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Unconscious attention modulates the silencing effect of top-down predictions

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ABSTRACT

The brain is considered to be proactive in that it continuously generates predictions about external environment stimuli. Recent Bayesian models of perception have demonstrated that prediction and attention operate synergistically to optimize stimulus processing. However, the relation between prediction and unconscious attention remains unclear given the relative neglect of unconscious attention in scholarly literatures. To investigate this issue, twenty participants (12 women) performed an orientation identification task in which a circular grating appeared either in the left or in the right visual field in a single 30–40 min session, during which 64-channel EEG data were acquired. Behavioral results showed an unconscious-attended effect and a facilitated effect. Importantly, prediction-related P1 and N1 silencing effects were observed in the unconscious-attended condition, probably reflecting that unconscious attention improves the precision of top-down predictions at an early stage of processing, thereby increasing the synaptic gain of predictor neurons. Moreover, unlike the early ERP components, P3 revealed a reversed pattern of results, which displayed a silencing effect of prediction only in the unattended condition, suggesting that the influence of unconscious attention on the silencing effect may change over time.

1. Introduction

Human beings do not process external environment stimuli passively, but continuously generate predictions about them based on prior similar experiences (Pezzulo, Butz, Castelfranchi, & Falcone, 2008). It is remarkable that building top-down predictions is a fundamental function of the brain, which facilitates interactions with sensory information, conserves human effort, and ultimately increases the chances of survival (Kveraga, Ghuman, & Bar, 2007).

An increasing number of studies have investigated the potential mechanism underlying the generation and representation of predictions in the brain, using paradigms that focused on emotional predictions (Barbalat, Bazargani, & Blakemore, 2013; Campanella et al., 2002; Ran, Chen, Pan, Hu, & Ma, 2014), reward predictions (Kahnt, Heinzle, Park, & Haynes, 2011; Kringelbach, 2005), and top-down visual and auditory perceptions (Hsu, Hämäläinen, & Waszak, 2014; Kahnt et al., 2011; Picton, 1992; Summerfield & Koechlin, 2008). For example, Summerfield and Koechlin (2008) have shown that the ventro-medial prefrontal cortex (vmPFC) was activated when the sensory inputs matched the observer's predictions.

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Attention, a cognitive process interacting with prediction (Summerfield & Egner, 2009), is suggested to modulate neural responses to stimuli at early and late stages of sensory processing. Electrophysiological studies have reported that selective attention frequently demonstrates amplitude enhancement in the N1 component time window (e.g., Talsma & Woldorff, 2005; Woldorff et al., 1993). Furthermore, a late positive-going deflection, the P3, has been observed to be larger for attended stimuli relative to unattended stimuli (see Doherty, Rao, Mesulam, & Nobre, 2005; Ross, Hillyard, & Picton, 2010), although several other reports did not detect this enhanced effect of attention (Lange, Krämer, & Röder, 2006; Näätanen, Teder, Alho, & Lavikainen, 1992). One can speculate that the discrepancy between the findings is probably due to differences in experimental design and task.

Despite that recent Bayesian models of perception have demonstrated that prediction and attention operate synergistically to optimize stimulus processing (Friston, 2009; Summerfield & Egner, 2009), little is known about the relationship between prediction and unconscious attention given the relative neglect of unconscious attention in scholarly literatures. As intuition might suggest, attention and consciousness are closely interwoven in everyday life. More precisely, when we attend to an object, we become aware of its attributes, and being aware of the object might result in attention directed toward it (Koch & Tsuchiya, 2007; Maftoon & Shakouri, 2012). Some recent scholars, however, have stated that attention and consciousness are dissociated phenomena that can be manipulated using different paradigms (e.g., Koch & Tsuchiya, 2007), indicating that conscious and unconscious attention may be two distinct ways of processing visual events and behaviors.

In the current study, we investigated, for the first time to our knowledge, how the neural mechanisms for top-down predictions were modulated by unconscious attention. Considerable research has shown that conscious processing of attention occurs within restricted areas, whereas unconscious processing of attention occurs in broader areas (Sato, Uono, Okada, & Toichi, 2010; Simons & Rensink, 2005), suggesting that unconscious attention may widen the scope of perception, thereby facilitating perceptual inference in the brain. In this account, unconscious attention might be suggested to boost the precision of predictions. Recent studies indicated that pre-awareness of incoming events facilitated reallocating of cognitive resources as well as preparation of behavioral coping strategies, leading to decreased brain activities (Ran, Chen, Pan, Hu, et al., 2014; Yang, Yuan, & Li, 2012). Thus, it is likely that the predictable stimuli might evoke reduced responses compared with unpredictable stimuli in the unconscious-attended condition, but not in the unattended condition. Such an effect of attention, however, may only occur at an early stage of processing, since the precision weighting of prediction is big at late stage of processing when stimuli were unattended. This may be due to the fact that humans are more confident in weighing the differences between top-down predictions and bottom-up evidence at this late stage (Bowman, Filetti, Wyble, & Olivers, 2013; Koster-Hale & Saxe, 2013).

To orthogonally manipulate prediction and attention, the present study adopted an orientation identification task in which a circular grating appeared either in the left or in the right visual field (Sato, Okada, & Toichi, 2007; Sato et al., 2010). A group of healthy volunteers ($n = 20$) were instructed to perform this identification task, and their brain responses were recorded using high temporal resolution event-related potential techniques. In this paper, we focused on P1, N1, and P3 components, as it has been proposed that these components are relevant for attention processes (Ross et al., 2010; Talsma & Woldorff, 2005).

2. Methods

2.1. Participants

Twenty healthy volunteer participants (12 women and 8 men; mean age = 20.25 years, *SD* = 1.44 years; all right-handed) with no history of neurological, psychiatric, or visual impairments as indicated by self-report took part in the experiment. The experiment procedure was conducted in accordance with the Helsinki guidelines as per the World Health Organization (Gilder, 1964). All participants gave informed consent and were paid for their participation. All the data were analyzed anonymously, and personal information was handled confidentially.

2.2. Stimuli

The prediction cue employed in the current experiment consisted of either the word '*left*' (indicating a 75% likelihood of target stimuli appearing on the left), '*right*' (indicating a 75% likelihood of target stimuli appearing on the right), or '*neutral*' (an unpredictable condition, with a 50% likelihood of target stimuli appearing on either side). All words were converted into JPG format, and standardized for luminance and contrast with Adobe Photoshop software. Attention cues were young–adult faces in which the eye gaze was directed either to the left or right. Importantly, the attention cues contained no information about the side of target stimulus. Using MATLAB software (Version 6.5.1, Mathworks Inc., Massachusetts, USA), circular gratings (target stimuli) were generated on a PC computer. Each target was presented in either the left or the right visual field.

2.3. Procedure

Participants were seated comfortably 90 cm from the computer screen and engaged in a grating orientation identification task. The task consisted of 38 blocks of 8 trials (*left prediction*: 11 blocks; *right prediction*: 11 blocks; *no prediction*: 16 blocks),