Aha! In perceptual Experience and Problem-Solving Cognition

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The Gestalt psychologists' theory of insight problem-solving was based on a direct parallelism between perceptual experience and higher-order forms of cognition (e.g., problem-solving). Similarly, albeit not exclusively, to the sudden recognition of bistable figures, these psychologists contended that problem-solving involves a restructuring of one's initial representation of the problem's elements, leading to a sudden leap of understanding phenomenologically indexed by the "Aha!" feeling. Over the last century, different scholars have discussed the validity of the Gestalt psychologists' perspective, foremost using the behavioral measures available at the time. However, scientists have gained a deeper understanding of insight problem-solving due to the advancements in cognitive neuroscience.

insight problem-solving | "Aha!" moment | Gestalt | perception

1. Introduction

The scientific understanding of insight problem-solving originates from the Gestalt psychologists in the early 20th century. Before the Gestalts, the prevailing viewpoint posited that the human mind inherently establishes associations during trial-and-error learning, leading to a mode of reproductive thinking. When confronted with problems to solve, individuals would merely reproduce solutions that they had previously correlated with successful outcomes by expanding, or modifying, their existing associations, implying the absence of genuinely novel creations (Thorndike 1911). Gestalt psychologists, instead, theorized that insight problem-solving unfolds through a paradigm of productive thinking. Within this framework, problem-solvers would overcome conventional associations and perceive problems through an entirely novel lens (Köhler 1925; Wertheimer 1959). These novel solutions emerge together with an abrupt sensation of apprehending, also termed an "Aha!" moment. For Gestalt psychologists, insight manifests as the transition from a state of uncertainty regarding the achievement of a problem's objective to an in-depth comprehension of the problem itself and thus its attendant solution (Maier 1940) in an off–on manner, as a whole, or as "Gestalt".

In his seminal work, Wolfgang Köhler (1925) documented a chimpanzee's attempts to access out-of-reach bananas. Fortuitously, the chimpanzee managed to see the crates in its cage as potential building blocks for a makeshift staircase. By stacking and ascending the assembled crates, the chimpanzee successfully accessed the bananas. Köhler concluded that the chimpanzee's reorganization of information in its visual field is what permitted the emergence of an insightful solution. The sudden off–on switch into awareness aligns with phenomena such as figure–ground reversals, in which "elements at one moment are seen as one unity, and at the same moment, another unity appears with the same elements" (Ellen 1982, p. 324). This perspective underscores the interplay between Gestalt's problem-solving outlook and the foundational principles of Gestalt perceptual experience. This parallelism becomes especially cogent when a cognitive problem and its solution are provided with pictorial representations, in geometric or graph-theoretic forms. For example, this is the case of the problems discussed by Max Wertheimer (1959) in the book *Productive Thinking*. In such contexts, the discovery of a solution to a problem materializes as the emergence of an ordering or reordering between the elements in the pictorial representation, which (at an abstract level) is comparable to the emergence of a perceptual organization on an array of optical stimuli. Indeed, the Gestalt psychologists argued that perceptual experience is an active and dynamic process involving the mind's inherent tendency to organize sensory information into coherent forms. To them, this process is not restricted to perception but expands also to the way in which we solve problems and how we experience the emergence of a solution as a whole (Köhler 1925; Wertheimer 1959).

Until recently, most of the academic discussions in support of, or in contrast to, the Gestalt theory on insight problem-solving have been based on behavioral studies. Those studies allowed fundamental steps forward in the cognitive understanding of problem-solving. However, it is thanks to neurophysiological results and new methodological paradigms, such as the use of self-reports when studying insight (Bowden et al. 2005; Kounios and Beeman 2009, 2014), that Neo-Gestalt (or Neuro-Gestalt) theorists of insight (as termed by Weisberg 2018) have been able to ground with neurophysiological evidence the view of insight as *a special process*, which is more in line with its initial conception.

2. The Role of Perceptual Experience in Problem-Solving Cognition: Was the Parallelism between Bistable Figures and Insight Problem-Solving Warranted?

A critical link between perceptual experience and the physiological markers of insight problem-solving is provided by the study of pupil dilation. One of the central ideas of the Gestalt psychologists was that the recognition of bistable figures, in terms of object interpretation, can rise suddenly following a reconfiguration of the visual constituents into a new, integrated Gestalt. Analogously, during problem-solving, a solution can unexpectedly emerge holistically, triggered by a reinterpretation of the constituent elements of the problem (Köhler 1925). Both instances entail a restructuring of the problem's elements, or figures, facilitating the emergence of a solution, or perception, into conscious awareness. This restructuring is phenomenologically marked by sensations of surprise, satisfaction, and pleasure, often articulated through the exclamation "Aha!" (Danek and Wiley 2017). When exposed to instances of perceptual and conceptual ambiguity, such as when confronted with bistable figures or attempting to unravel the solution to a problem, individuals tend to seek a recognizable structure within their perceptual or imaginative frameworks, akin to deciphering "connecting the dots" puzzles (Salvi et al. 2020). Undergoing an insight experience involves an underlying top-down subconscious reorganization of stimulus attributes, wherein the coherence of this configuration promptly engages conscious awareness (Salvi 2023).

Crucially, the question that arises pertains to whether this parallelism between perceptual experience and insight problem-solving is merely an illustrative analogy or whether the two share deeper commonalities. Nearly a century after Köhler's investigations, research has unveiled that this parallel between visual perception and insight problem-solving is, indeed, grounded in markedly similar behavioral proxies as physiological correlates. Laukkonen and Tangen (2017) demonstrated that observing a bistable version of the Necker cube (vs. two alternating cubes) can lead to more insights when solving following verbal problems that require reorganization. In a similar vein, Bianchi and colleagues found that prompting individuals to "think in opposites" in visuospatial problems encouraged insights more than an overt hint at the problem (Bianchi et al. 2020). Specifically, the authors showed how the prompt to think in terms of opposites fosters a representational change in problem-solving by extending the search space. Together, these studies demonstrated cross-modal facilitation of perception to insight problem-solving.

When confronted with bistable figures, individuals undergo a phenomenon known as "perceptual rivalry", wherein their visual perception oscillates between various potential interpretations, instead of remaining constant on a single one (e.g., as seen in the Necker cube effect). Neurophysiological studies have indicated that participants' pupil diameter increases when they engage in perceptual reorganization (Einhäuser et al. 2008). Specifically, investigations have observed a rise in average pupil diameter to greater than baseline before conscious recognition of bistable visual stimuli (Einhäuser et al. 2008; Kietzmann et al. 2011).

Based on the above-mentioned results, Salvi et al. (2020) demonstrated that pupil size increased with a 60.5% likelihood in trials resolved through insight (with peak dilation occurring around 200 milliseconds before individuals declared experiencing an insight, i.e., during the "Aha!" moment). The change in pupil dilation was observed regardless of insight accuracy, corroborating the idea that false insights have the same phenomenology as accurate insights (Danek and Wiley 2017; Laukkonen et al. 2020). In this experiment, the authors demonstrated that the two switches (the figurative and the conceptual one) are both associated with the same "corollary" behavioral response (i.e., pupil dilation) and thus that the Gestalt hypothesis is valid.

Further, the observed increase in pupil dilation suggests a potential involvement of the locus coeruleus–norepinephrine (LC-NE) system in association with the "Aha!" experience. Pupil dilation serves as an indirect marker of noradrenergic activity, which is associated with creativity, cognitive flexibility in problem-solving, and the functional integration of the overall attentional brain system. Various studies have highlighted the role of noradrenergic activity in these processes (Beversdorf et al. 1999; Campbell et al. 2008; Corbetta et al. 2008; Coull et al. 1999; de Rooij et al. 2018; Sara 2009). In our cognitive system, attention and consciousness fulfill separate roles and are linked to distinct brain structures, but they maintain a pronounced interconnection (Koch and Tsuchiya 2007). Structures such as the LC and the amygdala play crucial roles in notifying and alerting frontal cortical regions to redirect ongoing processing toward the significance of new stimuli or concepts (e.g., Duncan and Barrett 2007). The LC-NE system, specifically, has a designated function of interrupting current functional networks and, by triggering a "reset" in target structures, fosters the development of new networks by redirecting attention (Sara and Bouret 2012). A similar redirection of attention toward a particular thought occurs when individuals experience an "Aha!" moment, in which an insightful idea suddenly breaks into their train of thought, refocusing their attention on a potential solution to a problem.

While further exploration is needed (and encouraged) to fully elucidate the implications of this physiological response in both perceptual and problem-solving tasks, so far these studies have substantiated Gestalt psychology's conceptualization of insight problem-solving being akin to the reorganization of bistable figures. Moreover, they have provided evidence that the experience of insight is characterized by a non-continuous process, as the pupillary response could serve as an indicator of the transition from unconscious to conscious awareness (Laeng and Teodorescu 2002). While the outcomes of Salvi et al. (2020) have already been replicated by Becker et al. (2021), capturing the precise instant at which an idea materializes remains a multifaceted endeavor.

Thus far, it has been established that the shift in pupil size is observed approximately 200 milliseconds before individuals press a button to signify the occurrence of an "Aha!" moment. The variation in pupil size likely represents a physiological marker that may precede, follow, or coincide with the transition into awareness of the outcomes of unconscious processes (Salvi 2023). In summary, evidence from contemporary empirical work has demonstrated that the conceptual parallelism between ambiguous figures and insight problem-solving share physiological biomarkers, as well as a cross-modal facilitation of these two processes, suggesting a deeper link.

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