynamometer as a novel measure per se, and focused on the theoretical contribution it could provide by capturing insight experiences closer to real-time. Previous work on the relationship between insight and accuracy relied on self-report (Danek et al., 2014; Danek & Wiley, 2017; Hedne et al., 2016; Salvi et al., 2016; Webb, Little, & Cropper; 2016), and so it was possible that participants' confidence was a confound that explained the insight-accuracy relationship. Insight experiences are associated with confidence, and confidence is associated with accuracy, therefore feelings of insight might not be the variable predicting the accurate responses. Another possibility is that participants reflect on their confidence, and if they feel confident, then they report an insight experience. Both scenarios would undermine the informational value of the insight experience, suggesting that the phenomenology itself doesn't predict accurate responses to the creative problems. Reassuringly, our results indicated that capturing insight experiences much closer to real-time using the dynamometer replicated previous work on the insight-accuracy relationship. Impulsive feelings of insight appeared to be strong predictors of accuracy for problems that involve unconscious processing—what we conceptualise as metacognitive uncertainty—and the intensity of the experience was a further predictor. Therefore we concluded that, in all likelihood, the feeling of insight was a genuine predictor of accurate solutions, affirming its informational value.

In Experiment 2, we sought to test for the insight-accuracy relationship in a task that was more representative of everyday life. We noticed that descriptions of the so-called tip-of-the-tongue phenomenon had a strong resemblance to feelings of insight (Brown, 1991), what was termed the 'pop-up' experience. We developed a set of sensory stimuli—faces, aromas, and songs—that were familiar enough that people ought to know them, but unfamiliar enough that they might have trouble retrieving the identity. We reasoned that these stimuli would provide a good formula for eliciting an initial sense of uncertainty (but familiarity) about the stimulus, followed by a solution that suddenly appears in mind alongside an Aha! experience. We predicted that the insight-accuracy relationship would be observed under uncertainty—a period of time where the participant was unsure about the identity. To illustrate, imagine running into an old college friend that you haven't seen in years. You remember the classes you both attended, and the many conversations you've had together, nevertheless, you can't bring to mind their name. After saying your goodbyes (remembering to ask about their dog, whose name you somehow *do* remember), you then spend the next 10 minutes trying desperately to recall her name. Lots of different names come to you: Kirsty, Brooklyn, Hilary… but you discard each of them as incorrect—not feeling quite right. Then, just as you're about to give up, a name appears in your mind that immediately fills you with a sense of 'knowing': "it was Rachel!," you exclaim. You immediately feel relieved and wonder why it took so long to remember a name you know so well… and how obvious it seems in hindsight.

At least regarding the phenomenology (and not necessarily the processes that lead to the discovery), there appears to be little difference between problem solving insights, and suddenly discovering the identity of a person, the source of a familiar aroma, or the name of a song on the radio. Indeed, visual analogues of insight problems are already regularly used (Schooler & Melcher, 1995; Salvi et al., 2016). Therefore—in line with findings in problem solving—we expected that recollections accompanied by Aha! moments would be more likely to be correct than recollections that were not. We hoped that this result would illustrate the generalisability of the Eureka Heuristic—or at least the broader utility of the Aha! experience—and also show that more subtle feelings of insight occur regularly in daily life. As expected, Aha! moments and their intensity predicted the accuracy of identifications during uncertainty (responses provided after a short delay in reaction time). Given the results of Experiment 1 and 2, and previous work on the insight-accuracy relationship (Danek et al., 2014; Danek & Wiley, 2017; Hedne et al., 2016; Salvi et al., 2016; Webb, Little, & Cropper; 2016), we saw sufficient evidence to conclude that the insight experience does indeed carry useful information about the veracity of new ideas that appear in mind (in line with feelings-as-information theory, Schwarz, 2011). However, do people actually use their insight experiences to appraise their ideas, as the heuristic view would have it?

If people interpret their insight experiences as information about the quality or veracity of an idea, then Aha! moments ought to positively bias truth judgments. Experiment 3 sought to test this hypothesis by artificially inducing feelings of insight while presenting participants with general knowledge facts. We thought that, at least in theory, it might be possible to decouple the insight experience from its contents, such that a 'misattribution' effect occurs (Dougal & Schooler, 2007). Many such effects have been previously observed, where feelings that are artificially induced by one stimulus influence judgments on another (for reviews, see Whittlesea & Leboe, 2000; Carruthers, 2009; Schwarz, 2011). In our experiment, we triggered feelings of insight by scrambling one of the key words in a proposition. For example, we presented participants with the claim *"skanoorga* keep growing until they die." The participants were tasked with unscrambling the word 'kangaroos,' and the proposition would be unclear until they did (solving such anagrams is known to elicit Aha! moments, Novick

& Sherman, 2003). If the participants failed to solve the anagram in 15 seconds, the solution was presented on screen. The participants then judged whether the claim was true or false on a 12 point scale. As we hypothesised in our preregistration, participants who successfully solved the anagram rated the proposition as more true (regardless if it was true or false), and those solutions that were accompanied by Aha! lead to the highest truth ratings of all. Thus, we found evidence that people use feelings of insight heuristically, even when those feelings are irrelevant to the stimulus being judged. Regarding the Eureka Heuristic, we take this result as evidence that people do indeed turn to their Aha! moments as a shortcut for evaluating the veracity of their ideas. Our paradigm was borrowed from Dougal and Schooler (2007) who found a similar effect in the context of memory judgments. We have very recently replicated the Aha! misattribution effect in two more experiments conducted on a total of 1500 participants. Due to time constraints on this thesis, we haven't been able to report them here, but the preregistration can be accessed at: https://osf.io/qkx9p/.

Limitations and Directions for Future Research

There are myriad open questions, unsolved mysteries, and limits to the work in this thesis, and here I'll speak of them in a general sense (since a more specific discussion is provided in the respective Chapters), beginning with our work on the restructuring involved in visual images and insight problems (Chapter 1). First, there is want of replication (as with any new effect). It's also possible that there's an alternative explanation for our finding that observing a Necker cube can lead to more insights and better creative problem solving. We proposed the Conflict Monitoring System—which we still see as the best explanation—but it's possible that there is even an affective explanation for the result. For example, it might be that participants preferred observing Necker cubes (that is, found them more pleasurable and interesting) and so were more motivated to solve the subsequent insight problem (rather than the boredom evoked by staring at a normal cube!). Replications, while also capturing phenomenological states, would provide for an interesting follow-up. Future work may also test whether other conflicting stimuli can be used as a prime to improve insight problem-solving and elicit insight experiences, such as the classic Stroop task (Stroop, 1935). Moreover, neuroimaging evidence would improve our ability to make inferences about the involvement of the Conflict Monitoring System. For example, according to the conflict hypothesis, observing a Necker cube (or a conflicting Stroop stimulus) ought to improve subsequent insight problem solving specifically when it is associated with activation in the anterior cingulate cortex (i.e., the neural marker of conflict, Botvinick et al., 2001).

The dynamometer could be improved with better (particularly more nuanced) methods of analysing the data, and we proposed some alternatives in Chapter 3. Some participants also reported forgetting to squeeze the dynamometer or making mistakes along the way, which could be prevented by training participants for a longer period so that they can use the tool more efficiently and automatically. We also had some expectations that the dynamometer would circumvent verbal overshadowing effects, and therefore represent the insight experience with greater fidelity and minimise interference with the primary task (Creswell et al., 2016). However, we didn't test for verbal overshadowing effects in our experiment. In future research, it would be useful to find out whether the traditional warmth measure (Metcalfe & Wiebe, 1987) interferes more or less with problem solving relative to the dynamometer. The dynamometer could also prove valuable in neuroimaging research, and particularly when using electroencephalography (EEG) in order to capitalise on the high temporal resolution afforded by EEG.

Our experiments in Part 2 suggest that the Eureka Heuristic is a productive outlook on the insight experience, evidenced by the robust insight-accuracy relationship across a variety of tasks, and the finding that participants interpret their Aha! experiences to such an extent that it can be overgeneralised (misattributed) to another stimulus presented concomitantly. Nevertheless, hastily concluding that the Eureka Heuristic is the 'correct' model, or the best model, is probably premature. We've struggled to think of an alternative explanation for the misattribution result, but there are aspects of the Eureka Heuristic view that demand more evidence. For starters, it would be useful to demonstrate that participants have trouble articulating *why* an insight experience is correct. Although Maier (1931) and other work using subliminal hints (e.g., Bowden, 1997) show that the processes leading to insight are often hidden from awareness, it may be that participants can articulate *why* the solution is correct without knowing how they got there (although anecdotes suggest that it can take months or years to verify some insights, Nisbett, 2015). Our expectation is that feelings of insight carry information that's not necessarily articulable, and although it may be correctly articulated in some cases, we suspect that this is mostly a post hoc rationalisation (in line with confabulation research reviewed in Nisbett & Wilson, 1977; Carruthers, 2009, and Johansson et al., 2006). The insight experience is valuable precisely because a conscious understanding of a solution's veracity is not immediately available, and so figuring out why the solution is correct is far less important than simply having a sense that it is. Such a result would not be surprising in the context of other intuitive judgments where the source is difficult to articulate (a compelling example is found in semantic coherence judgments, where a solution to a remote associate is intuited even though the actual word isn't retrieved, e.g., Bolte, Goschke, & Kuhl, 2003).

We have also made specific hypotheses about the kinds of circumstances and states of mind that may attract more false insight experiences—i.e., a breaking down of an otherwise effective heuristic—and testing these is an exciting area for future work. To briefly return to one example: recent studies indicate that certain psychoactive substances—such as psilocybin, lysergic acid diethylamide (LSD), or nitrous oxide—are associated with an unusually high degree of insight or 'revelatory' experiences (Pahnke, 1966; Griffiths et al., 2006). Speaking about his revelations occasioned while inhaling nitrous oxide, William James (1874) wrote that:

> "Ontological emotion, however stumbled on, has something authoritative for the individual who feels it. But the worst of all mystical or simply personal knowledge is incommunicability. To the mere affirmation, "I KNOW that this is truth, therefore believe it!"…"

In James's usual manner, there is considerable information communicated in the one thought, perhaps even the punchline of this thesis. He describes the emotional authority that accompanies certain insight (or mystical) experiences, and laments how difficult it is to articulate the revelation or justify it. All he can say is, "I KNOW that this is truth, therefore believe it!," while knowing full well the insufficiency of such an argument. Yet, this is precisely the way—I have proposed—that insight experiences may function: we get the sense that an idea is true, but knowing *why* is secondary to capitalising on its contents, and so the mind has opted for the more efficient route of feeling rather than understanding (or at least describing). If the feelings that accompany ideas are 'turned up' by certain psychoactive substances, then our usual compass—our feelings of insight—may become a less trustworthy guide. Altered states may, on the one hand, reveal the profundity of ideas that we had not noticed before—or help to uncover new ideas—but 'the dark side of the moon' is the potential for a profound but misleading sense that a bad idea is a good one. The ability to interrupt a person's ordinary insight-reality correspondence in an experimental context may be enormously revealing about the underlying processes involved, and potentially informative regarding mental illnesses associated with delusions and false beliefs.

Concluding Remarks

In pulling the threads of this thesis together, what can we now say that we could not say before? Regarding Chapter 1, we can now say that there is more to the old analogy between sudden insight experiences and bistable illusions, and that they may draw on a shared cognitive process that allows people to change their otherwise constrained perspectives, which is ever so valuable for creativity and learning (Ohlsson, 2011). Regarding Chapter 2, we can now say that the two principal methods used to capture insight moments over the last 40 years were in fact capturing different things (Metcalfe & Wiebe, 1987; Bowden & Jung-Beeman, 2007). Regarding Chapter 3, we can say that the dynamometer is a valuable new tool for capturing both metacognitions during problem solving and the feeling of insight closer to real-time, and there is some evidence that the tool may better represent the visceral and embodied nature of the insight experience. Given Chapter 4, we can say that the Eureka Heuristic is a new way to look at the function of the insight experience in the context of decision-making, as an intuitive appraisal of a new idea appearing in mind. The results of Chapter 5 permit us to say that the insight experience has informational value about the truthfulness of solutions under uncertainty that goes beyond toy problems, and that insight phenomenology can influence decisions even when it is artificially induced, supporting the heuristic view. The overarching contribution of this thesis arises from a kind of temporal 'zooming out,' so that the moments before, during, and after insight experiences are seen as part of a greater functional whole. From a bird's eye view, we may see insight phenomenology as an intuitive sense of truth for ideas that spring from a rich but opaque unconscious.

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