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Time course influences transfer of visual perceptual learning across spatial location

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Visual perceptual learning describes the improvement of visual perception with repeated practice. Previous research has established that the learning effects of perceptual training may be transferable to untrained stimulus attributes such as spatial location under certain circumstances. However, the mechanisms involved in transfer have not yet been fully elucidated. Here, we investigated the effect of altering training time course on the transferability of learning effects. Participants were trained on a motion direction discrimination task or a sinusoidal grating orientation discrimination task in a single visual hemifield. The 4000 training trials were either condensed into one day, or spread evenly across five training days. When participants were trained over a five-day period, there was transfer of learning to both the untrained visual hemifield and the untrained task. In contrast, when the same amount of training was condensed into a single day, participants did not show any transfer of learning. Thus, learning time course may influence the transferability of perceptual learning effects.

1. Introduction

Visual perceptual learning (VPL) describes the improvement in performance of a psychophysical task with repeated practice (Fahle & Poggio, 2002). Over recent years, the use of VPL to augment visual function, both in healthy individuals and in those with specific visual disorders, has increased considerably. In the healthy visual system, positive benefits of VPL have been documented for motion perception (Zhang & Yang, 2014), speed of visual processing (Lev et al., 2014), reading speed (Chung, Legge, & Cheung, 2004), visual acuity and contrast sensitivity (Deveau, Lovcik, & Seitz, 2014). In amblyopia a number of studies have shown an enhancement in stereoscopic vision (Astle, McGraw, & Webb, 2011; Ding & Levi, 2011), contrast sensitivity (Polat, Ma-Naim, Belkin, & Sagi, 2004), spatial and stereo acuity (Xi, Jia, Feng, Lu, & Huang, 2014) following extensive training. In patients with visual cortical damage, VPL may be used to boost residual visual function, either by recruiting neighbouring cortical tissue or by increasing visual activity in partially damaged pathways. Indeed, there have been initial reports of some visual recovery following extended VPL of around 3 months in such patients (Das, Tadin, & Huxlin, 2014; Henriksson, Raninen, Näsänen, Hyvärinen, & Vanni, 2007; Huxlin et al., 2009; Sahraie et al., 2006, 2010). However, an effective short-term protocol would make such treatments more attractive as long-term training requires significant commitment and effort on behalf of the patient.

The transferability of visual improvements following VPL remains the subject of considerable debate. Initially, VPL was considered specific to the trained task, and not transferable to untrained retinal locations (Karni & Sagi, 1991), stimulus orientations (Poggio, Fahle, & Edelman, 1992) or other parameters (Ahissar & Hochstein, 1993; Fahle & Morgan, 1996; Fiorentini & Berardi, 1980). However, more recent work suggests that learning can be transferred spatially (Xiao et al., 2008) and across stimulus parameters (Liu, 1999) and tasks (McGovern, Webb, & Peirce, 2012).

Under a 'double training' paradigm, when separate areas of the visual field are trained on different tasks in an interleaved manner, it has been shown that there can be transfer of learning to an untrained location, indicating a lack of spatial specificity (Mastropasqua, Galliussi, Pascucci, & Turatto, 2015; Xiao et al., 2008). Furthermore, simultaneous or subsequent passive exposure to untrained stimulus attributes (such as an untrained motion direction) may induce transfer of learning across such parameters in the trained part of the visual field (Zhang et al., 2010; Zhang & Yang, 2014). Easier tasks are more likely to show transfer of learn-

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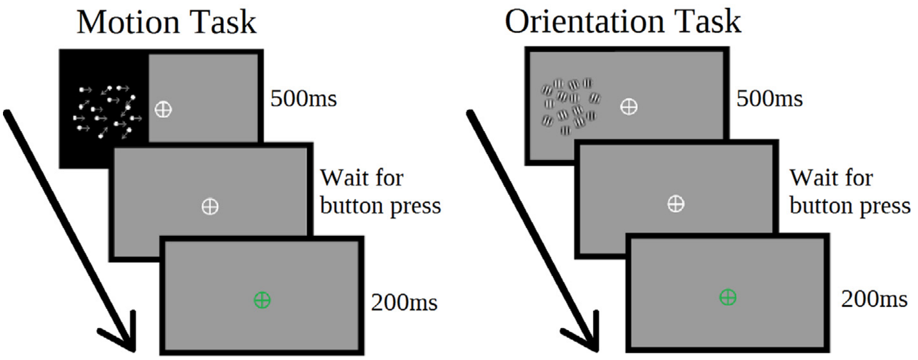

Fig. 1. The motion task (left) and the orientation task (right). Participants were shown the stimulus on one side of the screen for 500 ms. The stimulus then disappeared and the program paused until the subject gave their response. The fixation cross then flashed green or red for 200 ms to indicate a correct or incorrect response for the trial. The next trial then began immediately.

ing across stimulus parameters, such as motion direction (Liu, 1999) and orientation (Wang, Zhou, & Liu, 2013); this transfer effect has been shown to disappear if the training task is very difficult (Hung & Seitz, 2014). When the basic stimulus elements are comparable across tasks, perceptual learning can transfer even to unrelated tasks (McGovern et al., 2012). The type of learning demanded by a task is influential in determining the extent of transfer. For instance, if a task encourages learning of stimulus-specific rules then learning is likely to be less transferable compared to a task that encourages learning of rules that are generalisable to different stimuli (Green, Kattner, Siegel, Kersten, & Schrater, 2015). Increasing the amount of training has been shown to increase the specificity of perceptual learning effects across visual location and stimulus parameters (Jeter, Dosher, Li, & Lu, 2010; Mastropasqua & Turatto, 2015), likely due to sensory adaptation (Harris, Gliksberg, & Sagi, 2012).

Other factors, such as time course of learning, have not yet been fully investigated for their impact on the transferability of perceptual learning effects. A study looking at the effect of a foveal hyperacuity task found that when training of was delivered across two days, there was no transfer of learning to a similar untrained stimulus presented in the same retinal location. However, when an equivalent amount of training was delivered spread across four weeks, participants showed improvement of the untrained stimulus. This result indicated that increasing the time course across which training was delivered may increase the transfer of perceptual learning effects to similar, untrained stimuli (Aberg, Tartaglia, & Herzog, 2009). Here, we aimed to quantify the extent to which the effects of a simple five-day training protocol are transferred across spatial location (hemifield) and different stimulus elements (moving dots compared to sinusoidal gratings), when compared to a one-day training protocol.

2. Methods

2.1. Participants

Forty-four subjects (21 female and 23 male; M = 23.2 years; SD = 3.89 years) with normal or corrected-to-normal vision were included in the study. All were naïve to visual psychophysical experiments. The study was approved by the local InterDivisional Research Ethics Committee (IDREC) at the University of Oxford and all subjects gave written, informed consent. Research was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). 22 participants were assigned to a motion coherence training protocol (“motion training group”) and the remaining 22 to a sinusoidal grating orientation training protocol (“orientation training group”). In each of the two groups, 12 subjects participated in a training protocol lasting for one day (“one-day group”) and the remaining 10 participated in a training protocol lasting for five days (“five-day group”).

2.2. Experimental setup

Visual stimuli were programmed using Processing Java v2.0b6 (MIT) and Matlab (vR2012a) with Psychtoolbox, and were presented on a CRT monitor (ViewSonic E70fSB, 1280 × 1024 pixel resolution, 75 Hz refresh rate, 17-inch display) in a darkened room. Participants were positioned 57 cm from the screen and used a chin-rest to minimise head movements.

2.3. Visual stimuli and tasks

Two tasks were used in this project: a motion direction discrimination task and a sinusoidal grating orientation discrimination task, abbreviated as “motion task” and “orientation task” respectively. For the motion task (Fig. 1), participants identified whether a group of white coherently-moving dots (luminance 96.8 cd/m^2) had leftwards or rightwards motion, when displayed amongst randomly-moving distractor dots (“noise”) on a black background (luminance = 0.92 cd/m^2). Moving dots (n = 200) were presented within a circular area 13° in diameter centred 9° to the left or right of fixation (the edge of the stimulus aperture was 2.5° from fixation). The dot diameter was 0.15°, and they moved with a speed of 6°/s for a limited lifetime of 200 ms (12 frames), at a density of 1.5 dots/degree^2. Dots were born or reborn at random, non-overlapping locations within the stimulus aperture. Coherent motion direction was variable but restricted to within a 90° angle centred around the horizontal meridian. A high contrast stimulus was applied so it was more salient and easily detectable by the visual system.

For the orientation task (Fig. 1), participants identified whether the net orientation of sinusoidal gratings was vertically- or horizontally-oriented, when a proportion of the patches were oriented randomly (“noise”). Sinusoidal gratings (n = 50) were presented within a circular area 13° in diameter centred 9° to the left or right of fixation (the edge was 2.5° from fixation). Sinusoidal grating diameter was 1° and spatial frequency was 5 cycles/°. Gratings were 90% contrast, calculated using Michelson contrast with maximum luminance of 96.8 cd/m^2 and minimum luminance of 5.1 cd/m^2.

Feedback for both tasks was provided visually on a trial-by-trial basis. Tasks were self-paced, where after the 500 ms stimulus presentation, the program paused until user input was detected. It was emphasised that accuracy was more important than speed.