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Sudden insight is associated with shutting out visual inputs

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Abstract Creative ideas seem often to appear when we close our eyes, stare at a blank wall, or gaze out of a window—all signs of shutting out distractions and turning attention inward. Prior research has demonstrated that attention-related brain areas are differently active when people solve problems with sudden insight (the Aha! phenomenon), relative to deliberate, analytic solving. We directly investigated the relationship between attention deployment and problem solving by recording eye movements and blinks, which are overt indicators of attention, as people solved short, visually presented problems. In the preparation period, before problems eventually solved by insight, participants blinked more frequently and longer, and made fewer fixations, than before problems eventually solved by analysis. Immediately prior to solutions, participants blinked longer and looked away from the problem more often when solving by insight than when solving analytically. These phenomena extend prior research with a direct demonstration of dynamic differences in attention as people solve problems with sudden insight versus analytically.

Keywords Problem solving · Creativity · Eye movements · Visual attention · Cognitive neuroscience

One classic way that people "think outside the box" is to solve problems by insight, as when the solution to a problem suddenly emerges into consciousness in a *Eureka!* or *Aha*! moment (Kounios & Beeman, 2014). Insight relies on the sudden reorganization of the mental representation of a problem (Sternberg & Davidson, 1995). This reorganization often seems surprising to a solver, because he or she is typically unaware of how it occurred—yet the solver may be confident that the insight yields a correct solution to the problem. Insight contrasts with analytic solving: a conscious, deliberate search through a space of potential solutions. In this study we demonstrated that, as compared to analysis, insight solving is associated with turning attention inward and away from the visual presentation of a problem. This pattern begins before the presentation of a problem and recurs immediately prior to achieving solution.

Previous studies have provided indirect evidence for a relationship between internal attention and insight (reviewed by Kounios & Beeman, 2014). For example, electroencephalograms (EEGs) have revealed that, beginning approximately 1 s before an insight solution bursts into consciousness, a sudden surge in alpha-frequency activity occurs over right posterior cortex, relative to analytic solutions (Jung-Beeman et al. 2004). Given that the problems were presented visually and that alpha-frequency activity over visual cortex indicates the active suppression of input (Haegens, Nácher, Luna, Romo, & Jensen, 2011; Händel, Haarmeier, & Jensen, 2011), this alpha burst suggests that just prior to an insight, attention shifts away from the visual stimulus and toward internal processing.

Even before a problem is presented, distinct patterns of brain activity predict the subsequent manner of solving. During the preparatory period immediately before problem presentation, stronger activity in anterior cingulate cortex (ACC), among other areas, is associated with subsequent solving by

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insight, whereas stronger activity in visual cortex is associated with subsequent solving by analysis (Kounios et al. 2006). Thus, solving by insight apparently involves a specific type of cognitive control—perhaps enhancing the ability to shift processing from one problem representation to another—whereas solving by analysis apparently involves greater attention to incoming prepotent visual information.

These effects are subject to trial-by-trial fluctuations (Kounios et al. 2006). Slower attention shifts also influence the predominance of insight versus analytic solving. For instance, when people are in a positive mood, they are more likely to solve a problem by insight (Subramaniam, Kounios, Parrish, & Jung-Beeman, 2009). Moreover, individual differences in the tendencies to solve problems by insight versus analysis are associated with distinct patterns of resting-state (EEG) brain activity, patterns that are consistent with distinct deployments of attention (Kounios et al. 2008).

Overall, these findings provide indirect evidence that a decreased external focus of visual attention is associated with insight. In the present study, we directly tested this idea by monitoring overt measures of visual attention during three distinct periods: the preparatory interval before a problem is presented, the actual presentation of a problem, and just before the occurrence of a solution. We used several types of measures: blink duration and frequency, the number of fixations, and fixation position. Spontaneous blinking is inversely related to attention to a visual input. It corresponds to dopamine pathway activity integrity (Karson, 1983; Taylor et al. 1999) within the attention and cognitive control systems (van Bochove, Van der Haegen, Notebaert, & Verguts, 2013). Blinks reduce the processing of inputs—not only by physically blocking input, but also by cortically suppressing visual processing, even to unchanging retinal stimulation (Manning, Riggs, & Komenda, 1983; Volkmann, Riggs, & Moore, 1980). Decreasing visual inputs induces a shift in the balance of processing from external stimuli to internal representations. For example, when people blink more frequently, they are more likely to mind-wander (Smilek, Carriere, & Cheyne, 2010) and are less vigilant to external stimuli (Papadelis et al. 2007). People blink less frequently when visual attention is strongly engaged, and more frequently as their internal cognitive workload increases (Wood & Hassett, 1983). Moreover, the frequency of fixations between eye movements reflects the engagement of visual attention: When people attend to external stimuli, they frequently move their eyes to focus on various elements of the display (Klein, Kingstone, & Pontefract, 1992). However, in the absence of visual stimuli, the frequency and duration of eye movements are systematically related to internal thought processes (Ferreira, Apel, & Henderson, 2008; Henderson & Hollingworth, 1999). Thus, the frequencies and durations of both eye fixations and blinks can be used to examine attention while a visual stimulus is available and can index the state of stimulus-independent attention when a stimulus is absent, as during the preparatory interval before an expected problem is presented.

Finally, people move their eyes toward stimuli they want to attend to and away from stimuli they choose to ignore (though they can covertly move attention while keeping their eyes fixed; Posner, Cohen, & Rafal, 1982). People also tend to avert their gazes from distracting stimuli when they perform internal processing, such as searching through long-term memory (Ferreira et al. 2008).

We contrasted patterns of attention that led to solving with insight versus analysis. We analyzed three phases of each trial separately: (1)*preparation*: 2 s prior to the presentation of each problem; (2)*onset*: the first 2 s following problem presentation; and (3)*solution*: the 2 s prior to successful solving (Fig. 1a). We predicted that more attention to external stimuli, manifested as fewer blinks and more fixations, especially those directed at the problem stimuli, would precede analytic solutions. We also predicted that greater attention to internal processing, manifested as more blinks and fewer fixations, particularly avoiding the displayed problem words (hence, shifting fixations outside the problem box), would precede insight solutions. These differences were predicted to emerge just prior to solving (cf. Jung-Beeman et al. 2004) and also during the preparatory period (cf. Kounios et al. 2006).

Method

Participants

Thirty-eight Northwestern University students (20.12±3.04 years old; 22 females, 16 males) with normal or corrected-to-normal vision who were skilled readers, right-handed, and native speakers of American English participated in the experiment for partial course credit. Each experimental session lasted approximately 1 h.

Apparatus and stimuli

Each participant sat with his or her head positioned on a forehead-height eyetracking apparatus at a distance of 56 cm from the screen. The participants' chinrest was removed so that they could be free to speak, but they remained in the apparatus (forehead rest and side bars). The stimuli were presented on a 19-in. Viewsonic E90FB CRT monitor driven at 75 Hz with a 1,024×768 pixel resolution, subtending 33.6 pixels per degree. Eye data were recorded using an EyeLink 1000 Tower Mount (SR Research, Ontario, Canada) eyetracker with a temporal resolution of 1000 Hz. The EyeLink Experiment Builder software (SR Research) was used to program the experiment, for stimulus presentation, and for response recording.

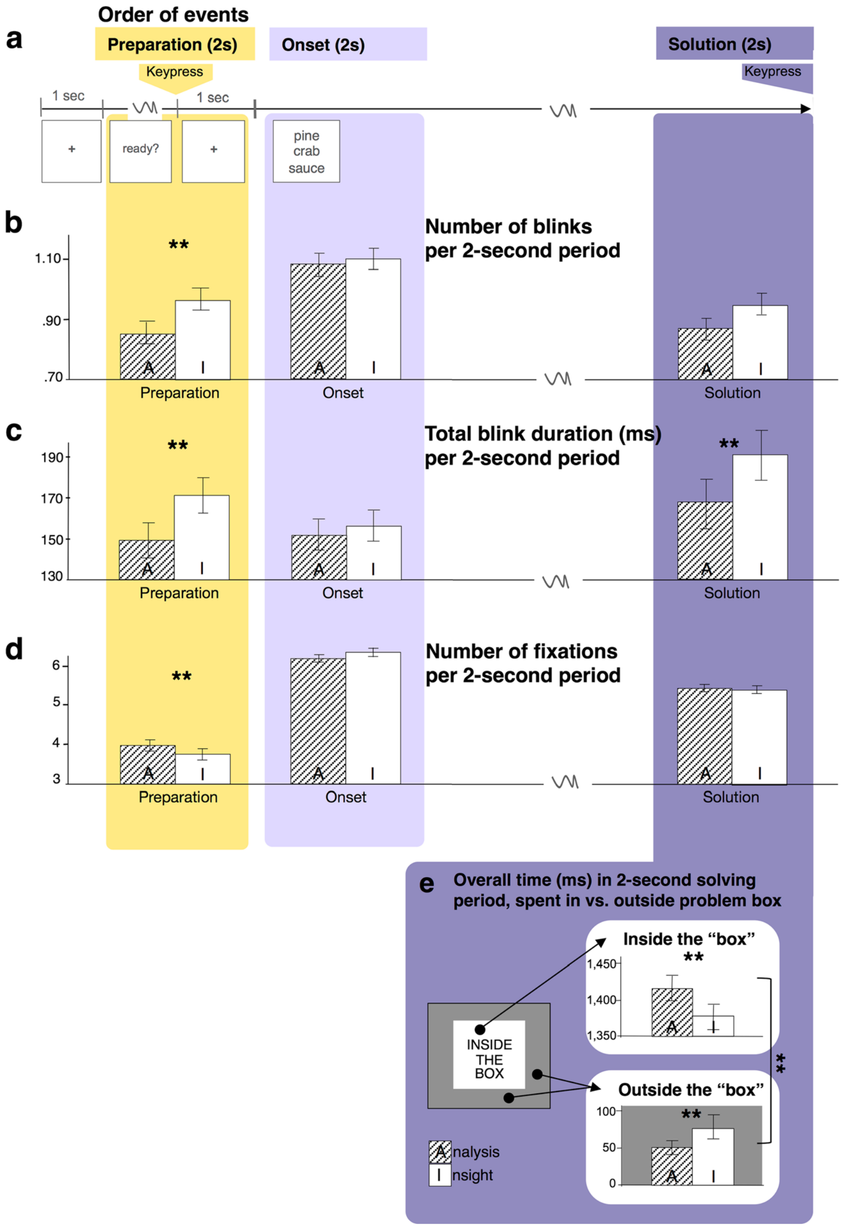

Fig. 1 (**a**) Each trial began with a fixation cross (for 1 s) and a "READY?" prompt displayed until the participant responded, followed by another fixation cross (also for 1 s). The last 2 s of these events comprised the preparation period. Then the three-word problem appeared (the first 2 s being the onset period) and remained on screen until participants pressed a button to indicate a solution (last 2 s=solution period). (**b**) Numbers of blinks across the preparation, onset, and solution periods. (**c**) Total blink durations across the preparation, onset, and solution periods. (**d**) Numbers of fixations across the preparation, onset, and solution periods. (**e**) Fixation locations during the solution period: on the problem words (inside the problem box) versus away from the words (outside the problem box)

We used the manufacturer's software for calibration, validation, drift correction, and computation of the eye movement parameters (blinks, saccades, and fixations). After a successful nine-point calibration procedure, the eye position calibration was checked every 40 trials to reduce possible eye position measurement errors due to participants' repositioning movements. Eye movements were recorded throughout the whole experiment.

Participants were asked to solve 120 compound remote associates (CRA) word problems (Bowden & Jung-Beeman, 2003; Jung-Beeman et al. 2004) and, following each solution, to report whether their solution was by insight or analysis. Each CRA problem consisted of three stimulus words (e.g., *crab*, *pine*, *sauce*) presented simultaneously. Solvers' task was to generate an additional word (e.g., *apple*) that could form a common compound word or a familiar two-word phrase with each of the three problem words (i.e., *crab apple*, *pineapple*, *apple sauce*), within the 15-s time limit. CRAs can be solved with insight or analytically. Self-reports differentiating between insight and analytic solving have been established in numerous behavioral and neuroimaging studies (Bowden & Jung-Beeman, 2003; Jung-Beeman et al. 2004; Kounios et al. 2006).

Stimuli were viewed binocularly. The problem words were written in black on a white background and were displayed in 28-point Times New Roman, with each character subtending 0.61° vertically. The three CRA words were presented in the standard horizontal orientation: one above, one at, and one below the center of the monitor, separated vertically by 2.04° of empty space.

Design and procedure

Prior to the experimental trials, participants were given three practice CRA problems and instructed how to distinguish insight from analytic solving. Solving with insight was described thus: "The answer suddenly comes to mind even though you are unable to articulate how you achieved the solution. Sometimes this is called the Aha! moment." Solving analytically was described in these terms: "You deliberately and consciously tested out different words until you found the solution, and you are able to report the steps that you used to reach the solution." Participants were informed that neither solving style was better or worse than the other.

Problems were presented in four blocks that were equated for difficulty on the basis of prior data (Bowden & Jung-Beeman, 2003). The order of the blocks was randomized, and within blocks the problems occurred in a pseudorandom order, to avoid related problems occurring in close proximity. Each trial began with a central fixation cross lasting 1 s, followed by a response prompt screen. Once participants were ready, they had to press the gamepad button to initiate the fixation cross appearing for another second, and then the three problem words were presented simultaneously on the screen. Following the verbal production of a solution, or at the time limit (15 s), the problem words were cleared and participants had to report, via buttonpress, whether they had solved the problem via insight or analysis (Fig. 1a). No feedback was given to participants regarding whether the solution they had provided was accurate.

Data analyses

An eye movement was classified as a *saccade* when its length exceeded 0.2° and its velocity exceeded 30°/s, or when its length exceeded 0.2° and its acceleration exceeded 9,500°/s. A blink was defined as a period of at least six consecutive milliseconds in which a pupil was not detected by the EyeLink software and that was preceded and followed by the movement of the eyelid over the pupil. The beginning and ending of the artifact defined the duration of each blink. Fixations were defined as periods in which the pupil was detected, in between two saccades. We compared the eye movements and eye blink data for problems solved via insight versus analysis. Finally, we defined a box circumscribing the problem words and examined when participants looked at the problem (*in the box*; see Fig. 1e) versus away from the problem (*outside the box*) during the solution period.

Results

Participants correctly solved 42.6 % (*SD*=11 %) of the problems. Of these, 59.0 % (*SD*=16 %) were solved with insight. Only problems correctly solved were analyzed (participants also provided incorrect solutions on an additional 10.2 % [*SD*=9.9 %] of the trials; 22.1 % [*SD*=24.5 %] of the incorrect solutions were labeled as insights). For the preparation period, we analyzed all problems solved in more than 2 s, since these are thought to accurately reflect both insight and analytic solving (e.g., Cranford & Moss, 2012). For the onset and solution periods, to avoid any overlap across the two analysis periods (2 s each), we analyzed just those problems solved in more than 4 s (*M*=70.7 %, *SD*=13.6 %, of all solutions). On average, for solutions longer than 4 s, participants solved 48.5 % (*SD*=21.9 %) by insight and 51.5 % (*SD*=21.9 %) by analysis. The average response times were, respectively, 6.71 s (*SD*=0.96 s) for insight and 8.73 s (*SD*=1.39 s) for analysis. Two-tailed *t* test results are reported for all contrasts.

During the preparation periods before problems later solved by insight, as compared to those solved by analysis, participants blinked more frequently [$t(37)=4.41$, $p=.001$] (Fig. 1b left) and marginally longer per blink [$t(37)=1.71$, $p=.095$], yielding reliably longer total blink durations [$t(37)=2.49$, $p=.017$] (Fig. 1c left). Likewise, in the solution periods prior to insight, as compared to analysis, participants blinked marginally more frequently [$t(37)=0.98$, $p=.150$] (Fig. 1b right) and reliably longer per blink [$t(37)=2.01$, $p=.041$], yielding reliably longer total blink durations [$t(37)=2.25$, $p=.030$] (Fig. 1c right). In the preparation period, the average durations per blink were 198 ms for insight (*SD*=113) and 161 ms for analytic (*SD*=93), and for the solution period the average durations per blink were 200 ms for insight (*SD*=228) and 169 ms for analytic (*SD*=175).

During the preparation period, participants made fewer fixations prior to problems eventually solved by insight than prior to those solved by analysis [$t(37)=-2.84$, $p=.007$] (Fig. 1d left). During the solution period, participants did not vary in how many fixations they made when solving by insight versus analysis. However, they differed in where they looked; that is, fixation location (inside vs. outside the problem box) interacted with the type of solution that was produced: 2×2 analysis of variance, $F(2, 36)=7.15$, $p=.011$. In general, participants fixated (summation of the durations across all fixations) mostly inside the problem box. However, this was affected by solution type. They fixated inside the problem box less when solving by insight than when solving analytically [*t*(37)=–2.41, *p*=.021], and fixated outside the problem box more when solving by insight than when solving analytically [*t*(37)=2.44, *p*=.019].

Discussion

All three measures indicated that during the preparatory and/or solution periods, overt attention differed when participants solved problems by insight versus when they solved by analysis. In chronological order (left to right in Fig. 1): During preparation, participants blinked more frequently and for a longer total duration prior to problems that they solved by insight rather than by analysis (numbers of blinks in Fig. 1b, left; total blink durations in Fig. 1c, left). Participants also moved their eyes less frequently in the preparation period before problems eventually solved by insight (Fig. 1d, left). These differences reflect within-participant trial-by-trial fluctuations in attention that were associated with how people subsequently solved a problem—by insight or by analysis.

In light of the different blink rates during the preparation periods (i.e., in the absence of meaningful stimuli), it is interesting to note that spontaneous blink rates have been linked to dopamine function (Chermahini & Hommel, 2010; Karson, 1983; Taylor et al. 1999). Indeed, increasing dopamine levels or activity (particularly in the D1 pathway) via lesions or pharmacology increases blink rates; conversely, decreasing dopamine decreases blink rates (Karson, 1983; Taylor et al. 1999). Dopamine function, in turn, is highly associated with the cognitive processes of attention and cognitive control, and anatomically with the dorsal ACC that contributes to these processes (Botvinick, Cohen, & Carter, 2004). In short, dopamine function is linked to the degree to which people maintain ongoing processes or switch to new processes (Chermahini & Hommel, 2010; Müller et al. 2007)—one type of cognitive flexibility thought to be important for creativity. In the present study, higher eye blink rates in the preparation period were associated with increased insight solving. We speculate that this relationship could be related to phasic increases in dopamine function.

At problem onset, differences in the blink and fixation patterns dissipated somewhat (Fig. 1b, c, and d middle). This was to be expected, because participants needed to fully attend to the problem in order to read the presented words.

Finally, we considered what happened during the solution period. Previous findings had revealed transiently increased alpha-band EEG activity over visual cortex just prior to insight (Jung-Beeman et al. 2004), putatively reflecting the suppression of distracting visual inputs to allow participants to retrieve weak internal associations that led to solutions. In our study, people blinked longer—in terms of both the total and average blink durations—and marginally more frequently when solving with insight than when solving by analysis (Fig. 1b and c).

We tested one final prediction. Previous results that had suggested visual sensory gating (i.e., increased alpha-band activity over visual cortex) immediately before insight may have occurred because in those EEG experiments participants were instructed to keep their eyes fixed and to minimize blinking. This sensory gating was interpreted as decreasing attention to the displayed problem words, likely because looking at these words would have elicited prepotent, but unhelpful, associations. Suppressing these inputs helped solvers to retrieve the nonprepotent associations that yield insights. In the present experiment, given the freedom to move their eyes, we predicted that participants would look more at the problem words prior to solving by analysis than prior to solving by insight, and would look away from the problem words more often prior to insightful than to analytic solutions. As predicted, although people generally remained looking at the problem words—that is, in the box (see Fig. 1e)—they spent more time looking outside the problem box just before solving by insight than just before solving by analysis.

Insight and analytic solving showed striking differences in their patterns of attention deployment, both during anticipation of the problem and in the moments leading to the solution. Although the present data are correlational, and cannot definitively show a causal relationship between patterns of attention and the type of solution, the fact that our blink and fixation measures differed before problems were presented (when the subsequent problem difficulty could not have had an effect) strongly suggests that starting (and unfolding) attention states were driving these differences. Future work that manipulates either patterns of attention (perhaps through the guidance of eye movements) or solving processes (perhaps through the choice problem type, preparation instructions, or solving instruction) might uncover more powerful evidence for a causal relationship.

In summary, analytic solving was associated with a focus of external attention to the problem itself—decreased blinking and increased fixations. In contrast, insight solving was associated with an internal focus rather than a focus on the problem stimulus—in the forms of increased blinking, decreased frequency of eye movements, and literally moving the eyes away from a problem stimulus just before the solution bursts into consciousness. This internal attention may shield the processing of weak associations and interconnections, rather than focusing on the strong—but misleading—associations elicited by the problem. These results are consistent with introspective reports that people often look at a blank wall or out the window, or shut their eyes altogether, when trying to solve a difficult problem or trying to retrieve a weak memory (Ferreira et al. 2008). Figuratively—and in this case, literally—thinking outside the box is associated with looking outside the box.

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