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Cross-modal prediction changes the timing of conscious access during the motion-induced blindness

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ABSTRACT

Despite accumulating evidence that perceptual predictions influence perceptual content, the relations between these predictions and conscious contents remain unclear, especially for cross-modal predictions. We examined whether predictions of visual events by auditory cues can facilitate conscious access to the visual stimuli. We trained participants to learn associations between auditory cues and colour changes. We then asked whether congruency between auditory cues and target colours would speed access to consciousness. We did this by rendering a visual target subjectively invisible using motion-induced blindness and then gradually changing its colour while presenting congruent or incongruent auditory cues. Results showed that the visual target gained access to consciousness faster in congruent than in incongruent trials; control experiments excluded potentially confounding effects of attention and motor response. The expectation effect was gradually established over blocks suggesting a role for extensive training. Overall, our findings show that predictions learned through cross-modal training can facilitate conscious access to visual stimuli.

1. Introduction

The increasingly influential framework of 'predictive processing' (PP) posits that the brain continuously generates and updates predictions about incoming sensory signals (Clark, 2012; Friston, 2005; Hohwy, 2013; Seth, 2014) according to principles of Bayesian inference. Accumulating empirical evidence suggests that perceptual predictions or expectations strongly influence conscious perception. For example the perceptual hysteresis effect shows that prior knowledge can enhance and stabilise conscious perception: previously perceived stimuli can bias conscious perception to represent subsequent stimuli in the same form (Hock, Scott, & Schöner, 1993; Kanai & Verstraten, 2005; Kleinschmidt, Büchel, Hutton, Friston, & Frackowiak, 2002; Williams, Phillips, & Sekuler, 1986). Recent evidence also suggests that prediction facilitates conscious access. Melloni and colleagues showed that thresholds of subjective visibility for previously seen degraded targets were lower than for novel degraded targets, with changes in threshold accompanied by a shift in a neurophysiological signature of conscious awareness to an earlier time point (Melloni, Schwiedrzik, Müller, Rodriguez, & Singer, 2011). Similarly Lupyan and Ward (2013) found that visually presented objects preceded by congruent auditory cues

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(spoken words) were faster to break through continuous flash suppression than those preceded by incongruent cues. These results, and others, collectively suggest that prior knowledge can enhance and accelerate conscious access.

In the current study, we were interested in how the learning of prior expectations changes the timing of conscious access. Specifically, we asked how training of cross-modal perceptual associations influences the speed of conscious access for predicted and unpredicted events. We intensively trained participants to learn a cross-modal predictive relationship between an auditory tone and a colour change of a visual target, and we tested in separate experimental sessions how the learned predictive association affected the timing of conscious access of the visual target. Training phases and test phases were interleaved in order to explore the temporal nature of the influence of cross-modal perceptual predictions on conscious access.

To precisely measure the timing of conscious access in the test phases, we employed the well-known motion-induced blindness (MIB) paradigm (Bonneh, Cooperman, & Sagi, 2001). In MIB, a peripheral visual target disappears and reappears from awareness periodically when it is presented superimposed on a rotating background pattern. Because disappearances and reappearances are clear-cut in MIB (as compared to, for instance, binocular rivalry), participants can reliably report the timing of conscious access to the target. Previous research using MIB has shown that subjectively unseen visual information can still be integrated and updated to form new object representations unconsciously (Mitroff & Scholl, 2005). More recently, Wu and colleagues demonstrated that a transient visual change (a flashed ring) can influence the timing of conscious access of an unseen target (Wu, Busch, Fabre-Thorpe, & VanRullen, 2009). These findings speak to the persistence of representations of target stimuli during periods of subjective invisibility during MIB. We hypothesised that conscious access to such representations could be influenced by cross-modal cues if strong associations were formed via extensive training. To test this, we delivered an auditory cue while visual target was rendered subjectively invisible via MIB, and we then gradually changed the colour of the target to assess how the congruency between the cue and the visual sensory event influenced the timing of subjective target reappearance. Timing was compared with that from control trials in which the target was physically removed. In this way, we were able to quantify the effects of prediction on awareness and while minimizing the impact of other cognitive process such as attention and response bias.

2. Methods

2.1. Participants

Participants were 26 healthy students from the University of Sussex (7 male, 18–31 years; mean age 23.15 years, normal or corrected-to-normal vision). All of them provided informed consent before the experiment and received £15 or course credits as compensation. Two participants were excluded from data analysis because they misunderstood the instructions as to key responses. The experiment was approved by the University of Sussex ethics committee.

2.2. Stimuli and procedure

Stimuli were generated using the Psychophysics toolbox (Brainard, 1997) and all visual stimuli were presented on a Dell Trinitron CRT calibrated display (resolution 1048 × 768; refresh rate 100 Hz) with a black background. Participants sat 50 cm away from the monitor. A linearized colour lookup table was used for gamma correction ($\gamma = 2.2$).

Participants took part in a total of 4 training blocks and 4 MIB (testing) blocks across two consecutive days. As shown in Fig. 1, each participant completed four interleaved training and MIB block on each day as follows: (i) Training (200 trials); (ii) MIB (90 trials); (iii) Training (100 trials); (iv) MIB (90 trials).

2.2.1. The training procedure

At the beginning of a training trial, participants were presented with a white fixation point and a blue target stimulus (Fig. 2). The fixation point and the target were both circular dots subtending 0.2° of visual angle. The fixation was presented at the centre of the screen and the target was to the upper-left of the fixation at 5.4° of visual angle. Participants were instructed to maintain their gaze at the central fixation point and to pay attention to the peripheral target during the entire trial. Following a delay (drawn from a random uniform distribution of 1–2 s) an auditory cue (500 Hz or 1000 Hz pure tone) was presented for 300 ms. One second following the auditory cue onset, the target changed its colour (instantaneously) from its initial blue to either red or green. Crucially, the pitch of the auditory cue predicted the colour change with 80% validity. For example, after the 500 Hz tone there was an 80% chance of a blue-to-red colour change and a 20% chance of a blue-to-green change. In this *training* task, participants were required to indicate the new colour of the target by pressing key '.>' (with the right index finger) or '/?' (with the right middle finger) as accurately and fast as possible. Feedback was presented on the screen after each correct and incorrect trial. The probability mapping between the cue and the colour change of the target, and the mapping between the colour changes and the response keys, were counterbalanced between participants.

2.2.2. The MIB procedure

In the MIB blocks (Fig. 3a and b), each trial also started with a central fixation point and a peripheral target. To induce MIB of the peripheral target, we presented a rotating pattern consisting of an array of 64 (8 × 8) grey crosses occupying