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Category-selective attention modulates unconscious processes in the middle occipital gyrus

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ABSTRACT

Many studies have revealed the top-down modulation (spatial attention, attentional load, etc.) on unconscious processing. However, there is little research about how category-selective attention could modulate the unconscious processing. In the present study, using functional magnetic resonance imaging (fMRI), the results showed that category-selective attention modulated unconscious face/tool processing in the middle occipital gyrus (MOG). Interestingly, MOG effects were of opposed direction for face and tool processes. During unconscious face processing, activation in MOG decreased under the face-selective attention compared with tool-selective attention. This result was in line with the predictive coding theory. During unconscious tool processing, however, activation in MOG increased under the tool-selective attention compared with face-selective attention. The different effects might be ascribed to an interaction between top-down category-selective processes and bottom-up processes in the partial awareness level as proposed by Kouider, De Gardelle, Sackur, and Dupoux (2010). Specifically, we suppose an "excessive activation" hypothesis.

1. Introduction

Understanding how top-down processes modulate bottom-up processes is a major challenge to reveal the mechanisms of adaptive perception processes in the brain. Based on much evidence, perception processes depend to a large degree on expectations derived from previous experience, and on generalized knowledge (Engel, Fries, & Singer, 2001). Gilbert and Sigman (2007) have advanced the concept of "brain states" to expand the conventional definition of top-down influences which are usually equated with attention (Gilbert & Sigman, 2007). They consider that the role of top-down influences is to set the cortex in a specific working state according to behavioral requirements.

Various previous studies demonstrated that even early visual processes can be modulated by top-down processes across a wide range of experimental paradigms (Rauss, Schwartz, & Pourtois, 2011). For example, Mechelli, Price, Noppeney, and Friston (2003), Mechelli, Price, Friston, and Ishai (2004) used the method of Dynamic Causal Modelling (DCM) and found that supraliminal category-selective (faces, houses and chairs) activations in extrastriate cortex are mediated both by bottom-up connections from early visual areas and by top-down connections from prefrontal cortex (Mechelli, Price, Friston, & Ishai, 2004; Mechelli, Price, Noppeney, & Friston, 2003). In addition, some studies showed that attentional load could modify activity in regions of the visual cortex (Kelley & Lavie, 2011; Rauss, Pourtois, Vuilleumier, & Schwartz, 2009). Other studies

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revealed that conscious visual perception is modulated by spatial attention (Gandhi, Heeger, & Boynton, 1999), feature-selective attention (Müller et al., 2006), and category-selective attention (Gazzaley, Cooney, McEvoy, Knight, & D'esposito, 2005). Moreover, in animal experiments, results showed that top-down processes could modulate the early cortical activity of sensory processes (Ito & Gilbert, 1999; Li, Pi ch, & Gilbert, 2004). Even in the absence of visual stimuli, activity in the visual cortex could be modulated by attention (Kastner, Pinsk, De Weerd, Desimone, & Ungerleider, 1999).

Besides the evidences of top-down effects on supraliminal processes, it is an important aspect to understand whether top-down processes can modulate unconscious processes to understand the mechanisms of perception, because we often process the majority of sensory information without consciousness. In addition, because unconscious stimuli can exert effects on motivation (Custers & Aarts, 2010), experience of control (Linser & Goschke, 2007), semantic processing (Dehaene et al., 2001), emotional processing (Luo et al., 2004; Whalen et al., 1998), cognitive control (Lau & Passingham, 2007; van Gaal, Ridderinkhof, Scholte, & Lamme, 2010), and object recognition (Stoerig & Cowey, 1997), top-down effects on unconscious processes might modulate these unconscious influences. In fact, some studies have revealed that unconscious (prime) processes are modulated by conscious top-down factors. For example, spatial attention can influence sensorimotor processes that are entirely separated from conscious perception (Sumner, Tsai, Yu, & Nachev, 2006) and unconscious letter prime effects (Marzouki, Grainger, & Theeuwes, 2007). There is also evidence showing that the effect of unconscious masked priming depends on temporal attention (Kiefer & Brendel, 2006; Naccache, Blandin, & Dehaene, 2002). Using fMRI and a continuous flash suppression paradigm, Bahrami, Lavie, and Rees (2007) observed reduced V1 activity under high attentional load even for invisible stimuli compared with that under low attentional load (Bahrami et al., 2007). Moreover, recent studies measuring event-related brain potentials demonstrated selective top-down influence of task sets on subliminal semantic processing and motor response selection (Kiefer & Martens, 2010; Martens, Ansorge, & Kiefer, 2011).

However, there is little research about how category-selective attention could modulate unconscious visual processes. Category-selective attention is based on discrimination and categorization of features of all the objects around us. Studies showed that feature-based attention is different from other attentional processes such as spatial attention (Kanai, Tsuchiya, & Verstraten, 2006; McMains, Fehd, Emmanouil, & Kastner, 2007). Combined with the evidence that early visual processes can be modulated by top-down factors, in the present study, we aimed at testing the hypothesis that the activity in the early visual cortex elicited by unconsciously perceived categories of pictures (i.e. faces and tools) might be selectively modulated by top-down processes of different types of category cues ("face" and "tool"). Specifically, according to the predictive coding theory (Rao & Ballard, 1999), we postulated that activity in the early visual cortex would decrease under congruent conditions (unconscious pictures with same type of category cues) compared with incongruent conditions (unconscious pictures with different type of category cues).

Furthermore, Kouider et al. assume that the representations at each processing level could be accessed independently from each other and advocated the concept of "partial awareness" (Kouider et al., 2010). In our experiment, the masked tools underlay partial awareness at a low processing level. The participants could sense the changes in contour and orientation of tool pictures but they were unable to recognize them. Therefore, we additionally analyzed the effect of category-selective top-down modulation on unrecognized masked tools with partial awareness.

2. Materials and methods

2.1. Participants

As paid volunteers, 21 adults (10 women, 11 men) aged 18–26 years (mean age 22.7 years) from Southwest University in China participated in this experiment. All participants gave written informed consent, were right-handed, had no history of current or past neurological or psychiatric illness, and had normal or corrected-to-normal vision. This study has been approved by the IRB at Southwest China University. Informed consent was obtained from each participant after the nature of the study was explained.

2.2. Stimuli

A sample consisting of 40 images of neutral facial expressions (20 females, 20 males) from the Chinese Facial Affective Picture System (Luo, Huang, Li, & Li, 2006), 40 pictures of tools and 20 pictures of other categories (e.g. animals, fruits) from the Internet served as stimuli. The mean valence and arousal for neutral faces were 4.31 (SD, 0.58) and 3.61 (SD, 0.51), respectively. In the formal experiment, the pictures were displayed centrally on a uniform gray background (RGB = 192, 192, 192) and subtended approximately 4.3 (height) $\times$ 3.8 (width) degrees of visual angle.

2.3. Procedure

The task programming, stimulus delivery, and recording of behavioral responses were carried out with E-prime 2.0 Software (Psychology Software Tools, Inc. http://www.pstnet.com). Stimuli were displayed on a back-projection screen placed at the back of the scanner bore, which was viewed by the participants via a mirror attached to the head-coil. Manual responses were recorded using an MRI-compatible button box.