Vision Research 128 (2016) 19–29

Contents lists available at ScienceDirect

Vision Research

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

Perceptual Learning of Facial Expressions

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ARTICLE INFO

Article history:
Received 8 April 2016
Received in revised form 18 August 2016
Accepted 18 August 2016

Keywords:
Facial expression
Perceptual learning
Specificity
Transfer

ABSTRACT

Perceptual learning is a phenomenon in which intensive training for a perceptual task may lead to significant improvement in the task performance. So far, the characteristics of the perceptual learning of facial expressions have not been investigated. In the current study, we trained subjects to distinguish facial expressions. With eight days of training, the subjects' discrimination performance improved significantly, and this improvement was generalized to faces with the same expression but different gender as the trained face. In the second experiment, we further examined the transfer of the learning effect between faces with different expression intensities. We found that the learning effect of happiness can be transferred from the high-intensity face to the low-intensity face, but the reverse was not true. Importantly, in all experiments, we measured the performance immediately after training and one month after training. The results showed that all learning effects and transfers were able to persist for at least one month, which implied that these findings revealed the long-term mechanisms of training. These results revealed the characteristics of facial expression learning and shed light on the mechanisms of perceptual learning for high-level vision.

1. Introduction

The recognition of others' facial expressions in social communications and interactions is a critical skill. People appear to be very sensitive to facial expressions. However, it is unclear whether people can be trained to attain an extraordinary sensitivity to facial expression detection and discrimination. In social media such as TV dramas, this topic has received increasing attention from the public. Here, we provide the first piece of scientific evidence to show that the ability to distinguish facial expressions can be improved by training.

With intensive training, perceptual abilities such as discriminating sensory features can be dramatically improved, which is often referred to as perceptual learning (Gold & Watanabe, 2010; Goldstone, 1998). Previous studies have found that a number of perceptual abilities are susceptible to training, including discriminating contrast (Yu, Klein, & Levi, 2004), orientation (Peng, Chen, Zhou, Thompson, & Fang, 2014; Schoups, Vogels, & Orban, 1995; Schoups, Vogels, Qian, & Orban, 2001), motion direction (Ball & Sekuler, 1987; Chen et al., 2015), texture (Karni & Sagi, 1991) and so on. It should be noted that learning can improve elementary feature discrimination and improve the recognition of complex stimuli such as objects (Furmanski & Engel, 2000) and face (Bi, Chen, Weng, He, & Fang, 2010).

It is important to study the neural mechanism of perceptual learning because it has a close relationship with human cortical plasticity (Gilbert, Sigman, & Crist, 2001). Psychophysical studies have shown that improvements resulting from elementary feature learning were strictly confined to the trained location and feature (Karni & Sagi, 1991). Such location and feature specificities may imply that learning occurs at the early stage of visual information processing in which the neuronal activity is sensitive to the stimulus location and feature. In contrast, the learning effect of complex objects or face stimuli can be transferred to a different untrained location, which is consistent with the fact that object- or face-selective neurons are location invariant (Bi et al., 2010). Redundant electrophysiological and fMRI studies have indeed revealed learning-related changes in the early visual cortex as a result of low-level visual feature training (Bao, Yang, Rios, He, & Engel, 2010; Furmanski, Schluppeck, & Engel, 2004; Schoups et al., 2001; Schwartz, Maquet, & Frith, 2002). In line with these findings, training with objects or faces causes neural response changes in an object- or face-selective cortex, such as the lateral occipital or inferior temporal areas (Bi et al., 2010; Kourtzi, Betts, Sarkheil, & Welchman, 2005; Op de Beeck, Baker, DiCarlo, & Kanwisher, 2006; Sigala & Logothetis, 2002). These findings

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http://dx.doi.org/10.1016/j.visres.2016.08.005
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converge to show that perceptual learning is an effective way to explore the mechanism of neural plasticity.

Recently, increasing amounts of evidence have shown that perceptual learning also incorporates a high-level process. Psychophysically, the specificity that is the signature of perceptual learning can be eliminated by a procedure called "double training" (Xiao et al., 2008). In addition, low-level feature discrimination can also be improved by training on a complex stimulus that is similar to the low-level feature (Wang et al., 2016). Specifically, Szpiro and Carrasco (2015) investigated the role of exogenous attention on perceptual learning and found that exogenous attention was able to boost the learning process. Some neurophysiological studies further showed that training on a low-level feature discrimination task can induce neuronal response changes in high-level areas such as the V4 and LIP (Law & Gold, 2008; Yang & Maunsell, 2004). Finally, modeling studies on psychophysical performance and neuronal firing have both implied that learning may not change the encoding process of a stimulus (Dosher & Lu, 1998; Law & Gold, 2009). In the current study, we aimed to study the specificity of learning and the way in which the learning effect was transferred to other stimuli.

We believe that it is important to study the learning mechanism for human facial expressions. On the one hand, understanding the plasticity of facial expression representations has important theoretical implications; on the other hand, because of the central role of facial expressions in interpersonal communication, our study may also have important clinical implications for disorders of social perception. Previous studies have depicted the characteristics of the perceptual learning of facial identity recognition (Gold, Bennett, & Sekuler, 1999) and face view discrimination (Bi et al., 2010). However, there was little evidence concerning the characteristics of the perceptual learning of facial expressions. To our knowledge, facial expression recognition was shown to improve with training (Bolte et al., 2006; Russo-Ponsaran, Evans-Smith, Johnson, Russo, & McKown, 2015; Silver & Oakes, 2001). However, this paradigm was mostly adopted as a clinical tool to address the symptoms of autism spectrum disorders. For a simple task such as the one in this study, the paradigm is not suitable for healthy adult training. Therefore, it is still unclear whether facial expression discrimination can be improved in healthy humans and what the underlying neural mechanism of facial expression learning is. Here, we adopted the visual perceptual learning paradigm to solve these problems.

2. General method

2.1. Participants

A total of fifty-nine naïve subjects (forty-nine females) participated in the study. There were 12, 10, 16, 11, and 10 subjects for Experiments 1, 2, 3, 4, and 5 respectively. None of them was involved in more than one experiment. They were right-handed with reported normal or corrected-to-normal vision and had no known neurological or visual disorders. Their ages ranged from 18 to 23. They gave written, informed consent in accordance with the procedures and protocols approved by the human subjects review committee of Southwest University. The work was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki).

2.2. Materials

Three-dimensional (3D) face models were generated by FaceGen Modeler 3.1 (http://www.facegen.com). No hair was rendered. A male face model and a female face model were generated by setting the gender slider to male and female, respectively. Other parameters were left in the default setting for neutral faces. Faces with completely happy or completely sad expressions were created with the setting Expression: SmileClosed or Expression: Sad to 1, respectively. We then made changes to the neutral, completely happy, and completely sad faces for each gender using WinMorph 3.0 (http://www.debugmode.com) to generate a symmetrical continuum of 101 images (morphs) that represented a gradual transition from completely happy or completely sad faces to neutral faces in step 1 (that is, the expression strength ranged from 0 to 100). The four morph continua used in this study are shown in Fig 1. For each continuum, the mean luminance and root-mean-square (RMS) contrast of all morphs were equalized. In each experiment, the same face exemplars were used for pre-training and post-training tests as well as for the training itself. In the morphing procedure, we first outlined all features in a pair of face images, including the eyes, mouth, nose, eyebrows, and contour of the face. The program then adjusted the features of one image to correspond to the shape of the other image. This procedure provided a smooth transition between the pair of face images.

Visual stimuli were generated by projecting a 3D stimulus model with the front view onto the monitor plane. The stimuli extended $3 \times 3^\circ$ of visual angle. They were presented on a Samsung 19-in LCD monitor, with a spatial resolution of 1024×768 and a refresh rate of 60 Hz. Subjects viewed the stimuli from a distance of 60 cm. Their head position was stabilized using a chin rest and a headrest. Throughout the experiments, subjects were asked to fixate a small green dot presented at the center of the monitor.

2.3. Procedure

2.3.1. Experiment 1

Each subject underwent eight daily training sessions to distinguish facial expressions by studying faces with completely happy or completely sad expressions. The daily session ($\sim$1 h) consisted of 25 QUEST staircases of 40 trials (Karni & Sagi, 1993). Half of the subjects were trained to distinguish happy faces, and the other half were trained to distinguish sad faces. In the happy expression facial training trial, for example, a completely happy face (referred to as happy_100 below) and a 100-θ happy face were each presented for 200 ms and were separated by a 600-ms blank interval. The temporal order was randomized. The spatial positions of the faces were randomly distributed within a $6.2^\circ \times 6.2^\circ$ area whose center was coincident with the fixation point, with a constraint that these two faces were separated by a $\geqslant 1.5^\circ$ visual angle. The subjects were asked to make a two-alternative-forced-choice (2-AFC) judgment on the expression strength of the second face relative to the first (stronger or weaker). A high-pitched tone was sounded following an incorrect response, and the next trial began 1 s after the response. The θ varied by trial and was controlled by the QUEST staircase to estimate the subjects' facial expression discrimination threshold (75% correct). Before, immediately after, and one month after the 8-day training, we tested the subjects' discrimination performance. Their facial expression discrimination thresholds were measured at the expression strength of happy_100 and sad_100 of both female and male faces. Eight QUEST staircases (same as above) were completed for each type of face and each subject within a single day. Before the experiment, the subjects practiced two staircases (80 trials) for each condition to become familiar with the stimuli and experiment procedure.

2.3.2. Experiment 2

In Experiment 1, we investigated the transfer of the learning effect between different face genders. However, we did not know whether the expression strengths of the male and female faces were matched. In the second experiment, we first matched the expression