Consciousness and Cognition 35 (2015) 53–65

Contents lists available at ScienceDirect

Consciousness and Cognition

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

Prior expectations facilitate metacognition for perceptual decision

M.T. Sherman [a,b,*], A.K. Seth [b,c], A.B. Barrett [b,c], R. Kanai [a,b]

[a] School of Psychology, University of Sussex, Falmer BN1 9QH, UK
[b] Sackler Centre for Consciousness Science, University of Sussex, Falmer BN1 9QJ, UK
[c] Department of Informatics, University of Sussex, Falmer BN1 9QJ, UK

ARTICLE INFO

Article history:
Received 27 May 2014
Available online 16 May 2015

Keywords:
Metacognition
Expectation
Decision making
Perceptual confidence
Attention

ABSTRACT

The influential framework of 'predictive processing' suggests that prior probabilistic expectations influence, or even constitute, perceptual contents. This notion is evidenced by the facilitation of low-level perceptual processing by expectations. However, whether expectations can facilitate high-level components of perception remains unclear. We addressed this question by considering the influence of expectations on perceptual metacognition. To isolate the effects of expectation from those of attention we used a novel factorial design: expectation was manipulated by changing the probability that a Gabor target would be presented; attention was manipulated by instructing participants to perform or ignore a concurrent visual search task. We found that, independently of attention, metacognition improved when yes/no responses were congruent with expectations of target presence/absence. Results were modeled under a novel Bayesian signal detection theoretic framework which integrates bottom-up signal propagation with top-down influences, to provide a unified description of the mechanisms underlying perceptual decision and metacognition.

1. Introduction

Metacognition, or 'cognition about cognition', reflects the knowledge we have of our own decision accuracy and comprises an important, high-level component of decision making in both perceptual and cognitive settings. In perceptual decision, metacognition is often operationalized as the trial-by-trial correspondence between (objective) decision accuracy and (subjective) confidence. A key question in perceptual metacognition is how, and indeed whether, metacognition is affected by top-down influences such as attention and expectation. In the case of attention, it has long been known that it can improve visual target detection (Posner, 1980). However, the relationship between attention, confidence, and metacognition remains unclear. While Kanai and colleagues found that perceptual metacognition persists when attention is diverted (Kanai, Walsh, & Tseng, 2010), other studies suggest that the absence of attention can lead to overconfidence (Rahnev et al., 2011; Wilimzig & Fahle, 2008).

Inspired by the growing influence of 'predictive processing' or 'Bayesian brain' approaches to perception and cognition (for reviews, see Clark, 2013; Summerfield & de Lange, 2014), empirical work on top-down attention is now complemented by a growing focus on the role of top-down expectations in decision making. In Bayesian terms, expectations can be

* Corresponding author at: School of Psychology, Pevensey Building, University of Sussex, Falmer BN1 9QH, UK.
E-mail address: M.Sherman@Sussex.ac.uk (M.T. Sherman).

http://dx.doi.org/10.1016/j.concog.2015.04.015
1053-8100/

conceived as prior beliefs that constrain the interpretation of sensory evidence. It has been shown that prior knowledge, either of stimulus timing ('when') or of stimulus features ('what'), facilitates low-level processing, as reflected in measures such as reaction time (Stefanics et al., 2010) and contrast sensitivity (Wyart, Nobre, & Summerfield, 2012). Such improvements are often accompanied by the attenuation of both the BOLD responses and ERP amplitude following expected relative to unexpected perceptual events (Egner, Monti, & Summerfield, 2010; Melloni, Schwiedrzik, Müller, Rodriguez, & Singer, 2011; Wacongne et al., 2011). As well as facilitating low-level perception, expectations may influence conscious content. This idea is supported by evidence for expectations inducing subjective directionality in ambiguous motion (Sterzer, Frith, & Petrovic, 2008) and lowering the threshold of subjective visibility for previously seen versus novel visual stimuli (Melloni et al., 2011). These effects are similar to those exerted by top-down attention. However, while it has been argued that attention and expectation reflect similar processes (Desimone & Duncan, 1995; Duncan, 2006), orthogonal manipulations of attention and expectation have demonstrated that, although they are tightly intertwined, they can have separable effects on neural activity (Hsu, Hämäläinen, & Waszak, 2014; Jiang, Summerfield, & Egner, 2013; Kok, Rahnev, Jehee, Lau, & de Lange, 2012; Wyart et al., 2012).

One influential process theory within the Bayesian brain framework is predictive coding (Beck et al., 2008; Clark, 2013; Friston, 2009; Hohwy, 2013; Lee & Mumford, 2003). Predictive coding also posits that efficient processing is achieved by constraining perceptual inference according to the prior likelihood of that inference ('expectations'). Here, the predictive models underlying perception are generally assumed to be multilevel and hierarchical in nature (Clark, 2013; Friston, Adams, Perrinet, & Breakspear, 2012), incorporating priors related both to low-level stimulus features, and to high-level features representing object-level invariances. Plausibly, priors concerning subjective confidence for perceptual decisions may be implemented at high levels of the hierarchy. Based on this possibility, we set out to investigate whether the top-down influences of attention and prior expectation modulate perceptual metacognition.

To address whether expectation can improve metacognition we orthogonally manipulated both attention and expectation. This separated their effects, and was achieved by adopting a dual-task design. In a Gabor detection task, expectations were manipulated by informing participants of the probability of Gabor presence or absence as it changed over blocks. In this way, certain blocks induced an expectation of Gabor presence and others, of absence. In half of the blocks, participants were instructed to additionally perform a concurrent visual search task that diverted attention away from the detection task.

Objective performance can be assessed by using type 1 signal detection theory (SDT). By comparing signal type (e.g. present, absent) and response (present, absent), type 1 SDT enables a computation of independent measures of objective sensitivity and decision threshold (d' and c, respectively). We used type 2 SDT to assess metacognitive sensitivity. By obtaining trial-by-trial retrospective confidence ratings, metacognitive sensitivity and confidence thresholds can be computed from response accuracy and decision confidence. We used two such methods – type 2 D', which is a direct analogue of type 1 d' (Kunimoto, Miller, & Pashler, 2001), and meta-d' (see Section 2.5.2 or Barrett, Dienes, & Seth, 2013; Maniscalco & Lau, 2012; Rounis, Maniscalco, Rothwell, Passingham, & Lau, 2010). Given that prior expectations have been shown to facilitate low-level processing, we hypothesized that expectations would also improve metacognitive sensitivity. We tested this hypothesis by considering the congruency between participants' yes/no decision and the block-wise expectation of Gabor presence or absence. Specifically, we hypothesized that metacognitive sensitivity would be greater following expectation-congruent type 1 decisions (e.g. reporting target presence when expecting target presence), than following expectation-incongruent decisions (e.g. reporting presence when expecting absence).

2. Methods

2.1. Participants

Twenty-one participants (14 female) completed the experiment. All were healthy students from the University of Sussex, aged 18 to 31 ($M = 20.4$, $SD = 3.2$) and had normal or corrected-to-normal vision. The sample size for adequate power was computed using GPower 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007), with estimated effect sizes derived from pilot studies. Data from one participant were excluded because their visual search task performance deviated by more than 1.5 *SD* from the mean (98.6% correct) and another, for having no variability in their confidence reports (100% confident). This left data from 19 participants for analysis, all of whom demonstrated, averaging over conditions, a Gabor detection d' and visual search accuracy that was within 1.5 *SD* from the mean. Participants were offered course credits for participating and informed, written consent was obtained. The experiment was approved by the University of Sussex ethics committee.

2.2. Stimuli and setup

Stimuli were generated using the Psychophysics toolbox for Matlab (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007) and presented on a 20 inch Dell Trinitron CRT display (resolution 1048×768; refresh rate 85 Hz). Participants were tested individually in darkened rooms and were seated 60 cm away from the screen. Both stimuli and background were linearized using a Minolta LS-100 photometer ($\gamma = 2.23607$, Weibull fit). The background was grayscale and uniform.