Consciousness and Cognition 51 (2017) 236–242

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

Prior expectations modulate unconscious evidence accumulation

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A B S T R A C T

Unconscious processes have been shown to affect both perception and behaviour. However, the flexibility of such processes remains unknown. Here we investigate whether unconscious decisional processes can adapt to the utility of sensory information. To this end, we had participants gradually accumulate information from noisy motion stimuli, until a decision was reached. We titrated conscious awareness of these stimuli by simultaneously presenting a dynamic dichoptic mask. Crucially, we manipulated the likelihood that the suppressed portion of each presentation would contain useful information. Our results show that the statistics of the environment can be used to modulate unconscious evidence accumulation, resulting in faster choices. Furthermore, computational modelling revealed that this modulation is due to a change in the quality of unconscious evidence accumulation, rather than a conscious change in strategy. Together, these results indicate that unconscious decisional mechanisms are capable of optimising performance by flexibly adapting to the statistical environment.

1. Introduction

While for many years the existence of unconscious processing was the subject of intense debate (Eriksen, 1960; Holender, 1986; Merikle & Daneman, 1998), today it is generally accepted that unconscious processes can affect both our perception and behaviour (Kouider & Dehaene, 2007; Van den Bussche, Van den Noortgate, & Reynvoet, 2009). Furthermore, recent evidence suggests that information can be accumulated in the absence of conscious awareness and be used to improve decision-making (Vlassova, Donkin, & Pearson, 2014). However, the nature of these unconscious decisional mechanisms remains unclear. In particular, the extent to which these mechanisms can engender flexible adaptive behaviour in the absence of awareness remains unknown.

Our ability to flexibly adapt to the current state of the world allows us to modify our behaviour to optimise performance. Previous studies have demonstrated that prior experiences and expectations can influence subsequently made choices (e.g. de Lange, Rahnev, Donner, & Lau, 2013; Mulder, Wagenmakers, Ratcliff, Boekel, & Forstmann, 2012; for a review see Summerfield & de Lange, 2014). Such context-driven effects have also been shown to occur in the absence of awareness. For example, the magnitude of unconscious perceptual priming effects has been found to depend on the likelihood that stimuli masked from visual awareness contain useful information (Bodner & Masson, 2001, 2003; Bodner, Masson, & Richard, 2006; Jaśkowski, Skalska, & Verleger, 2003; Kinoshita, Mozer, & Forster, 2011). However, it remains unclear whether the statistics of the environment can exert a similar influence on unconscious decisional processing. If the environmental statistics dictate that the unconscious content is likely to contain valuable decision-relevant information, are we more likely to utilise this information? Likewise, when the unconscious content has no utility, are we able to ignore or discount it?

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http://dx.doi.org/10.1016/j.concog.2017.04.001
Received 29 December 2016; Received in revised form 20 March 2017; Accepted 3 April 2017
1053-8100/

Here, we address these questions by investigating whether the statistics of the environment in which decisions are made can bias the unconscious accumulation of evidence. Using the dichoptic suppression paradigm developed by Vlassova et al. (2014), we were able to titrate perceptual awareness of random-dot kinematograms. This paradigm allows us to investigate how the accumulation of evidence in the absence of visual awareness can affect our perceptual decision-making. Subjects were asked to make decisions about the direction of motion in these partially suppressed stimuli: the first 400 ms of each trial was suppressed from conscious awareness and was immediately followed by an additional 300 ms of unmasked visible motion. We induced decisional expectations by presenting the stimuli in two contexts: in one, the motion direction in the suppressed portion of the trial was more likely to be congruent with the motion direction of the visible portion. In a second context, the suppressed motion stimulus was more likely to contain purely random motion.

We modelled participants' performance using a drift diffusion model (Ratcliff, 1978), according to which decisions are made by the gradual accumulation of evidence over time, until such a point when the amount of information in favour of a particular choice has reached a decision threshold and a response is obtained. This allowed us to disentangle the different mechanisms driving the decisional process, such as differentiating between changes in performance driven by changes in the rate of evidence accumulation or changes driven by strategic shifts of the decision threshold. Our results indicate that the statistical context in which decisions are made can modulate the rate at which unconscious information is accumulated. Our results therefore highlight that our perceptual decision-making processes can flexibly adapt the rate of unconscious accumulation in line with the potential utility of incoming sensory information.

2. Materials and methods

2.1. Participants

19 participants (7 male; 18–33 years of age) were prescreened for inclusion in this experiment. 5 participants were excluded because they could not identify the catch trials above 90% correct, while an additional 3 participants were excluded because they reported seeing the suppressed grey dots (suppression breaks) on more than 20% of the trials (see Section 2.4). A further 3 participants were removed as they were responding before the stimulus presentation had finished and a technical issue prevented us from recording these responses accurately. Finally, one participant was excluded for being unable to perform the task (performance on the motion discrimination task remained at chance throughout 7 days of training). This left us with 7 participants (2 male; 18–33 years of age), all of whom were able to accurately report the catch trials (M = 96.65%, SD = 1.54) and who had minimal suppression breaks (M = 5.78%, SD = 5.40). All participants had normal or corrected-to-normal vision, and provided informed written consent. Participants were compensated for their time at a rate of 10€ per hour, for 7 total hours completed over 7 days of testing.

2.2. Apparatus

Participants were seated in a dark room on a height-adjustable chair at a distance of 43 cm from a BenQ XL2420-B LCD screen, with a resolution of 1657 × 932 and a refresh rate of 75 Hz. Participants' heads were stabilised using a chin and headrest housing a mirror stereoscope apparatus adjusted for each subject. This stereoscope uses circular mirrors to display images presented on the screen separately to each eye, which perceptually overlap one another to form a single image when viewed binocularly. Stimuli were presented using MATLAB (R2012b) Psychophysics Toolbox 3 (Brainard, 1997; Pelli, 1997), on a HP 2400 Workstation machine running Windows 7 Professional (SP1).

2.3. Stimuli

The motion stimuli used in this study were random dot kinematogram (RDK) displays, which are commonly used in research in perceptual decision-making (for a review see: Smith & Ratcliff, 2004). The RDK stimulus parameters were set to those previously reported in Vlassova et al. (2014), as follows: 100 grey dots (21 cd/m^2) were displayed within an invisible 8.2° circular aperture, with a central 0.7° fixation point. Participants were instructed to fixate on this point throughout the experimental sessions in order to facilitate fusion. Each dot was a 1 × 1 pixel square and moved at a speed of 6.1° per second. Dots were presented on a black background at a density of 1.9 dots/deg^2. In order to conserve dot density, dots that moved along a trajectory that would place them outside of the circular aperture were wrapped around to the opposite side and maintained their original motion direction. Three uncorrelated random sequences of dot movement were generated, and frames were interleaved so that each coherent dot was only correlated with dots three frames forwards or backwards and not the subsequent frame (Roitman & Shadlen, 2002; Shadlen & Newsome, 2001). That is, coherent dots were first displayed for one frame, and then three frames later they were displaced by 0.25° in the direction of the overall coherent motion, while remaining dots were replotted randomly. In this way, coherently moving dots could not be individually tracked over time.

During suppressed trials, RDK dots were suppressed from conscious awareness using a dynamic dichoptic mask configuration that has been previously shown to effectively suppress dot-motion stimuli from conscious awareness for durations up to 500 ms (Vlassova et al., 2014). The mask consisted of 350 green dots (58.5 cd/m^2), each a 1 × 1 pixel. Mask dots were displayed within an invisible 9.8° circular aperture, around a central 0.7° fixation point, with an average dot density of 3.3 dots/deg^2. During the visible trials, RDK dots were rendered visible by changing the mask to 25 green dots, resulting in an average dot density of 0.24 dots/deg^2. The dots moved concentrically around the central fixation point (clockwise) at a rate of 1.67 revolutions per second, and were presented on every third frame only. The ocular dominance of each participant was assessed using a simple pointing test, and in order to facilitate suppression of the RDK stimulus, the mask stimulus was presented to each participant's dominant eye.