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Investigation of Insight with Magic Tricks: Introducing a Novel Paradigm

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Abstract

This thesis proposes a new approach to investigate insight problem solving. Introducing magic tricks as a problem solving task, we asked participants to find out the secret method used by the magician to create the magic effect. Based on the theoretical framework of the representational change theory, we argue that magic tricks are ideally suited to investigate insight because similar to established insight tasks like puzzles, observers' prior knowledge activates constraints. In order to see through the magic trick, the constraints must be overcome by changing the problem representation. The aim of the present work is threefold: First, we set out to provide a proof of concept for this novel paradigm by demonstrating that it is actually possible for observers to gain insight into the magician's secret method and that this can be experienced as a sudden, insightful solution. We therefore aimed at showing that magic tricks can trigger insightful solutions that are accompanied by an Aha! experience. The proposed paradigm could be a useful contribution to the field of insight research where new stimuli beyond traditional puzzle approaches are sorely needed. Second, the present work is aimed at contributing to a better understanding of the subjective Aha! experience that is currently often relied on as important classification criterion in neuroscientific studies of insight, yet remains conceptually vague. The new task will therefore be used to further elucidate the phenomenology of the Aha! experience by assessing participants' individual solving experiences. As a third question, we investigated the influence of insight on memory. A positive impact of insight on subsequent solution recall is often implicitly assumed, because the representational change underlying insightful solutions is assumed to facilitate the retention of solution knowledge, yet this was never tested.

A stimulus set of magic tricks was developed in collaboration with a professional magician, covering a large range of different magic effects and methods. After recording the tricks in a standardized theatre setting, pilot studies were run on 45 participants to identify appropriate tricks and to ensure that they were understandable, surprising and difficult. In the main experiment, 50 participants watched the final set of 34 magic tricks, with the task of trying to figure out how the trick was accomplished. Each trick was presented up to three times. Upon solving the trick, participants had to indicate whether they had found the solution through sudden insight (i.e. with an Aha! experience) or not. Furthermore, we obtained a detailed characterization of the Aha! experience by asking participants for a comprehensive quantitative (ratings on a visual analogue scale with fixed dimensions) and qualitative

evaluation (free self-reports) which was repeated after 14 days to control for its reliability. At that time, participants were also required to perform a recall of their solutions.

We found that 49% of all magic tricks could be solved and specifically, that insightful solutions were elicited in 41.1% of solved trials. In comparison with noninsight solutions, insightful solutions (brought about by representational change) were more likely to be correct and reached earlier. Quantitative evaluations of individual Aha! experiences turned out to be highly reliable since they remained identical across the time span of 14 days. Qualitatively, participants reported more emotional than cognitive aspects. This primacy of positive emotions was found in qualitative as well as in quantitative evaluations, although two different methods were used. We also found that experiencing insight leads to a facilitated recall of the respective solutions since 64.4% of all insight solutions were recalled correctly, whereas only 52.4% of all noninsight solutions were recalled correctly after a delay of 14 days.

We demonstrated the great potential of our new approach by providing a proof of concept for magic tricks as a problem solving task and conclude that magic tricks offer a novel way of inducing problem solving that elicits insight. The reliability of individual evaluations of Aha! experiences indicates that, despite its subjective character, it can be justified to use the Aha! experience as a classification criterion. The present work contributes to a better understanding of the phenomenology of the Aha! experience by providing evidence for the occurrence of strong positive emotions as a prevailing aspect. This work also revealed a memory advantage for solutions that were reached through insight, demonstrating a facilitating effect of previous insight experiences on the recall of solutions. This finding provides support for the assumption that a representational change underlying insightful solving experiences leads to long-lasting changes in the representation of a problem that facilitate the retention of the problem's solution. In sum, the novel approach presented in this thesis is shown to constitute a valuable contribution to the field of insight research and offers much potential for future research. Revealing the relationship between insight and magic tricks, the framework of the representational change theory is applied to a new domain and thus enlarged. Combining the novel task domain of magic tricks with established insight tasks might help to further elucidate the process of insight problem solving which is a characteristic and vital part of human thinking and yet so difficult to grasp.

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1 COMPREHENSIVE INTRODUCTION

1.1 Outline of the Research Context

1.1.1 Relevance

The problem of insight remains one of the great mysteries of cognition. At the core of human intelligence, this paradoxical experience has so far withstood any attempts to fully reveal its inner workings. Understanding the exact mechanisms of insight is "one of the central questions of the psychology of thinking" (Mayer, 1995, p. 3) that generations of researchers have grappled with. Ohlsson ranks it among "the perennial problems of cognitive psychology" (Ohlsson, 1992, p. 1).

Insight is a fundamental cognitive process that occurs in several different contexts, for example if a problem is suddenly solved, a situation is reinterpreted or a joke is explained (Kounios & Beeman, 2009, p. 210).

Clearly, insight and creativity are closely related (e.g. Guilford, 1950, 1987). There exist several, mainly anecdotic accounts of great inventors' illuminations (see Gruber, 1995, for a comprehensive, but also critical analysis of these historical sources). For example, at the "Benzolfest", a ceremony held by the German Chemical Society in his honour on the 11th of March 1890, August Kekulé vividly described the sudden enlightenment that led him to discover the structure of the benzene ring:

> *Ich drehte den Stuhl nach dem Kamin und versank in Halbschlaf. Wieder gaukelten die Atome vor meinen Augen. […] Alles in Bewegung, schlangenartig sich windend und drehend. Und siehe, was war das? Eine der Schlangen erfasste den eigenen Schwanz und höhnisch wirbelte das Gebilde vor meinen Augen. Wie durch einen Blitzstrahl erwachte ich; auch diesmal verbrachte ich den Rest der Nacht um die Consequenzen der Hypothese auszuarbeiten.* (Schultz, 1890, p. 1306)

Translation by the author: "I turned my chair towards the fireplace and fell into a light slumber. Again, the atoms were gambolling before my eyes. […] All in motion, squirming and writhing like snakes. And lo! What did I see? One of the snakes caught its own tail and the structure whirled tauntingly before my eyes. I awoke as if struck by lightning; and again I spent the rest of the night to work out the consequences of the hypothesis."

This anecdote should not give the impression that such a stroke of genius does arise completely out of the blue. Quite often it is preceded by months or even years of careful study. In a way, a prepared mind is needed for truly ingenious insights (as detailed, for example, by Ippolito & Tweney, 1995; or by Kounios et al., 2006).

Nevertheless, insights can result in important discoveries or innovations. Embedded in this larger perspective, insight can be regarded as an ubiquitous process which is highly relevant for the scientific, technological or cultural advancement of a society. Unfortunately, a typical characteristic of insight is that it cannot be forced. Currently, the circumstances that give raise to insightful moments are largely unknown, but in the long run, it might be possible to identify facilitating conditions (e.g. Dow & Mayer, 2004). Therefore, the field of insight research may provide us with new methods to foster innovation - an invaluable asset in a world that becomes increasingly complex and poses new challenges every day.

1.1.2 Scope and Definition

Only few studies deal with insight in contexts such as scientific discoveries (Dunbar, 1995), identifying a blurry object (Bowers, Regehr, Balthazard, & Parker, 1990) or grasping the meaning of metaphors and jokes (Ritchie, 2004). Typically, it is investigated in the context of human problem solving. In this thesis, we focus on insight in the problem solving domain, following Mayer's definition: "The term *insight* has been used to name the process by which a problem solver suddenly moves from a state of not knowing how to solve a problem to a state of knowing how to solve it" (Mayer, 1995, p. 3). This operational definition regards insight as a transition event that can be measured empirically. Insight as a moment of sudden knowledge of the solution is thought to follow from *restructuring* processes (Duncker, 1945; Kaplan & Simon, 1990; Ohlsson, 1984a), to be discussed in detail in 1.2.1 and 1.3. Furthermore, insight is often reported to be accompanied by a strong response, the *Aha! experience* (Kaplan & Simon, 1990; Gick & Lockhart, 1995). This is often taken as the discriminative criterion to set it apart from analytic and gradual problem solving (Metcalfe, 1986; Evans, 2008).

The terms insight, Aha! experience and restructuring are used rather inconsistently in the literature, sometimes synonymously. We need to clarify that for the present purpose, we use the term restructuring according to Ohlsson's definition as "a change in the problem solver's mental representation of the problem" (Ohlsson, 1984b, p. 119), to be detailed in 1.3. Insight therefore results from restructuring of the problem representation and refers to the sudden comprehension of the solution of a problem. It will be used as the more general term. We specify Aha! as the phenomenological experience that accompanies insight. Behaviourally, it is the best observable aspect of insight and we will therefore use the Aha!

experience as an indicator that insight has occurred (this decision will later be justified and discussed in detail, see 1.5.1).

Scientific interest in problem solving is far from new. Since the end of the 19^{th} century, the question how humans solve difficult problems has been a classical research topic in psychology. The next chapter describes the historic development of the field of insight research which was influenced by three main theories: Associationism, Gestalt psychology and information processing accounts (Funke, 2003).

1.2 Historical Background

1.2.1 The Foundations of Insight Research

The dawn of insight research dates back to the 1920s of the last century, to the time when the Gestalt Psychologists (Köhler, 1921; Wertheimer, 1925, 1959; Duncker, 1926, 1935; Koffka, 1935) set out to empirically investigate human and animal problem solving behaviour. In one of his chimpanzee experiments, Wolfgang Köhler confronted the animal with the task of reaching a banana that was hung high up on the ceiling of the cage, with several boxes scattered on the floor (Köhler, 1921). After several fruitless (sic!) jumping attempts, the chimpanzee turned away and sat motionless for a while. Then, suddenly, he reached for the boxes, stacked them on top of each other, climbed on the stack and got hold of the banana (see figure 1). According to Köhler, this action sequence could not be explained by a simple stimulus-response association as suggested by behaviourists (e.g. Watson, 1913), because it was not part of the ape’s general repertoire of behaviour (prior experience) nor was it produced by trial and error. Instead, he suggested that the animal acted insightfully. As a possible limitation, it must be mentioned that the chimpanzee was not able to reproduce this behaviour during the next trial. Only after Köhler had built the stack for him four times (Köhler, 1921, p. 103) did the animal succeed in reliably producing the stack solution.

Figure 1. Problem solving in animals. After unsuccessfully trying to reach the banana by jumping, a chimpanzee manages to reach the fruit by stacking boxes on top of each other and climbing on them. (Picture taken from Köhler, 1921, p. 97)

This approach constituted an attack on the theory of associationism that was predominant at the time. Under the assumption that the mind consists of ideas and of associations between these ideas that are established through prior experience, thinking was described as following a chain of associations from one idea to the next (Mandler & Mandler, 1964; Mayer, 1995). Therefore, associationists (e.g. Thorndike who worked with cats) regarded a given problem solving task as a stimulus with which several possible responses are associated, with the strongest association being automatically chosen. This view reduces problem solving to either the mere reproduction of previously learnt behaviour or to blindly trying out new stimulus-response combinations by trial and error that can lead to accidental success (Thorndike, 1898). In contrast, the Gestalt school of thought regarded problem solving as an active process of *productive thinking* (Wertheimer, 1959), as opposed to simple reproductive thinking. Productive thinking means that the problem solver reorganizes his perception of the problem through structural changes. Karl Duncker, a disciple of Köhler and Wertheimer, focused on the conditions requiring such structural changes and stressed that, in contrast to the associationists' assumptions, prior experience is not necessarily helpful, but can even be a hindrance by leading to a fixation on certain problem aspects (functional fixedness, or "funktionale Gebundenheit", Duncker, 1935). In this case, the mental representation of the problem must be changed in order to reach a solution.

The Gestalt psychologists postulated that such structural changes always lead to an improvement, described as a driving force from a defective Gestalt (i.e. a problem), assumed to cause strain and tension for the thinker, towards a "good Gestalt" (Wertheimer, 1959, p. 239). For example, Wertheimer explains "der Begriff, den ich von einer Sache habe, wird in solchem Prozesse oft nicht nur bereichert, sondern verändert, verbessert, vertieft" (Wertheimer, 1925, p. 175), which can be translated to "in such a process, my conceptual understanding of the matter at hand is not only enriched, but transformed, improved, elaborated". For this hypothetical transformation process, he coined the term restructuring (in German "Umstrukturierung", Duncker, 1935, p. 34; or even "Umkrempelung" and "Einschnappen", Wertheimer, 1925, p. 173 and 174). Although, especially in the beginning, the Gestalt psychologists put emphasis on visual perception processes (e.g. Wertheimer's parallelogram from 1925), they turned their attention to problem solving in general and applied their ideas to a wide range of practical, mathematical and scientific problems. A classical one of them will now serve to illustrate the meaning of restructuring.

In the Candle Problem (Duncker, 1935), participants are asked to attach a candle to a door so that it can burn properly. Among the available objects are a box of matches and a box of tacks, as depicted in figure 2.

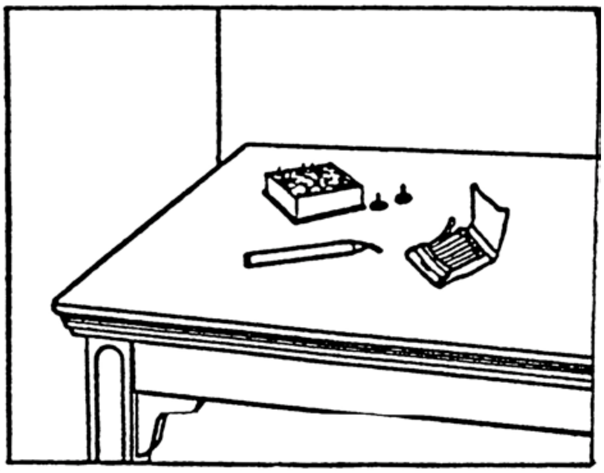

Figure 2. The Candle Problem (Duncker, 1935). *Problem:* You have a candle, some matches, and a box of tacks. Support the candle on the wall. *Solution:* Empty the tackbox. Tack the box to the wall. Set the candle on the platform formed by the box. (Picture and text taken from Isaak & Just, 1995, p. 313)

According to Duncker, prior knowledge restricts the function of the boxes to a container (functional fixedness, Duncker, 1945), here a container for tacks. The solution is to restructure the problem situation by changing the function of the box: to empty it, attach it to the door with a few tacks and use it as a small shelf to place the candle on. The previous function of the box as "container" must be changed to the new function "platform". Restructuring is the process that drives this change. Eventually, an insightful solution is reached.

In his investigations on mental set (1942), Luchins, another disciple of Max Wertheimer, transferred the concept of functional fixedness (mainly used with regard to the function of objects by Duncker, 1935, 1945) to problem solvers' fixation on one, previously successfully applied solution method. The repeated application of this method leads to a fixation so that for subsequent problems, alternative solution methods are not considered anymore even if they now were more appropriate.

The concepts of restructuring and insight were taken up by other researchers, for example, Donald Hebb, commonly more known for his work on cell assemblies and learning, proposed a basic model for restructuring on the neuronal level (Hebb, 1949). In 1.3 we will present a modern theoretical framework for these concepts that was suggested by Ohlsson (1992).

Of course, from a contemporary point of view (nearly 100 years later!), the Gestalt school of thought must be criticized with regard to several points. Methodologically, the experiments remained largely descriptive and lack the experimental precision required today (e.g. control conditions). Theoretically, the concepts of insight and restructuring remained underspecified, so that no testable hypotheses could be derived. However, we should credit these early experimental psychologists for the audacity and creativity with which they set out to investigate problem solving. For a very detailed account and a critical acclaim of the Gestalt psychologists' work, please refer to Ohlsson (1984a). It should also be noted that there has been a fundamental debate about the validity and usefulness of the Gestalt concept of insight as a special process (specifically, Weisberg & Alba, 1981; and the reply by Dominowski, 1981), but this is beyond the scope of the present work and will not be considered further. To conclude, we agree with Michael Eysenck: "The Gestalt work is not a Jurassic creature to be buried in the cemetery of psychological theory" (Eysenck & Keane, 2000, p. 399).

1.2.2 The Information Processing Account

In the late 1950s and 1960s, influenced by the cognitive revolution, thinking came to be regarded as processing of information. In information processing terms, a problem is defined as a discrepancy between the present situation and the goal situation (Betsch, Funke,

& Plessner, 2011) while the operators how to get from one to the other are unknown. With their problem space theory, Newell and Simon (1972) introduced a comprehensive theory of problem solving that is still very influential today. Human problem solving is regarded as a search in a problem space which contains all possible states of a problem, amongst them the initial state and the goal state. Moreover, there exists a set of operators that allow transformations from one state into another. The problem space can be visualized in so-called state graphs. In this context, Dunbar differentiates two main types of problems (Dunbar, 1998): While in ill-defined problems, e.g. stopping climate change, the initial and goal states as well as the possible operators that can be applied may be incomplete or unknown, well-defined problems like a mathematical equation have clearly defined states and operators. A classical example is the Tower of Hanoi that was invented in 1883 by the French mathematician Édouard Lucas as a solitaire game. Today widely used as a neuropsychological testing tool, this puzzle consists of a wooden game board with three disks of different diameters placed on three pegs. The task is to rearrange the disks from their initial position to match a specified goal position while obeying certain rules (compare Faber, 2008). The Tower of Hanoi state graph (figure 3) comprises 27 possible states which can be reached from any neighbouring state by one movement. The problem solver is asked to find the shortest path between two given states (start and goal state). Thanks to the accessibility and clarity of its state graph (see below), the Tower of Hanoi represents an ideal paradigm to investigate problem solving strategies in the framework of the problem space theory (e.g. Simon, 1975; Anzai & Simon, 1979; Kotovsky, Hayes, & Simon, 1985). For example, the general problem solver, a computer program developed by Newell and Simon (Newell, Shaw, & Simon, 1959), was able to solve Tower of Hanoi problems due to this high formality.

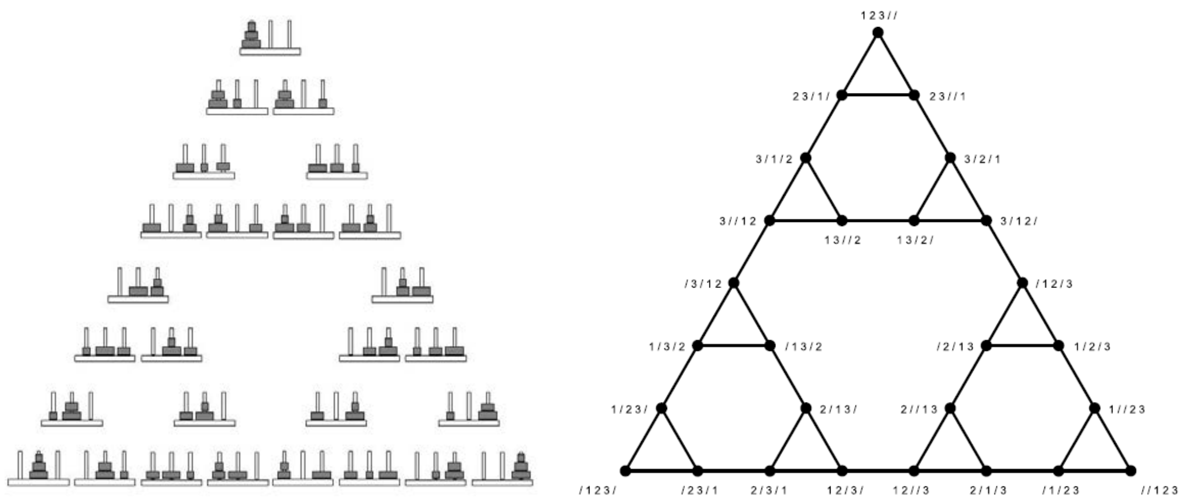

Figure 3. Tower of Hanoi problem space. A spatial distribution of all possible states of the Tower of Hanoi puzzle (left) which forms the basis of the more abstract state graph (right). (Figure taken from Faber, 2008, p. 12)

According to Dunbar (1998), different analytic strategies can be employed: When using heuristics, problem solvers are searching for the goal state with a rule of thumb that will lead to a correct pathway in most cases, but not in all. In contrast, algorithms give guaranteed solutions, but only for certain problems. A very systematic strategy is the hill climbing technique, in which the problem solver looks one move ahead and moves to a position that resembles the goal state the most (Greeno, 1974). Following this rule may be deceptive if a move seems to lead the subject closer to the goal but in fact takes him further away. In those situations, the appropriate strategy to employ is a means-end-analysis. This requires the problem solver to calculate the difference between the initial state and the goal state. If the latter cannot be achieved immediately, the problem must be further decomposed into one or more subgoals which must be solved on the way until the final state may be reached (Simon, 1975; Goel & Grafman, 1995).

At first glance, it seems impossible to integrate the concept of insight into the information-processing account. Yet there have been several fruitful attempts to explain insight within this framework (Kaplan & Simon, 1990; MacGregor, Ormerod, & Chronicle, 2001; and, the most relevant one for the present work, Ohlsson, 1984b; Knoblich, Ohlsson, Haider, & Rhenius, 1999). Ohlsson and Knoblich's approach will be presented in detail in section 1.3. However, instead of the variegated types of problems used by the Gestalt psychologists (most of them ill-defined, with a very large problem space), problem solving research in the 60s and 70s focused on well-defined tasks like the Tower of Hanoi. For example, the general problem solver (Newell et al., 1959) is restricted to these types of formalized tasks. Consequentially, insight research dropped out of the focus of mainstream psychology, as pointed out by Michael Wertheimer (Wertheimer, 1985), the son of Max Wertheimer.

However, after this period of relative quietness, the field of insight research has now received renewed scientific interest that was reflected in Sternberg and Davidson's seminal book *The Nature of Insight* (Sternberg & Davidson, 1995). Despite more than a century of research dedicated to it, the true nature of the insight mechanism still remains elusive. But this fascinating phenomenon has taken hold of researchers again. Since Köhler and Wertheimer's first writings, considerable progress has been made. Most importantly, theoretical accounts have been developed that allow systematic inference and testing of different hypotheses and thus make up for the lack of theory inherent in the Gestalt school of thought. We will now outline the main theoretical advances and some empirical results from recent insight research that form the basic framework for the present thesis.

1.3 Theoretical Framework: The Representational Change Theory

Adopting the central concept of the Gestalt theory of thinking, Ohlsson (1984b) also based his theoretical account on restructuring (see 1.1.2 for the definition). As the more general term for changes in the mental representation of a problem, he uses the expression *representational change*. By proposing the representational change theory, he was able to reconcile the two seemingly incompatible approaches to human problem solving just presented: On the one hand, the Gestalt concept of insight, the sudden appearance of a solution, leaving problem solvers unable to report any conscious solution strategies, and on the other hand, the information-processing view of problem solving as a consciously controlled, step-wise search process through a space of alternatives (Newell & Simon, 1972). Here, a short outline of the theory will be given (based on Ohlsson, 1984a, 1984b, 1992; and Knoblich et al., 1999).

In the representational change theory, past experience is assumed to be a key factor in problem solving. Obviously, in many situations it is helpful and efficient to rely on prior knowledge because complexity is reduced - for example, always opening bottles of wine with a corkscrew. However, sometimes problem solvers' prior knowledge (expressed in assumptions how to solve the problem at hand) is wrong or inappropriate for a given situation, for example if the corkscrew is missing. In this case, the previously useful assumptions ("bottles are to be opened with a corkscrew") turn into constraints that are hindering to act successfully. More specifically, following the Gestalt tradition, the representational change theory assumes that prior knowledge and inappropriate assumptions lead to an incorrect representation of the problem and thus prevent a solution (e.g. pushing the cork into the bottle). An *impasse* is thought to occur after repeated failure.

Ohlsson introduces a new conceptualization of insight by emphasizing the impasse as a precondition for insight to occur (impasse – insight – sequence). An impasse denotes "a mental state in which problem-solving has come to a halt; all possibilities seem to have been exhausted and the problem-solver cannot think of any way to proceed" (Ohlsson, 1992, p. 4). Consequently, if problem solving proceeds smoothly from a question to the answer, for example, if a lengthy multiplication problem is solved, the solution would not be regarded as insightful. On the other hand, if prior knowledge imposes an over-constrained, biased mental representation of the problem, the problem solver gets stuck in an impasse with the impression that the task is unsolvable. Problem solving attempts cease. Through restructuring, the impasse can be broken and an insightful solution can be reached.

Ohlsson postulates as the function of restructuring "to change the set of applicable operators" (1984b, p. 120). Restructuring means that certain encodings are changed, and consequently, the mental representation of a problem is changed, too. Turning back to our previous example of the Candle Problem, the encoding of the box as a container would be an inappropriate assumption that must be overcome in order to solve the problem. Relaxing the initially over-constrained problem representation, the problem can be solved by using a container as a platform.

Ohlsson (1992) suggested such a *relaxation of constraints* as one possible mechanism by which restructuring might be accomplished. Constraint relaxation is thought to be necessary if there exist certain self-imposed constraints that unnecessarily prevent a solution (for example, assumptions about rules that do not apply and that were never explicitly stated). To reach a break-through, these constraints need to be relaxed. Other mechanisms that could be recruited in order to change mental problem representations (e.g. elaboration, re-encoding) were also postulated by Ohlsson, but these will not be discussed here.

Knoblich and colleagues (1999) took up Ohlsson's suggestions by showing how the constraint relaxation hypothesis could be used to predict individual problem difficulty in the domain of matchstick arithmetic problems, compare 1.4.

To further illustrate the idea of constraint relaxation, consider the following example (Inverted Pyramid Problem, Ohlsson, 1992): “A giant inverted steel pyramid is perfectly balanced on its point. Any movement of the pyramid will cause it to topple over. Underneath the pyramid is a $100 bill. How would you remove the bill without disturbing the pyramid?“ (Schooler, Ohlsson, & Brooks, 1993, p. 183).

The difficulty of this insight problem lies in the implicit constraint that the dollar bill must not be damaged. This prior knowledge element of the mental representation of the task acts as a constraint on the set of applicable actions. Only if this constraint is relaxed, can a solution be found: Putting a match to the dollar bill and burning it.

But we must also consider two cases in which restructuring is not possible at all (Ohlsson, 1984b): First, if the correct encoding is already activated, no restructuring is needed (for example, if the problem solver was just primed to think of platforms). Second, restructuring cannot occur if the correct encoding is not available to the problem solver (for example, if he had never encountered the concept of a platform). Later on (section 6.4), we will discuss these two cases applied to the paradigm used in the present work.

Ohlssons’ representational change theory has become very influential in recent insight research (e.g. Haider & Rose, 2007; Luo & Knoblich, 2007; Öllinger, Jones, & Knoblich, 2008) and its assumptions are now part of current definitions of insight, for example, “The term ‘insight’ is used to designate the clear and sudden understanding of how to solve a problem. Insight is thought to arise when a solver breaks free of unwarranted assumptions, or forms novel, task-related connections between existing concepts or skills” (Bowden, Jung-Beeman, Fleck, & Kounios, 2005, p. 322). In the following, we will present several studies that provide empirical evidence for this theory.

1.4 Empirical Findings

The literature on insight is extensive, besides Sternberg’s comprehensive book (Sternberg & Davidson, 1995), a review by Chu and MacGregor (2011) provides an overview on more recent developments. The following studies were selected because they represent important findings with regard to the theoretical framework of this thesis.

Knoblich and colleagues (Knoblich, Ohlsson, & Raney, 2001) tested specific predictions derived from the representational change theory in an eye-movement study on matchstick arithmetic tasks. In this task, Roman numerals are constructed out of matchsticks and participants are asked to transform an incorrect arithmetic statement into a correct one by moving only a limited number of matchsticks (Knoblich et al., 1999). In their study, they could not only replicate previous behavioural findings (Knoblich et al., 1999), but also found matching eye-movement data. They demonstrated that, shortly before the solution occurred, successful solvers allocated their attention to those elements of the problem that previously had been neglected due to self-imposed constraints (compare Grant & Spivey, 2003). In this case, prior arithmetic knowledge had imposed the constraint that only the numerals in an equation could be manipulated, but not the operators (-/+/=). If this constraint was relaxed, attention was turned towards the operators and the problem could quickly get solved. This can be regarded as indirect evidence for constraint relaxation. In the same study, Knoblich et al. (2001) further demonstrated that for successful solvers, the number of long fixation times increases throughout the problem solving process. The longest fixation times were found in the last time interval before the solution, i.e. shortly before insight occurred, there was a phase without systematic eye-movement patterns. This was interpreted as physiological evidence for the impasse – insight sequence postulated by the representational change theory. The basic idea was that in such an "idling" phase more appropriate representations could be established that yield a new insight.

Additional behavioural evidence for constraint relaxation was provided by Knoblich et al. (1999) who found that the degree of necessary constraint relaxation was mirrored in the differential difficulty of individual problems. That is, problems that required multiple constraints to be relaxed were more difficult than those for which only one constraint had to be overcome. This finding was later replicated (Öllinger, Jones, & Knoblich, 2006).

These matchstick arithmetic studies empirically support the conception of restructuring through constraint relaxation. Of course, studies from other task domains are needed to strengthen this claim (see Jones, 2003; Kershaw & Ohlsson, 2004).

Durso et al. (Durso, Rea, & Dayton, 1994) conducted a pioneering study in which they tried to directly assess restructuring by collecting information from participants about their task representation. To do so, they asked participants to repeatedly rate the key words of the task (a verbal riddle) with regard to their similarity. Based on these ratings, a so-called Pathfinder Scaling Algorithm was used to model problem solvers' latent mental representations of the task. Comparing successful and unsuccessful solvers, they could show that the initial representations of both groups were rather similar and centred around wrong, inappropriate concepts (i.e. constraints in Ohlsson's terminology) – but that shortly before they came up with the correct solution, successful solvers' representations had changed to focusing on the relevant aspects of the task. This is a first attempt to actually model the underlying problem representations (see also Hélie & Sun, 2010; Thagard & Stewart, 2011).

Based on these encouraging findings, we decided to develop a novel problem solving task that builds on the theoretical framework of the representational change theory. In section 1.6, this new approach is presented.

1.5 Methodological Issues

From an experimental psychologist's viewpoint, the investigation of insight poses methodological challenges. How can this enigmatic process be investigated under laboratory conditions and how can any insight experiment fulfil the requirements of a rigorously controlled empirical study?

> *An insight is so capricious, such a slippery thing to catch in flagrante, that it appears almost deliberately designed to defy empirical inquiry. To most neuroscientists, the prospect of looking for creativity in the brain must seem like trying to nail jelly to the wall.* (Dietrich & Kanso, 2010, p. 822)

Reading this statement, the following question arises: Perhaps the main hindrance is not the jelly-like substance, but the usage of the nails - which simply are not appropriate for this task? Consequently, another method must be found to solve the problem. For example, a possible solution could be to reduce the room temperature to freeze the jelly and then pin it on the wall with glue.

Similarly, insight researchers are on the constant lookout for appropriate tasks and paradigms to tackle their topic. MacGregor and Cunningham have recently pointed out the "relative dearth of problems" (2008, p. 263). In this thesis, we will therefore suggest a novel paradigm. Before that, we will discuss two of the main methodological difficulties in investigating insight problem solving.

1.5.1 Has Insight Occurred?

Obviously, the insight phenomenon itself is very hard to grasp. There is no clear behavioural marker indicating that insight has taken place. Even if a problem is solved, it is not discernible if restructuring or more analytical processes (e.g. hill-climbing, as postulated by the problem space theory) were involved. In general, researchers have taken different approaches to handle this difficulty, each emphasizing different aspects for defining insight (Öllinger & Knoblich, 2009). Researchers focussing on a task dimension (as detailed by Öllinger & Knoblich, 2009) argue that there exist problems which always require restructuring for a solution due to their inherent structure (compare also next section). If such "insight problems" are solved, it is commonly assumed that restructuring has taken place (e.g. Chronicle, MacGregor and Ormerod, 2004). This approach is problematic because the definition of insight becomes circular, as Öllinger and Knoblich point out (Öllinger & Knoblich, 2009, p. 3): „Insight problems are problems that require insight, and insight occurs when insight problems are solved", see also Dominowski and Dallob (1995).

Fleck et al. (2004; 2008) have taken another route by recording thinking-aloud-protocols and trying to infer from them if restructuring was involved. More recently, researchers interested in detecting possible neural correlates of insight have begun to rely on the phenomenological feature of insight, the Aha! experience (Bowden et al., 2005; Sandkühler & Bhattacharya, 2008). The Aha! experience is generally described as very pleasant, connected with emotional arousal and with a strong certainty that the solution is correct (Sternberg & Davidson, 1995). This phenomenological approach (compare Öllinger & Knoblich, 2009) uses subjective reports of Aha! experiences to differentiate insightful ("with Aha!") from noninsightful ("without Aha!") solving events.

At present, we think that the latter approach to determine the occurrence of insight is the most reasonable one. We agree with Bowden and colleagues (2005) who argue that any problem can be solved either with or without restructuring (i.e. with or without insight), depending on whether an over-constrained problem representation was imposed through prior knowledge or not. For example, as already discussed in 1.3, in Duncker's Candle Problem (1935), if someone has previously used a box as a platform, no constraint exists and therefore the solution is obvious and can be reached without the impasse – insight sequence postulated by Ohlsson (1992). In other words, "the presence or absence of insight resides in the solver's solution rather than in the problem" (Bowden & Jung-Beeman, 2007, p. 88). Consequently, one has to control for the occurrence of insight by directly asking the problem solvers about it. In agreement with Bowden et al. (2007), we regard the Aha! experience as the best observable aspect of insight. Therefore, in the current work, we provided our participants with clear descriptions of insightful ("with Aha!") and noninsightful ("without Aha!") solution experiences and asked them to sort their solutions on a trial-by-trial basis into these two categories. Adopting Bowden's approach (2007), we assume that these reports are reliable markers of restructuring and insight. For this purpose, the following instruction was used:

> *We would like to know whether you experienced a feeling of insight when you solved a magic trick. A feeling of insight is a kind of "Aha!" characterized by suddenness and obviousness. Like an enlightenment. You are relatively confident that your solution is correct without having to check it. In contrast, you experienced no Aha! if the solution occurs to you slowly and stepwise, and if you need to check it by watching the clip once more. As an example, imagine a light bulb that is switched on all at once in contrast to slowly dimming it up. We ask for your subjective rating whether it felt like an Aha! experience or not, there is no right or wrong answer. Just follow your intuition.* (Adapted from Jung-Beeman et al., 2004)

Of course, such a "phenomenological" approach to assessing the occurrence of insight also entails serious drawbacks: First, it heavily depends on the subjective judgement of participants (and this burdens participants with a second task that might have an impact on their problem solving performance). Second, the close relationship between the Aha! experience and insight is merely an assumption that is plausible, but has not been tested empirically so far. Third, in comparison to the widely used problem-based approach (e.g. Chronicle, MacGregor, & Ormerod, 2004), it reduces the number of valid "insight" trials in any study, because the problem solver categorizes many trials as not insightful.

1.5.2 Which Tasks to Use?

There is an ongoing debate about whether such a thing as an "insight problem" (that can only be solved through insightful processes) truly exists. Many studies compare a previously fixed set of "insight tasks" with a set of "noninsight tasks". For example, Gilhooly and Murphy (2005) classified a large set of problems using a cluster analysis and later based their comparisons on these two sets (Gilhooly & Fioratou, 2009). We decided to take another approach. In the context of the representational change theory (Ohlsson, 1992; Knoblich et al., 1999), the present work is based on the following rationale:

Any problem can be solved with or without insight (see above). Consequently, "insight problems" per se do not exist. However, there are tasks that seem especially suited to trigger insightful solutions, namely those that "have a high probability of triggering an initial representation which has a low probability of activating the knowledge needed to solve the problem" (Ohlsson, 1992, p.10). We therefore asked participants trial-wise to report on the occurrence of insight, and at the same time, we implemented a special task domain which meets Ohlsson's criterion: Magic tricks. They seem to be perfectly suited because in general, magic tricks only work because the observer is misled into generating a wrong representation of the problem. In contrast to many insight problems, magic tricks have already been "tested" for centuries and only those that reliably trigger biased representations have survived until today. We therefore predict that magic tricks will often be solved with insight.

In terms of problem solving theory (as presented in section 1.2.2), we categorize magic tricks as ill-defined problems because there is no clearly definable problem space. Of course, the goal state and the start state are quite clear (even if some aspects of the problem might be deliberately hidden from the spectator). However, the operators that can be applied to get from one state to the other are not only unknown, because the full set of magic methods has for centuries been kept secret by the magicians' society with its convention to observe secrecy, but also theoretically unlimited.

1.6 A New Approach to Investigate Insight

This thesis proposes a new approach for the investigation of the insight phenomenon. Magic tricks are introduced as a problem solving task: The problem solver is asked to find out the secret method used by the magician to accomplish the trick. Already in the 19^{th} century, experimental psychologists have tried to link psychology to the ancient art of conjuring (Jastrow, 1888). More recently, it has been suggested by Kuhn et al. that magic techniques could be adopted as research tools for cognitive science (Kuhn, Amlani, & Rensink, 2008). First pioneering studies have already been published in the field of visual attention in which special magic tricks were deployed as stimuli (e.g. Kuhn & Tatler, 2005; Kuhn, Tatler, Findlay, & Cole, 2008; Kuhn, Kourkoulou, & Leekam, 2010; Cavina-Pratesi, Kuhn, Ietswaart, & Milner, 2011). For example, Kuhn and Land (2006) presented their participants with a magic trick in which a ball seems to vanish in mid-air. The ball is repeatedly thrown up in the air by the magician and then caught again. After two real throws, a fake throw is performed while the ball is secretly concealed in the magician's hand. Interestingly, 63% of the observers reported to have seen the ball leave the hand, move up in the air and disappear - even though it was no longer physically present, but covered by the magician's palm. This illusory percept seems to be based on social cues like the magician's head direction and eye gaze (both implying that the ball actually moved up during the fake throw). Recently, the first neuroimaging study on magic tricks was conducted by Parris and colleagues (Parris, Kuhn, Mizon, Benattayallah, & Hodgson, 2009) who could show that the dorsolateral prefrontal cortex and the anterior cingulate cortex are involved in the perception of magic tricks. As impressively demonstrated in these studies, magic tricks can be used to learn more about human visual perception and attention (see Kuhn, Amlani, et al., 2008, for a thorough discussion).

However, in the present work, we have developed yet a different approach by proposing to use magic tricks to investigate human problem solving. We will now shortly outline our rationale why magic tricks are ideally suited as an insight paradigm (to be further elaborated in section 2.2.1). Comparable to classical insight problems (Weisberg, 1995), magic tricks take advantage of the fact that self-imposed constraints are activated by prior knowledge (Ohlsson, 1992; Öllinger & Knoblich, 2009). Deliberately, magicians exploit spectators' implicit assumptions as part of their methods (e.g. if a bottle is held with two hands, it must be a heavy, solid object). The magician benefits from the fact that these constraints are activated highly automatically and that it is very hard to overcome them (Tamariz, 1988). An over-constrained mental representation of the problem (in this case, finding a plausible explanation for the magic effect) is the consequence. We therefore assume that this paradigm can actually elicit representational difficulties (compare Ash, Cushen, & Wiley, 2009). The only possibility to overcome these difficulties and "solve" the magic trick is to relax the constraints, as suggested by Ohlsson and Knoblich et al. (Ohlsson, 1992; Knoblich et al., 1999). Of course, as already discussed, it is also possible to reach a solution without any restructuring, but in a smooth and continuous way. This would be the case if a person's prior knowledge does not lead to any constraints (due to a different knowledge base, or due to previous experience with magic or perhaps simply because of a recent activation of appropriate concepts) and therefore, their mental representation is not constrained and already includes the solution. Based on these considerations, we asked participants to differentiate Aha! trials from trials in which no restructuring was necessary (see above).

To develop a suitable set of magic stimuli for our research question, we collaborated with Thomas Fraps, a professional magician. 40 magic tricks that seemed feasible for a filmed performance were preselected according to sensory (only visual effects in a silent performance) as well as cognitive (relatively simple, short tricks with only one magic effect) requirements. These tricks were then performed and recorded in a standardized stage setting with a digital video camera. The resulting video clips of magic tricks were extensively tested in three pilot studies on a sample of 45 students who were asked to rate the clips through a questionnaire with regard to parameters such as cleverness, astonishment and comprehensibility. Taking into account these results, half of the video clips were improved and re-recorded in a second recording session. The final stimulus set consisted of 34 magic tricks that covered a wide range of different effects (e.g. transposition, restoration, vanish) and methods (e.g. misdirection, gimmicks, optical illusions). They are listed in detail in appendix A.

We claim that with these kinds of stimuli, we can approach real-world problem solving, in contrast to strictly controlled paper-and-pencil tasks (e.g. the nine-dot problem or the Tower of Hanoi) that are artificially construed. In this respect, we follow the Gestalt tradition whose researchers didn’t shy away from using hands-on problems, in which participants tacked boxes to the wall, burned candles and swung ropes to try out their solution ideas (e.g. Duncker, 1926; or Maier, 1930). We suggest a shift of paradigm, away from artificial problems towards more naturalistic problems. In our opinion, the field of problem solving research could profit greatly from a new type of tasks: Problems that people are genuinely interested in, problems that vex them, problems that they are intrinsically motivated to solve – and not only because the experimenter told them to work it out.

1.7 Research Questions and Aims of Thesis

With regard to the mechanisms of insight, many questions remain. In the present thesis, we focused on three research questions (see below). Each of these is covered in one chapter (2, 3, and 4), with each chapter structured like an individual manuscript. Note that we conducted one large study that comprised three different tasks which yielded all the data presented here:

1. Problem solving of magic tricks
2. Qualitative and quantitative assessment of Aha! experience
3. Recall of solutions after 14 days delay

To avoid redundancy, we included a general method section in the first manuscript (chapter 2) with shared method parts (participants, stimuli and main procedure), and described other method elements that are relevant for only one research question directly in the method section of the respective chapter. The three research questions are now presented.

1.7.1 Working Wonders? Investigating Insight with Magic Tricks

First, answering the need for new stimuli, we aimed at introducing magic tricks as a new paradigm for insight research. After selecting and recording a set of magic tricks, extensive piloting was necessary to improve the trick videos and to establish that they could actually be solved (feasibility of the task). Our goal was to provide a proof of concept for the new paradigm by demonstrating that insightful solutions are reliably triggered.

1.7.2 It's a Kind of Magic - New Insights into the Nature of Aha!

Second, we aimed at contributing to a better understanding of the subjective Aha! experience that is currently often relied on as important classification criterion in neuroscientific studies of insight, yet remains conceptually vague. Different dimensions of the Aha! experience such as suddenness (Metcalfe, 1986), happiness (Gick & Lockhart, 1995) or impasse (Ohlsson, 1992) have been postulated. Therefore, assuming a multidimensional construct where the interplay of different components establishes the Aha! experience, we assessed the relative importance of the involved components by obtaining both qualitative and quantitative Aha! ratings from participants, individually for each dimension.

1.7.3 Facilitated Recall of Insight Solutions

Third, we investigated the impact of insightful solution experiences on memory performance. This impact is often implicitly assumed, yet was never systematically tested in a comparable design. We aimed at providing empirical support for Knoblich et al.'s (1999) transfer hypothesis that the restructuring process underlying insightful experiences leads to persisting changes in the representation of a problem (transfer hypothesis). Specifically, we hypothesized that insight solutions (with Aha! experience) would be remembered better than noninsight solutions (without Aha! experience).

2 WORKING WONDERS?

INVESTIGATING INSIGHT WITH MAGIC TRICKS

2.1 Abstract

Introducing magic tricks as an insight problem solving task, we propose a new approach to investigate restructuring, the key mechanism that yields sudden insight into the solution of a problem. We argue that magic tricks are ideally suited because in order to gain insight into the magicians' secret method, observers must overcome implicit constraints through restructuring. Exposing 50 participants to 34 different magic tricks, the utility of this paradigm is tested. Each trick was repeated up to three times and participants were asked to find out how the trick was accomplished. Upon solving a trick, participants indicated if they had reached the solution either through sudden insight (accompanied by an Aha! experience) or analytically (without Aha! experience). Insight was reported in 41.1% of solutions. In comparison with noninsight solutions, insight solutions were more likely to be true and were reached earlier. Overall, 49% of trials were solved showing that this paradigm is feasible. Providing a proof of concept, this study demonstrates the great potential of using magic tricks as a new problem solving domain that reliably elicits insight.

Own contribution remark: The research questions were put forward by Dr. Michael Öllinger and myself, and discussed with Prof. Benedikt Grothe. The idea of using magic tricks came from me. Selection, recording and preprocessing of magic tricks was carried out by the magician Thomas Fraps and myself. The experiment was jointly designed by Dr. Michael Öllinger and myself. Matus Simkovic was of great help in programming the experiment. All data presented in this thesis was collected by myself. Eline Rimane and Timo Schiele served as raters for the magic trick solutions. I conducted the behavioural data analysis and discussed it intensely with Dr. Michael Öllinger. The EEG data analysis was conducted in collaboration with Dr. Björn Schelter at the Center for Data Analysis and Modeling in Freiburg. All three manuscripts, including creation of figures, were written by myself.

2.2 Introduction

Sometimes, genius strikes. This moment of sudden comprehension is known as insight, is assumed to follow from restructuring processes and is often accompanied by an Aha! experience (Sternberg & Davidson, 1995). Insightful problem solving is a fundamental thinking process and nearly one century of psychological research has been dedicated to demystifying it (Bowden et al., 2005), yet the true nature of the insight phenomenon remains elusive (see Chu & MacGregor, 2011, for a review).

The feeling of suddenly knowing the solution to a problem is generally accompanied by a strong affective response and a certainty that the solution is correct (Sternberg & Davidson, 1995). Furthermore, insight is thought to be based on underlying restructuring processes (Duncker, 1945; Kaplan & Simon, 1990; Ohlsson, 1992). Following the Gestalt psychologists' understanding of restructuring, Ohlsson (1992, p.12 and p.40) defined it as "a change in the perception of a particular object, situation or problem - as seeing the problem in a new way". In general, restructuring occurs when prior knowledge is altered or when crucial information that has not been noticed before is added to the mental representation of a problem. More specifically, the representational change theory (Ohlsson, 1992; Knoblich et al., 1999) assumes that prior knowledge and inappropriate assumptions result in self-imposed constraints that establish a biased representation of the problem (or the goal) and thus prevent a solution. One possibility to change the biased representation (to restructure it) is by constraint relaxation, i.e. the over-constrained assumptions must be relaxed. For example, in Katona's Triangle Problem (1940), participants were asked to build four equilateral triangles with only six matchsticks. This problem is unsolvable in a two-dimensional problem representation. It is necessary to overcome the self-imposed "two-dimension" constraint and search for a solution in a three-dimensional representation where the problem can be solved by building a tetrahedron.

As Kounios and Beeman (2009) point out, the phenomenon of insight occurs in a number of domains: generating creative ideas, solving tricky problems, identifying a blurry object (Bowers et al., 1990), grasping the meaning of metaphors and jokes (Ritchie, 2004) or modifying dysfunctional thinking patterns in psychotherapy (Beck, 1976).

In the past, researchers have confined themselves to investigating restructuring and insight mostly in the framework of a small set of insight problems. Reviewing the tasks available so far, MacGregor et al. (2008) identified a need for new sources of insight problems and suggested rebus puzzles as one potential addition. Another relatively new set of problems, already widely used (e.g. Jung-Beeman et al., 2004; Sandkühler & Bhattacharya, 2008), are Compound Remote Associates (CRA) problems. In these tasks, three words are presented and participants are asked to find a compound word that relates to all three of them in a meaningful way, e.g. given the words pine, crab and sauce, the correct solution would be "apple" with the resulting compounds: pine apple, crab apple, and apple sauce. They were adapted from the Remote Associates Test (Mednick, 1962) by Bowden and Jung-Beeman (2003a). However, like so many classical problem solving tasks, both of these are restricted to verbal material and rely on access to an answer that is already stored in memory (the solution word) rather than on the generation of a truly novel solution. In the spatial domain, matchstick arithmetic tasks (Knoblich et al., 1999) are an important and relatively new contribution. Still, although the use of these tasks has brought forward fruitful results, it seems appropriate to take a more unconventional approach beyond the problem domains used so far to better understand the underlying cognitive processes in insight problem solving (Knoblich et al., 2001; Öllinger et al., 2006, 2008).

2.2.1 Restructuring in Magic Tricks

We propose a new task domain to investigate insight: Magic tricks. The ancient art of conjuring could perhaps be called "applied psychology" in the sense that magicians systematically exploit the limitations of human visual perception and attention. Magicians manipulate higher cognitive functions like reasoning by deliberately evoking inappropriate constraints in spectators that prevent them from seeing through the magic trick. The experiment begins when the curtain is raised – and, just as any skilled experimenter, the magician keeps improving his methods from performance to performance based on the data (feedback) that is provided by the audience and their reactions.

Historically, psychologists' attempts to link magic and psychology date as far back as the 19th century (Jastrow, 1888). More recently, it has been suggested that magic techniques could be adopted as research tools for cognitive science and first studies have already been published in the field of visual attention with special magic tricks as stimuli (e.g. Kuhn & Tatler, 2005; Kuhn & Land, 2006; Kuhn, Tatler, et al., 2008; Parris et al., 2009; Kuhn et al., 2010). These studies demonstrate how magic tricks can be utilized to learn more about human visual perception and attention (see Kuhn, Amlani, et al., 2008, for a thorough discussion).

In the present study, we take this one step further by presenting magic tricks and asking participants to find out how the trick worked, i.e. which method was used by the magician to create the magic effect. We assume that if people overcome the over-constrained problem representation induced by the magician and find the "solution" of a magic trick, this should be the same process as restructuring in insight problems. We see two main reasons why such a task domain of "solving" magic tricks is well suited to investigate restructuring processes:

First, similar to classical insight problems (Weisberg, 1995), the domain of magic tricks also takes advantage of the fact that people's prior knowledge activates self-imposed constraints (Ohlsson, 1992; Öllinger & Knoblich, 2009). Besides sleight of hand, many magic tricks exploit implicit assumptions of the spectator as part of their methods (e.g. if someone makes a throwing motion, he will throw a ball). The magician benefits from the fact that these constraints are activated highly automatically and that it is very hard to overcome them (Tamariz, 1988). Consequently, the search space (Newell & Simon, 1972) for possible explanations of an observed trick is fairly constrained. In contrast to insight research, the magic problem does not consist of a riddle, a puzzle or a task, but instead it is consolidated by the discrepancy between the observed event with unexpected outcome (Parris et al., 2009) and the prior knowledge activated by such an apparently familiar event. This discrepancy often leads the magician's audience into an impasse – a state of mind in which people are completely puzzled and have no idea how this magic effect could possibly have taken place. To overcome such an impasse and find the solution, the over-constrained assumptions must be relaxed (Ohlsson, 1992; Öllinger et al., 2008).

Second, a magic trick can be considered as a highly intriguing problem, which strongly motivates the observer to find a solution. Observing something impossible happening right in front of our eyes poses a challenge for our rationality, and therefore, after the first sensation of wonder and astonishment has passed, the situation is critically analysed. Anyone who has ever witnessed a magic performance, will remember the strong desire to know how the magic effect is achieved (the usual response being "Let me see that again!"). The spectator simply can not believe his eyes and asks for a second chance to find an explanation. Of course, magicians rarely offer such second chances, but that is exactly what we did in the present work.

We infer from the first point that gaining sudden insight into the inner working of a magic trick is based on restructuring. This does not exclude that tricks can also be solved in a more analytical and step-wise way, as also discussed in classical insight problems (Metcalfe, 1986; Weisberg, 1995; Evans, 2008). To measure restructuring, we will use the subjective Aha! experience as a classification criterion to differentiate between insight solutions (solutions accompanied by an Aha!) in contrast to noninsight solutions (solutions without

Aha!). That is, we adopted the frequently and successfully applied procedure (e.g. Jung-Beeman et al., 2004; Kounios et al., 2006, 2008) introduced by Bowden (2005; 2007) of asking participants directly if they had experienced an Aha! or not. As a manipulation check, we assessed participants' feeling of certainty for each solution, expecting that insight solutions would be connected to a high rating of certainty because this aspect (i.e. the strong feeling that the solution is correct) is stressed in the instruction (see general method, 2.3.3).

For our experimental rationale, it is important to note that each magic trick consists of an *effect* and of a *method* (Tamariz, 1988; Ortiz, 2006). The magic effect is what the observer perceives (e.g. the vanish of a coin) and the method is how the trick works, the secret behind the effect (e.g. skill, mechanical devices, misdirection). Conjurers employ a method to produce an effect (e.g. Lamont & Wiseman, 1999). Typically, the magician tries to guide the spectators' attention away from the method and towards the effect. In the present study, participants experienced the effect and were then asked to discover the method.

A second important point to consider is that in contrast to most verbal puzzles or riddles, magic tricks do not have one clear unambiguous solution. Of course, for each magic trick, there exists one true solution, that is, the method that was actually used by the magician. Still, other methods to achieve the magic effect might be conceivable (Tamariz, 1988). In fact, almost every conjuring effect can be achieved by several different methods, for example, Fitzkee compiled a list of possible methods for 19 basic effects that comprises 300 pages (Fitzkee, 1944, quoted according to Lamont & Wiseman, 1999, p. 7). Which method is applied by the conjurer depends on the individual strengths of each method and on the exact performing situation (e.g. large vs. small audience). Participants might find the true solution, but might perhaps also come up with another plausible solution or alternatively, a solution that is actually impossible (given the information from the video clips).

An example of a magic trick illustrates our account (trick #20, see appendix A. The full video clip can be found at http://www.youtube.com/watch?v=3B6ZxNROuNw). A coffee mug and a glass of water are presented to the audience. The magician pours water into the mug, as depicted in the left panel of figure 4. Holding the mug with his arms stretched, the magician snaps his fingers - then he turns the mug upside down and a large ice cube drops out (figure 4, right panel). In a few seconds, the water has turned into ice. How does this work?

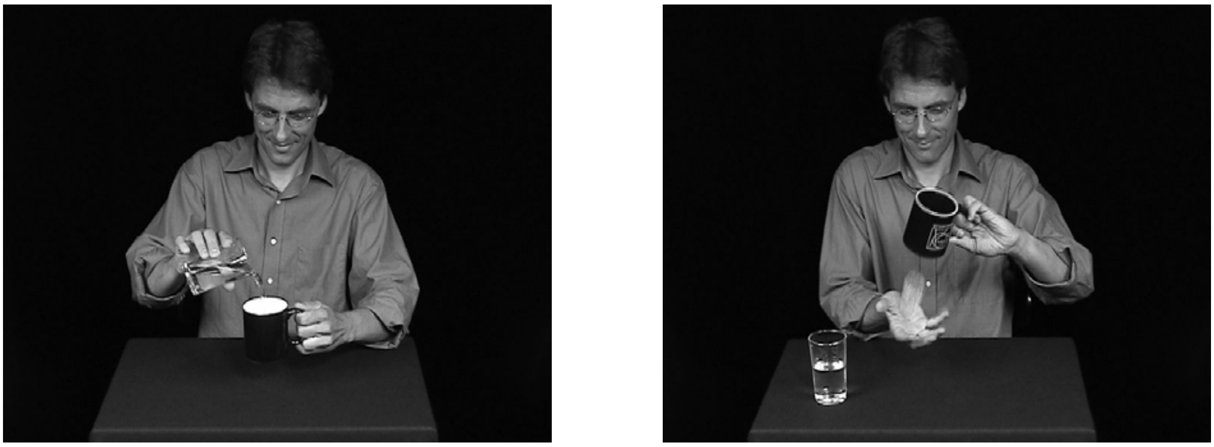

Figure 4. Example of a magic trick. Screenshot from the beginning (left panel) and from the end of the trick (right panel). This screenshot was taken from the video clips that were produced for this study and used as stimuli.

Most people react with astonishment and disbelief because according to their prior knowledge, this is not possible (Parris et al., 2009). Water can turn into ice, but not in such a short period of time (at room temperature), and additionally, it does not turn into a perfect ice cube by itself. Seemingly, causal relationships and laws of nature that were acquired through past experience have been violated (Parris et al., 2009; Ohlsson, 1992). An artful magician induces the impression that he controls the natural laws in a supernatural way and can bend them as he wishes. Besides astonishment, the spectator is faced with the open question of how the magician did the trick. Trying to answer this question, the observer analyses the situation and initiates attempts to find an explanation. A problem is consolidated that must be solved.

In this problem solving process, the observers' prior knowledge imposes an over-constrained problem representation (Knoblich et al., 1999). Wrong assumptions turn into constraints that restrict the search space and prevent the spectator from seeing through the trick. These assumptions are skilfully evoked by the magician, for example:

1, The mug and the glass are real, ordinary objects
2, The water is real water
3, The mug is empty
4, The water is poured into the mug
5, It is a real ice cube
6, There is no water left in the mug after the ice cube has fallen out

Some of these assumptions may be correct, but others are wrong, and these are the crucial assumptions that create the magic effect. They have become constraints that must be relaxed in order to discover the method.

In the present example, only the third assumption is wrong. The “empty” mug is actually filled with a piece of special white napkin, glued to the bottom of the mug, and the ice cube. Because the inner side of the mug is also white, the observer can neither detect the napkin nor the transparent ice cube if the mug is kept in motion while casually showing it empty. The water is indeed poured into the mug, but is fully absorbed by the napkin. And voilà, only the ice cube falls out when the mug is turned upside down –it’s magic!

We argue that if the observer achieves to overcome the initial constraint (empty mug), his search space is restructured (Wertheimer, 1959) and new solution possibilities are opened up allowing him to find the correct solution (napkin) or to think of other possibilities to contain the water (e.g. double bottom).

Taken together, we claim that a magic trick can be regarded as a challenging problem, and that the spectator takes the role of a problem solver who attempts to find out how the magician did the trick. The following flowchart (figure 5) illustrates the interplay between the magician’s actions and spectator’s experience.

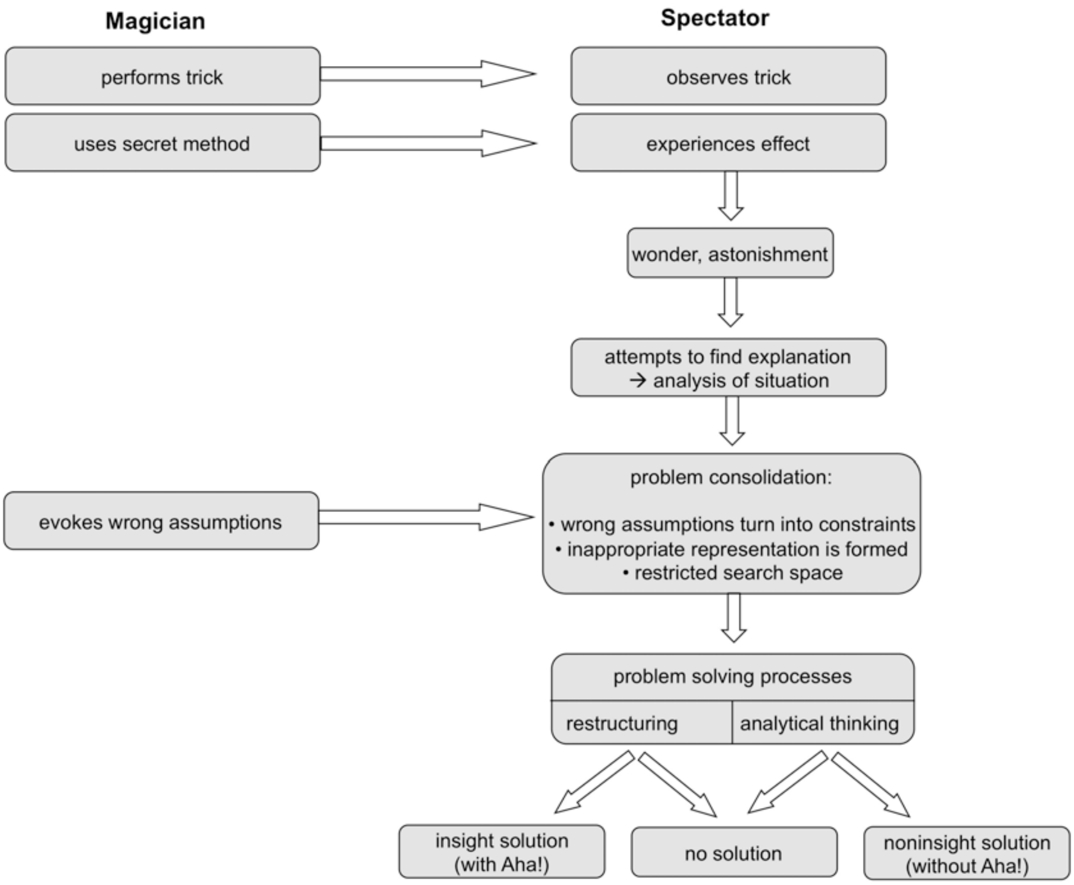

Figure 5. Interaction between magician and observer. A magic trick is performed by the conjurer, who uses a secret method (e.g. skill, mechanical devices, misdirection). The spectator observes the magic trick and experiences the magic effect (e.g. a violation of laws of nature or a logical impossibility). Relevant cognitive processes assumed to be active in the spectator are depicted that eventually might lead to a solution of the problem. Please note that insight solutions as well as noninsight solutions can be either true or false (see 2.4.1).

Introducing a new task, the present study asks whether magic tricks are appropriate to investigate insight problem solving. As one possible indicator to differentiate insight from noninsight problems, participants' IQ (Raven Matrices, SPM-Plus, Raven, 2008) was assessed to analyse its influence on solving performance and in particular, on the frequency of solutions obtained through sudden insight. Gilhooly et al. (2005) found that problem solvers' Raven scores account for a high proportion of variance in noninsight problems, but not in insight problems (but see Chein, Weisberg, Streeter, & Kwok, 2010, for an alternative interpretation of these results). Specifically, we therefore expected to find no correlation between IQ scores and the occurrence of insight solutions. Besides testing the feasibility of our new paradigm, we aim at providing a proof of concept that solving magic tricks reliably elicits insight.

2.3 General Method

As noted above (1.7), all the data presented stems from one large study comprising several different parts. The procedure of each individual part is only described once, namely in the methods of the respective manuscript. However, the present section provides also shared methodological details such as a description of the sample and stimuli and the main task (solving magic tricks). Figure 6 provides an overview of the experimental design of the study. There were two separate testing sessions with 14 days delay.

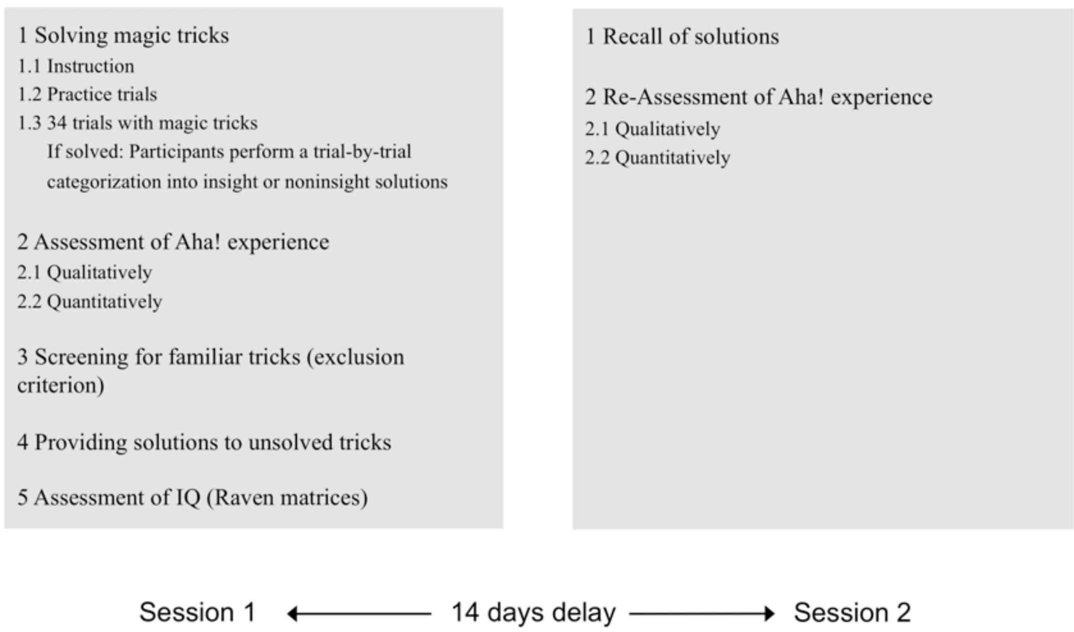

Figure 6. Overview of the experimental design. The study consisted of two separate testing sessions with 14 days delay. Session 1 lasted two hours and session 2 one hour.

2.3.1 Participants

50 healthy volunteers, most of them students (mean age 24.4 ± 3.3; range from 20 to 33, 16 male), were recruited through announcements at the University of Munich and were paid 32 € for their participation. After giving informed consent, each participant was tested individually. None of them had any neurological diseases and all had normal or corrected-to-normal acuity. All participants returned for session 2 exactly 14 days after the first testing time point. Two participants were excluded because they did not solve any of the presented tasks, resulting in a final sample size of 48.

2.3.2 Stimuli

With the aid of a professional magician (TF), a careful pre-selection of magic tricks was conducted with regard to sensory as well as cognitive requirements: Only visual effects that could be performed in absolute silence, with no other interactive elements necessary (e.g. assistant, interaction with the audience). We used short tricks, with only one effect and one method. 40 magic tricks were selected and recorded in a standardized setting, again with the magician TF. We ran three pilot studies on another sample of 45 students to ensure that the tricks were understandable, i.e. that participants perceived the intended magic effect. Tricks were also rated with regard to the extent of surprise that they caused (see appendix A). Three tricks that turned out to be not feasible for a filmed performance were eliminated, and 17 tricks had to be improved in a second recording session (e.g. better camera angle). The final number of stimuli was 34 (plus 3 for practice trials). The video clips that ranged from 6 s to 80 s were presented on a 17" computer screen displayed by the Presentation® software version 12.1. The tricks covered a wide range of different magic effects (e.g. transposition, restoration, vanish) and methods (e.g. misdirection, gimmicks, optical illusions) and are listed in detail in appendix A.

2.3.3 Procedure Session 1

Participants were seated in a distance of 80 cm in front of a computer screen. After filling in an informed consent, participants were orally instructed by the experimenter. Their task was to watch magic tricks and to discover the secret method used by the magician. Following Bowden and Jung-Beeman's approach (2007), participants were asked to categorize their solution experiences into insight and noninsight solutions. As already noted in 1.5.1, the instruction for these judgements read as follows (adapted from Jung-Beeman et al., 2004): "We would like to know whether you experienced a feeling of insight when you solved a magic trick. A feeling of insight is a kind of "Aha!" characterized by suddenness and obviousness. Like an enlightenment. You are relatively confident that your solution is correct without having to check it. In contrast, you experienced no Aha! if the solution occurs to you slowly and stepwise, and if you need to check it by watching the clip once more. As an example, imagine a light bulb that is switched on all at once in contrast to slowly dimming it up. We ask for your subjective rating whether it felt like an Aha! experience or not, there is no right or wrong answer. Just follow your intuition." The experimenter interacted with participants until they felt prepared to differentiate between these two experiences.

After three practice trials, a randomized sequence of 34 magic tricks was presented. If a trick was solved, participants had to indicate on a trial-by-trial basis whether they had experienced an Aha! during the solution. If participants failed to solve the trick, the video clip was repeated up to two more times while solving attempts continued.

As soon as they had found a potential solution, participants were required to press a button. The button press stopped the video clip and terminated the trial. A dialogue with the following question appeared: Did you experience an Aha! moment? Participants indicated Yes or No with a mouse click. Subsequently, they were prompted to type in their solution on the keyboard and gave a certainty rating of how confident they felt about the correctness of their solution on a scale from 0 to 100%. Figure 7 illustrates the procedure.

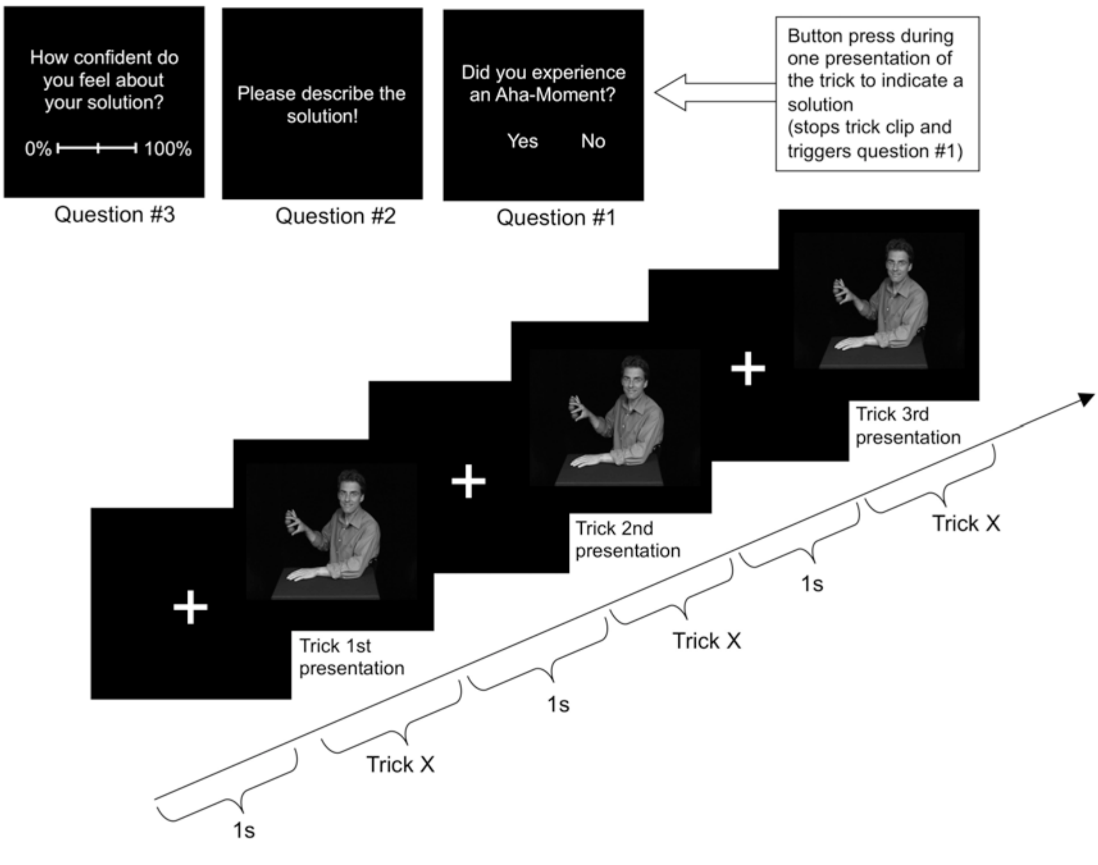

Figure 7. Procedure of one trial. Different phases and timing are displayed. Note that individual tricks vary in length.

Please note that participants never received any feedback about the accuracy of their solutions. To control for familiarity of tricks, at the end of the experiment participants received a questionnaire with screenshots from all 34 tricks and were asked to indicate whether the solution to a trick was previously known to them. These tricks were excluded on an individual level and handled as missing data. In addition, the Raven Matrices (SPM-Plus, Raven, 2008) were administered as a measure of fluid intelligence. Participants were instructed according to the manual and completed the Raven test in approximately 45 minutes. Session 1 lasted about two hours.

Trick repetition: Solving a magic trick is arguably a very difficult task. Therefore, we improved observers’ chances of discovering the method by breaking an old magicians’ rule: Never show the same trick twice! For the reader interested in magic, please consult Lamont et al. (Lamont, Henderson, & Smith, 2010) for a critical discussion of that point. First evidence that trick repetition increases the likelihood of detecting the method was provided by Kuhn and Tatler (2005). In a pilot study (see 2.3.2), we confirmed this finding and could show that in about 50% of trials, participants were able to detect the method after one repetition of the trick. In the present paradigm, to increase the overall solution rate, each trick was repeated up to three times.

2.4 Results

2.4.1 Data Analysis

Participants solved magic tricks and categorized their solutions into insight (with Aha!) and noninsight solutions (without Aha!), therefore the condition (insight or noninsight solution) was determined by participants’ responses (binary data). Solution Rate (number of solved tricks), Solution Accuracy (true or false) and Presentation (number of times that the trick was presented until participants solved the trick or until they failed after the third presentation) were the dependent variables. Repeated measures analyses of variance (ANOVA) of the mean number of solved tricks were used for statistical analyses. All p-values are Greenhouse-Geisser corrected.

Participants’ solutions were coded off-line as true or false by two independent raters, Cronbach’s alpha as a measure of inter-rater reliability was 0.99. *True solutions* were identical with the procedure that the magician had actually used. *False solutions* consisted of methods that were impossible with respect to the conditions seen in the video clip. If no solution at all had been suggested, the tricks were coded as unsolved.

In some trials (5.4% of all solutions), participants suggested an alternative, but potentially conceivable method (see introduction, 2.2.1). We added those to the true solutions category. Adding them to the false solutions category instead, would not have changed the results in any way. Furthermore, a small percentage of all trials (5.2%) had to be discarded because the tricks were already familiar to participants.

2.4.2 Solution Rate and Accuracy

For this analysis, results were collapsed over repetitions. 45.8% of all trials (34 tricks x 48 participants yielded a total of 1632 trials) were not solved, i.e. participants watched the trick three times without suggesting a solution. Those trials were excluded from further analyses because no insight could occur. In 49%, participants suggested a solution (coded as either true or false). For 41.1% of the solved magic tricks, participants had reported insight. The remaining 58.9% were classified as noninsight solutions. Figure 8 shows the percentages of true and false insight and noninsight solutions. The ratio of true/false solutions clearly varies between the two solution categories (15.6/4.6% vs. 16.1/12.7%).

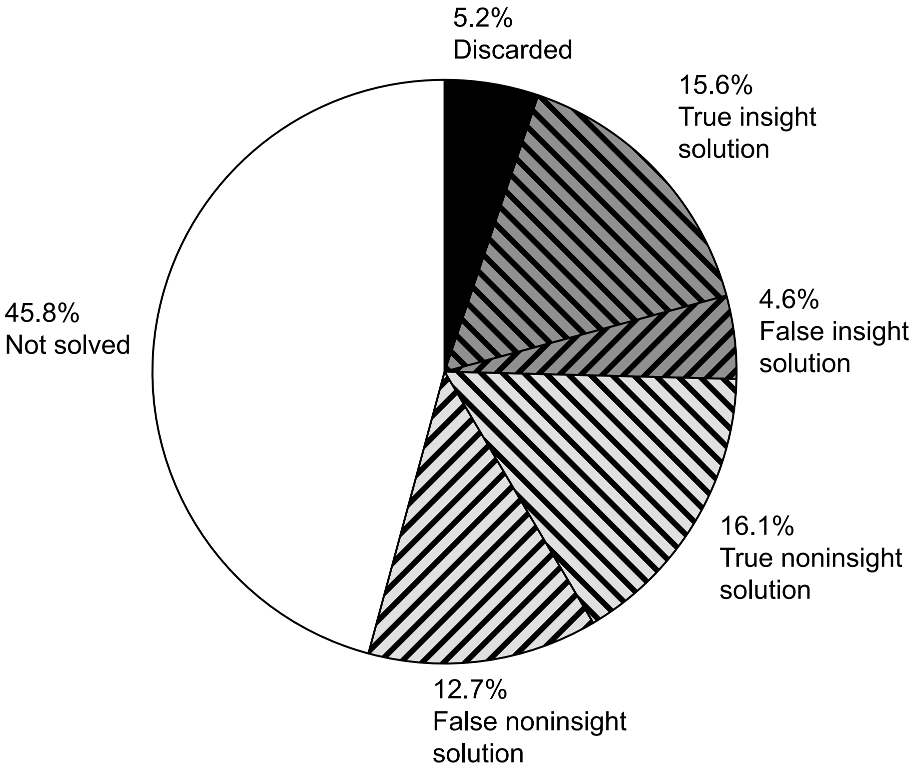

Figure 8. Overview on the data from session 1. Mean percentages of not solved and solved tricks, and their proportion of true and false solutions in the insight and noninsight categories. True insight solution: true or plausible solution + reported Aha! experience; False insight solution: impossible solution + reported Aha! experience; True noninsight solution: true or plausible solution, without Aha! experience; False noninsight solution: impossible solution, without Aha! experience.

An ANOVA for repeated measures with the factors Solution Type (insight vs. noninsight) and Solution Accuracy (true vs. false) was conducted, with the number of solved tricks as dependent variable. It revealed a significant main effect of the factor Solution Type ($F(1, 47) = 7.18$, $p < .05$, $\eta^2_{partial} = .13$) with more noninsight than insight solutions and a significant main effect of Solution Accuracy ($F(1, 47) = 37.05$, $p < .01$, $\eta^2_{partial} = .44$) with more true than false solutions. In addition, this analysis indicated a significant interaction between the two factors ($F(1, 47) = 12.47$, $p < .01$, $\eta^2_{partial} = .21$). Figure 9 depicts the mean number of solved tricks for each factor level.

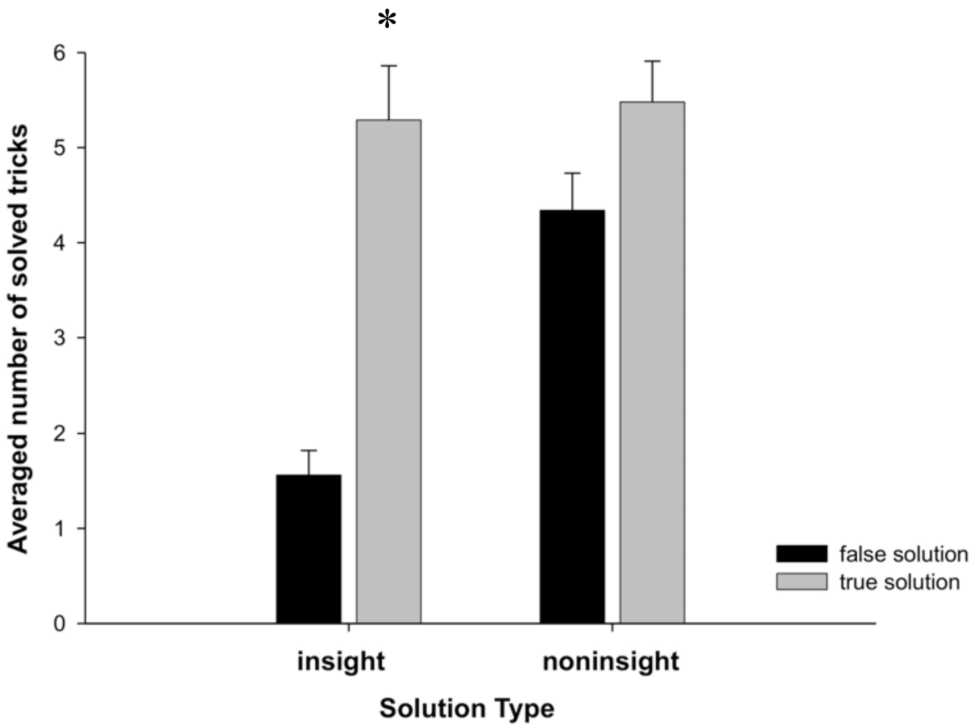

Figure 9. Mean number of solved tricks (out of 34) as a function of Solution Type and Accuracy. Error bars denote standard errors of the mean. Grey bars indicate true solutions, black bars false solutions. Significant differences are marked with an asterix.

Follow-up t-tests showed that there were significantly ($t(47) = 7.35$, $p < .01$, Cohen's dz = .98) more true insight solutions (*M* = 5.29, *SD* = 3.91, grey bar) than false insight solutions (*M* = 1.56, *SD* = 1.83, black bar). This is in contrast to noninsight solutions with no significant difference between the number of true (*M* = 5.48, *SD* = 3.0) and false (*M* = 4.33, *SD* = 2.73) solutions. Therefore, the significant main effect of the factor Solution Accuracy is based on solutions obtained through insight.

2.4.3 Trick Repetition

Tricks were presented up to three times, a trick could thus be solved during the first, second or third presentation. To investigate the influence of repetition on the ratio of insight vs. noninsight solutions, again using the number of solved tricks as dependent variable, we conducted an ANOVA for repeated measures with the factors Solution Type (insight vs. noninsight) and Presentation (Pt1, Pt2 and Pt3) that yielded significant main effects for both factors (Solution Type, $F(1, 47) = 7.12$, $p < .05$, $\eta^2_{partial} = .13$, and Presentation, $F(2, 94) = 82.42$, $p < .01$, $\eta^2_{partial} = .64$). The first main effect was already described. For the main effect of the factor Presentation, follow-up paired t-tests showed that significantly less tricks were solved in Pt1 ($M = 1.1$, $SD = 1.6$) than in Pt2 ($M = 7.8$, $SD = 3.5$) with $t(47) = 14.16$, $p < .01$, Cohen's dz = 1.9 and also significantly less than in Pt3 ($M = 7.8$, $SD = 3.3$) with $t(47) = 11.97$, $p < .01$, Cohen's dz = 1.8. There was no significant difference between Pt2 and Pt3. Figure 10 depicts the mean number of solved tricks for each level of Solution Type and Presentation.

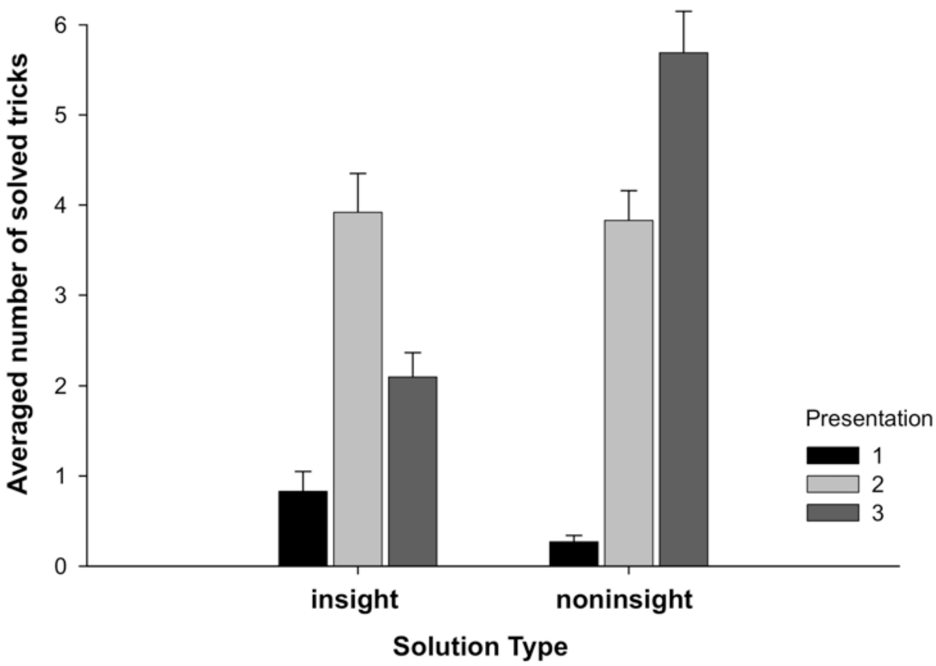

Figure 10. Mean number of solved tricks (out of 34) as a function of Solution Type and Presentation. Error bars denote standard errors of the mean. Black bars depict the number of solutions during the first presentation of the trick, light grey bars depict solutions during the second presentation and dark grey bars depict solutions during the third presentation.

There was a significant interaction, $F(2, 94) = 32.31$, $p < .01$, $\eta^2_{partial} = .41$. Insight solutions occurred most frequently during the second presentation of the trick (bar shaded in light grey) and then during the third presentation (bar shaded in dark grey). For noninsight solutions, this pattern is reversed. We can also see the main effect (only very few solutions during the first presentation, black bars). Therefore, depending on the number of repetitions of the trick, the ratio between insight and noninsight solutions varied significantly.

2.4.4 Individual Performance

On an individual level, we correlated the number of solved tricks (a measure that is independent from whether the produced solution was true or false, as described in the response coding procedure) with the percentage of reported insight solutions (using the percentage instead of the total number of insights corrects for the individually varying solution rates) and found that high solution rates are associated with high percentages of insight solutions (see figure 11). This relationship is significant ($r = .31$, $p < .05$). Regardless of the accuracy of those solutions, participants who solved many tricks showed a tendency to experience more insight events.

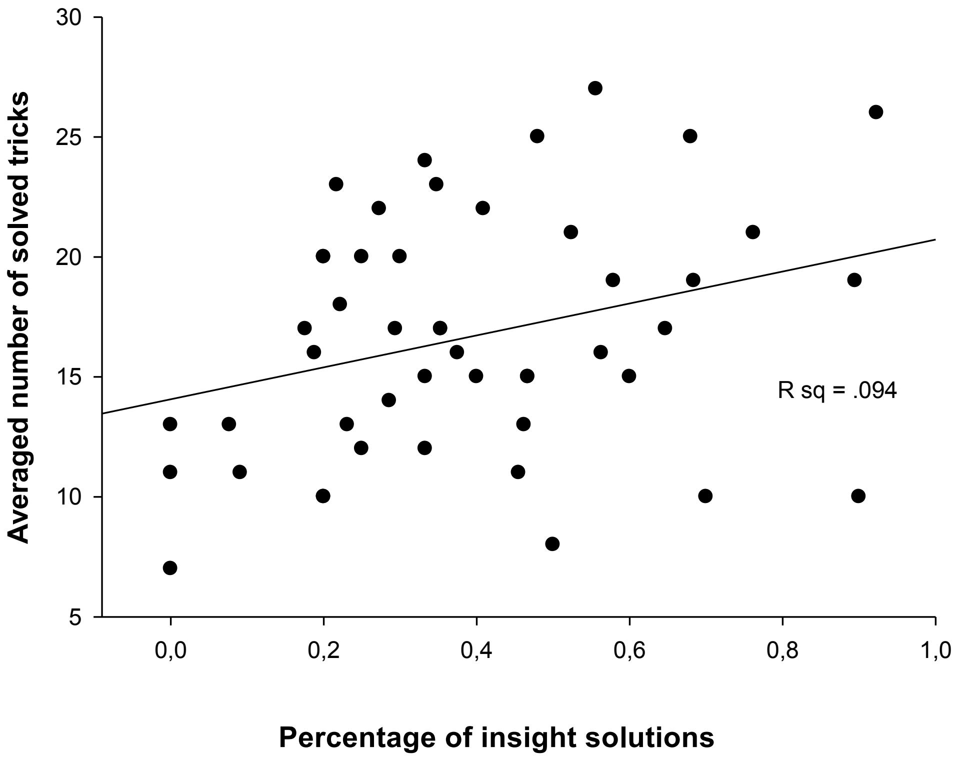

Figure 11. Positive correlation between individual solving rate (averaged number of solved tricks, out of 34) and percentage of insight solutions. Each black dot corresponds to one participant.

To control for the influence of demographic variables (age, sex, education) as well as of participants' IQ (as measured by the Raven Matrices, SPM-Plus, Raven, 2008) on performance in our new paradigm, correlations were calculated. None of these variables did influence the number of insight solutions or the solving performance (number of solved tricks). A significant positive correlation between the educational level and the solving performance ($r = .45$, $p < .01$) was the only exception. That is, a high level of education was associated with a high number of tricks solved.

As a manipulation check, participants were asked to give certainty ratings for each solution, indicating on a scale from 0 to 100% how confident they felt about the correctness of the respective solution. Comparing the mean certainty of insight solutions (mean rating of 84.62%) to the mean certainty of noninsight solutions (63.08%), a significant difference ($t(45) = 11.22$, $p < .01$) was found.

2.5 Discussion

We introduced magic tricks as a new problem solving domain and tested if this could be an appropriate paradigm to study insight problem solving.

In 41.1% of all solutions, participants reported an Aha! experience, which was used as an indicator for the occurrence of insight. Since this is the first problem solving study with this stimulus material, no direct comparisons are possible – but the present occurrence of insight events is slightly lower than in studies using a different problem solving domain (verbal puzzles). For example, Subramamian et al. (2009) report that 50.8% of all solutions were rated as insightful. Participants in a study by Jung-Beeman et al. (2004) indicated insight for 56% of all solutions, Kounios et al. (2008) report identical numbers. Sandkühler and Bhattacharya (2008) found that 55.6% of all solutions were insightful ones (operationalized as involving high ratings of suddenness). By definition, insight is a rare event. That our participants rated less solutions as insightful might be accounted for by task characteristics that lead to greater difficulty levels in attaining an insightful solution. In particular, the requirement of producing a truly novel solution rather than just retrieving a well known solution word could make magic tricks more difficult than verbal puzzles like the frequently used RAT (Mednick, 1962). In any case, only future studies using the same problem solving task will allow a comparison of results. The present study aimed at providing a proof of concept and we argue that the new paradigm elicits a sufficient number of insight events for that.

49% of the presented tricks were solved and we found significantly more true solutions than false ones. This shows that our magic trick paradigm is feasible and of appropriate difficulty.

Comparing the two solution types with respect to their accuracy, we found a different ratio of true to false solutions in each solution category. Insight solutions were significantly more often true than false, whereas noninsight solutions were equally true or false. Consequently, insight seems to be mainly connected to true solutions. Assuming that full insight into a problem is based on restructuring, this result becomes clear. “To gain insight is to understand something more fully” (Dominowski & Dallob, 1995, p. 37) and insightful problem solving requires a deeper or more appropriate understanding of the problem (Sandkühler & Bhattacharya, 2008). Without restructuring, the chances for producing a true or a false solution were nearly even. At least for the domain of magic tricks, this finding suggests a clear advantage of insightful problem solving over more analytical ways of thinking.

Another possible explanation for the significant interaction between Solution Type and Solution Accuracy might be that noninsight solutions reflect participants’ tendency to provide rather a “confabulated” solution than no solution at all – and in many cases (12.7% of all trials), this confabulated solution, obtained through a more analytic, not truly insightful strategy, was in fact false.

Another finding has also interesting theoretical implications. Remarkably, in the present experiment, 4.6% of all trials consisted of false insights, i.e. trials in which participants solved the trick, indicated that they had experienced insight, but suggested a methodically impossible solution. The existence of false insights has been debated, for example Sandkühler (2008, p.2) states that “a true insight must lead to a correct solution”. The Gestalt psychologists assumed that restructuring “always moves towards a better structural balance”, believing in a “certain infallibility in restructuring” (Ohlsson, 1984a, p. 68). This is in accordance with the immediate feeling of certainty (Sternberg & Davidson, 1995) that is often reported after insightful solutions (as it was the case in the present study, too). In contrast, Sheth et al. report the occurrence of incorrect solutions that were rated as highly insightful by problem solvers (2009, p. 1273). Ohlsson (1984a, quoted in Ohlsson, 1992, p. 3) originally defined insight as “the sudden appearance in consciousness of the complete and correct solution”. Acknowledging the existence of false insights, he later stated in a revision of his theory that the criterion of correctness of a solution is not useful for a definition of insight (Ohlsson, 1992). His conclusion that correctness of solution is a "contingent characteristic which accompanies some insights but not all" (1992, p. 3) is clearly supported by our data. We conclude that the present findings prove the existence of false insights, but show that they are far less likely than true insights.

These results also correspond to the certainty judgements collected from participants after each solution. As expected, the mean certainty for insight solutions was significantly higher than the one for noninsight solutions showing that participants actually followed the instruction criteria. Summing up, if participants had found a solution through insight, they felt more certain about it and in fact, the solution was more likely to be the true one. If participants had found a solution through a more analytical way of thinking, they felt less certain and indeed, they produced more false solutions.

The repetition data revealed another important difference between the two solution types: Insight solutions were reached earlier than noninsight solutions. The present paradigm involved up to three presentations of the magic trick (which could be solved during any of these three presentations). Clearly, during the 1st presentation (Pt1), hardly any tricks were solved (on average, for both solution types together, only 1.1 tricks). Participants first had to understand the magic effect, and most trick clips ended a few seconds after the magic effect had taken place, leaving no time for any problem solving attempts. Therefore, during Pt1 it was too early to understand the method. The significant interaction between Solution Type and Presentation reveals a more fine-grained pattern of results. Insight solutions occurred more often in Pt2 than Pt3, but for noninsight solutions, this pattern was reversed (more noninsight solutions in Pt3 than Pt2). Increasing the number of repetitions reduced the frequency of spontaneous insights into the inner working of the trick, and instead fostered more analytical problem solving strategies. We explain this finding in the following way: Watching Pt2, many participants gained sudden insight into the trick (insight solution). But if participants did not experience insight during Pt2, they instead formed various hypotheses about possible solutions, i.e. analytical problem solving attempts began. Consequently, solutions found during Pt3 could not be classified as insight solutions anymore, because they were not sudden, but based on previous solving attempts and the systematic exclusion of hypotheses. Therefore, if more repetitions than three were included in an experimental paradigm, we would predict even less insight events with increasing repetitions.

Analysing the data on an individual level, we found that high solution rates are associated with high percentages of insight experiences. This effect is surprising, because considering the significant main effect (insight < noninsight), a negative correlation would have been expected. That is, participants who provided solutions to many tricks (regardless of whether these solutions were true or false) were more likely to solve them via insight. Note that this finding is independent from solution accuracy, because the solution rate measure includes both true and false solutions.

Based on the findings presented so far, we can now discuss our proposal of using magic tricks as a new task domain for insight research.

We found that magic tricks can be solved either with or without insight, just like other tasks that are used to investigate insight (e.g. CRA problems, Bowden & Jung-Beeman, 2003b). This is advantageous because it allows for a comparison of both processes (insight and more strategic, analytical problem solving) without changing the type of problem used. From a theoretical point of view, our results support the idea that any given problem may pose representational obstacles for some solvers, but not for others (Ash et al., 2009) and therefore may be solved through insightful processes or through more analytical processes (Bowden et al., 2005).

As predicted, participants' fluid intelligence score (Raven matrices) was not correlated to the occurrence of insight solutions. This finding further supports our account of magic tricks as an insight problem solving task for which performance is supposed to be independent from intelligence measures (Gilhooly & Murphy, 2005).

To better understand why a magic trick is a difficult problem solving task, we may refer to the distinction made by Kershaw and Ohlsson (2004) of three difficulty factors in insight problems. Their findings were based on the 9-dot-problem only, but this distinction seems plausible with respect to other problem solving tasks, too. Although perceptual factors (Köhler, 1921) and process factors (Newell & Simon, 1972) are clearly important for our new task domain, we specifically selected certain kinds of magic tricks so that the problem difficulty was determined by knowledge factors. Note that it is not a lack of knowledge, but a biased representation of information (compare figure 5) that hinders the observer from discovering the method.

Our results provide first evidence for the utility and great potential of magic tricks as a problem solving domain. Further studies are warranted to test other theoretical assumptions like imposed constraints and inappropriate problem representation. For example, a possible next step would be to investigate problem solvers' constraints in more detail to find out which types of constraints exist, how they are imposed and finally overcome. Because the constraints encountered by problem solvers are known (and exploited, see introduction, 2.2.1) by the magician, magic tricks represent an ideal domain to systematically manipulate them. This idea will be further elaborated at the end of this thesis (section 6.4). We conclude that the present work offers a new, feasible approach for investigating the complex phenomenon of insight.

3 IT'S A KIND OF MAGIC – NEW INSIGHTS INTO THE NATURE OF AHA!

3.1 Abstract

Insightful problem solving is a vital part of human thinking, yet difficult to grasp. Recent neuroscientific studies rely on the Aha! experience as subjective classification criterion for solving a problem with or without insight. However, the concept of Aha! is rather vague and relies on face validity. Assuming a multidimensional construct, we aim to systematically explore the phenomenology of Aha! by breaking it down into five previously postulated dimensions. As a new approach, 34 video clips of magic tricks were presented to 50 participants who had to find out how the magician accomplishes the trick, and to indicate whether they had experienced an Aha! during the solving process. To obtain a detailed characterization of individual Aha! experiences, participants then had to perform a comprehensive quantitative and qualitative assessment which was repeated after 14 days to control for its reliability. 41.1% of solutions were accompanied by an Aha! experience. The quantitative assessment remained stable across time in all five dimensions. Participants reported more emotional than cognitive aspects, with happiness as the most important dimension. We demonstrated that despite its subjective character, the Aha! experience is reliable and therefore it might be justified to use it as an indicator for insightful problem solving.

Own contribution remark: The research questions were put forward by Dr. Michael Öllinger and myself, and discussed with Prof. Benedikt Grothe. The idea of using magic tricks came from me. Selection, recording and preprocessing of magic tricks was carried out by the magician Thomas Fraps and myself. The experiment was jointly designed by Dr. Michael Öllinger and myself. Matus Simkovic was of great help in programming the experiment. All data presented in this thesis was collected by myself. Eline Rimane and Timo Schiele served as raters for the magic trick solutions. I conducted the behavioural data analysis and discussed it intensely with Dr. Michael Öllinger. The EEG data analysis was conducted in collaboration with Dr. Björn Schelter at the Center for Data Analysis and Modeling in Freiburg. All three manuscripts, including creation of figures, were written by myself.

3.2 Introduction

Sometimes, the solution to a difficult problem pops into mind suddenly (J. E. Davidson, 1995) and unexpectedly (Metcalfe, 1986). Ever since the Gestalt psychologists (Köhler, 1921; Duncker, 1945; Wertheimer, 1959) began to investigate problem solving, the phenomenon of insight has been of great interest to psychologists (Sternberg & Davidson, 1995). Insight is often reported to be accompanied by an affective response, the "Aha! experience" (e.g. Gick & Lockhart, 1995). This is taken as the discriminative criterion to set it apart from analytic and gradual problem solving (Metcalfe, 1986; Evans, 2008). From an information processing account, insight is assumed to be closely linked to an underlying restructuring process (Ohlsson, 1992).

Bühler provided the first reports about Aha! experiences in thinking, describing a moment "in which suddenly, the lights come on" (translated from Bühler, 1907, p. 341). Traditionally, it has been regarded as an interesting epiphenomenon of insight (e.g. Ormerod, MacGregor, & Chronicle, 2002) or even the defining feature of insight (Kaplan & Simon, 1990; Gick & Lockhart, 1995) that defies closer empirical inquiry due to its subjective nature. For a long time, the Aha! experience „has been neglected as being too warm and soft for cool, hard Cognitive Science" (Metcalfe, 1995, p. xi), but meanwhile, the importance of this aspect has been recognized (e.g. Gick & Lockhart, 1995). Furthermore, the recent interest in possible neural correlates of insight has led to a surge in studies that presuppose the subjective Aha! experience to be the clearest observable aspect of insight (Jung-Beeman et al., 2004). Consequently, problem solvers' individual judgements of the subjective experience of an Aha! are indispensable for those studies to classify a solution as insightful and to distinguish it from solutions without insight (Bowden et al., 2005; Aziz-Zadeh, Kaplan, & Iacoboni, 2009). Despite its successful use as a solution type classification criterion and its importance for the interpretation of almost all neuroscientific studies on insight problem solving (e.g. Jung-Beeman et al., 2004; Kounios et al., 2006; Sandkühler & Bhattacharya, 2008), the Aha! experience, as far as we know, has not been investigated in more detail. One hindrance is the methodological difficulty of its assessment (e.g. introspective judgements about the occurrence of Aha!), another one might be conceptual problems (what defines an Aha! experience?). Although the cited studies rely heavily on reported Aha! experiences, there is no general and explicit agreement on a definition of this concept. The common denominator is that an Aha! occurs if a solution suddenly pops into mind. Other aspects like a feeling of surprise, certainty that the solution is correct or a gestalt-like quality of the solution are stressed or disregarded to various degrees across studies (Ohlsson, 1992; Sandkühler & Bhattacharya, 2008; Bowden et al., 2005). The theoretical assumption that prior impasse is a necessary precondition for Aha! experiences to occur (Ohlsson, 1992; Knoblich et al., 2001; Jones, 2003; Öllinger et al., 2006) is taken up by some (e.g. Schooler et al., 1993; Sandkühler & Bhattacharya, 2008) and questioned by others (e.g. Bowden et al., 2005). The conceptual vagueness makes it very difficult to compare findings across studies, and thus it seems critical to further elucidate the phenomenology of this special experience (compare Gick's call, 1995, for further research on the affective aspects of problem solving).

The aim of the present study is to provide a detailed analysis of the Aha! experience during sudden moments of insight. We assume a multidimensional model where the interplay of different components establishes the Aha! experience. We will assess the relative importance of the involved components, using a two-fold approach:

- Qualitative assessment: Free self-reports obtained from participants will be analysed and categorized.
- Quantitative assessment: Five previously postulated dimensions are subjected to a rating of importance by participants (compare Sandkühler & Bhattacharya, 2008).

The qualitative assessment was conducted as follows: Directly after the end of the experiment, participants were given the opportunity to describe their thoughts and emotions during insight moments by introspectively reporting on their subjective Aha! experience. This self-report was performed prior to the quantitative assessment to avoid possible transfer effects (so that participants could freely describe their actual experience without being influenced by the given dimensions).

For the quantitative assessment, we used five dimensions of the Aha! experience that were postulated previously:

1. Suddenness: That insightful solutions are experienced as very sudden was demonstrated by Metcalfe (Metcalfe, 1986; Metcalfe & Wiebe, 1987) who showed that although problem solvers are able to accurately judge their progress towards solution (recorded in feeling-of-warmth ratings) for noninsight problems, they are unable to do so for insight problems. This finding was further confirmed by Davidson (1995).

2. Surprise: Based on introspection and informal observation, Gick and Lockhart (1995) suggest a division of the Aha! experience in two components: Surprise and suddenness. In their account, the surprise aspect can vary by strength and it can be accompanied by either positive (delight) or negative (chagrin) emotions. In order to

disentangle surprise from these accompanying emotions, we decided to assess the emotional component separately, adding “Happiness” as a new dimension.

3. Happiness: Because Gick and Lockhart (1995) proposed the emotional response to vary between the positive and negative pole, we used a scale with “unpleasant” and “pleasant” as two extremes. There is also anecdotical evidence for this dimension of the Aha! experience, for example Gruber (1995) who analyzed Darwin’s notes from the time of his great discovery on 28th September, 1838 and from them, inferred “a state of elevated happiness” (1995, p. 425).

4. Impasse: Ohlsson postulated that prior impasse is a necessary precondition for Aha! experiences to occur (1992). An impasse is defined as a state of mind where problem solving behaviour ceases (Ohlsson, 1992; Öllinger et al., 2008; Sandkühler & Bhattacharya, 2008). Measuring participants’ eye-movements while they were solving insight problems, Knoblich et al. (2001) found an increase in the number of long fixation times for successful solvers. The longest fixation times occurred shortly before a solution was found. This means, directly before insight occurred, there was a phase without systematic eye-movement patterns. This was interpreted as an “idling” phase in which more appropriate representations could be established that yield a new insight.

5. Certainty: Obviousness of a solution, i.e. the strong feeling of certainty that an insightful solution is correct, was stressed as an additional aspect by Bowden and Jung-Beeman (2007). This “intuitive sense of success” related to insightful solutions is also often described in the context of scientific discoveries (Gick & Lockhart, 1995, p. 215).

Adopting a similar procedure from MacGregor and Cunningham (2008) who collected a global self-rating of insight after participants had worked on several different insight problems, we decided to conduct both the qualitative and the quantitative assessment in a comprehensive manner after all tasks were completed. This procedure of asking participants to report their overall feeling of Aha! allowed us to collect the most basic, overarching characteristics of the insight experience, independent from individual fluctuations caused by differences between single problems (e.g. a very difficult task in contrast to a less difficult one that might lead to less strong Aha! experiences).

Furthermore, we aim at providing empirical support for Bowden’s claim (2005) of the reliability of subjective judgements (Aha! vs. no Aha!) in insight research by demonstrating that participants’ quantitative ratings are temporally stable. The differential assessment of the five dimensions was therefore repeated after a two week delay to allow a comparison with the first rating time point. The present study addresses the following two hypotheses:

1. Multidimensionality: We will show that the Aha! experience is a syndrome of well-defined characteristics. Assuming multidimensionality, we hypothesize that all five dimensions should be equally important.
2. Reliability: We will investigate if quantitative ratings of Aha! experiences are stable across time and predict a high reliability.

3.3 Method

3.3.1 Participants

This data is based on the same 48 participants which are described in the general method section (2.3.1).

3.3.2 Stimuli

The testing material consisted of 34 video clips of magic tricks. Stimulus development and a complete list of the tricks are described in detail in 2.3.2. The magic tricks were presented to participants as a problem solving task ("Please try to find out how the trick works!").

3.3.3 Procedure

There were two separate testing sessions with 14 days delay (see figure 6 for an overview of the entire study). In session 1, participants' task was to watch video clips of magic tricks and to think of a solution how the trick could work. If participants failed to solve the trick, the video clip was repeated up to two more times while solving attempts continued. If a trick was solved, they had to indicate on a trial-by-trial basis whether they had experienced an Aha! during the solution. Participants' faces were filmed with a digital camera throughout the experiment. After completing all tricks, participants were asked to evaluate their Aha! experiences. 14 days later, participants were invited again for a second assessment. Session 1 (magic tricks and Aha! assessment) lasted two hrs and session 2 (re-assessment of Aha! experience) lasted 1 hr. In addition, session 2 included a recall of solutions. This part of the method and the corresponding data will be presented in chapter 4.

3.3.3.1 Session 1: Magic tricks

For the procedure of session 1, please refer to 2.3.3.

3.3.3.2 Session 1: Assessment of Aha! experience

3.3.3.2.1 Session 1: Qualitative assessment (”Free self-report”)

After completing all 34 magic clips, participants were asked to give introspective self-reports (“Think of the feelings of Aha! that you have just experienced during the experiment. Now, please describe these Aha! experiences in your own words!”). Participants used the keyboard for typing in their descriptions. There was no time limit for this task.

3.3.3.2.2 Session 1: Quantitative assessment (”Rating of importance”)

Subsequently, participants had to rate their experience on five different dimensions (“Please rate your Aha! experiences by selecting a position on each of these scales!”): Suddenness (slow solution - fast solution), Surprise (not surprising - surprising), Happiness (unpleasant - pleasant), Impasse (no impasse - impasse), Certainty (uncertain - certain). For each dimension, a visual analogue scale was displayed on the screen. As default, the cursor was set in the middle of the scale and participants moved it along the scale using the mouse to select a position. The left end of the scale corresponded to a value of 0 and the right end to a value of 100, but participants did not see any numbers. Participants were instructed to refer only to their Aha! solutions, not to the noninsightful solutions. The screen showed the words “Please rate your Aha! experiences!” above the visual analogue scale for each dimensions’ rating.

To control for familiarity of tricks, at the end of the first session participants received a questionnaire with screenshots from all 34 tricks and were asked to indicate whether the solution of a trick had been known to them previously. These tricks were excluded on an individual level and handled as missing values (5.2% of all trials).

3.3.3.3 Session 2: Re-Assessment of Aha! experience

To control for its stability across time, the same qualitative and quantitative Aha! assessment was conducted 14 days later. The procedure was identical to session 1. Again, participants were explicitly asked to refer to the Aha! experiences they had had during the experiment (now two weeks ago) and to describe them from memory.

3.4 Results

3.4.1 Data Analysis

Only the data from the Aha! assessment is relevant for the present research question and presented here. For a detailed analysis of solution rates, solution accuracy, trick repetition, individual performance and influence of demographic variables, please refer to chapter 2 (section 2.4). Note that for 41.1% of all solved magic tricks, participants indicated that they had experienced an Aha! during the solving process. Of course, the subsequent assessment of the Aha! experience referred only to those events.

The quantitative data was analysed with a repeated measures ANOVA of the mean rating across participants, followed by pair-wise post hoc comparisons (t-tests) between the five individual dimensions. The qualitative data was analysed with McNemar tests. All p-values are Greenhouse-Geisser corrected.

3.4.2 Assessment of Aha! Experience

3.4.2.1 Reliability of quantitative Aha! ratings across time

Participants had rated their individual Aha! experience on five different dimensions (1^{st} rating), with a repetition after a 14 day delay (2^{nd} rating). We addressed the stability of those ratings by comparing the two time points. For six participants, the second rating was missing.

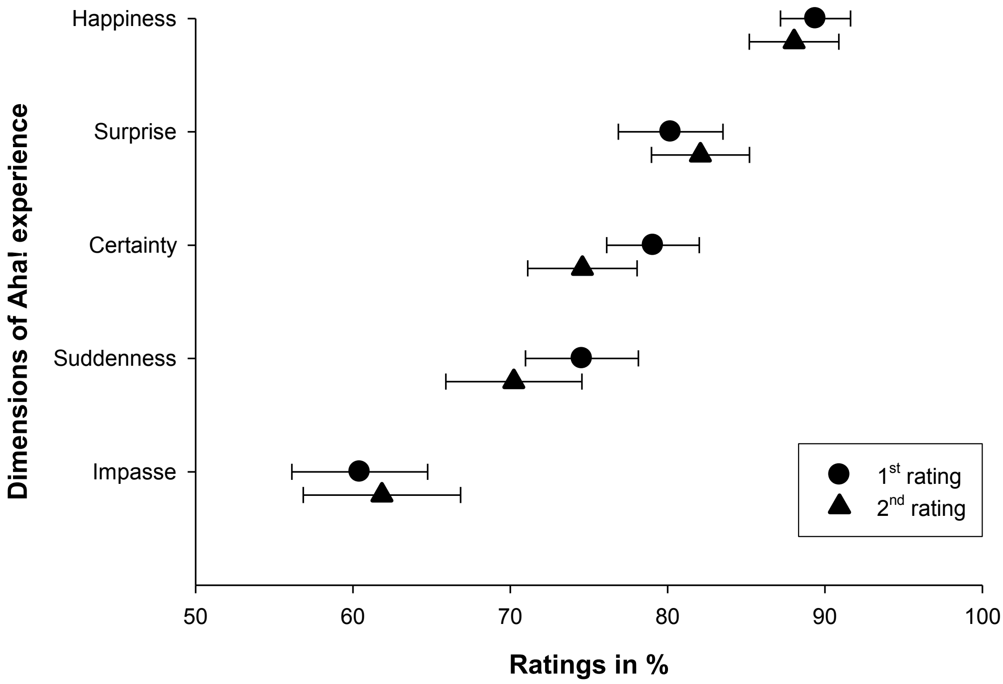

Figure 12. Comparison of the averaged 1st (circle) and 2nd (triangle) Aha! rating for each dimension. For each time point, the mean rating across participants is depicted. Horizontal bars denote standard errors of the mean.

Figure 12 shows that the 2nd rating does not differ substantially from the 1st rating. This observation was statistically confirmed by a repeated measure ANOVA with the factors Session (two levels: session 1 and session 2) and Dimension (five levels: suddenness, surprise, happiness, impasse and certainty) that revealed no significant main effect for the factor Session ($F(1, 41) = 1.1$, $p = .3$). Thus, participants' ratings remained stable across 14 days.

There was a significant main effect for the factor Dimension, $F(4, 164) = 16.43$, $p < .01$, indicating that there were differences between the dimensions. We will focus on the two dimensions that significantly differed from all others, those with the highest (Happiness) and the lowest (Impasse) rating, respectively. Pair-wise post hoc comparisons revealed that the dimension Happiness (mean rating of 88.5%) was rated significantly higher than all other dimensions (all $p < .05$). Impasse ratings were in general lower (mean of 60.9%), and differed significantly from all other dimensions (all $p < .05$). Thus, the feeling of being stuck in an impasse was in comparison less often reported.

3.4.2.2 Categorization of statements from the free self-reports

Each of the 48 participants produced a free report of their individual Aha! experiences that was repeated after a 14 day delay (again, for six participants the second rating was missing). The full statements from all participants are provided in appendix B (translated from German). These statements were sorted into five main categories (see below). In order to implement this without any a priori assumptions about the nature of Aha! experiences, the categories were compiled by a rater who was blind to the experimental rationale, based solely on the statements of the 1st evaluation. This means, the rater read all statements from the 1st evaluation and then collapsed them into meaningful, self-created categories. Subsequently, using a rating scheme with these self-created categories, three independent raters categorized all statements (both 1st and 2nd evaluation). A categorization was valid if at least two of the three raters assigned the same category for one statement. Each of the participants' statements could be assigned to more than one category, because often, several different aspects (belonging to different categories) were mentioned in the self-reports.

1. Cognitive Aspects
    a. Elaboration (compare Ohlsson, 1992): A solution is found because a crucial detail is detected
    b. Restructuring (compare Ohlsson, 1992): A new way of looking at the problem, separate parts suddenly fit together, everything falls into place
2. Emotional Aspects
    a. Happiness: Feelings of joy, contentment, pleasure, positive arousal
    b. Tension Release: Strain is released, feelings of relaxation and relief
    c. Performance-related Emotions: Pride, drive, increased motivation, competitiveness, satisfaction
3. Somatic Reactions: Physiological arousal or other reactions related to the body
4. Reproduction of Instruction: To enable participants to classify their solutions as insightful (with Aha!) or not insightful (without Aha!), it was necessary to provide them with a standard description of an Aha! experience (see general method, 2.3.3). If participants simply repeated parts of that description, this category was assigned, including the following aspects: Suddenness, rapidness, clarity of solution, certainty about the correctness of solution, light bulb metaphor and common conceptions of Aha! experiences (e.g. "struck by lightning, the penny has dropped").
5. Other: Rest category

3.4.2.3 Analysis of statements from the free self-reports

Table 1 shows how often the aspects had been named and provides one prototypical example each.

Table 1. Categorization of free Aha! evaluations with prototypical examples taken from participants' statements (translated from German). Their corresponding frequencies are listed separately for the two evaluation time points, as well as summed up (last column).

#	Category	Example	Frequency 1st evaluation	Frequency 2nd evaluation	Total frequency
1a	Cognitive (Elaboration)	I detected a small detail and suddenly, the things that I had observed previously make sense.	8	1	9
1b	Cognitive (Restructuring)	What in the beginning didn't fit together suddenly makes sense.	6	2	8
2a	Emotional (Happiness)	I am happy and get into a good mood.	20	23	43
2b	Emotional (Tension Release)	I feel relieved and relaxed.	8	11	19
2c	Emotional (Performance-related Emotions)	- I was much more motivated to continue working on the task. - Like a competition between me and the magician, and in Aha! moments, I felt like the winner. - I feel so much more intelligent.	12	12	24
3	Somatic Reactions	Like a shot through my body.	3	3	6
4	Reproduction of Instruction	I suddenly feel an enlightenment.	29	22	51
5	Other		6	4	10
			Σ 92	Σ 78	Σ 170

For the 1st evaluation, comparing the cognitive and the emotional categories (1a+1b vs. 2a+2b+2c) with a cross tab, we found that 24 participants mentioned emotional aspects (but no cognitive ones) whereas only 5 participants mentioned cognitive aspects (but no emotional ones). This difference was significant (McNemar test, $p < .01$).

After two weeks, this difference was even more pronounced: For the 2nd evaluation, 30 participants mentioned emotional, but no cognitive aspects (in contrast to only 2 participants with the reverse pattern), and the McNemar test was significant with $p < .01$.

Regarding the three emotional subcategories, clearly the most relevant aspect was happiness (mentioned 43 times). Performance-related emotions (24 times) and the feeling of tension release (19 times) seemed to be equally important aspects of the Aha! experience.

Apart from reproductions of the instruction, which dealt mainly with the solution strategy used (Aha! vs. more analytic solving styles), only few cognitive aspects were mentioned.

Somatic reactions were only mentioned by three participants at each time point. Two statements were from the same participants, i.e. at the 2nd evaluation, two participants described the same physiological reactions as they had during the first one. In the first case, this was “a slight pull in my chest and tummy”, and the second participant expressed the feeling “like a shot through my body”.

Category 4 was used as a manipulation check. Obviously, participants remembered the instruction well or used the same characteristics, with 51 total instances of naming one of these aspects.

3.4.3 Behavioural Aspects

The video recordings of participants’ behaviour during the solution process may serve to illustrate the emotional response following Aha! experiences. Here we present two paradigmatic cases (figures 13 and 14). The participants shown gave written consent for the publication of this material.

Insight solution

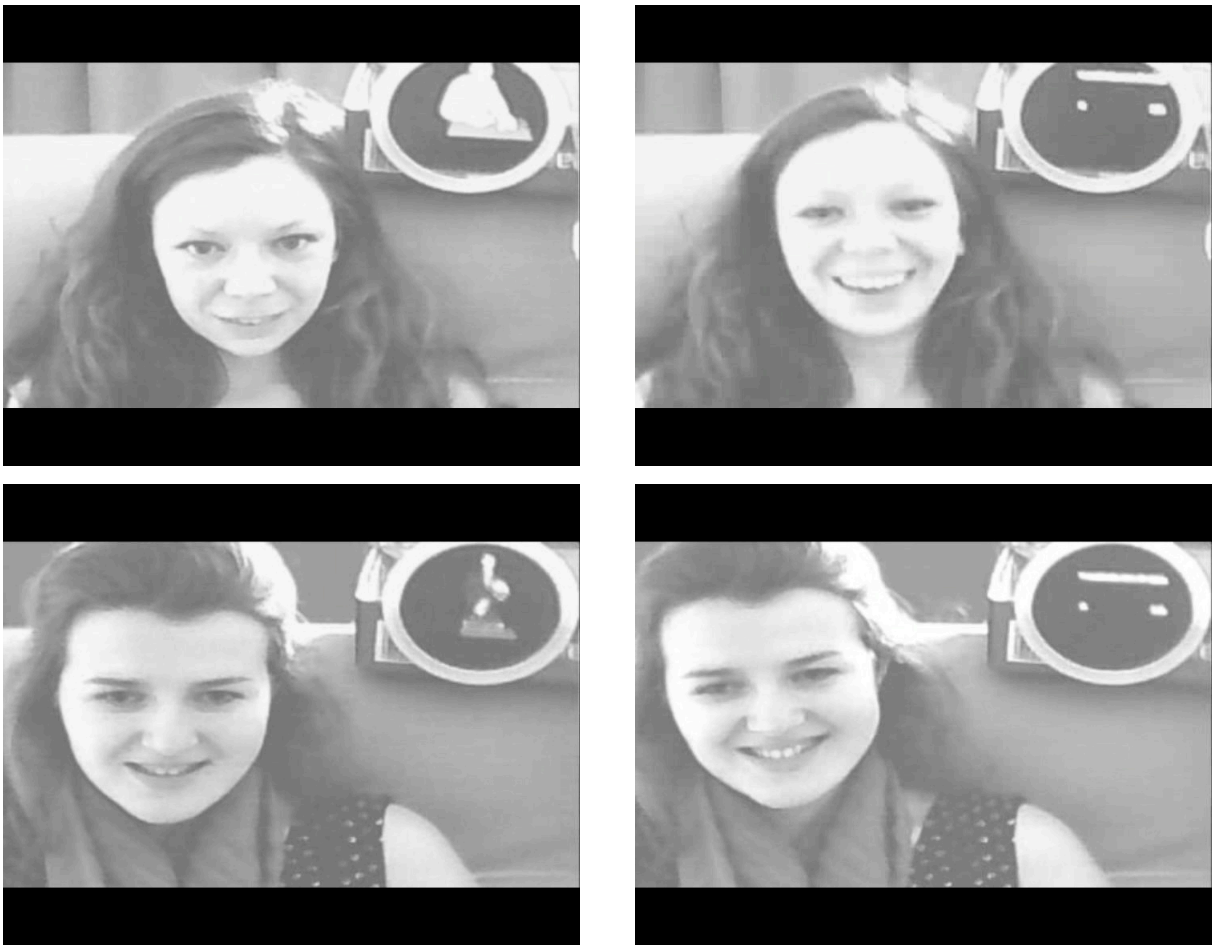

Figure 13. An insight solution. Stills from the video recordings that were run during the entire experiment. The behavioural response of two participants directly before (left panel) and after (1 s later, right panel) an insight solution is shown.

Noninsight solution

Figure 14. A noninsight solution. Stills from the video recordings that were run during the entire experiment. The behavioural response of two participants directly before (left panel) and after (1 s later, right panel) a noninsight solution is shown.

Comparing the right upper panel of figure 13 with the right upper panel of figure 14, there are striking differences in the behavioural response of the same participant. In both cases, the participant is shown 1 s after she discovered the secret method of a magic trick, but in figure 13, she later reported her solution as being “insightful” (with Aha! experience), whereas in figure 14, she classified it as noninsight solution. We can see that the participant reacts quite differently, with a positive affective response to the insight solution (figure 13) that is completely missing for the noninsight solution (figure 14). The other participant (lower panel) exhibits the same pattern.

3.5 Discussion

The present study aimed at providing evidence for the assumed multidimensionality of the Aha! experience during sudden moments of insight. Specifically, we hypothesized that this multidimensional construct could be broken down into five dimensions of equal importance. Furthermore, we predicted that quantitative ratings of Aha! experiences would be stable across time. The new stimulus domain proved to be well suited to reliably trigger Aha! experiences, since 41.1% of all solutions were classified as Aha! solutions. Results from the quantitative rating of these Aha! experiences will be considered first.

Our hypothesis of equal importance was not confirmed. Instead, we found one prevailing aspect: Happiness was rated higher than all other dimensions. Therefore, in our paradigm, a pleasing feeling seems to be the most important characteristic of the Aha! experience. This primacy of positive emotions is also reflected in participants' qualitative statements, as discussed below.

Impasse was rated lower than all other dimensions, thus this aspect appears to be less important than previously thought (Ohlsson, 1992). This might be attributed to our new stimulus domain. We argue that watching a magic trick directly puts the observer in a state of impasse – namely in the first moment of astonishment and wonder about the magic effect. At first, the observer is left completely baffled, without any solution prospect. But later, after the problem solving process has been initiated, participants don't necessarily experience an impasse. This finding is in accordance with results from a study on the Candle Problem (Duncker, 1945) by Fleck et al. (Fleck & Weisberg, 2004) who found only few instances of impasse in verbal protocols obtained during the problem solving process.

The 2nd quantitative rating did not differ from the 1st in any dimension (see figure 12), therefore participants' ratings of Aha! experiences remained stable across time. To evaluate such a fleeting moment by pinpointing several dimensions on a scale is arguably quite a difficult task. It is thus impressive that participants were able to recall their Aha! experience so vividly after 14 days that they rated it in the same way as before. This finding provides empirical support for Bowden's claim (2005) for the usefulness and reliability of self-reports in insight research.

A weakness of our visual analogue scale is the lack of negatively poled questions, reflected in the answers' general trend towards the positive pole. The temporal stability of the ratings might thus partly be explained by reduced variability caused by this positive bias. Another alternative explanation for the ratings' stability must also be considered: It is conceivable that participants did not actually remember their Aha! experiences, but instead reported what they remembered reporting in session 1. However, this seems unlikely for two reasons: First, to make it difficult to remember the previous rating, we had deliberately implemented a visual analogue scale without any numbers. There was only a white line on which the red cursor had to be positioned by moving the mouse along the line. In this way, participants could never know the value to which the selected position corresponded and could therefore not retain any numbers, only a visual image of the scale. We argue that it is nearly impossible that participants were able to retain this visual impression for two weeks for five different dimensions. Second, participants were clearly instructed to remember the actual Aha! experience, not the previous rating. Nothing could be gained from disobeying this instruction, since there was no reward connected to the outcome. We conclude that the finding of no differences between the two rating time points shows that the method of directly questioning participants yields temporally stable indicators of the occurrence of Aha! experiences.

In order to obtain further information about the actual experience of problem solvers, participants were asked for a free verbal description of their Aha! experiences, directly after the experiment, before being presented with the presupposed dimensions. Of course, this self-report might not be completely free, but could have been influenced by the previous instruction. Therefore, we included only statements that had not been part of the instruction (compare general method, 2.3.3). A qualitative analysis of this data revealed positive emotions (mentioned in 25% of all statements) as the prevailing aspect of Aha! experiences. This is in accordance with results from the quantitative ratings in which the dimension Happiness was of highest importance. This statement from one of the participants may serve as an illustration: “A moment of bliss. I am happy and get into a good mood.” (compare appendix B). With the present analysis, we provide empirical evidence for the occurrence of strong positive emotions during sudden moments of insight.

Now we will consider two new aspects that were mentioned in participants’ free self-reports: Performance-related aspects (14%) and a feeling of “release of tension” (11%). The comparably high frequency of performance-related statements (e.g. “I feel really clever now” or “The magician can’t fool me anymore because by now, I could do the trick by myself”) was not expected, and might be attributed to the special task situation with our problem solvers being confronted with the magician as a kind of “rival” and thus engaging in a competition with him. Therefore, they might be only task specific and we would not expect similar reactions to classic insight puzzles without any opponent.

We found evidence for another new aspect, tension release, with 11% (19 out of 170) of the Aha! descriptions focusing on this feeling (e.g. "I feel relieved and relaxed now" or "feeling of relief after a phase of strain caused by failure"). It seems plausible to assume that tension arises if there exists no obvious solution for a problem. During unsuccessful problem solving attempts, the tension builds up further. If at last, quite unexpectedly, a solution is found, the tension will rapidly decline. Apparently, this is an important aspect still missing from current definitions of the Aha! experience.

We sought to compare our empirical findings with theoretical assumptions. Ohlsson (1984a) summarized the Gestalt psychologists' major ideas about restructuring and insight in a set of principles. There are some overlaps with aspects found in the free self-reports: In category 2c (performance-related emotions), participants repeatedly described heightened motivation ("I am much more motivated to continue working on the task"). This closely resembles proposition N (Ohlsson, 1984a, p. 70) in which an "energizing effect on problem solving behaviour" is described.

Other aspects also match Ohlsson's descriptions: "Recentering as a displacement of attention from one part of the situation to another […] reveals what the central part of the situation really is" (Ohlsson, 1984a, p. 70). This corresponds to category 1a (elaboration) and matches the idea of selective encoding (J. E. Davidson, 1995). Selective encoding means that certain features which were not obvious before (and not encoded) are suddenly detected by the problem solver as relevant for a solution. For example, one of our participants noted that "Through a detail, the entire action sequence becomes clear".

In comparison to emotional aspects, cognitive aspects of the Aha! experience were mentioned less often. A possible explanation might be that the affective response felt more prominent so that participants "forgot" to report their thinking patterns or problem solving strategies. Or, even more likely, since the instruction (see general method, 2.3.3) was centred around cognitive aspects like suddenness and certainty about solution, perhaps participants felt obliged to describe "new", namely emotional aspects, which had not been part of the instruction. We should also keep in mind that about 50% of participants actually mentioned "suddenness", but that this was rated as mere reproduction of the instruction.

With respect to future experiments, we point out that there is a wealth of information to be gained through subjective self-reports. Most participants took several minutes to diligently describe their thoughts, using vivid and expressive language (compare participants' full descriptions in appendix B). We recommend the use of such direct, qualitative self-reports as a promising tool to learn more about the subjective phenomenology of Aha! Of course, there are obvious limitations to such an introspective method: It is highly subjective, and general conclusions can only be drawn with caution. Durso even suggested that because participants were shown to be unable to correctly judge their progress toward a solution (Metcalfe, 1986), "…self-reports following insight are equally unreliable." (Durso et al., 1994, p. 94). Yet we argue that for the elusive phenomenon of insight, subjective Aha! reports might provide information that would not be accessible through more rigorous experimental methods. Other researchers have already successfully used verbal protocols to elucidate the processes during insight problem solving (Kaplan & Simon, 1990; Fleck & Weisberg, 2004; Dominowski & Buyer, 2000; see also Fox, Ericsson, & Best, 2011, for a recent meta-analysis on verbalization procedures in general). We suggest that the traditional approach of using pre-defined "insight problems" and assuming the occurrence of insight in the case of a solved problem, without taking into account participants' individual problem solving experiences, should always be complemented by subjective measures (e.g. Aha! self-reports, detailed Aha! evaluations, thinking-out-loud protocols) obtained from participants.

Comparing participants' behaviour (recorded on video tape) directly after insight and noninsight solutions further validates the strong emotional impact of Aha! experiences. The affective response to solutions found through insight is reflected in smiling, laughter and other positive facial expressions whereas the responses to noninsight solutions are less strong or completely missing. A quote from one of our participants may serve to illustrate this: "Explosively, the bad feeling of frustration and confusion turns into a feeling of happiness and I feel a swell of pride."

In sum, the present results provide evidence for the multidimensionality of the Aha! experience and point to a feeling of happiness as the prevailing characteristic. This primacy of positive emotions was found in qualitative as well as in quantitative ratings, although two different methods were used (free self-reports and ratings on a visual analogue scale with fixed dimensions). By revealing the temporal stability of individual Aha! ratings, we could show that despite its subjective character, the Aha! experience is a clearly measurable factor. An interesting question for future research is whether these findings would also apply to classical insight problems. Another open question concerns the possible influence of personality variables. We speculate that personality differences might lead to differential emphasis on each of the five dimensions of the Aha! experience. This study demonstrates that the Aha! experience should not only be regarded as an interesting epiphenomenon or trial-sorting criterion, but that the phenomenon itself can be investigated systematically and fruitful results can be gained.

4 FACILITATED RECALL OF INSIGHT SOLUTIONS

4.1 Abstract

The present study investigates a possible memory advantage for solutions that were reached through insightful problem solving. We hypothesized that insight solutions (with Aha! experience) would be remembered better than noninsight solutions (without Aha! experience). 34 video clips of magic tricks were presented to 50 participants as a problem solving task, asking them to find out how the trick was achieved. Upon discovering the solution, participants had to indicate whether they had experienced an Aha! during the solving process. After a delay of 14 days, a recall of solutions was conducted. Overall, 55% of previously solved tricks were recalled correctly. Comparing insight and noninsight solutions, 64.4% of all insight solutions were recalled correctly, whereas only 52.4% of all noninsight solutions were recalled correctly. We therefore demonstrated a facilitating effect of previous insight experiences on the recall of solutions.

Own contribution remark: The research questions were put forward by Dr. Michael Öllinger and myself, and discussed with Prof. Benedikt Grothe. The idea of using magic tricks came from me. Selection, recording and preprocessing of magic tricks was carried out by the magician Thomas Fraps and myself. The experiment was jointly designed by Dr. Michael Öllinger and myself. Matus Simkovic was of great help in programming the experiment. All data presented in this thesis was collected by myself. Eline Rimane and Timo Schiele served as raters for the magic trick solutions. I conducted the behavioural data analysis and discussed it intensely with Dr. Michael Öllinger. The EEG data analysis was conducted in collaboration with Dr. Björn Schelter at the Center for Data Analysis and Modeling in Freiburg. All three manuscripts, including creation of figures, were written by myself.

4.2 Introduction

In contrast to analytical problem solving, insight problems are characterized by a sudden, unexpected solution that is often accompanied by a so-called “Aha! experience” (Metcalfe, 1986; Sternberg & Davidson, 1995). Implicitly, it is often assumed that insightful experiences lead to strong memory effects. For example, insight tasks like the nine-dot problem (Scheerer, 1963) are never presented without controlling for prior exposure to the problem. Already at the dawn of insight research, Köhler (1921) reported that his apes were more efficient (shorter solution times compared to the first attempt) in re-solving problems to which they had previously found an insightful solution.

Still, there is a scarcity of studies explicitly addressing this question (Dominowski & Dallob, 1995). An exception is a recent study from Dominowski and Buyer (2000) revealing near-perfect performance in several insight problems which had been successfully solved one week before. This “re-solution effect” was not present if participants had failed to solve a problem and then had been shown the solution. This finding was explained by differences between solvers and nonsolvers with regard to their mental representation of a problem, with the solvers building a better integrated and more complete representation.

The idea that Aha! experiences lead to a facilitation of later recall was first posited by Auble et al. (Auble, Franks, & Soraci, 1979). They presented participants with initially incomprehensible sentences, followed by a cue that revealed the meaning of the sentence. There was a facilitating effect on immediate recall of sentences with Aha! in contrast to sentences without Aha! (Aha! was defined as initial noncomprehension of a sentence followed by comprehension – please note that this differs substantially from the present conceptualization of an Aha! experience, as outlined below). Since participants were not asked about their understanding of the sentence until after the cue was presented 5 s later, possible attempts to solve the problem without cue were not assessed. Therefore, Auble’s findings are limited to cued solutions and thus only concern the phenomenon of “outsight” (aptly termed so by Sheth et al., 2009, in contrast to “insight”). We agree with Luo and Knoblich who state that “without doubt, the phenomenon of interest is internally generated insight.“ (Luo & Knoblich, 2007, p. 79). Consequently, we decided to use a paradigm in which no cues were provided, so that all solutions might be found by participants themselves (self-generated).

Wills et al. (Wills, Soraci, Chechile, & Taylor, 2000) investigated self-generated insight with pictorial stimuli in the context of the “generation effect”, a memory advantage for self-generated over provided items. They found a facilitating effect on immediate recall for connect-the-dot pictures that were drawn by participants (connecting dots until the full picture appeared) in contrast to a presentation of the already complete picture. It was argued that this result was mediated by the Aha! that participants could only experience in the first condition, when the figure became suddenly identifiable during drawing.

To conclude this overview, there is first evidence that insightful experiences facilitate recall of initially uncomprehended stimuli in the verbal (sentences) and visual (pictures) domain. An impressive recall performance was demonstrated, too, for solved classical insight problems. However, from our point of view, there is one limitation common to all reported studies: A failure to distinguish between insight and noninsight solutions. We agree with Bowden and colleagues (Bowden et al., 2005; Bowden & Jung-Beeman, 2007) in their argument that any problem can be solved with insight, but also without insight. Following this rationale, a direct assessment of the occurrence of insightful experiences is required which poses methodological challenges, but might lead to more valid results. Please refer to section 1.5.1 for a detailed discussion of that issue. We regard the subjective Aha! experience as the clearest defining characteristic of insight problem solving (Gick & Lockhart, 1995) that accompanies only insightful solutions, and follow Bowden's recommendation (2005) of using participants' subjective reports of Aha! experiences to sort solutions into insight (Aha! reported) and noninsight solutions (Aha! not reported). The occurrence of an insight experience is thus directly determined by the problem solver. If its occurrence is simply assumed without direct feedback from the problem solver, as it was done in previous work (Auble et al., 1979; Dominowski & Buyer, 2000; Wills et al., 2000), it is difficult to claim that the reported findings actually stem from insightful experiences. To our knowledge, the present study is the first one that, with the purpose of investigating memory effects, differentiates between insight and noninsight solutions, using direct Aha! judgments by participants.

In the present work, we will investigate a possible memory effect in the problem solving domain. We address the question whether gaining sudden insight into the solution of a difficult problem yields strong and long-lasting memory effects, facilitating subsequent recall of a solution.

Besides empirical findings, our hypothesis is theoretically motivated by Knoblich's account (Knoblich et al., 1999) who claimed that the representational change (Ohlsson, 1992) underlying insightful experiences leads to persisting changes in the representation of a problem (transfer hypothesis). Confirming this claim, at least for short time intervals, they could show transfer effects from one solved problem to others with the same source of difficulty. The basic idea is that the successful solution of an insight problem is preceded by a change of the problem and/or goal representation. Those representational changes persist over time. For example, in the nine-dot problem, solvers realize that they have to overcome the virtual boundaries of the nine-dot square. They relax a constraint (the virtual boundaries), and this constraint stays relaxed. Therefore, later on, they will be able to remember that the boundaries must be transgressed (i.e. transfer takes place). We will try to extend these findings not by investigating short-time transfer from one problem block to another within one experimental session, but by introducing a rather long delay (14 days) and asking for a recall of solutions to previously solved problems. To reach this aim, the newly developed problem solving domain of magic tricks will be used. Participants watch magic tricks and are asked to find out how the magician achieves the magic effect. We argue that magic tricks are especially well suited to investigate representational change, because in order to gain insight into the magicians' secret method, observers must overcome implicit constraints (as outlined in greater detail in 2.2.1).

In addition, the subjective Aha! experience can lead to strong emotional responses (Gick & Lockhart, 1995; Jung-Beeman et al., 2004) which might further strengthen the memory trace (for a review, see LeDoux, 1996, 2000).

Specifically, we hypothesize that insight solutions (accompanied by an Aha! experience) will be remembered better than noninsight solutions lacking the Aha! experience.

We base our hypothesis on two arguments: First, in noninsight solutions, no representational change occurred. Second, the Aha! experience together with its typical strong emotional response is lacking. If representational change and the experience of Aha! are indeed factors that lead to strong and long-lasting memory effects, we may expect better recall for insight than noninsight solutions.

4.3 Method

4.3.1 Participants

As described in the general methods (2.3.1), 48 participants took part in this experiment.

4.3.2 Stimuli

We investigated possible memory effects of insight in the new domain of magic tricks that was shown to trigger strong Aha! experiences (compare chapters 2 and 3). The testing material consisted of 34 video clips of magic tricks. Stimulus development and a complete list of the tricks are described in 2.3.2. The magic tricks were presented to participants as a problem solving task (“Please try to find out how the trick works!”).

4.3.3 Procedure

4.3.3.1 Session 1: Solving magic tricks

The procedure of the experiment was already described in 2.3.3. Only one additional part that is relevant for the present analysis will be described here (compare figure 6).

Providing solutions to unsolved tricks: After the screening for familiar tricks, individually for each participant, solutions to their unsolved tricks were revealed by presenting the same screenshots as in the familiarity questionnaire with a line of text that explained the solution. Although we were only interested in the recall of self-generated solutions (compare introduction, 4.2), this procedure was necessary to ensure that the memory load during recall was the same for each participant. In this way, all participants had to recall the solutions to 34 magic tricks during the second testing session. The recall data from unsolved tricks was not taken into account for the analysis.

4.3.3.2 Session 2: Solution recall

After 14 days, the second testing session was conducted. Participants were instructed to recall the solutions in the following way: “Two weeks ago, you observed magic tricks and were asked to find out how the magician achieves the magic effect. Either you found it out by yourself or you were shown the solution. Now we would like to know which of the solutions you can still remember. Please look at the pictures carefully and try to remember the solution, then type it in. If you can’t remember the solution, simply write ‘Forgot solution’. It is also possible that you have forgotten not only the solution, but the entire trick - please indicate these cases by writing ‘Forgot trick’.” Furthermore, it was stressed that they should not generate any new solutions, but only rely on memory. Again, the pictures used to control for familiarity (described above) were used as a reminder of the trick (a second viewing of the entire trick clip was avoided in order to prevent participants from creating new solutions while watching the clip). Participants viewed the trick pictures, typed their answers directly below the picture on the screen and proceeded to the next trick by pressing the enter button.

4.4 Results

4.4.1 Data Analysis

The coding procedure for participants' solutions was already described (see 2.4.1). Recall performance was coded as matched and failed by two independent raters (Cronbach's alpha of 0.99). *Matched recall* means that a participant recalled the same true or false solution as in session 1. The *failed recall* category comprised three cases: forgot trick, forgot solution or false memory (if solutions from session 1 and 2 did not match).

Analysing the influence of insightful solution experiences on memory performance, we had to deal with the problem of varying solution rates across participants (ranging from 7 to 27 solved tricks, with a mean of 16.7). To correct for this, the mean number of solved tricks for each factor level was weighted, participant-wise, with the participant's individual solution rate. This means, for each participant, the absolute frequency of solved tricks in each category (e.g. true or false, insight or noninsight solution) was divided by the respective participant's individual solution rate. The resulting value indicates which percentage of the individual total number of solved tricks falls into each category. For example, if participant A solved a total of 16 tricks, and 8 of them with insight, this would yield a percentage of 50% insight solutions, and the remaining 50% would consist of noninsight solutions. In this way, it could be assured that each participant contributed equally to the statistical analyses. The same rationale applies to the recall rate. Since every participant had solved a different number of tricks, the number of correctly recalled solutions (= matched recall) was dependent on the individual solution rate. For example, a participant who had only solved three tricks could not reach a higher number of correctly recalled tricks than three. To correct for this, the recall rate was also weighted with the individual solution rate, i.e. divided by it.

A 2x2x2 repeated measures ANOVA of the weighted number of solved tricks was conducted, followed by paired t-tests. All p-values are Greenhouse-Geisser corrected.

4.4.2 Data from Session 1: Solving Magic Tricks

Please refer to figure 8 in section 2.4.2 for an overview on the data obtained in session 1. The present study investigates self-generated insight and, specifically, the influence of Aha! experiences on subsequent recall. Therefore, trials with no solution were excluded from the analysis because no Aha! experiences could occur. The following analysis is based on the 800 (49%) solved trials.

4.4.3 Data from Session 2: Recall Performance

In session 2, participants had to recall their solutions. Figure 15 depicts the weighted mean number of solved tricks for each factor level (note that the percentages always refer to the total number of solved trials) and illustrates that overall, of all solved trials, more were recalled correctly (matched recall, 55%, in grey) than incorrectly (failed recall, 45%, in white), there were more noninsight solutions (61%, plain colour) than insight solutions (39%, striped) and more true (65%, right half of the circle) than false solutions (35%, left half).

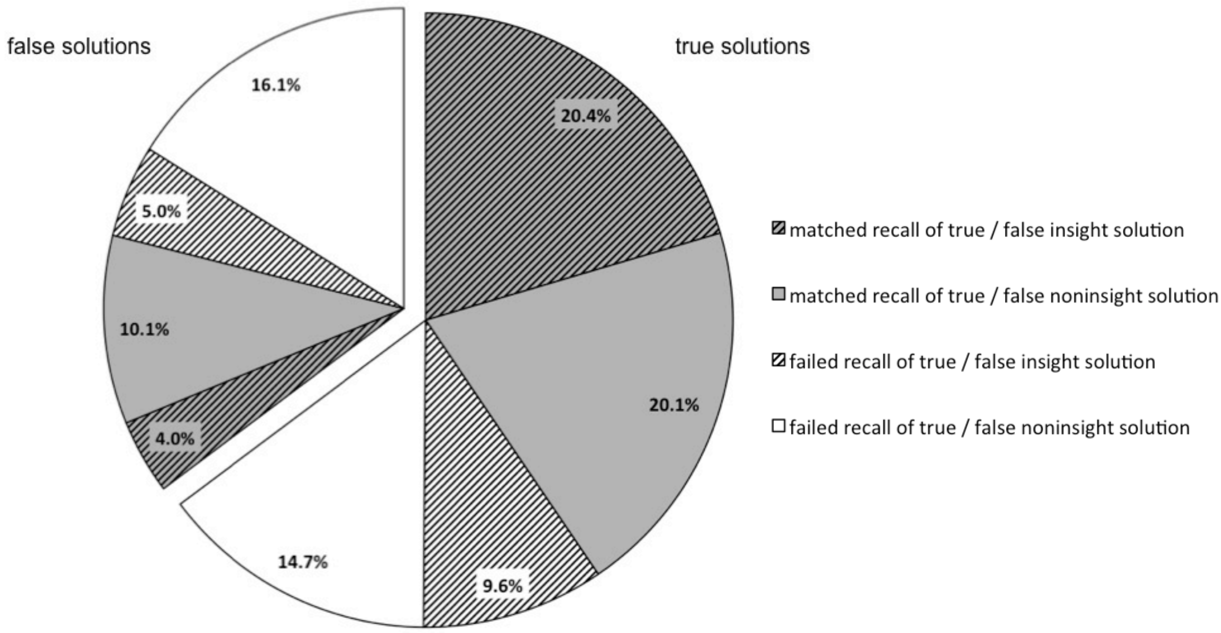

Figure 15. Overview on the data from session 2. Weighted mean number of solved tricks (in %) and their proportion of matched and failed recall in the insight and noninsight categories, depicted separately for false and true solutions.

Correcting for the overall lower occurrence of insight trials, we obtained the following values for a direct comparison between insight and noninsight solutions with regard to the number of matched recall events: 64.4% of all insight solutions were recalled correctly, whereas only 52.4% of all noninsight solutions were recalled correctly. However, for statistical analyses, we had to take into account the variable Solution Accuracy and only corrected for the individual varying solution rates, but not for the lower occurrence of insight. A 2x2x2 ANOVA for repeated measures with the factors Solution Type (insight vs. noninsight), Accuracy (true vs. false) and Recall (matched vs. failed) was conducted, with the weighted number of solved tricks as dependent variable. It revealed significant main effects for two factors: Solution Type with $F(1, 47) = 10.78$, $p < .01$, $\eta^2_{partial} = .19$ and Accuracy with $F(1, 47) = 45.99$, $p < .01$, $\eta^2_{partial} = .50$. There was no significant main effect for Recall.

There were significant two-way interactions between Solution Type and Accuracy, $F(1, 47) = 6.96$, $p < .05$, $\eta^2_{partial} = .13$, Solution Type and Recall: $F(1, 47) = 4.64$, $p < .05$, $\eta^2_{partial} = .09$ and finally, between Accuracy and Recall: $F(1, 47) = 36.03$, $p < .01$, $\eta^2_{partial} = .43$.

We wanted to investigate the influence of insight experiences (factor Solution Type) on subsequent recall of these solutions. But due to the significant interaction between Accuracy and Recall, the two factor levels of Accuracy (i.e. true and false solutions) must be considered separately, therefore figure 16 refers only to false solutions and figure 17 only to true solutions.

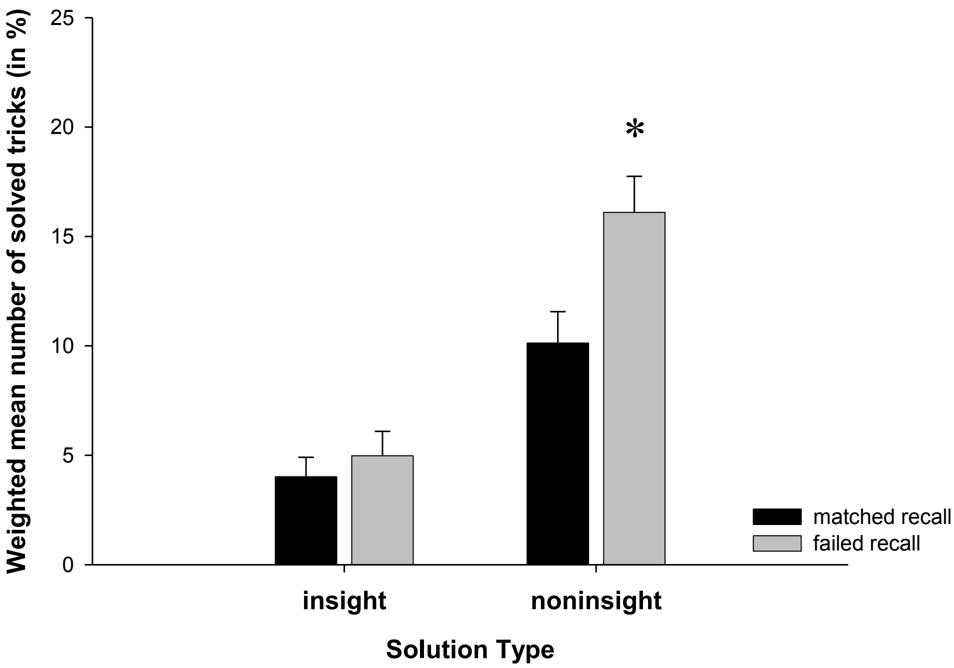

Figure 16. Recall of false solutions. The weighted mean number of solved magic tricks (in % of all 800 solved trials) is depicted as a function of Solution Type and Recall. Note that only false solutions are presented (see figure 17 for true solutions). Error bars denote standard errors of the mean. Significant differences between matched (black bars) and failed (grey bars) recall are marked with an asterix.

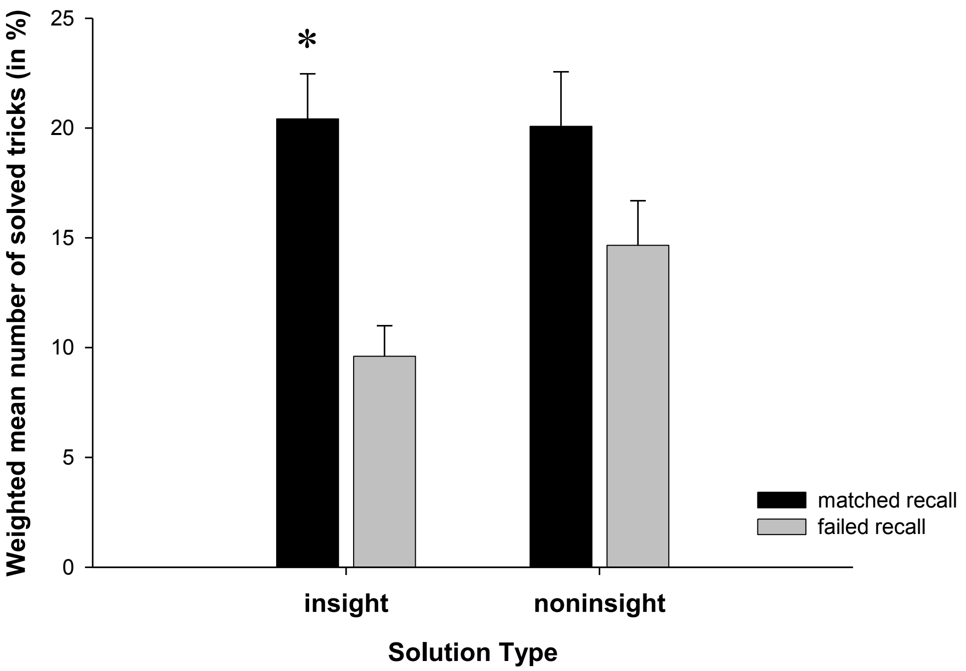

Figure 17. Recall of true solutions. The weighted mean number of solved magic tricks (in % of all 800 solved trials) is depicted as a function of Solution Type and Recall. Note that only true solutions are presented. Error bars denote standard errors of the mean. Significant differences between matched (in black) and failed (in grey) recall are marked with an asterix.

Note that the number of solved tricks in each category (compare figure 15) was weighted by the individual solution rate of each participant, as described in section 4.4.1.

A comparison of the two figures shows that in general, false (i.e. impossible) solutions (figure 16) are more likely to be forgotten (grey bars > black bars) whereas true solutions (figure 17) are more likely to be recalled correctly (black bars > grey bars).

Due to the significantly higher number of noninsight solutions relative to insight solutions (see figure 15), we could not directly compare the number of matched / failed recall events between insight and noninsight solutions. For example, in figure 17, the percentage of matched recall events is about the same for insight and noninsight, but the two categories are not directly comparable because the insight category is based on a much lower number of trials (we would have to correct for the lower occurrence of insight trials, see above). Therefore, we asked if the ratio of failed / matched recall would be different in each of the two categories (insight and noninsight). Assuming a memory advantage for insight solutions, there should be more matched than failed recall events in the insight category, but not in the noninsight category.

First, only false solutions are considered (figure 16): Follow-up paired t-tests yielded a significant difference between matched and failed recall solely in the noninsight category

($t(47) = 2.63$, $p < .05$, Cohen's dz = .39) – in contrast to the insight category with no difference. Only 10.1% of noninsight, false solutions were recalled correctly, and for 16.1% the recall failed.

Second, only true solutions are taken into account (figure 17): Here, follow-up paired t-tests showed that insight solutions included a significantly higher percentage of matched recall (20.42%) than failed recall (9.61%) with ($t(47) = 4.6$, $p < .01$, Cohen's dz = .61). For noninsight solutions, the percentages did not differ significantly.

In sum, the present analysis revealed differential ratios of failed / matched recall in the two Solution Type categories with more matched than failed recall events for insight solutions (in the case of true solutions) and more failed than matched recall events for noninsight solutions (in the case of false solutions). We take this as evidence for a facilitating effect of previous insight experiences on the recall of solutions.

4.5 Discussion

The present work addressed the question whether gaining sudden insight into the solution of a difficult problem would facilitate the recall of these solutions relative to noninsight solutions. On average, participants were able to solve 49% of the presented tasks and recalled 55% of solutions. The rather low solution rate was expected, because we used real magic tricks that, of course, are difficult to solve. Previously, we had decided against eliminating extremely difficult ones, hoping that these might trigger especially strong Aha! experiences if solved. The present recall rate of 55% is much lower than the 98% found by Dominowski and Buyer (2000). We explain this by the higher number of problems implemented. Compared to the six insight problems used by Dominowski and Buyer, our participants had to keep in mind 34 different magic tricks including solutions. In contrast to their design, we did not present the entire problem again during recall, but only showed a reminder of the trick (a still from the video). This increased the number of failed recall events, because participants had forgotten a substantial amount of tricks. The low recall rate could also be attributed to the longer time delay (14 days instead of seven days).

The data obtained confirmed our hypothesis. We predicted that insight solutions would be remembered better than noninsight solutions. Regarding only true solutions, it was found that insight solutions included a significantly higher percentage of matched recall (20.42%) than failed recall (9.61%). According to Cohen (1988), the corresponding effect size of dz = .61 can be regarded as a strong effect. For noninsight solutions, no significant difference existed. Therefore, the previously experienced Aha! seems to lead to a memory advantage.

This finding extends the previously stated transfer hypothesis (Knoblich et al., 1999) to a much longer time delay (14 days) and to the recall of solutions to previously solved problems. It provides support for the proposal that the representational change (Ohlsson, 1992) underlying insightful solving experiences leads to long-lasting changes in the representation of a problem that lead to full retention of the problem's solution.

One possible explanation for this finding could be the high emotional involvement (compare the somatic marker hypothesis by Damasio, 1996) during an Aha! experience that might facilitate the retention of this solution in memory (Seifert, Meyer, Davidson, Patalano, & Yaniv, 1995). The case of posttraumatic stress disorder is one example for how strong emotions, experienced during the traumatic event, can hinder forgetting (e.g. Van der Kolk, 1994). This is also meaningful from an anatomical perspective. It has been suggested (Öllinger, 2005) that during insight problem solving, there is an intense interplay between the hippocampus and the amygdala. The amygdala is known as a crucial region for processing of emotionally relevant stimuli (e.g. R. J. Davidson & Irwin, 1999) whereas the hippocampus subserves memory consolidation (e.g. Tulving & Markowitsch, 1998). In an fMRI stuy, Luo et al. (Luo & Niki, 2003) detected hippocampus activity during insight problem solving of Japanese riddles. Still, since the neural basis of insightful experiences remains unclear (see Dietrich & Kanso, 2010, for a very thorough review), further research is warranted to confirm these speculative explanations.

A pertaining methodological challenge in insight research is the question of how the occurrence of insight can be accurately assessed (Haider & Rose, 2007; Luo & Knoblich, 2007). The present study demonstrates that the method of obtaining direct insight judgements from participants can reveal interesting differences between insight and noninsight events. Of course, a consequence of this procedure is that less trials are classified as "insightful", compared to the traditional approach of simply treating all solved trials as insightful events. But in this way, we can be sure that the subjective insight experience is actually measured and this might help us to get a firmer grip on this elusive phenomenon.

A drawback of the present study is the rather high number of false solutions (17.3% of all trials) that made it impossible to simply dismiss them. We therefore analysed true and false solutions separately and found differential ratios of failed / matched recall for insight and noninsight solutions in both cases. Interestingly, both patterns speak for the same facilitating effect of insight solutions on recall performance, but one pattern is reversed to the other. In the case of true solutions, there are more matched than failed recall events for insight solutions. In the case of false solutions, there are more failed than matched recall events for noninsight solutions.

In sum, using a new problem solving paradigm, the present work demonstrates that insight solutions are remembered better than noninsight solutions. This finding is in accordance with the theoretical assumption of representational change and the resulting transfer of knowledge about a solution. A replication of these results, also with stimuli from classical insight task domains, must be awaited and future studies addressing the neural basis of this effect are needed to clarify the role of the insight experience in memory.

5 NEURAL CORRELATES OF INSIGHT: AN EEG STUDY

We conducted a pilot study in order to test a possible procedure to investigate the neural correlates of insight through electroencephalography (EEG) recordings. The aim was to search for a neural signature characterizing insight problem solving and specifically, the underlying restructuring process. There is some evidence that restructuring is detectable in the EEG signal, expressed in a rapid signal change on the level of neural activation patterns.

5.1 Background

Attempts have been made at investigating the neural basis of insight problem solving with functional magnetic resonance imaging (fMRI) and EEG. In a recent EEG study, Sandkühler et al. (Sandkühler & Bhattacharya, 2008) used CRA problems (Bowden & Jung-Beeman, 2003a) to disentangle the different components of the ongoing insight process. The most relevant component, namely restructuring, seemed to be related to an effect in the alpha frequency band (8-13Hz) that was apparent over right prefrontal regions. With the same stimuli, Jung-Beeman and colleagues (2004) reported a sudden burst of gamma band activity (40Hz) in the anterior superior temporal gyrus (right hemisphere) about 0.3 s prior to the solution (only for insight solutions as compared to noninsight solutions). In the corresponding fMRI activity patterns, the same region seemed to be involved. These findings might indicate that the interplay between alpha and gamma activation characterizes the neural signature of restructuring. Alpha activity is suspected to desynchronize the existing mental representation of the problem. The following gamma synchronization might be a strong indicator for the integration of information that precedes the solution (see Öllinger & Knoblich, 2009). Luo and Knoblich (2007) measured participants' brain activity at the moment of grasping the meaning of ambiguous sentences. In the fMRI part of the study, two main areas were found to be associated with that moment of insight: the anterior cingulate cortex and the left lateral prefrontal cortex. In an EEG experiment that was conducted in parallel, measuring event-related potentials, they observed a more negative deflection in the time window of 250-500 ms for insight versus noninsight events.

However, despite these encouraging findings, Dietrich and Kanso have pointed out in their thorough review (2010) that no clear picture has emerged yet with regard to identifying crucial brain regions, not to speak of a distinct signature of this event in terms of neural activation patterns.

Using the new domain of magic tricks, we expected to find an alpha band desynchronization and a subsequent burst in gamma band activity as a possible neural correlate of restructuring.

5.2 Method

5.2.1 Participants

Eight healthy volunteers (mean age 25.2 ± 2.3; two male) were paid 8€ per hour for participating in the experiment. None of them had any neurological diseases and all had normal or corrected-to-normal acuity. The design and procedure of the EEG study was approved by the ethics committee of the Ludwig-Maximilians-Universität München.

5.2.2 Stimuli

In contrast to the procedure applied in the previous experiment (chapters 2-4), we now used additional stimuli, namely solution clips in which the solution to each magic trick was revealed. Thus, we investigated externally triggered insight. This allowed us to pinpoint the earliest moment in which participants could grasp the solution to one exact frame of the video clip. This was denoted as “earliest possible insight moment”. Based on data gathered in three previous pilot studies (see general method, 2.3.2), 18 of the magic tricks were specifically selected so that none of the tricks could be solved during the first presentation of the video clip.

5.2.3 EEG Recording

The EEG signal was recorded from 64 electrodes mounted in an elastic cap (Easy Cap), located at standard left- and right-hemisphere positions over frontal, central, parietal, occipital, and temporal areas (using the extended international 10/20 system sites). The horizontal electrooculogram (EOG) was recorded as the voltage between electrodes placed 1 cm to the left and right of the external canthi to measure eye movements, and the vertical EOG was recorded from an electrode beneath the left eye, referenced to the right mastoid, to detect eye blinks. Trials containing these artefacts were excluded. EEG and EOG signal was amplified by a Brain Amp amplifier with a bandpass of 0.01–80 Hz, digitized at 1000 Hz by a PC-compatible computer, and averaged off-line.

A time window of 0.5 s before the response (button press indicating the subjectively experienced moment of insight, as described in 5.2.4) until 0.5 s after the response was initially chosen for detailed analysis with Brain Vision Analyzer 1.05, because it has been shown that EEG components associated with insight begin approximately 0.3 s before the response (Jung-Beeman et al., 2004).

5.2.4 Procedure

Each participant went through one testing session of two hours (including application of electrodes), with 40 minutes for watching the 18 magic tricks and their solutions in randomized order. Participants were seated in a distance of 80 cm in front of a computer screen and instructed by the experimenter to watch the stimuli carefully. During the solution clip, they were required to indicate the moment of insight (when the solution is understood) by bi-manually pressing a button on the keyboard.

This was the procedure of one trial: After a fixation cross of 1 s, a trick clip was presented on the screen, followed by another fixation cross, and a reminder screen “Now you will see the solution! Please press the button immediately when you understand how the trick works!”. Directly after the reminder, the respective solution clip was shown. During the solution clip, participants pressed the button once they understood the solution. This interrupted the solution clip, and triggered the following question screen: “Did you experience an Aha! moment?”. Participants indicated Yes or No with left/right button presses. After the answer, the solution clip continued until the end of the clip. Subsequently, the presentation of the next trick started with another fixation cross. The Presentation® 12.1 software was used for stimulus presentation and data collection.

5.3 Data Analysis

Data analysis was conducted in collaboration with Dr. Björn Schelter at the Center for Data Analysis and Modeling in Freiburg.

Due to the small number of trials (n=18), computing standard event-related potentials was not meaningful. We therefore decided to use time-frequency analyses to look for sudden changes in the frequency bands of interest (alpha, 8-13Hz, and gamma, >30Hz) before or during the insight moment. Besides the traditional time–frequency analysis technique, the short time Fourier transform, also wavelet analyses were used to break down the EEG signal into its frequency components (Samar, Bopardikar, Rao, & Swartz, 1999).

The following time window (with respect to participants' button press indicating that the solution had been understood) was initially chosen for analysis: -0.5 to 0.5 s. A second time window was used, of one second starting from the earliest possible insight moment. Data was averaged across all participants and analysed by time-frequency analyses. Later, the EEG signal was also averaged across tricks and time-frequency analyses were applied for each participant individually, using both non-Laplacian and Laplacian preprocessing of the data.

5.4 Results

The procedure turned out to be not suited to produce reliable data. Our analyses yielded very heterogeneous activity patterns, varying from trick to trick. This means, dependent on the stimulus presented, a different pattern of frequency bands contributed to the signal. There are several possible sources of this variance: First, due to the large variance in reaction times (averaged across all 18 tricks, the mean standard deviation of participants' reaction times was 3.4 s), the time window of -0.5 to 0.5 s around each participants' response included different frames of the video clip. Therefore, averaging across participants yielded no meaningful results, because each participant saw a different stimulus display during the moment of insight. Second, averaging across tricks was also problematic, because EEG signal recordings largely differed between tricks. This is probably due to the heterogeneity of the magic trick stimuli themselves. Third, this variance could also be attributed to the influence of the dynamic, complex video stimulus itself, as compared to the mainly static stimuli commonly used in EEG studies.

In sum, this pilot study showed that the current procedure could not be used to reveal any clear activity patterns related to the insight moment. We partly explain this by the heterogeneity of the magic tricks and conclude that a stimulus-based analysis is necessary to better understand the task before it can be used in a meaningful way to search for neural mechanisms underlying insight. Another explanation is that EEG recordings are too susceptible to the influence of dynamic stimuli. Therefore, for future research we recommend to use fMRI as an alternative method which has already been successfully used in studies with dynamic stimuli, even with magic tricks (Parris et al., 2009).

6 COMPREHENSIVE DISCUSSION

6.1 Critical Appraisal of the Magic Trick Paradigm

The present thesis is concerned with insight problem solving. Magic tricks were introduced as a problem solving task, asking participants to find out how the trick was accomplished. Based on the representational change theory (Ohlsson, 1992; Knoblich et al., 1999), we argued that magic tricks are ideally suited to investigate insight because in order to gain insight into the magicians' secret method, observers must overcome implicit constraints through restructuring. The solving rate of 49% (with an insight rate of 41.1% of these solutions) provides evidence for our conception of magic tricks as an insight task and shows that the paradigm is of appropriate difficulty. In comparison with noninsight solutions, insightful solutions were more likely to be true and reached earlier.

As detailed in 1.5.1, we adopted Bowden's approach (Bowden et al., 2005) to determine the occurrence of insight. We combined this approach with an a priori selection of a task (magic tricks) that is likely to trigger misleading initial problem representations. That 41.1% of trials were categorized as insightful indicates that our approach is feasible and replicates other findings using the same type of trial-wise insight judgements (Jung-Beeman et al., 2004; Kounios et al., 2008).

We predicted (see 1.5.2) that magic tricks could also be solved through analytical solving processes and in fact, 58.9% of all solved trials were solved without insight. This finding can be explained in terms of the representational change theory. We argue that these are examples of cases in which no restructuring is needed because no constraints were activated, as suggested by Ohlsson (1984b). This means, in 58.9% of trials, problem solvers' mental representation of the problem was not over-constrained, but already included the concepts which are relevant for a solution. Therefore, the solution could be discovered by analytic problem solving strategies, systematically checking different hypotheses, without restructuring the entire problem representation. From a theoretical point of view, our results support the claim that any given problem may pose representational obstacles for some solvers, but not for others (Ash et al., 2009) and therefore may be solved either through insightful processes or through more analytical processes (Bowden et al., 2005). For an insight task, the feature of two possible solving strategies (with and without insight) is advantageous, because both strategies can be compared while the task type remains constant. This is particularly helpful for studies tackling the neural basis of insight (as outlined in 6.4). In this respect, magic tricks are similar to CRA problems (Bowden & Jung-Beeman, 2003a) which have already been successfully used to identify possible neural correlates (Jung-Beeman et al., 2004; Kounios et al., 2006).

The data collected allowed us to establish a ranking order within the stimulus set of 34 magic tricks with regard to solution rate and rating of insight (see appendix A). For future studies, the percentage of insight trials could be raised by specifically selecting only those magic tricks that have a low degree of difficulty as well as are frequently solved with insight. Since the aim of the present work was to introduce a novel paradigm, advantages and disadvantages of the magic trick task domain will now be discussed.

From our point of view, the greatest advantage of using magic tricks as problem solving stimuli is that this offers access to problem solvers' constraints. In terms of the representational change theory (Ohlsson, 1992; Knoblich et al., 1999), prior knowledge can lead to constraints. We argue that magic tricks represent an ideal domain to access and systematically manipulate these constraints, because the very constraints that are encountered by the observer of a certain magic effect are well known to the magician. This is an advantage over other problem solving tasks like CRA problems (Bowden & Jung-Beeman, 2003a) or the nine-dot problem (Maier, 1930; Scheerer, 1963). For the latter problem, the main constraint is also known (i.e. to extend the lines across the imaginary boundaries of the square), but hint studies showed that relaxing this constraint is not sufficient for a solution (Kershaw & Ohlsson, 2004), so there must be additional, still unknown constraints. It should be noted that other insight problem domains exist which also allow a clear identification of constraints, for example matchstick arithmetic tasks (Knoblich et al., 1999). Furthermore, magicians deliberately strengthen these constraints by subtly evoking incorrect assumptions about the objects used. For example, if the magician wants to induce the (wrong) impression that a half-ball is an ordinary, solid ball, he might casually let it bounce on the table. This method of actively inducing inappropriate problem representations is advocated by Ash (2009) and was already used by Duncker (1945) and, of course, by magicians all over the world. Experimentally manipulating these constraints opens interesting possibilities for future research.

In the present context, priming studies seem to be well suited for this purpose, as already suggested by Öllinger (2005). For example, if the main constraint that prevents a solution of the trick consists of the fact that a ball is usually perceived as a whole (but is in fact a half-ball), the constraint could be relaxed by priming the concept of a half-sphere before presenting the magic trick. In this case, higher solving rates would be expected (and no restructuring would occur, compare 1.3). On the other hand, this constraint could be enforced by priming the concept of a solid, complete ball (like the globe) which might prevent people from considering the possibility of dividing it in half. Here, we predict lower solving rates. A confirmation of these hypotheses would provide clear evidence for the mechanism of constraint relaxation as one way of restructuring an initially over-constrained problem representation, as postulated by Knoblich et al. (1999).

We have claimed that new, more authentic tasks are needed for insight research. We argue that magic tricks are "ecologically valid" stimuli in the sense that efforts to understand the tricks are naturally set in motion. During the testing, we observed that participants were highly motivated to solve the presented tricks, even after many trials. Magic tricks are less artificially construed than the classical insight problems in which participants have to solve verbal riddles, logical brainteasers, mathematical problems or connect dots according to arbitrary rules. They are authentic because they take place in familiar situations with ordinary objects like coins or cigarettes. The present work indicates that such authentic stimuli can be as valuable as strictly controlled paper-and-pencil tasks. A systematic comparison of magic tricks with traditional types of stimuli (e.g. with regard to motivational aspects) would be needed to further substantiate this claim. Preliminary studies comparing magic tricks to three classical insight problems have already been conducted (not presented here).

Inducing positive mood could be another important advantage of using magic tricks in insight research. It has been shown previously that positive affect facilitates insight (e.g. Bolte, Goschke, & Kuhl, 2003; Isen, Daubman, & Nowicki, 1987; Subramaniam et al., 2009; Sakaki & Niki, 2011). Isen and colleagues (1987) induced positive mood by presenting a comedy film (*Gag reel)* to participants shortly before they began working on Duncker's Candle Problem (1935). A control group who had watched a neutral film (a math film, *Area under a curve)* produced significantly less solutions than the positive mood group. In an fMRI study, Subramaniam et al. (2009) found that participants who were high in positive mood solved a greater number of CRA problems with insight than participants who were lower in positive mood. These effects seemed to be related to increased brain activity in the anterior cingulate cortex (ACC), see also Kounios et al. (2006). It seems plausible that in the present study, participants' emotional state was positively influenced by watching the magic tricks, similar to watching a comedy film. Verbal reports of participants' individual solution experiences showed the high emotional impact of solving a magic trick. Although we did not directly assess mood since no mood markers were collected prior to testing, it was obvious that participants liked to watch the tricks and were highly motivated to do the task. Perhaps the drop-out rate of zero can also be accounted to that. Participants in the pilot studies scored very high on the question “How much did you like the trick?” with a mean of 2.94 (on a rating scale from 1 = not at all to 4 = very much). We speculate that the positive mood induced by watching magic tricks also facilitated insight in the present study. In future experiments using magic tricks, we recommend to systematically control for mood.

As Bowden et al. (2005) have pointed out, one recurrent difficulty in insight research is the use of very small sets of problems. Often, only one individual problem is presented to the problem solver (e.g. the nine-dot problem, Maier, 1930; Scheerer, 1963; see for example Chein et al., 2010). This poses methodological problems, especially in neuroscientific studies that require many repetitions to attain a reasonable signal-to-noise ratio. There are a few accounts that try to deal with this problem by using larger series of problems, for example, Jung-Beeman et al. (2004) with a large set of CRA problems (see above). However, it is questionable if, while solving 186 of these verbal problems, participants’ subjective insight experience remains the same during the length of the entire experiment. The 80th Aha! experience probably feels different from the 1st Aha! experience, and might not be a very strong sensation anymore. Of course, the same argument could also be applied to our stimulus set of 34 magic tricks (presented in randomized order). We therefore conducted an additional analysis of our data set by distributing trials into three groups (the first 11 trials, the middle 12 trials and the last 11 trials) and then comparing the number of Aha! experiences across these groups. The frequency of Aha! experiences did not differ between the three groups. Furthermore, we claim that magic tricks are better suited to trigger strong insight experiences than the verbal problems used by Jung-Beeman et al. (2004), because the emotional involvement is much higher, as just discussed. We claim that finding the solution to a magic trick results in a very intense experience, even after many repetitions, and this makes them potentially very valuable for studies requiring a large number of trials. On the other hand, the heterogeneity of magic tricks (and thus of the different trials) constitutes a major drawback that will be discussed together with other disadvantages now.

The implementation of magic tricks as a problem solving task requires some methodological considerations. First, a magic trick is a dynamic, complex visual stimulus, and hard to be controlled. Creating homogenous stimuli is nearly impossible in that domain, because the movements differ from trick to trick, even if the objects stay the same (e.g. a coin). Depending on the question asked, this heterogeneity renders magic tricks useless for some researchers. Second, extensive pre-testing is necessary. We conducted three behavioural pilot studies on a sample of 45 students to identify appropriate tricks, to improve them, to ensure that they were understandable and that they could actually be solved. Third, the stimulus development is very time-consuming. The tricks must be pre-selected according to the question of interest; the magic equipment and an appropriate setting to record the tricks must be provided. In the present work, after the first pilot study, a second recording session was necessary in order to improve the stimuli. Fourth, close collaboration with a professional magician is required because of the high demands during recording. The magician must be able to perform the tricks flawlessly, while at the same time, he cannot rely on direct interaction with an audience. Also, we decided to record the tricks in silence, another challenge for a magician who might normally use verbal cues to further distract the spectator or to elicit inappropriate assumptions.

In summary, there is a trade-off between producing a very rich, motivating stimulus that triggers strong insight experiences and the difficulties to control it. We claim that it is worthwhile to undertake the effort and hope to have demonstrated the great potential of using magic tricks as a problem solving task.

6.2 The Phenomenology of Aha! Experiences

In the insight problem solving literature, participants' subjective solving experience is often subsumed under the term "Aha! experience". Likewise, we have specified the Aha! as the phenomenological experience that accompanies insightful solutions (compare introduction 1.1.2). Although many studies, in particular those with a neuroscientific approach (e.g. Mai, Luo, Wu, & Luo, 2004; Luo, Niki, & Phillips, 2004), rely on this subjective experience as a trial sorting criterion, comparing insight vs. noninsight trials, the concept remains vague. In a first attempt to systematically assess separate aspects of the Aha! experience, we collected comprehensive quantitative and qualitative evaluations of participants' insight experiences. The quantitative assessment remained stable across 14 days showing the high reliability of this subjective experience. With respect to individual dimensions, participants rated happiness as the most important dimension. Qualitatively, participants reported mainly emotional aspects, too. A primacy of positive emotions was thus found in both types of ratings, although two different methods were used (free self-reports and ratings on a visual analogue scale with fixed dimensions). The present work therefore provides evidence for the occurrence of strong positive emotions during sudden moments of insight which seem to constitute the prevailing aspect of the Aha! experience.

This result is in accordance with recent modelling work on the Aha! experience (Thagard & Stewart, 2011). In the so-called EMOCON model, Thagard and Stewart assume that the Aha! experience, triggered by the new combination of mental representations (i.e. restructuring in our terms), is a pattern of neural activity that arises through convolution. Convolution, the key explanatory mechanism of their model, can be understood as "[…] a mathematical operation that interweaves structures" (Thagard & Stewart, 2011, p. 1), for further details Thagard's paper should be consulted. On the level of neural activity patterns, the Aha! experience is conceptualized as the convolution of an emotional response with a new combination of mental representations. The positive emotional reaction ("the ecstasy of discovery", Thagard & Stewart, 2011, p. 10) that was found to be the prevailing aspect of the Aha! experience in the present work, is proposed to arise from automatic appraisal mechanisms that judge each new combination of mental representations with regard to its relevance (Thagard & Stewart, 2011). If the new combination is non-trivial, surprising and highly relevant for the problem solver, a strong emotional response is triggered. This certainly applies to the solutions of the magic tricks that have to be found out by our participants. Currently, this neurocomputational account simulates only simple visual patterns, but it must be credited for providing one possible explanation for the mysterious Aha! experience on a neural level.

From a methodological point of view, the present investigation shows that direct qualitative self-reports can be helpful to learn more about the phenomenological aspects of insight. We argue that despite the obvious limitations of this introspective method (detailed, for example, by Schooler, 2011), subjective Aha! reports might provide information that would not be accessible through more rigorous experimental methods. Other researchers have successfully used verbal protocols to elucidate the processes during insight problem solving (Kaplan & Simon, 1990; Fleck & Weisberg, 2004; Dominowski & Buyer, 2000). In fact, Fox (Fox et al., 2011) strongly advocates the use of verbal protocols to elucidate thinking processes, concluding from a carefully conducted meta-analysis on 94 studies that if certain standardized reporting methods are implemented, these measures are non-reactive, i.e. do not alter performance in any way (as was reported by Schooler et al., 1993). Ericsson and Simon (1993) provide detailed recommendations for these standardized methods. To conclude, we suggest that the traditional approach of using pre-defined "insight problems" and assuming the occurrence of insight in the case of a solved problem, without taking into account participants' individual problem solving experiences, should always be complemented by subjective measures such as Aha! self-reports, detailed Aha! evaluations or thinking-out-loud protocols.

6.3 The Consequences of Insight: Facilitated Recall of Insight Solutions

As a third research question, we investigated the impact of insight on memory performance. Specifically, we hypothesized that gaining sudden insight into the solution of a difficult problem would facilitate the recall of these solutions relative to noninsight solutions. The data obtained confirmed our hypothesis. 64.4% of all insight solutions were recalled correctly, whereas only 52.4% of all noninsight solutions were recalled correctly.

This recall advantage could result from the high emotional involvement during an Aha! experience that might facilitate the retention of insight solutions in memory (as suggested by Seifert et al., 1995) in contrast to noninsight solutions for which the emotional response is lacking. Following the somatic marker hypothesis with its claim that a somatic state can become linked to a memory content (Damasio, 1996), a possible mechanism could work like this: The emotional state experienced during the insight moment (recognized and classified by participants as "Aha! experience") becomes linked to a cognitive state, namely the information about the solution of the problem. It is now generally acknowledged that emotional events are remembered with greater accuracy and vividness than neutral events (Reisberg & Hertel, 2004). The most prominent example are flashbulb memories (Brown & Kulik, 1977). However, the functional mechanisms of this memory enhancement are widely debated and still not clarified (Levine & Pizarro, 2004; Van Giezen, Arensman, Spinhoven, & Wolters, 2005). At present, the impact of positive emotions (thought to be involved in Aha! experiences, Gick & Lockhart, 1995) is less well documented than that of negative emotions, for which there is plenty of evidence for a memory enhancement effect. A recent example is provided by Pezdek (2003) who questioned US college students about their memory of the events on September 11th (World Trade Center attacks) and found more accurate event memory in the New York sample (shown to be more distressed by this event) than control samples from Hawaii and California. However, other studies have shown detrimental effects of strong emotions on recall performance (e.g. Adolphs, Denburg, & Tranel, 2001), at least on the memory for details. In sum, the effects of emotion on recall performance are not completely understood yet.

However, from an anatomical perspective, the possible link between strong emotional reactions and memory for insightful solutions would also be meaningful. It has been suggested (Öllinger, 2005) that during insight problem solving, there is an intense interplay between the hippocampus and the amygdala. The amygdala is known as a crucial region for processing of emotionally relevant stimuli (e.g. R. J. Davidson & Irwin, 1999) whereas the hippocampus subserves memory consolidation (e.g. Tulving & Markowitsch, 1998). In an fMRI stuy, Luo et al. (Luo & Niki, 2003) detected hippocampus activity during insight problem solving of Japanese riddles. In the framework of the representational change theory (Ohlsson, 1992; Knoblich et al., 1999), this proposal can be further elaborated: It was claimed recently that the dorsolateral prefrontal cortex (DLPFC) might play an important role in determining the goal representation of a given problem (Frith, 2000). The basic idea is that the DLPFC biases the response space by activating a set of potential solution strategies which initially seem to be appropriate to solve the problem at hand (Frith, 2000). However, because these solution strategies are based on wrong assumptions (i.e. constraints), the initial representation is incorrect and no solution can be found (Ohlsson, 1992) unless the constraints are relaxed. There is evidence for this proposal from a study on brain-lesioned patients (Reverberi, Toraldo, D'Agostini, & Skrap, 2005) where it was impressively demonstrated that patients with lesions to the lateral frontal lobe were more successful than healthy controls in solving very difficult insight problems (matchstick arithmetic tasks) that required many constraints to be relaxed. This was explained by the representational change theory (Ohlsson, 1992; Knoblich et al., 1999) as well as by Frith's account (2000). Therefore, the DLPFC might be the brain site where constraints are activated by prior knowledge. Just like other insight problems, magic tricks require the observer to overcome theses constraints that are induced by the magician, as detailed in the introduction. We assume that there is a mismatch between the initially activated, biased problem representation and the observed magic effect, e.g. a flying table. In this example, one constraint would consist of initially representing the table as an ordinary, normal object – and flying is clearly not compatible with our prior knowledge about tables (including e.g. their weight). The crucial brain site for detection of such cognitive conflict might be the anterior cingulate cortex (ACC), as shown by Mai et al. in an ERP study on Chinese riddles (Mai et al., 2004) and also by Luo et al. (Luo et al., 2004) in an imaging study. There is further evidence for an implication of the ACC in insight processes (Starchenko, Bekhtereva, Pakhomov, & Medvedev, 2003; Kounios et al., 2006; Aziz-Zadeh et al., 2009). It is conceivable that the detected mismatch triggers the emotional arousal that is mediated by the amygdalae and that facilitates the encoding of such a newly gained insight into the memory system. However, since the neural basis of insightful experiences still remains unclear (see Dietrich & Kanso, 2010, for a very thorough review), further research is warranted to confirm these speculative explanations.

The finding of a memory advantage for insightful solutions is related to the early works of the Gestalt theory of thinking, in which a positive relationship between restructuring and learning was discussed. Normatively, “good” productive thinking was set apart from “bad” reproductive thinking. In a way, these ideas are very modern, disapproving of the blind “drill” (Wertheimer, 1959, p. 234) that was (and sometimes still is) used as the standard teaching method in schools. Max Wertheimer visited classes and observed teaching, for example, during lessons of geometry, and in his last book from 1959, there is an appendix “Suggestions for teaching about area”.

In the present work, we have demonstrated a facilitating effect of previous insight experiences on the recall of solutions after a delay of 14 days. This finding is in accordance with the theoretical assumption of representational change and the resulting transfer of knowledge about a solution. Based on the somatic marker hypothesis, we offer a first explanation of this memory advantage by the well-known effects of strong emotional reactions on recall performance. A replication of these results, also with stimuli from classical insight task domains, must be awaited and future studies addressing the neural basis of this effect are needed to clarify the role of the insight experience in memory (see next section).

6.4 Future Research

In the course of the present work, several aspects emerged that seem to be valuable for future research. Specifically, three processes that have been identified as playing a crucial role in insight problem solving can ideally be addressed within the task domain of magic tricks: Attention, functional fixedness and mental set.

For example, Grant and Spivey (2003) showed that visually guiding participants’ attention towards the critical feature of Duncker’s radiation problem (Duncker, 1945) significantly increased solution rates (compare also Knoblich et al., 2001). This corresponds to the magicians’ often-used method of misdirecting (e.g. Fraps, 2006; Kuhn, Tatler, & Cole, 2009; Kuhn & Martinez, 2012) observers’ attention to irrelevant locations, e.g. guiding attention away from the secret action that is performed with the left hand by loudly clicking the fingers of the right hand. Similarly to the participants in Grant and Spivey’s study (2003), observers trying to solve a magic trick that is based on misdirection must change their problem representation by re-directing their attention to the relevant locations. Of course, the magician will typically prevent this, for example by exploiting gaze following mechanisms, as was clearly demonstrated by Kuhn et al. (2009). However, for experimental purposes, for example to investigate the influence of attention on solving rates, two versions of the same trick could be developed, one with the typical misdirection and another one in which the magician guides participants' attention to the relevant location. We would expect that the latter manipulation would yield higher solution rates.

Another well-known concept that Duncker developed to explain the difficulty of one of his classical insight problems (the Candle Problem), is that of functional fixedness (Duncker, 1935), compare section 1.2.1. Functional fixedness is exploited by magicians when they present everyday objects like a glass of wine and therefore automatically activate observers' implicit knowledge about these objects (e.g. that glasses break when dropping to the floor). In the case of a magic trick, this knowledge usually turns out to be wrong (the glass remains intact because it is a gimmick, and not a real glass) and that constitutes the surprising effect. Observers must overcome these implicit constraints in order to be able to solve the trick. The relative difficulty of a trick in which functional fixedness is exploited therefore provides information about the malleability of the specific constraints.

There is a third process discussed in the insight literature that can be manipulated through magic trick stimuli: Mental set (Luchins, 1942). Magicians force their audience into a certain mental set by wrapping a story around their magic effect. For example, an observer is asked to put his freely selected card back into a deck of cards and shuffle them. Great emphasis is put on the fact that the card should be put deeply in the middle of the stack and that the cards must be very carefully shuffled, for a very long time etc. The mental set induced in this case would be that the cards are now in completely random order (of course, later on the magician will effortlessly find the card in question right on top of the stack or even behind the observer's ear). Only if the observer achieves to overcome this mental set can the solution of the trick be found out. Magic trick paradigms could thus complement current studies on how mental set influences the probability of insight (e.g. Öllinger et al., 2008).

Magic tricks offer another experimental possibility that might be of interest to problem solving researchers: We have described two cases in which no restructuring can occur (compare 1.3), the first case could be investigated through a priming study (see above). The second case could be implemented as follows: Ohlsson (1984b) suggests that if the correct encoding is not available to the problem solver, no restructuring can occur. This means, the problem remains unsolvable. This case might not be very useful in adult participants. However, we propose that children represent an ideal sample population for investigating that situation. Children have a smaller knowledge base at their disposal and many concepts are not yet familiar to them. Researchers could profit greatly from the large amount of evidence from developmental psychology indicating critical periods of development of different concepts. The smaller knowledge base of children makes two different experimental manipulations possible, depending on whether the knowledge element is acting as a constraint or whether it is required for the solution. First, tricks would be used for which certain prior knowledge elements (e.g. knowledge about the solidity of glass objects) activate constraints in adults. Testing children that have not developed this concept yet, we would expect that they will be less hampered by self-imposed constraints resulting from prior knowledge and thus, for them the problem might be easier to solve than for adults. Second, tricks would be used which require the same knowledge elements for a solution. In this case, we predict that children should not be able to solve the problem at all, because they are lacking this concept.

As already discussed in the introduction (1.5.1), we adopted Bowden et al.'s (2005) approach to determine the occurrence of insight through participants' trial-wise insight ratings. Thus, we relied on the assumption that the subjective Aha! experience is a marker for insight. This is plausible, but has not been tested empirically so far. In fact, it is very difficult to think up a method to test this question because independent behavioural markers of restructuring (apart from the insight rating) would be needed. The problem could be solved if we succeeded in identifying distinct neural activity patterns resulting from restructuring. First promising steps towards this goal have already been made. In 2004, Jung-Beeman et al. conducted one of the first studies aiming at neural correlates of restructuring (see 5.1 for a short overview). Contrasting insight with noninsight events based on categorizations by participants, they found that insight solutions were associated with a burst of high-frequency (in the gamma frequency band, 40Hz) activity over right anterior temporal electrodes. In the corresponding fMRI activity patterns, the same region seemed to be involved. These findings are very valuable, but since they are again based on the insight rating approach, they cannot contribute to verifying or refuting the assumption that subjective insight ratings are actually a marker for restructuring. However, the basis for the next step is provided: If this finding is replicated, especially with tasks from other, non-verbal domains, the gamma burst might be used as a possible indicator to infer the occurrence of insight. Therefore, further research on the neural correlates of restructuring is warranted. The present thesis reported a first attempt to implement magic tricks in an EEG study design. However, the procedure used did not yield meaningful data. One limiting factor was the low number of trials, another the high variability in reaction times across participants. It is also questionable whether EEG is the appropriate method for dynamic video stimuli. In contrast, neuroimaging techniques have already been successfully used with video stimuli of magic tricks, although for a completely different research question (Parris et al., 2009). We suggest that magic tricks represent an alternative, non-verbal task to the CRA problems used by Jung-Beeman et al. (2004), since they also allow for a comparison of both solving modes (restructuring and analytical problem solving) while keeping the problem type constant. As Kounios and Jung-Beeman (2009) point out, it remains unclear whether their reported results are specific to verbal problems. Therefore, our new paradigm constitutes a valuable contribution to the field of insight research. Combining the novel task domain of magic tricks with established tasks such as CRA problems also in neuroscientific studies, could help to further elucidate the process of insight problem solving which is a characteristic and vital part of human thinking and yet so difficult to grasp.

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8 APPENDICES

Appendix A: List of Magic Stimuli

	Trick Name	Magic Effect	Trick Description	Solved[1]	With[2] Aha!	Surprise[3]
1	Knives	Transposition	Two differently coloured knives change places	14,58	28,57	2,55
2	Orange	Transformation	An orange is transformed into an apple	16,67	50,00	3,57
3	Monte	Transposition	A card swaps places with another one	22,92	27,27	2,82
4	Rope	Restoration	A rope is cut in two pieces and restored to one	25,00	50,00	2,50
5	Coin Trick 1	Vanish	Out of three coins, one vanishes	27,08	23,08	2,91
6	Billiard Balls	Appearance	A little red ball multiplies	29,17	35,71	2,71
7	Coin Trick 2	Appearance and Vanish	A coin is held up in the air, vanishes and reappears	31,25	40,00	2,61
8	Card Trick 1	Telekinesis	Cards turn over by themselves	31,25	33,33	2,54
9	Rubik's Cube	Transformation	Rubik's cube is solved by throwing it up in the air	33,33	50,00	3,17
10	Salt	Vanish	Salt is poured in the fist from where it disappears	33,33	43,75	3,04
11	KetchupBottle	Vanish	A ketchup bottle is put in a bag and disappears	35,42	29,41	3,27
12	Coin Trick 3	Transposition	A coin wanders from the hand under a napkin	37,50	44,44	2,58
13	Bottled Scarf	Vanish	A red scarf disappears from a closed bottle	39,58	36,84	3,00
14	Pen	Penetration	Paper is pierced by a pen, but remains intact	43,75	42,86	2,75
15	Money	Transformation	Sheets of white paper turn into 50 Euro bills	43,75	28,57	3,00
16	Matchsticks	Penetration	One matchstick wanders through another one	45,83	50,00	2,59
17	Glass	Vanish	A champagne glass is covered by cloth and disappears	47,92	39,13	2,26
18	Red Scarf	Appearance	A large red scarf appears from nowhere	47,92	60,87	2,73
19	Card Trick 2	Restoration	A card is ripped in pieces and restored	50,00	33,33	3,22
20	Ice Cube	Transformation	Water is transformed into an ice cube	50,00	25,00	3,14
21	Coin Trick 4	Penetration	A coin penetrates a sealed glass	52,08	20,00	3,00
22	Ball	Transformation	A ball gets transformed into a cube	52,08	36,00	2,50
23	Card Trick 3	Penetration	Cards are chained to each other and unchained without damage	54,17	30,77	3,25
24	Flying ball	Telekinesis (Levitation)	A ball is floating between the magician's hands	54,17	42,31	3,00
25	Card Trick 4	Transformation	Cards in a glass change their colours	58,33	42,86	2,50
26	Coin Trick 5	Transposition	3 coins wander from one hand into the other	62,50	40,00	2,67
27	Salt 'n Pepper	Vanish	Salt and pepper are poured into one hand and the pepper disappears	64,58	32,26	3,13
28	Flying Bun	Telekinesis (Levitation)	A bun is covered by a napkin and starts to fly	66,67	37,50	2,50
29	Bouncing Egg	Physical impossibility	A real egg is bounced repeatedly on the floor without breaking	72,92	25,71	3,05
30	Scarf to Egg	Transformation	A scarf turns into an egg	77,08	70,27	2,67
31	Bowling Ball	Topological impossibility (size)	A large bowling ball is carried in a thin suitcase	81,25	28,21	2,83
32	Coat Hanger	Topological impossibility (size)	A coat hanger is pulled from a small purse	83,33	50,00	2,88
33	Cigarette	Vanish	Cigarette and lighter disappear while the magician tries to light his cigarette	85,42	53,66	3,17
34	Spoon	Transformation	A spoon is put into the magician's mouth and when removed, it has changed into a fork	95,83	65,22	2,88

Tricks are sorted according to their difficulty (starting from the least solved ones).
[1] Percentage of participants who solved the trick (after repeated viewing)
[2] Percentage of participants who indicated an Aha! experience (of those participants who had solved it)
[3] In a pilot study, 50 participants rated their level of surprise caused by the magic effect from 1 (not at all surprised) to 4 (very much surprised). The mean rating for each trick is indicated.

Appendix B: Free Self-Reports by Participants

1. A moment of bliss. I am happy and get into a good mood. An increasing certainty. Everything becomes perfectly clear, a tingling in my head.

2. I'm excited and I feel no doubt about this sudden solution.

3. A sudden discovery, unexpected, a feeling of "that's how the solution must be", no hesitation.

4. A feeling of definite knowledge or alternatively, a first sensation of knowledge that is not necessarily confirmed in the next step, but initially, feels certain and irrefutable. A sense of triumph because one has seen through the trick. "Gotcha!"-feeling. Yes, of course, there is no other way! As long as any doubts about the correctness remain, it is no Aha! effect.

5. I perceive a certain movement of the hand, from which I can infer how the trick could possibly work. Thus, it can only be detected at a certain time point of the trick. Classic Aha! experience, a feeling of seeing through the trick all at once.

6. For me, I experienced an Aha! either when I could see the solution in my mind or when I had the feeling of knowing the solution. This feeling is similar to being motivated to do something, knowing that it is exactly the right thing. With Aha! experiences, I am much more motivated to continue working on the task or problem.

7. I did not experience any Aha!

8. Sometimes it was a very strong feeling, as if I had solved an extremely difficult case that mattered greatly. Other times, it was more like "ok, now I got you and I know how you did it". In the first case, the excitement was much greater, in the second case, it was more relieving.

9. It can perhaps be described as a flash, suddenly I knew the answer, even if shortly before, I didn't have a clue. It's a wonderful, positive feeling and for me, it felt a bit like relief.

10. It's like a small tension that gets released suddenly and a positive and liberating feeling emerges.

11. Suddenly, without prior warning, the only plausible solution pops out in my mind. Feeling of joy.

12. In a split second, I'm struck by a flash of genius.

13. When suddenly the brain knows how it happened.

14. Very good. I believe that the magician can't fool me anymore because by now, I could do the trick by myself. With an Aha! experience, I feel very sure about the solution.

15. Suddenly, everything becomes perfectly clear, the missing link is found. It is awesome to suddenly see through the trick, because I feel very clever. It just clicks and it is a very positive feeling. Like a reward for thinking so hard. I feel lively and happy to have figured it out. A feeling of bliss.

16. When the different parts fall into place and my considerations make sense. A slight pull in the chest.

17. It‘s like a shot through my body. Being awakened from previous ignorance, I feel really happy.

18. Explosively, the bad feeling of frustration and confusion turns into a feeling of happiness and I feel a swell of pride.

19. I detected a small detail and suddenly, the things that I had observed previously make sense. It feels like the penny has dropped, and I feel a bit proud to be so certain now, although I had no clue just a few seconds before.

20. I feel that suddenly, I know the solution, thrilled, excited, pleased to have understood something.

21. It seems as if in this moment, all confusion in my brain becomes resolved and I should have known it earlier, simply because it is so logical. The Aha! experience can really be described as the feeling of switching on a light bulb. And I feel somehow affirmated and positively relaxed.

22. I had no Aha! experiences.

23. Abruptly, it becomes clear what's hidden behind all this. When I search for a solution, and suddenly the tension gets released, because I figured it out. A release of tension occurs in my head.

24. „It dawned on me“ is a saying which can very well be connected with this effect; you have thought about a certain matter for a while and suddenly, there is a detail you had not noted earlier which now is leading you in a different direction. It's also a moment of relief and relaxation – time seems to have come to a standstill for a short while. Maybe it's some sort of very short flow experience.

25. In contrast to the other moments I didn't have to check the realisation; the solution seemed to be unambiguous, mostly like remembering something. Usually I'm quite certain about it.

26. Suddenly one knows or believes to know how it works without checking it in detail.

27. The moment comes quite suddenly, as if the idea jumps directly into your mind and doesn't develop step by step by reflection. I am happy about the surprising knowledge.

28. A sudden image appears before my inner eye, triggering off an impulse for action. The further course of the magic trick becomes uninteresting, the focus is on the image which seems to be the solution or actually is the solution.

29. You can't understand why you didn't see that before although it is so simple. It didn't come about by logical reflections but rather simply because it has to be as it is.

30. Like a sudden relief after a time of tension, a feeling of happiness. What in the beginning didn't fit together suddenly makes sense. Thoughts can keep flowing where before they were in front of a barrier.

31. The sudden understanding of the solution. The solution becomes visible before my inner eye in a flash.

32. During an Aha! experience you suddenly realize a detail; somehow you are happy to have seen through the magic trick.

33. Satisfaction at having found the correct solution.

34. With an Aha! experience I suddenly feel an enlightenment; it is as if quite suddenly the light was switched on or a switch turned.

35. Very quick feeling, easy and liberating.

36. I think the magician always did something to distract me from his tricks. So, after the second viewing, I concentrated on what had changed or had disappeared. As soon as I did so, I had this Aha! experience and I was happy.

37. Very happy and surprising.

38. An Aha! experience feels good. Here, once in a while, suspicious hand movements of the magician were interpreted as important for a sudden understanding of the trick; other Aha! experiences felt like a sudden memory of a similiar trick. Aha! experiences felt like ideas, similar to agreeable memories suddenly having come back.

39. Beautiful, surprised by oneself.

40. Can't remember exactly, but it feels a bit like a sudden intuition and like „Oh, that's it! Why didn't I find out earlier?“.

41. The Aha! experience is marked by a feeling of joy and personal satisfaction triggered off by finding the solution.

42. Through a detail, e.g. the cut-off upper part of the spoon, the entire action sequence becomes clear, respectively foreseeable and further details can be detected, e.g. that the magician once again puts the spoon in his hand and quickly takes it out again.

43. Rather nice…you observe what you can see and try to explain how it works and then a decisive detail strikes you – suddenly you have an idea how it could work. As if you had found the last missing part of the puzzle in order to reconstruct the rest of the picture.

44. It feels like an enlightenment, a sudden inspiration how the problem can be solved. Suddenly all pieces of information fit together which before had not fitted together.

45. It feels good because suddenly I know something. It feels alright and, in a way, makes me happy.

46. Aha! experiences could be compared to a quick jump in my head. I didn't have to think rationally about how the trick worked, but it simply came to me.

47. I feel as if a light had been switched on in my head and I'm thinking of my Latin teacher who kept speaking about this. We had lots of Aha! experiences with him.

48. A click in my head, as if someone had turned a switch but, nevertheless, very relaxing and I feel so much more intelligent.

Repetition of Free Self-Reports (14 days later)

1.-5. missing

6. Aha! experience – a short inspiration how to get out of this hopeless situation. This feeling gives me wings that make me continue working on the problem which I had not been able to solve before. And, naturally, I immediately feel inclined to solve further problems, as it seems you now can do anything, no matter which task you have been set.

7. No Aha! experiences.

8. I had two different kinds of Aha! experiences. With one, I felt like suddenly having an idea how the trick had been done – sort of thunder-struck! With the other Aha! experience, I felt as if I had reflected for a moment, I was rather relieved to have seen through the trick, whereas with the first kind I felt as if I had tricked the magician himself by understanding his trick.

9. I found the solution rather fast, I didn't have to think about it at all and I had no clues from which to start thinking. There was a feeling of relief connected with the Aha! experience, it was a very positive feeling.

10. Some sort of tension is released, it is a relaxing, positive sensation and it also gives you some kind of feeling of success.

11. I was excited, felt good and satisfied, it felt as if the solution had suddenly appeared in my head.

12. The Aha! experience came suddenly and unexpectedly.

13. It suddenly appears in my head how the trick works and it somehow feels great to find this out, well, the feelings are: gladness, joy to have found out and curiosity, as you can't always be sure if it really works like that.

14. Very good, I think I know exactly what has just happened. I have exactly understood the trick or the situation, I am quite sure to be right.

15. It simply goes snap und you've got it! Before it happens you keep thinking about it and don't quite get round it, but when the Aha! experience occurs, then you suddenly understand everything – it's like an insight into the whole situation.

16. Like a slight pull in my chest and tummy.

17. Excitement and a feeling like a warm swirl going through my body. I feel relieved and relaxed, joyful.

18. A sudden change from a feeling of insecurity and fear of failure to a feeling of joy and pride. Especially in this moment of change, I'm experiencing an incredible energy
flowing through my body.

19. I am glad and proud to have found a solution, relieved, for a short while I forget what is happening around me.

20. I feel surprised that I have understood something, I am content, maybe even proud of myself, I feel pretty good and agreeable. It certainly is a positive feeling, making me more enthusiastic and full of energy.

21. An Aha! experience feels good, as if I actually saw a light switched on, suddenly everything appears to be quite clear.

22. I had none.

23. Like a flash of genius, as if suddenly everything became clear, you keep brooding and then it suddenly appears, tension disappears, you feel released, a bit euphoric.

24. As if a light was switched on, something that before I hadn't properly paid attention to now turned out to be the cause of a whole series of effects.

25. Sudden remembrance, dissatisfaction about not having discovered it earlier.

26. Suddenly I know the answer, it is as if a light lightened up the darkness.

27. It is as if the idea appeared suddenly out of nowhere and came into my mind. I'm glad about the surprising knowledge and I'm very content.

28. Suddenly an image appears in my mind's eye, everything else around me becomes uninteresting and the concentration is focused only on that image which could be, respectively is, the solution of a problem.

29. Strange that I haven't seen the solution earlier, it turned out to be much easier than I would have expected. At some point, the understanding is simply there.

30. It was a feeling of relief combined with a feeling of happiness after a phase of strain caused by failure.

31. A sudden moment, a feeling of understanding as if it began to dawn on me.

32. It felt good to have found the solution. It was like a competition between me and the magician, and in an Aha! moments, I felt like the winner.

33. When I discovered the solution, I sudddenly was content about myself.

34. It is like a sudden flash of insight, as if someone had switched on a lamp bringing light into the darkness. This moment comes as a surprise and without warning.

35. A slight feeling as is something fell off. For a short moment, you get a feeling of a clear sight.

36. With some tricks, the understanding came suddenly, very easy and I felt glad.

37. Surprising and funny.

38. You have an Aha! experience when understanding connections, thus creating a meaningful image. It can be compared to the good feeling of having finished something that had cost you a lot of time and effort, a positive feeling of understanding.

39. Beautiful. Surprised. Fulfillment of my ambitions. Cool.

40. A moment when you think: Yes, that's it! Why didn't I see that before!

41. An Aha! experience is very satisfying, you think you have finally understood how it works and that you have unmasked the trick. Also in other situations, Aha! experiences feel like that. Immediately, you are completely sure about it.

42. Suddenly the solution appears quickly in my mind. In most cases, it is quite a different track than I had expected before. All the other steps simply follow.

43. I have a smaller or greater experience of success when I believe to have understood the trick.

44. A problem is suddenly understood and solved, it's like a stroke of genius and sometimes you don't even know how you found the solution.

45. A feeling of great satisfaction, a redeeming, relaxing moment, making me feel happy and satisfied.

46. A moment that liberates your mind, relieving your mind from strain, you feel enlightened.

47. I was ever so pleased about having seen through the trick, respectively a little less pleased.

48. A relaxing feeling, feels good and at the same time you don't feel as excited as before.

9 LIST OF PUBLICATIONS

Faber, A. H., Fraps, T., von Müller, A., Grothe, B., & Öllinger, M. (under review at *Cognition*). Working wonders? Investigating insight with magic tricks. – Chapter 2 of the thesis

Faber, A. H., Fraps, T., von Müller, A., Grothe, B., & Öllinger, M. (under review at *Creativity Research Journal*). It's a kind of magic – new insights into the nature of Aha! – Chapter 3 of the thesis

Faber, A. H., Fraps, T., von Müller, A., Grothe, B., & Öllinger, M. (2012). Aha! experiences leave a mark: Facilitated recall of insight solutions. *Psychological Research* (accepted for publication) – Chapter 4 of the thesis

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11 EIDESSTATTLICHE VERSICHERUNG / AFFIDAVIT

Hiermit versichere ich an Eides statt, dass ich die vorliegende Dissertation “Investigation of Insight with Magic Tricks: Introducing a Novel Paradigm” selbstständig angefertigt habe, mich außer der angegebenen keiner weiteren Hilfsmittel bedient und alle Erkenntnisse, die aus dem Schrifttum ganz oder annähernd übernommen sind, als solche kenntlich gemacht und nach ihrer Herkunft unter Bezeichnung der Fundstelle einzeln nachgewiesen habe.

I hereby confirm that the dissertation “Investigation of Insight with Magic Tricks: Introducing a Novel Paradigm” is the result of my own work and that I have only used sources or materials listed and specified in the dissertation.

Own contribution remark: The research questions were put forward by Dr. Michael Öllinger and myself, and discussed with Prof. Benedikt Grothe. The idea of using magic tricks came from me. Selection, recording and preprocessing of magic tricks was carried out by the magician Thomas Fraps and myself. The experiment was jointly designed by Dr. Michael Öllinger and myself. Matus Simkovic was of great help in programming the experiment. All data presented in this thesis was collected by myself. Eline Rimane and Timo Schiele served as raters for the magic trick solutions. I conducted the behavioural data analysis and discussed it intensely with Dr. Michael Öllinger. The EEG data analysis was conducted in collaboration with Dr. Björn Schelter at the Center for Data Analysis and Modeling in Freiburg. All three manuscripts, including creation of figures, were written by myself.

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Signature

Amory Faber