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Predictive information speeds up visual awareness in an individuation task by modulating threshold setting, not processing efficiency

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ABSTRACT

Theories on visual awareness claim that predicted stimuli reach awareness faster than unpredicted ones. In the current study, we disentangle whether prior information about the upcoming stimulus affects visual awareness of stimulus location (i.e., *individuation*) by modulating processing efficiency or threshold setting. Analogous research on stimulus *identification* revealed that prior information modulates threshold setting. However, as identification and individuation are two functionally and neurally distinct processes, the mechanisms underlying identification cannot simply be extrapolated directly to individuation. The goal of this study was therefore to investigate how individuation is influenced by prior information about the upcoming stimulus. To do so, a drift diffusion model was fitted to estimate the processing efficiency and threshold setting for predicted versus unpredicted stimuli in a cued individuation paradigm. Participants were asked to locate a picture, following a cue that was congruent, incongruent or neutral with respect to the picture's identity. Pictures were individuated faster in the congruent and neutral condition compared to the incongruent condition. In the diffusion model analysis, the processing efficiency was not significantly different across conditions. However, the threshold setting was significantly higher following an incongruent cue compared to both congruent and neutral cues. Our results indicate that predictive information about the upcoming stimulus influences visual awareness by shifting the threshold for individuation rather than by enhancing processing efficiency.

1. Introduction

Driving through an unfamiliar city, looking for the colleagues you promised to pick up, you might face a challenging visual perception task. Luckily, having some prior (i.e., predictive) knowledge about what your colleagues look like will facilitate becoming aware of them. Indeed, several consciousness theories have proposed mechanisms by which prior information modulates visual awareness. For example, according to Clark (2013) prior information is one of the key aspects to determine which stimuli reach visual awareness and at what speed. While the effect of prior information on visual perception has already been investigated extensively in paradigms that require stimulus *identification*, it remains unclear how it influences the distinct visual process of stimulus *individuation* (i.e., the spatial tagging of an object in a visual scene). The current study investigates whether and how prior information influences visual awareness in individuation.

The influence of prior information on visual perception has typically been investigated in paradigms that require the identification of visual input. In these experiments, participants need to categorize a degraded or masked stimulus (e.g., distinguishing a face from a house picture masked by noise). Predicted stimuli are typically perceived faster and more accurately. In order to gain more insight into the modulations of identification by prior information, formal models such as the drift diffusion model (DDM) and signal detection theory (SDT) have been used to disentangle the underlying mechanisms (for a review, see Mulder, van Maanen, & Forstmann, 2014; Summerfield & de Lange, 2014). In the DDM (see Fig. 1; Ratcliff & Rouder, 1998), evidence is accumulated at a certain rate (i.e., drift rate) from a starting point toward an upper or lower criterion bound. The distance between the upper and lower bounds is called boundary separation. The total response time is the sum of this evidence accumulation time plus any cognitive processes preceding or following the decision process (i.e., non-decision time). Critically, the parameters of the decision

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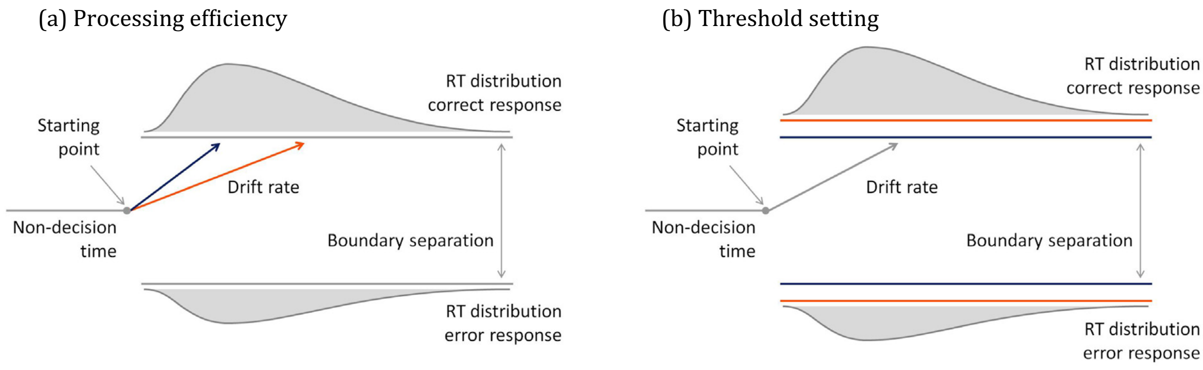

Fig. 1. Prior information can influence visual perception by modulating processing efficiency (panel a) or threshold setting (panel b), respectively mapped onto the DDM parameters drift rate and boundary separation. The DDM is depicted including the non-decision time and starting point parameter. Hypothetical reaction time (RT) distributions for the correct and error responses are plotted at the corresponding upper and lower boundary. Increased processing efficiency and more lenient boundaries are indicated in blue, while decreased processing efficiency and more conservative boundary settings are depicted in orange. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

process (e.g., drift rate, boundary separation and starting point) can be mapped onto distinct mechanisms by which expectations can influence the accumulation process. First, if prior information improves visual *processing efficiency*. This is reflected in increased drift rate (see Fig. 1a). Second, prior information can reduce the required amount of accumulated information. This is reflected by the distance between the starting point and decision boundaries henceforth referred to as *threshold setting* (see Fig. 1b). Importantly, threshold setting encompasses both starting point placement and boundary separation, although only the latter is relevant in the current experimental paradigm (see below).

Using these and related formal models, a number of studies have investigated how prior information influences stimulus identification. By manipulating the predictability of a shape in a shape discrimination task, Domenech and Dreher (2010) found using the LATER model (Reddi & Carpenter, 2000) that prior information influences threshold setting rather than processing efficiency. A cue predicting the movement direction in a random-dot motion paradigm influenced threshold setting but not processing efficiency (using the DDM: Mulder, Wagenmakers, Ratcliff, Boekel, & Forstmann, 2012; using a linear ballistic accumulator model: Forstmann, Brown, Dutilh, Neumann, & Wagenmakers, 2010). Using the DDM, Dunovan, Tremel, and Wheeler (2014) found that the identification of a house or face masked by noise was influenced by a house or face cue through the modulation of threshold setting. Interestingly, this modulation increased with the reliability of the cue (50, 70 or 90% accuracy) establishing a clear causal link between prior information and threshold setting. By contrast, using SDT Lupyan and Ward (2013) showed that cueing the word 'circle' or 'square' in a shape discrimination paradigm modulated processing efficiency (i.e., d') but not threshold setting (i.e., response criterion).

The results from these identification paradigms suggest that prior information influences visual awareness by modulating threshold setting. However, visual awareness studies usually require participants to report whether any item was perceived, irrespective of its identity (Baars, 1994; Overgaard & Sandberg, 2012; Sandberg, Timmermans, Overgaard, & Cleeremans, 2010; Sergent & Dehaene, 2004; Tononi & Koch, 2008). Interestingly, participants can often report where something was seen without knowing what was presented (Ramsøy & Overgaard, 2004). Similarly, to corroborate awareness reports, participants are commonly asked to report the location of a stimulus (i.e., individuation) rather than its identity (e.g., Yang & Blake, 2012). Therefore, to investigate how prior information influences visual awareness, it is critical to probe its effect on stimulus individuation. According to the individuation–identification theory (Leslie, Xu, Tremoulet, & Scholl, 1998), the number of objects in a scene (i.e., individuation) and object identity are determined in two separate processes. This idea resonates with theories claiming that spatial information plays a unique role in visual processing, separate from the identification process (Sagi & Julesz, 1984). This notion is also supported in object file theory (Kahneman, Treisman, & Gibbs, 1992), where an object file is created based on spatial and temporal information, while its content is determined separately. As the individuation and identification stage are functionally and neurally different (Xu, 2009), prior information may influence perception via different mechanisms in these two visual processes.

Indirect evidence for distinct mechanisms underlying stimulus identification and individuation comes from the spatial attention literature. First, while object-based attention (crucial for identification) is associated with the ventral processing stream, location-based attention (crucial for individuation) depends on the dorsal processing stream (Arrington, Carr, Mayer, & Rao, 2000; Chen, 2009; Chou, Yeh, & Chen, 2014). Second, in stark contrast to the modulation of threshold setting presented above, prior information about the location of the upcoming stimulus has been argued to enhance stimulus identification by increasing processing efficiency (Anton-Erxleben, Abrams, & Carrasco, 2010; Smith, Ratcliff, & Wolfgang, 2004; however, for an alternative interpretation see Schneider, 2011). So in similar identification paradigms, location cueing boosts processing efficiency while identity cueing modulates threshold setting. It could be argued that – as locating a stimulus is crucial to individuation – location cueing boosted processing efficiency in the individuation process and not in the identification process. However, this interpretation of the results remains to be tested as an identification task was used rather than an individuation task.

To investigate how prior information affects visual awareness of stimulus location in an individuation paradigm, we developed a cued masking task analogous to the identification studies described above. The picture of a house or a face (i.e., the target) was briefly presented above or below fixation, followed by a masking stimulus. Prior to the target presentation, participants were presented with a house or face cue that predicted the target identity with 80% accuracy, or with a cue that provided no prior information (a question mark). This manipulation generated three trial types: congruent, incongruent and neutral trials. Participants responded as fast and as accurate as possible to the location and not to the identity of the target picture by pressing an upper or