



Looking for ideas: Eye behavior during goal-directed internally focused cognition[☆]



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ABSTRACT

Humans have a highly developed visual system, yet we spend a high proportion of our time awake ignoring the visual world and attending to our own thoughts. The present study examined eye movement characteristics of goal-directed internally focused cognition. Deliberate internally focused cognition was induced by an idea generation task. A letter-by-letter reading task served as external task. Idea generation (vs. reading) was associated with more and longer blinks and fewer microsaccades indicating an attenuation of visual input. Idea generation was further associated with more and shorter fixations, more saccades and saccades with higher amplitudes as well as heightened stimulus-independent variation of eye vergence. The latter results suggest a coupling of eye behavior to internally generated information and associated cognitive processes, i.e. searching for ideas. Our results support eye behavior patterns as indicators of goal-directed internally focused cognition through mechanisms of attenuation of visual input and coupling of eye behavior to internally generated information.

1. Introduction

The peculiar gaze of someone deeply absorbed in thought or “staring into space” suggests that eye behavior during internally focused attention might be different from states of externally focused attention. In fact, recent research provides evidence that mind wandering, the involuntary slipping away of attention from an external task to an unrelated internal train of thought, is associated with characteristic changes in eye behavior such as spontaneous pupil activity (Franklin, Broadway, Mrazek, Smallwood, & Schooler, 2013; Smallwood et al., 2011, 2012). Besides this spontaneous form of internally focused cognition, there are also many goal-directed cognitive activities which require a voluntary shift of attention to an internal focus such as planning or idea generation. For such activities external visual information is irrelevant and can even be distracting. Eye behavior is assumed to differ between states of goal-directed internally and externally focused cognition. This study aims to examine the characteristic eye behavior during goal-directed internally focused cognition.

“Internally directed cognition” or stimulus-independent thought (Smallwood & Schooler, 2006) refers to cognition with an attentional focus on internally generated information rather than the external environment. Internally generated information results from memory retrieval of internal representations and combinations and modifications of those representations (mental simulations, ideas, dreams; see Chun, Golomb, & Turk-Browne, 2011; Dixon, Fox, & Christoff, 2014). The literature suggests that eye behavior may respond to and even support internal cognition in at least two ways: first, by means of attenuation of potentially distracting perceptual input, and second, by means of a coupling of eye behavior to internally generated information and processes. We will briefly

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review evidence in support of these two hypothesized mechanisms.

1.1. Attenuation of visual input

Due to limited information processing capacity, processing external and internal information simultaneously impairs performance in one domain or both (Chun et al., 2011; Dixon et al., 2014). On the one hand, external tasks are impaired by internal events, like daydreaming or trying to solve a puzzle whilst driving a car (He, Becic, Lee, & McCarley, 2011; Savage, Potter, & Tatler, 2013). On the other hand, tasks requiring internally focused cognition, like thinking about an amazing new idea and how to implement it, can get interrupted by more or less irrelevant external events, such as an e-mail popping up on one's desktop. External (perceptual input) and internal (self-generated) information are competing for limited processing resources (Chun et al., 2011). Therefore, being able to focus on one's internal stream of thought and effectively shielding it from distracting external information has a high influence on the resulting performance. Active attenuation or shut out of external information can occur at different levels of visual perception.

At the neural level, research using EEG alpha frequency activity and functional MRI suggests an active suppression of visual input when participants have to solve a divergent thinking task with high internal processing demands. For example, EEG alpha activity is assumed to reflect a top-down mechanism for suppression of external visual information processing (Benedek, Bergner, Könen, Fink, & Neubauer, 2011; Benedek, Schickel, Jauk, Fink, & Neubauer, 2014; Fink & Benedek, 2013). Moreover, the right inferior parietal cortex was implicated in the down-modulation of visual information processing during high internal attention demands (Benedek et al., 2016; for an overview, see Benedek, 2017).

At the level of eye behavior, the most straightforward mechanism would be to simply look away from distracting stimuli (e.g. avoid eye contact: gaze aversion) or close the eyes. Indeed, gaze aversion and eye closure were frequently observed during demanding internally focused cognition and are thought to reduce cognitive load and thereby free up cognitive resources (Doherty-Sneddon & Phelps, 2005; Mastroberardino & Vredeveldt, 2014; Vredeveldt, Hitch, & Baddeley, 2011). The frequency of gaze aversion depends on cognitive load. The more resources an internally focused task demands, the more resources need to be recruited/withdrawn elsewhere, e.g. via gaze aversion or eye closure, to prevent performance impairments (Doherty-Sneddon & Phelps, 2005).

Very short eye closures – blinks – may also reduce the processing of visual input and enhance internally focused cognition. Solving problems through spontaneous insight was associated with higher blink rates as compared to analytical problem solving (Salvi, Bricolo, Franconeri, Kounios, & Beeman, 2015). The relationship between mind wandering and blink rate is currently not clear (Mooneyham & Schooler, 2016; Smilek, Carriere, & Cheyne, 2010; Uzzaman & Joordens, 2011), but demanding internally focused cognition tasks like idea generation and insight problem solving are typically accompanied by higher blink rates (Akbari Chermahini & Hommel, 2012; Salvi et al., 2015; Ueda, Tominaga, Kajimura, & Nomura, 2015), supporting the hypothesis of an active decoupling strategy.

Besides actual interruption of the visual input via blinks or gaze aversion, the processing of external visual information can also be attenuated. One potential oculomotor mechanism for attenuation would be disaccommodation. To focus on an object in three-dimensional space the eyes need to be aligned (eye vergence) and the lens adjusted to the object's distance. These changes are associated with changes in pupil diameter. The three processes – eye vergence, lens constriction and pupil size changes – are coupled in the so-called convergence reflex or near response triad (Delank & Gehlen, 2006; McLin & Schor, 1988; Myers & Stark, 1990). Defocusing an object results in blurring and double vision, impairing further processing of visual information. Therefore, eye vergence is an important variable in research on covert attention - when attention is shifted to another location without moving the eyes (Solé Puig, Pérez Zapata, Aznar-Casanova, & Supèr, 2013) - and dyslexia (e.g. Kapoula et al., 2007), and it could also play a role in goal-directed internally focused cognition as suggested by the phenomenon of “staring into space”. The phenomenon of “staring into space” refers to the peculiar gaze people have when they are deeply absorbed in thought. “Staring into space” seems to be characterized by a strong stare (lack of eye movements) and the eyes seem to focus at a distance far away.

In a similar way, attenuation of visual perception could also be achieved by means of reduced microsaccade activity. When fixating static stimuli, neuronal adaptation leads to perceptual fading within seconds. To counteract perceptual fading, our eyes perform fixational eye movements (microsaccades, drift and tremor), of which microsaccades are considered the most important ones (Martinez-Conde, Macknik, Troncoso, & Dyar, 2006; Martinez-Conde, Otero-Millan, & Macknik, 2013; McCamy et al., 2012). Microsaccades cannot be generated voluntarily, but they can be suppressed voluntarily for a few seconds (Bridgeman & Palca, 1980; Winterson & Collewun, 1976). As external visual information is not needed during periods of internally focused cognition, there is no need to counteract fading through microsaccades. Fading may even facilitate internally focused cognition by reducing distracting visual input. So far, the role of eye vergence and microsaccades for internally focused cognition has not been addressed by research.

1.2. Coupling to internally generated information

When we remember a special occasion or think about the upcoming holiday, we often seem to actually look at a mental picture in our mind's eye. This notion has been supported by research on mental imagery and memory retrieval, showing that eye movements are commonly coupled to cognitive processes during internally focused cognition (Ferreira, Apel, & Henderson, 2008; Johansson, Holsanova, Dewhurst, & Holmqvist, 2012; Johansson, Holsanova, & Holmqvist, 2005). When retrieving information about objects from memory, eye behavior patterns reflect those made while actually looking at the scene (Johansson et al., 2005). Even when eye movements during encoding are prohibited through continuous fixation of a certain point, eye movement patterns during retrieval reflect spatial characteristics of the remembered material, as one was looking at it. Those eye movements during retrieval seem to play an important role for retrieval itself, as prohibiting them impairs retrieval (Johansson et al., 2012).

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