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EDITORIAL

The whole is more than the sum of its parts – addressing insight problem solving concurrently from a cognitive and an affective perspective

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ABSTRACT
The last 15 years have witnessed a surge of new studies and increased efforts to better understand the elusive phenomenon of insight. This special issue reflects the expanding field of research on insight problem solving. To counter unresolved definitional and methodological challenges, a series of papers was collected that allows for a high degree of comparability by using similar methods of measurement, including either an assessment of the subjective Aha! experience or restructuring or both. As a result, some converging findings across studies and paradigms could be identified. We believe that future work should continue on this path, moving towards a consensus of how insight should be measured.

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One hundred years after Wolfgang Köhler's groundbreaking work on chimpanzee cognition, which was the starting point for the scientific investigation of insight problem solving, it seems timely to review the progress that has been made on this research topic. After a period of impasse, the field is now buzzing and alive again: In the last 15 years, new methodological approaches have revived the study of insight and enabled new research questions, for example, about the phenomenology of insight, the role that insight might play in learning, its temporal dynamics and neural correlates.

Although there is still no consensus on how exactly insight should be measured or defined, the focus has recently shifted away from a task-based definition, using only correct solutions of so-called insight problems, towards a more participant-based definition, using a combination of solution correctness and problem solvers' subjective experience as criteria. One possible definition is based on Mayer's concept of insight as a "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). Insight can then be defined as "a complex, nonlinear transition process that consists of an *affective component* (the subjective Aha! experience) and a *cognitive component* (the sudden representational change or restructuring, leading to a correct solution)" (Danek, 2018, p. 51).

We welcome the recent theoretical push towards addressing both components and are happy to report that in this special issue, all authors either assessed Aha! phenomenology (or related dimensions such as pleasure, suddenness or confidence) or attempted to induce restructuring (defined as a switch from incomprehension or miscomprehension to comprehension). The authors of four papers have even made the effort to measure both concurrently, mostly by assessing Aha! as self-report and manipulating restructuring (Ammalainen & Moroshkina, 2021; Becker et al., 2021; Spiridonov et al., 2021; Vallée-Tourangeau et al., 2021). As will become clear in the following, a frequent topic was how the phenomenology of insight, often operationalised as subjective ratings of the Aha! experience, changes as a function of various factors such as task type, solution type, or priming. We will briefly summarise the main contribution of each paper and point out converging findings across studies.

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Insight into a Gestalt – the Aha! experience as a function of solution type

Korovkin et al. (2021) used the ten-penny problem that has two valid solutions, a scheme type that looks like a star and an asymmetric type that does not fit any specific scheme. The scheme type solution was rated as more insightful, elegant and sudden compared to the asymmetric type. The authors argue that the Aha! experience arises if the solution fits an existing scheme and can therefore be encoded and evaluated holistically, as a scheme or "Gestalt". Essentially, Korovkin et al. (2021) demonstrate that the Aha! experience is determined by features of the solution – and not by features of the problem. Although the problem remained the same, the resulting solution experience, measured by a number of rating scales (e.g. pleasure, suddenness, confidence), differed, depending on which type of solution was found. This dataset may be the most convincing to date showing that an a priori categorisation of problems into insight and non-insight problems is highly problematic – and that instead, researchers should focus on categorising solutions into insight and non-insight solutions, depending on the subjective solution experience of the solver. However, this should not be taken as an encouragement to completely forgo any task analyses and to rely solely on Aha! self-reports. This caveat is underscored by another paper of this special issue by Webb et al. (2021), who point out that accuracy and Aha! are predicted not by the same, but by different patterns of individual difference measures. Careful a priori problem analyses and selection remain important to ensure that tasks are used that have a high probability of requiring restructuring for a solution. This aspect is further underscored by the results of Skaar and Reber (2021).

The Aha! experience influences motivation via metacognitive feelings

Based on the integrative fluency account (Topolinski & Reber, 2010), Skaar and Reber (2021) implemented a comprehensive assessment of the subjective experience of problem solvers, with a focus on the motivational consequences of Aha! experiences. A mediation model showed no direct relationship between an insightful problem solving strategy and motivation but an indirect one that was fully mediated by metacognitive feelings (i.e. fluency, positive affect, certainty). This study measured the Aha! experience as a function of task type, comparing two tasks with regard to the resulting subjective solution experience: Matchstick arithmetic problems, which are traditionally perceived as insight problems, and a simple water-level task, requiring no restructuring. Importantly, participants reported the use of multiple solution strategies, including both "step-by-step" and "sudden insight" strategies for both task types. Similar to the study by Korovkin et al. (2021), this finding confirms that a priori categorisations into insight and non-insight problems cannot guarantee specific solution strategies. A final, methodological point may be of interest to the reader: It was shown that one-item measures of the subjective solution experience (Aha! dimensions) are as reliable as multi-item measures (Skaar & Reber, 2021).

Three papers in this special issue measured changes in the Aha! experience as a function of hint type (Ammalainen & Moroshkina, 2021; Becker et al., 2021; Spiridonov et al., 2021). The hints were either helpful (true hints) or were intended to lead to an impasse to provoke restructuring (false hints). Moreover, Ammalainen and Moroshkina (2021) also manipulated whether hints were reportable or unreportable (subliminal priming).

The Aha! experience is diminished by hints towards the solution – especially when participants know that they helped

Using a rather sophisticated stimulus design, Ammalainen and Moroshkina (2021) created a set of anagrams so that for each anagram, an incorrect "solution" exists that is shorter than the correct solution by just one letter. False pictorial hints primed that pseudo-solution (the short word) while true hints primed the correct solution. The manipulation worked as expected, with higher solution rates for true versus false hints. Further, this study showed an overall effect of hints on the Aha! experience, because correct solutions that were produced without any hints (no hint condition) led to higher Aha! ratings compared to the hint conditions. This is in contrast to previous work (Bowden, 1997) showing increased subjective insight ratings for conditions with true, but unreportable, hints. The question whether Aha! strength was influenced by restructuring/no restructuring, that is, by the particular conditions of false/true hints, could not be resolved, but was also addressed by Becker et al. (2021), whose study suggests neurocognitive processing differences depending on restructuring.

Neurocognitive processing differences for problems solved with true vs. false hints and with vs. without Aha! experience

Becker et al. (2021) aimed to experimentally dissociate restructuring from the Aha! experience. The need for restructuring in Compound Remote Associate (CRA) problems was manipulated by using triads with semantically ambiguous words so that one of the two meanings (either more or less related to the solution) could be primed. A binary measure of Aha! was obtained after each solution. Interestingly, even when no restructuring was required, Aha! experiences were reported. Thus, at least for CRA problems, it cannot be implied that restructuring occurred just because an Aha! was reported. The no restructuring conditions with versus without Aha! differed on a neural[1] level as well as with respect to pupil diameter, which indicates neurocognitive processing differences. If the cognitive and the affective components of insight can be dissociated for other tasks as well (i.e. that only one of them occurs, independent from the other), this underlines the importance of including measures of both components in future studies instead of continuing to infer restructuring from Aha! measures. However, these first findings may apply only to CRA problems which perhaps constitute a somewhat special class of problems (Spiridonov et al., 2021; Webb et al., 2016). They must be weighed against evidence indicating that restructuring and Aha! are in fact, linked, as hypothesised by the Gestalt psychologists and as shown recently (Danek et al., 2020; Kizilirmak et al., 2018). A crucial point that should not be overlooked is that Becker et al. (2021) used a binary Aha! measure. Therefore, their findings cannot speak to how the strength or the quality of the Aha! experience may differ depending on whether restructuring occurred or not. Nevertheless, the differentiation between occurrence of Aha!, restructuring, and type of problem solving process (with/without impasse) is also highlighted by Spiridonov et al.'s (2021) second experiment.

Hints influence problem-solving accuracy, but not the Aha! experience

Spiridonov et al. (2021) modified CRA problems to create two conditions with different probabilities of an impasse (a similar manipulation to Becker et al., 2021). True hints led to higher solution rates than false hints (in line with Ammalainen & Moroshkina, 2021; Becker et al., 2021), but hint conditions neither had an effect on the self-reported Aha! experience, nor on any of its dimensions such as pleasure or confidence. In a second experiment, a new method to differentiate between different solution types was implemented: To capture the dynamics of individual solution patterns, participants had to choose between four graphical illustrations of how their solution process progressed (e.g., gradual steps towards the solution, or so-called pop-out insights, but also the more classical insight sequence including an impasse). Correctness predicted the choice of graphical patterns, with pop-out solutions most frequently chosen for correct solutions compared to all other patterns. In sum, Spiridonov et al. (2021) report a dissociation regarding the impact of priming: Performance changes as a function of prime condition, but not the subjective phenomenology of insight. They also question whether CRA problems are comparable with other, more classical insight problems.

Aha! strength does not decrease with a large number of uniform problems

Kizilirmak et al. (2021) compared Aha! strength for correct and incorrect solutions, but also for induced comprehension (solution presented after impasse). Besides another demonstration of the correctness effect (higher Aha! ratings for correct vs. incorrect solutions), the study revealed different ERP amplitudes for correct and incorrect solutions, as well as for induced comprehension. Moreover, the authors also compared two different durations for problem-solving attempts (14 s vs. 4 min). Here, it became evident that the strength of the Aha! is not just dependent on correctness but also on problem difficulty. When failing for a long time to solve a problem and then being presented with the solution, Aha! ratings were generally higher. This can be interpreted as a confounding effect of

[1]This difference was with regard to activation of the anterior cingulate cortex, a region associated with prediction errors and cognitive conflict monitoring (Botvinick et al., 2001; Botvinick, 2007).

problem difficulty. On the other hand, another study showed that solution difficulty and Aha! are independent (Kizilirmak et al., 2018). Another important finding was that, Aha! ratings did not decrease (nor increase) over time, that is, over repeated encounters of the same problem type. This may be a reassuring message for researchers using large sets of problems (e.g., CRAs, matchstick arithmetic tasks), as is necessary for all neuroimaging studies.

Multimodal interactions with problem elements are associated with higher solution rates than only mental interactions

Vallée-Tourangeau et al. (2021) assessed the solution pathways taken to solve the Triangle of Coins problem while comparing different degrees of interactivity: Real-world interactions with the problem elements (high interactivity) versus only mental interactions (low interactivity). Problem-solving performance was better in the high-interactivity condition (where solvers could drag and drop coins on the screen) than in the low-interactivity condition. The authors point out that the high-interactivity condition is a better analogue for real-world creative problem solving than the low-interactivity condition. This paper further provides an excellent example of how a detailed qualitative analysis of the entire solution pathway can be achieved on the level of individual participants, by tracing their moves from video recordings. Interesting patterns could be observed: Incorrect initial solution strategies that must be abandoned for a solution, perseverance on unproductive trajectories (a form of impasse), and, at least in those three case studies, a more step-wise than sudden solution process. Moreover, some participants even discovered the solution only after "accidentally" solving the problem (they were at first unaware that they had already found it).

Two papers in the present issue were concerned with the question of whether and how incubation phases may benefit insight problem solving (Rummel et al., 2021; Sanders & Beeman, 2021).

Overnight cueing increases solution rates for problems with a high likelihood of impasse

Sanders and Beeman (2021) manipulated participants' initial problem representations by presenting puzzles in a more or less fixating version. These versions were designed to differ in the degree to which restructuring was required since the dominant representation that needed to be abandoned for a solution was either enforced or not. For this study, a targeted memory reactivation paradigm was adopted for problem solving: Sound cues that had previously been paired with the puzzles were played during sleep. While there was no main effect of cueing, a significant interaction between cue and fixation was found. In the more-fixating problems, cueing led to higher solving rates, indicating that the fixating information was overcome. This fits with the idea that unconscious processing and perhaps restructuring of information occurs during sleep.

Brief incubation periods that divert attention away from the problem affect neither solution rates nor the Aha! experience

Rummel et al. (2021) tested whether more or less attention-demanding tasks that filled a short incubation period (<15 min) would be beneficial for insight problem solving of magic tricks. Insight affect was measured on a global Aha! rating scale as well as on six further dimensions (adopted from Danek & Wiley, 2017; and also used by Spiridonov et al., 2021; Webb et al., 2017). No incubation effect was found, even if covariates such as working memory capacity or state or trait mind-wandering were controlled for. Regarding Aha! phenomenology, correct solutions received higher Aha! ratings than incorrect ones, which represents another demonstration of the correctness effect of insight. Correct solutions were also perceived as more pleasurable, as more relieving (but not more surprising), as occurring more suddenly, and solvers felt more certain about them (replicating Danek & Wiley, 2017). The global Aha! rating increased from the first to the second assessment time point (but compare Kizilirmak et al., 2021).

Inter-individual differences affect Aha! experience and solution rates independently

Webb et al. (2021) investigated the relationship between inter-individual differences in schizotypy, divergent thinking (DT), fluid reasoning and frequency of correctly solved problems, as well as the strength of Aha! experiences. To this end, they compared these relationships for classical insight problems, classical analytical problems and CRAs, which were regarded as both (to a degree). The authors found that DT-flexibility was a negative predictor of the Aha! experience for all problem types, while DT-originality was a positive predictor for all. They suggested that the easier it is for a participant to adapt the search strategy (= no impasse, no considerable restructuring), the lower should be the feeling of insight. Regarding schizotypy, the unusual experiences dimension was a positive predictor of the Aha! experience, while cognitive disorganisation was a negative predictor. In comparison, problemsolving accuracy for CRAs was best predicted by fluency, whereas the schizotypy dimension introvertive anhedonia positively predicted accuracy in classic insight problems. In summary, what predicts Aha! experiences does not also predict correctness. In other words, the reason for individual differences in the subjective assessment of the Aha! experience is probably not rooted within our ability to solve problems correctly.

Solution rates, but not subjective solution experience, are influenced by task-irrelevant sound

In three experiments, Marsh et al. (2021) manipulated whether task-irrelevant sound occurred as well as the type of sound. They measured the influence of this distractor on problem-solving performance in CRA problems, and on self-reported solution strategy (4-point scale from full incremental to full insight including a feeling of Aha!). The authors observed a consistent effect of task-irrelevant sound (no sound ≤ uniform sound < continuously changing sound) on solution rates, but not on how participants perceived their problem-solving process. Importantly, Marsh et al. (2021) also varied whether the task-irrelevant sound contained meaningless phonetic information or meaningful verbal (semantic) information and found that meaningless "speech" did significantly impair solution rates, but less so than meaningful speech. This pattern suggests that the effect of semantic disruption and task-irrelevant sound per se have different disruptive effects on problem-solving success in CRAs, which supports the idea that CRA problem solving is based on a two-phase process of semantic search for a solution and solution evaluation.

Closing remarks

This special issue presents a selection of papers that tackled the nature of the subjective Aha! experience in problem solving, illuminating which factors influence it and how it is related to solution correctness. Although the papers gathered here represent a wide range of approaches to investigating insight problem solving, they have used comparable methods, which enabled us to identify several converging findings.

The result that correct solutions are associated with higher Aha! ratings than incorrect ones was repeatedly found. In fact, it occurred in all five studies that analysed the relationship between Aha! and correctness of solution (Becker et al., 2021; Kizilirmak et al., 2021; Marsh et al., 2021; Rummel et al., 2021; Spiridonov et al., 2021). Note that this relationship is typically termed the *correctness effect* when solution correctness predicts continuous Aha! ratings, but *accuracy effect* when a binary measure of Aha! predicts correctness (see Threadgold et al., 2018, for this helpful differentiation). However, this relationship is not perfect and should be interpreted with care, as the results of Webb et al. (2021) suggest that the Aha! experience has no direct roots in the accuracy of a participant. Further, it has been shown that sometimes, incorrect solutions can lead to high Aha! ratings, too ("false insights", Danek & Wiley, 2017).

Three studies (Ammalainen & Moroshkina, 2021; Becker et al., 2021; Spiridonov et al., 2021) used hints in order to manipulate the probability that restructuring would occur in verbal tasks (Russian and German CRA problems and anagrams). In all three studies, hints that primed the correct solution were found to increase solution rates compared to irrelevant priming conditions. This finding was generally taken as an indication for the occurrence of restructuring. However, even though Becker et al. (2021) also found support for neurocognitive processing differences between true and false hints, it has yet to be determined whether restructuring truly occurred. This is methodologically challenging, as a direct assessment of restructuring requires some measure of solvers' internal problem representations and how they change during problem solving. To this end, the meticulous tracing of individual problem-solving processes as employed by Vallée-Tourangeau et al. (2021) represents a promising way forward. Another converging finding across the three studies was that the subjective experience of the solution process did not differ as a function of hint condition. This means, whether a true or false hint was provided did not affect participants' self-reported Aha! experiences. Notably, however, Ammalainen and Moroshkina's (2021) results suggest that Aha! ratings are generally higher when no hint is provided. This is in line with the literature on extrinsic and intrinsic motivation, where the self-rewarding aspect of actions is diminished when an extrinsic reward is provided (Bates, 1979; Jordan, 1986). Several neuroimaging studies already suggested that insight is associated with the activation of reward-related brain structures, which would be in line with a view of insight as an intrinsic reward in problem solving (Kizilirmak et al., 2019; Ludmer et al., 2011; Tik et al., 2018).

To conclude, research on insight problem solving is moving forward at an impressive pace. However, we see the danger of fragmentation of the field. Instead of conducting separate studies on Aha! and on restructuring, we should aim towards investigating the phenomenon of insight as a whole and towards more congruency across operationalisations. The affective component of insight seems at first glance easier to grasp, and we have seen a remarkable rise in studies measuring Aha! experiences, as also reflected in this special issue. Nevertheless, we would like to remark that not every study that includes a measure of Aha! experiences actually contributes to our understanding of the key cognitive process of insight, that is, the restructuring that leads to a solution. We expect that future studies that measure or manipulate both, the process and the experience of insight, will contribute most to our understanding and would like to encourage our colleagues to conduct such studies. The old Gestalt saying still rings true today: *The whole is more than the sum of its parts* – and it applies to the scientific investigation of insight as well.

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