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Perceptual learning effect on decision and confidence thresholds

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ABSTRACT

Practice can enhance of perceptual sensitivity, a well-known phenomenon called perceptual learning. However, the effect of practice on subjective perception has received little attention. We approach this problem from a visual psychophysics and computational modeling perspective. In a sequence of visual search experiments, subjects significantly increased the ability to detect a "trained target". Before and after training, subjects performed two psychophysical protocols that parametrically vary the visibility of the "trained target": an attentional blink and a visual masking task. We found that confidence increased after learning only in the attentional blink task. Despite large differences in some observables and task settings, we identify common mechanisms for decision-making and confidence. Specifically, our behavioral results and computational model suggest that perceptual ability is independent of processing time, indicating that changes in early cortical representations are effective, and learning changes decision criteria to convey choice and confidence.

1. Introduction

Perceptual ability improves with practice, a well studied phenomenon known as perceptual learning (Goldstone, 1998; Kawato et al., 2014; Watanabe & Sasaki, 2015). Most studies in perceptual learning focus on objective visual perception, i.e. changes in task performance. However, the ability to discriminate visual stimuli is only the *objective* side of visual perception; every perceptual decision is also associated with subjective aspects, such as confidence. Although confidence and accuracy usually correlate, recent findings suggest that in some conditions the two may dissociate (Del Cul, Dehaene, Reyes, Bravo, & Slachevsky, 2009; Graziano & Sigman, 2009; Lau & Passingham, 2006, 2007; Rounis, Maniscalco, Rothwell, Passingham, & Lau, 2010; Zylberberg, Roelfsema, & Sigman, 2014). Moreover, it has long been suggested that confidence is related to subjective awareness (Peirce & Jastrow, 1884) whereas accuracy may only reflect processing capacity (Lau, 2008). Therefore, in order to create a complete picture of perceptual learning, it is important to understand the effect of

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practice on both visual discrimination performance and subjective confidence. Reciprocally, perceptual learning may be a good experimental vehicle to understand dissociations between choice and confidence in perceptual decisions.

Several studies have shown that subliminal and unattended presentation of stimuli can lead to learning when paired in time with an attention-capturing visible stimulus (Seitz, Lefebvre, Watanabe, & Jolicoeur, 2005; Seitz & Watanabe, 2003, 2005). However, the converse has been much less explored. How does learning affect subjective experience? Are subjective aspects of vision affected in the same way as objective performance? One notable exception is the study by Schwiedrzik, Singer, and Melloni (2011) in which subjects trained on a perceptual task improved sensitivity and subjective awareness on the *same* task for which they were trained. It remains unclear whether learning to identify a shape transfers to a *different* task setting and, whether objective and subjective aspects of perception share the same underlying mechanisms. Can practice in a visual discrimination task change confidence thresholds? Or, alternatively, changes in confidence are explained merely by an increase in signal strength? In this work, we designed an experiment to distinguish between these two alternatives. By measuring simultaneously confidence and choice in different tasks during an extensive learning period, we seek to understand the specific underlying mechanisms of practice on objective and subjective learning.

Our experiment is divided in three phases. During the learning phase, subjects were extensively trained in a visual search task, which involves identifying a shape among distractors (Sigman & Gilbert, 2000). Before and after training, subjects performed two well known protocols which parametrically vary the visibility of the trained target: the attentional blink task (Raymond, Shapiro, & Arnell, 1992) and a visual masking task (Breitmeyer, 1984; Enns & Di Lollo, 2000). Given that practice improves the ability to identify a trained shape, we empirically tested if this ability is transferred to a different task in which subjects need to detect the same target shape. In addition, we measured the specific effect of learning on confidence. Our main aim in this study is to compare the ability of different classes of signal detection theoretic models to account for the data and identify which aspects of the decision making process change with learning and whether those changes vary or not across tasks.

2. Materials and methods

2.1. Subjects and experimental design

A total of 7 subjects participated in this study (4 males, age 24.9 ± 2.1). All subjects gave written informed consent, were naïve about the aims of the experiment and reported normal or corrected-to-normal vision. Subjects performed several sessions of psychophysical tasks, as illustrated in Fig. 1A. Each session was performed on a different day. The sequence started with one session of the attentional blink (AB) task and one session of the visual masking (VM) task. Then, subjects entered the learning phase that consisted of several sessions of the same visual search task. Finally, subjects repeated one session of the AB and one session of VM tasks. One subject did not perform the AB task; he/she only completed the VM tasks, once before and once after the learning phase.

2.2. Stimuli

Visual stimuli were presented on a 19 in. monitor (Samsung Syncmaster 998 MB) at a viewing distance of 75 cm. Stimuli in all experiments were black on a uniform gray background.

2.3. Visual search task

Each trial consisted of a 1500 ms cycle, as illustrated in Fig. 1B. A 5×5 array consisting of a central fixation cross and 24 shapes in the remaining locations was presented for 200 ms. The array subtended $10.9° \times 10.9°$. During the subsequent 1300 ms inter-stimulus interval, the subject had to report whether or not a target shape was present by pressing the appropriate key on a computer keyboard. Each participant was trained to find a triangle of a certain orientation among an array of distractors (triangles of other orientations). Target and distractors were equilateral triangles on four different orientations (up, down, left, right) and 1.6° in size. On "target present" trials, the trained stimulus appeared in one randomly selected location within the array. In 20% of the trials the target was absent. Each session consisted of 8 blocks of 150 trials. Subjects performed training sessions until the percentage of correct responses within a session achieved 85%. Five subjects did 6 training sessions and two did 7 sessions. Three subjects were trained for left-, two for down-, and two for right-oriented triangles. Screen resolution was set to 1024×768 and the refresh rate, 85 Hz.

2.4. Attentional blink task

Each trial consisted on a rapid serial visual presentation of 18 stimuli, each one presented for 100 ms (Fig. 1C). The sequence started with 4–6 distractors followed by the first target (T1), a banana-shaped outline. A variable number of distractors (ND, from 0 to 7) separated T1 from the second target (T2), an equilateral triangle of the same shape and the same possible orientations as the triangles in the visual search task. Finally, enough distractors were added to complete