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The effect of spatial frequency on perceptual learning of inverted faces

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ABSTRACT

We investigated the efficacy of training adults to recognize full spectrum inverted faces presented with different viewpoints. To examine the role of different spatial frequencies in any learning, we also used high-pass filtered faces that preserved featural information and low-pass filtered faces that severely reduced that featural information. Although all groups got faster over the 2 days of training, there was more improvement in accuracy for the group exposed to full spectrum faces than in the two groups exposed to filtered faces, both of which improved more modestly and only when the same faces were shown on the 2 days of training. For the group exposed to the full spectrum range and, to a lesser extent, for those exposed to high frequency faces, training generalized to a new set of full spectrum faces of a different size in a different task, but did not lead to evidence of holistic processing or improved sensitivity to feature shape or spacing in inverted faces. Overall these results demonstrate that only 2 h of practice in recognizing full-spectrum inverted faces presented from multiple points of view is sufficient to improve recognition of the trained faces and to generalize to novel instances. Perceptual learning also occurred for low and high frequency faces but to a smaller extent.

1. Introduction

Perceptual learning refers to an increase in the ability to extract information from the environment, as a result of practice and experience (Gibson, 1969; for other definitions see Ball & Sekuler, 1987; Fiorentini & Berardi, 1981; Schoups, Vogels, & Orban, 1995). It has been demonstrated for simple stimuli such as gratings (Ball & Sekuler, 1987; Fahle, Edelman, & Poggio, 1995; Fiorentini & Berardi, 1981; Karni & Sagi, 1991; McKee & Westheimer, 1978; Poggio, Fahle, & Edelman, 1992; Schoups, Vogels, & Orban, 1995) and for complex visual stimuli such as shapes and objects (Furmanski & Engel, 2000; Gold, Bennett, & Sekuler, 1999; Rubin, Nakayama, & Shapley, 1997; Sigman & Gilbert, 2000; Yi, Olson, & Chun, 2006). Improvement is often specific to the stimuli used during training (for reviews, see Levi & Li, 2009; Sagi & Tanne, 1994). For example, practice with feedback improves accuracy on a spatial frequency discrimination task, but changing the spatial frequency of the target by an octave, or its orientation by 90° abolished these effects (Fiorentini & Berardi, 1981). Specificity was also found after training on the discrimination of the direction of motion, on the perception of contour, and on figure-ground segmentation (Ball & Sekuler, 1987; Fiorentini & Berardi, 1981; Rubin, Nakayama, & Shapley, 1997; Sigman & Gilbert, 2000; Yi, Olson, & Chun, 2006). The results for more complex stimuli such as objects are mixed. Some authors found improvement restricted to the trained set of objects such as triangles of a particular size and orientation (Sigman & Gilbert, 2000) whereas others showed that improvement in recognition of common grey-scaled objects transferred almost completely across changes in image size (Furmanski & Engel, 2000).

Perceptual learning had also been used to explore the plasticity of domains in which adults have expertise, such as face processing. Practice with feedback over several days significantly improves accuracy for recognizing the identity of upright faces despite the fact that before training adults had had a lifetime of exposure to that category of stimuli (e.g., Dolan et al., 1997; Gold, Sekuler, & Bennett, 2004; Gold, Bennett, & Sekuler, 1999; Hussain, Sekuler, & Bennett, 2009a, 2009b). Recently, Hussain, Sekuler, and Bennett (2011) also showed that this improvement was maintained on retests approximately 1 year after training. The effects of training with upright faces have sometimes been found to transfer to novel faces (Jim/Anti-Jim, Bi et al., 2010; another twin picture, Robbins & McKone, 2003), and sometimes not (Hussain, Sekuler, & Bennett, 2009b, 2011). In contrast, the training effects do transfer to novel points of view (Dwyer et al., 2009), changed illumination (Moses, Ullman, & Edelman, 1995), and changes in size and visual field (Bi et al., 2010).

Adults' poorer processing of inverted faces than of upright faces (Yin, 1969) is typically attributed to limited exposure to this face category (e.g., Rossion, 2009). A few studies have examined whether increased exposure – through training – can improve adults' discrimination of inverted faces (Bi et al., 2010; Dwyer

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et al., 2009; Hussain, Sekuler, & Bennett, 2009b; Laguesse et al., 2012; Moses et al., 1995; Robbins & McKone, 2003). All demonstrated that training with inverted faces is effective but to a lesser extent than what is observed for upright faces when the latter were used for comparison (Bi et al., 2010; Dwyer et al., 2009; Hussain, Sekuler, & Bennett, 2009b; Moses et al., 1995; Robbins & McKone, 2003). From these studies, evidence of generalization to novel inverted faces is mixed: Hussain, Sekuler, and Bennett (2009b) found limited evidence for it while Laguesse et al. (2012) showed a significant decrease of the face inversion effect after training with inverted faces even though novel face identities were used at post-test. The authors attributed their success to the length of the challenging training they used (2 weeks), the large number of faces they presented during training (30 faces), the different depth-rotated views of the training faces and their inclusion of a pre-test and a of post-test composed of novel face identities.

In the present study, we also attempted to enhance the training effects for inverted faces by discouraging the learning of specific instances and instead encouraging the development of an effective processing strategy that could be generalized to new instances. Specifically, we trained one group of participants with multiple faces, each of which was presented from a number of points of view. In addition, we examined whether spatial frequency filtering influenced learning. To this end, we presented a second group of participants with high spatial frequency faces that emphasize the featural information that adults can use almost as efficiently in processing inverted as upright faces (e.g., Collishaw & Hole, 2000; Maurer, Le Grand, & Mondloch, 2002; Rossion, 2008, 2009) and a third group of participants with low spatial frequency faces that de-emphasize those features to encourage the use of more global information of the type that adults use efficiently for upright but not inverted faces (e.g., Goffaux & Rossion, 2006; Maurer, Le Grand, & Mondloch, 2002; Rossion, 2008, 2009). Although some studies showed that adults use the same mid-spatial frequencies to process upright and inverted faces (Boutet, Collin, & Faubert, 2003; Gaspar, Sekuler, & Bennett, 2008; Watier, Collin, & Boutet, 2010; Willenbockel et al., 2010), it has also been demonstrated that holistic/global face perception is supported by low spatial frequencies in adults (Goffaux & Rossion, 2006). Based on the latter evidence, we expected high-pass and low-pass filtering to selectively encourage the learning of featural or of holistic/configural strategies that might in turn affect differently the patterns of generalization.

The training paradigm was based on the short regime used by Hussain, Sekuler, and Bennett (2009b) to induce improvements with full-spectrum inverted faces. Specifically, participants were trained over 2 days to view a face then find it among 10 facial images. In order to test transfer of training, half the participants were trained with the same 10 faces on the second day of training, and half, with a set of 10 new faces. Unlike Hussain, Sekuler, and Bennett (2009b), the target face varied across 7 different viewpoints, while the choice faces were always presented in full-front view. This variation was introduced to encourage the learning of a general strategy, rather than specific images.

To further explore the extent of learning and its generalization to novel exemplars, participants were also tested before and after the 2 days of training on 4 tasks composed of full spectrum faces not used during training and of a different size than the trained faces: a simultaneous face matching task (Task 1), a delayed face matching task (Task 2), a composite task that measures holistic face processing (Task 3) and the Jane task that measures sensitivity to differences in the shape of features and their spacing (Task 4). Changes from pre-test to post-test in the trained groups were compared to those obtained from a control group that was tested twice at the same intervals but without intervening training. Based on the previous study by, Hussain, Sekuler, and Bennett (2009b) using the same training paradigm, we expected that generalization to novel instances of inverted faces would be unlikely (Task 1–Task 2). We also thought that any enhancement in holistic processing (Task 3), or in sensitivity to feature spacing (Task 4), would be most likely after training on low spatial frequency faces because of its emphasis on global processing and that any enhancement in featural processing (Task 4) would be most likely after training to high spatial frequency faces because of its emphasis on featural information.

1.1. Methods

1.1.1. Participants

The sample consisted of 64 participants between the ages of 18 and 30 years ($X = 21$; SD = 2.7) who participated either for remuneration or for credit in a psychology course. All had normal or corrected-to-normal vision. Specifically, their linear letter acuity (Lighthouse Visual Acuity Chart) was at least 20/20, they showed fusion at near on the Worth four-dot test and they had stereo acuity of at least 40 arcsec on the Titmus test. Sixteen participants were assigned to each of the 3 training groups and 16 to the control condition and not trained at all.

1.1.2. Procedure

The Research Ethics Board of McMaster University approved the study. Informed written consent was obtained from all participants prior to testing and they received a debriefing form at the end of the experiment. Participants came to the lab for 1 h on 4 consecutive days. On the first and last day, they completed the pre-test and post-test, respectively. On the second day and third day, except for the control group, they received training with feedback on inverted faces.

1.1.2.1. Pre-test and post-test. Participants were seated in a dark room 100 cm from a Dell Trinitron P1140 computer screen (51 cm diagonally) controlled either by a Mac Mini running on OSX 10.4.2 (Tasks 1 and 2) or a PowerMac G4 cube running on OS.9.2.1 (Tasks 3 and 4). Stimulus presentation was controlled by Superlab (version 4.0.7b for Tasks 1 and 2 and version 1.77 for Tasks 3 and 4). Stimuli always consisted of grey scale images of faces. Accuracy (% correct responses) and reaction times (ms) were recorded.

The order of the task was counterbalanced across participants but remained identical for each participant from the pre-test to the post-test.

Tasks 1 and 2 were adapted from Busigny and Rossion (2010) to test participants' recognition abilities for faces presented across different viewpoints. They were AB-X tasks in which participants used the mouse to click on the face with the same identity as the target face presented at the top of the screen from two ¾ profile faces presented at the bottom of the screen (Task 1) or on another screen (Task 2). In Task 1, a trial started with a fixation cross presented for 100 ms and was followed by 3 faces (the target face, the matching face, and the distractor) presented simultaneously. The trial ended with participant's response and was followed by the next trial after a 100 ms inter-stimulus interval (ISI). In this task, stimuli subtended approximately 5.7° by 7.1° of visual angle from the testing distance of 100 cm. Task 2 was the same except that the target face disappeared after 100 ms, and following a 500 ms delay, the matching and distractors face appeared and remained on the screen until the participant's response. In this task, each face subtended approximately 7.1° by 9.2° of visual angle from the testing distance of 100 cm. In both tasks, there were 60 trials per block.

Task 3 used the composite face effect, originally described by Young, Hellawell, and Hay (1987) and Hole (1994), to measure holistic face processing. We used a variant of the task and more