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Perceptual learning and recognition confusion reveal the underlying relationships among the six basic emotions

Yingying Wang[a,b], Zijian Zhu[a,b], Biqing Chen[a,b] and Fang Fang[a,b,c,d,e]

[a]Academy for Advanced Interdisciplinary Studies, Peking-Tsinghua Center for Life Sciences, Peking University, Beijing, P. R. People's Republic of China; [b]IDG/McGovern Institute for Brain Research, Peking University, Beijing, P. R. People's Republic of China; [c]School of Psychological and Cognitive Sciences, Peking University, Beijing, P. R. People's Republic of China; [d]Beijing Key Laboratory of Behavior and Mental Health, Peking University, Beijing, P. R. People's Republic of China; [e]Key Laboratory of Machine Perception (Ministry of Education), Peking University, Beijing, P. R. People's Republic of China

ABSTRACT
The six basic emotions (disgust, anger, fear, happiness, sadness, and surprise) have long been considered discrete categories that serve as the primary units of the emotion system. Yet recent evidence indicated underlying connections among them. Here we tested the underlying relationships among the six basic emotions using a perceptual learning procedure. This technique has the potential of causally changing participants' emotion detection ability. We found that training on detecting a facial expression improved the performance not only on the trained expression but also on other expressions. Such a transfer effect was consistently demonstrated between disgust and anger detection as well as between fear and surprise detection in two experiments (Experiment 1A, $n = 70$; Experiment 1B, $n = 42$). Notably, training on any of the six emotions could improve happiness detection, while sadness detection could only be improved by training on sadness itself, suggesting the uniqueness of happiness and sadness. In an emotion recognition test using a large sample of Chinese participants ($n = 1748$), the confusion between disgust and anger as well as between fear and surprise was further confirmed. Taken together, our study demonstrates that the "basic" emotions share some common psychological components, which might be the more basic units of the emotion system.

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Basic emotion; facial expression; emotion detection; discrete; perceptual learning

Introduction

The nature of emotion is one of the most debating yet unresolved questions in cognitive psychology research. One popular theory, the basic emotion model, suggests that a few discrete emotion modules serve as the basic building blocks which constitute the complicated emotion system (Ekman, 1989; Ekman & Cordaro, 2011). Based on this theory, identifying the basic emotion units would be critical to reveal the mechanisms underlying emotion. In a series of cross-culture studies, researchers have found that six emotions (i.e. disgust, anger, fear, happiness, sadness, and surprise) were widely expressed and well recognised by people from different cultures (Ekman et al., 1987; Ekman & Friesen, 1971; Ekman, Sorenson, & Friesen, 1969; Izard, 1994). Such pan-cultural existence implies a deep biological and genetic origin of these emotions (Ekman, 1989; Izard, 2007; Susskind et al., 2008). Therefore, researchers have defined these emotions as the primary units of the emotion system, suggesting that all other emotions are composed by these emotions and that these emotions cannot be broken down into more basic psychological components (Ekman, 1992).

The cross-cultural evidence is convincing, yet it is not impeccable. One major deficit is that the original evidence for universally recognition of the facial expressions for the six basic emotions is mostly based on above chance recognition accuracy (Jack, 2013; Russell, 1994). However, above chance

CONTACT Fang Fang ffang@pku.edu.cn

performance fails to acknowledge subjects' response bias and is not sensitive enough to identify the systematic cultural differences reported in previous studies (Ekman et al., 1987; Jack, Blais, Scheepers, Schyns, & Caldara, 2009; Matsumoto, 1992; McAndrew, 1986). Besides, the original experimental procedure that used the method of three alternative forced choice was criticised as being a discrimination task rather than a recognition task (Nelson & Russell, 2013). The forced-choice response format also causes other problems. When multiple choices were allowed or when false positives were carefully inspected, researchers found that subjects often attributed qualitatively different basic emotion labels to the same facial expression and the same expression was interpreted as reflecting very different emotions (Frank & Stennett, 2001; Jack et al., 2009; Kayyal & Russell, 2013).

In recent years, using various psychophysical methods, Jack and colleagues have revealed clear culture differences in basic emotion perception (Blais et al., 2008; Jack et al., 2009; Jack, Caldara, & Schyns, 2012; Jack, Garrod, Yu, Caldara, & Schyns, 2012). They showed that East Asians recognised basic facial expressions in a different way than West Caucasians, and importantly, East Asians showed confusions between some of the basic facial expressions (i.e. disgust vs. anger and fear vs. surprise). In a recent study, Jack, Garrod, and Schyns (2014) analysed the facial muscle movements that people relied on to recognise emotions other people expressed, and found high overlap between fear and surprise expressions as well as between disgust and anger expressions in Western Caucasians. They suggested that the six basic emotions should be narrowed down to four categories (Jack et al., 2014; Jack, Sun, Delis, Garrod, & Schyns, 2016). Poor discrimination among the facial expressions for the basic emotions has also been found in other studies (see Nelson & Russell, 2013; Russell, 1994 for reviews). For example, Beaupre and Hess (2005) tested people of different ethnicities in Canada and found that French Canadians frequently misattributed disgust to anger expressions. Likewise, Japanese people are bad at discriminating and recognising negative facial expressions (e.g. Matsumoto, 1992; Russell, Suzuki, & Ishida, 1993). In fact, the original study by Ekman and Friesen (1971) also showed that New Guinea people were bad at discriminating fear from surprise expressions. Taken together, it seems that the basic emotions are not so discrete as the basic emotion model (Ekman, 1989, 1992; Ekman & Cordaro, 2011) suggested. Therefore, re-examining the basic emotion theory is necessary.

Another assumption of the basic emotion theory is that, as the primary emotion units, the six emotions should have their own independent biological and neural basis (Ekman, 1992; Ekman & Cordaro, 2011). Accordingly, neuroscience studies have identified the core brain areas for fear (Amygdala, Adolphs, Russell, & Tranel, 1999; Adolphs, Tranel, et al., 1999; Adolphs, Tranel, Damasio, & Damasio, 1994, 1995; Broks et al., 1998; Calder et al., 1996; Feinstein, Adolphs, Damasio, & Tranel, 2011; Schmolck & Squire, 2001) and disgust (Insula and Basal Ganglia, Adolphs, Tranel, & Damasio, 2003; Calder, Keane, Manes, Antoun, & Young, 2000; Phillips et al., 1997, 1998; Ruiz et al., 2013; Sprengelmeyer, Rausch, Eysel, & Przuntek, 1998). However, brain regions critical for the representation of anger, happiness, sadness, and surprise remain unclear (Murphy, Nimmo-Smith, & Lawrence, 2003). Meanwhile, although different neural substrates have been suggested to subserve different emotions in some meta-analysis (Murphy et al., 2003; Phan, Wager, Taylor, & Liberzon, 2002; Vytal & Hamann, 2010), results in these studies are inconsistent with each other and have not yet been replicated successfully (e.g. Barrett, 2006; Barrett, Lindquist, Bliss-Moreau, et al., 2007; Lindquist, Wager, Kober, Bliss-Moreau, & Barrett, 2012; Mauss & Robinson, 2009; Russell, 2003). Lindquist et al. (2012) suggested that there is no specific area or circuit for each basic emotion and each emotion-related brain area might process more than one basic emotion.

Here we tested the discrete hypothesis of the basic emotion theory. For the first time, we applied the perceptual learning technique, a phenomenon that repetitive training improves sensory performance enduringly, to facial expression detection. Perceptual learning in low-level vision has been characterised as highly specific to the trained attributes, suggesting its dependence on early visual cortical areas (Sagi, 2011; Schoups, Vogels, Qian, & Orban, 2001). In recent years, researchers have started to test the effects of perceptual learning on high-level vision, such as perception of shape, object, and face (Bi, Chen, Weng, He, & Fang, 2010; Furmanski & Engel, 2000; Sigman & Gilbert, 2000). In addition to specificity, a large degree of generalisation of learning has been established in high-level vision. Those transfer effects suggest shared neural mechanisms of the trained and tested stimuli and provide a way to deduce the relationship between their neural representations (Bi et al., 2010; Chen, Cai, Zhou, Thompson, & Fang, 2016; Furmanski & Engel, 2000). Taking advantage of this characteristic, we used a perceptual learning procedure to unravel the underlying relationships among the six emotions. In the first experiment, significant transfer effects were found, in which training on detecting a facial expression improved the performance not only on the trained expression but also on some other expressions, indicating shared components between these emotions. In the second experiment, we examined the emotion recognition performance in a large sample of Chinese subjects. Considerable confusions between disgust and anger expressions as well as between fear and surprise expressions were found, demonstrating that the six emotions were not entirely independent at the perceptual level. Therefore, we propose that some common psychological components might underlie the six basic emotions, questioning the six emotions being the primary units of the emotion system. We report how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in each study.

Experiment 1: perceptual learning on facial expression detection

To unravel the underlying relationships among the six basic emotions, we employed a perceptual learning procedure, which can causally change perceptual performance. We examined whether training on detecting a facial expression could improve people's detection performance on other expressions. If the six emotions are truly independent of each other, as suggested in the basic emotion model, then we would expect that any learning effect on an expression would not transfer to other expressions. However, if a transfer effect is found, this might suggest that more basic components exist in the emotion system. Two experiments were conducted, one using facial images from actors of different ethnic groups and the other using facial images from Chinese actors.

Experiment 1A: transfer effects of expression detection learning

Method

Participants

We determined the subject sample size based on our previous study on face perceptual learning (Bi et al., 2010). Seventy Chinese participants (40 females, aged 18–30) with normal or corrected-to-normal vision were recruited from Peking University, Beijing, China. All participants were naïve to the purpose of the study and had no known neurological or visual disorders. This work was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). Participants gave written, informed consent in accordance with the procedures and protocols approved by the human subject review committee of Peking University. The participants were randomly assigned to seven groups (ten in each group): six groups received detection training on anger, disgust, fear, happiness, sadness, and surprise, respectively; and a seventh group received no training. Participants were paid for participating in the experiment.

Stimuli

All visual stimuli were displayed on a uniform gray background (12.5 cd/m^2) at a viewing distance of 73 cm with their head stabilised on a chin rest. The display was IIYAMA colour graphic monitor (model: HM204DT; refresh rate: 85 Hz; resolution: 1024 × 768; size: 22 inch). Images of 24 Asian, African, European- and Latino- American adults (12 males and 12 females) depicting the six basic emotions and the neutral expression were selected from the NimStim face database (Tottenham et al., 2009). Images of the same individuals were selected for all emotions, and each emotion (except for surprise) was expressed by the models with both opening and closed mouths to control for perceptual differences that can vary from one expression to another. Therefore, 48 images were used for each emotion condition. For surprise expression, because it was expressed only with opening mouths, the 24 images were repeated twice. The images were converted to grayscale and cropped to show only the face region. All the face images were matched for their mean luminance (12.5 cd/m^2) and root-mean-square (RMS) contrast (0.58). The RMS contrast of an image was defined as the standard deviation of pixel luminance values divided by the mean pixel luminance (Bex & Makous, 2002; Pelli & Bex, 2013). Each face subtended a visual angle of 3.6° × 3.3° and was embedded in a 9.2° × 9.2° area of static, white Gaussian noise. We randomly jittered the face position in this noise area to avoid low-level visual feature learning at a specific location.

Procedure

The experiment consisted of three phases (Figure 1 (B)): pre-training test (Pre), facial expression detection training (Training), and post-training test (Post).

During the Pre phase, participants from all the seven groups underwent two sessions for measuring their facial expression detection thresholds with the six basic emotions. A session (about 1 h) consisted of 24 QUEST (Watson & Pelli, 1983) staircases of 48 trials, 4 staircases for each emotion. Consequently, detection threshold for each emotion was tested with 8 staircases. The order of the six emotions within a session was randomised for each participant. Each emotional face for one basic emotion was presented once (twice for a surprise face) in a staircase. In a trial, one emotional face and one neutral face were presented successfully in a random order, each for 500 ms. Those two faces were separated by a 500 ms interval. Afterwards, a blank screen with a central fixation point appeared and participants made a two-alternative forced choice (2-AFC) judgment on which interval contained an emotional face. The QUEST staircase began with an easy-to-detect stimulus (e.g. an emotional face embedded in weak noise). Then, noise strength (i.e. RMS contrast of noise) was adjusted by the staircase to find the noise strength level at which subjects could detect the facial expression at 75% correct. The detection threshold for the facial expression was defined as the reciprocal of the RMS contrast of the noise.

During the Training phase, participants from the six training groups underwent six training sessions for facial expression detection (one session on a day). One group was trained with only one basic emotion. A session (about 1 h) consisted of 24 QUEST staircases of 48 trials. The same psychophysical procedure (e.g. the structure of the experimental trials) as that in the Pre phase was used. Feedback was given on each response by colour changing of the fixation point. To measure the time course of the training effect (i.e. the learning curve), detection thresholds from the 24 staircases in a daily training session were

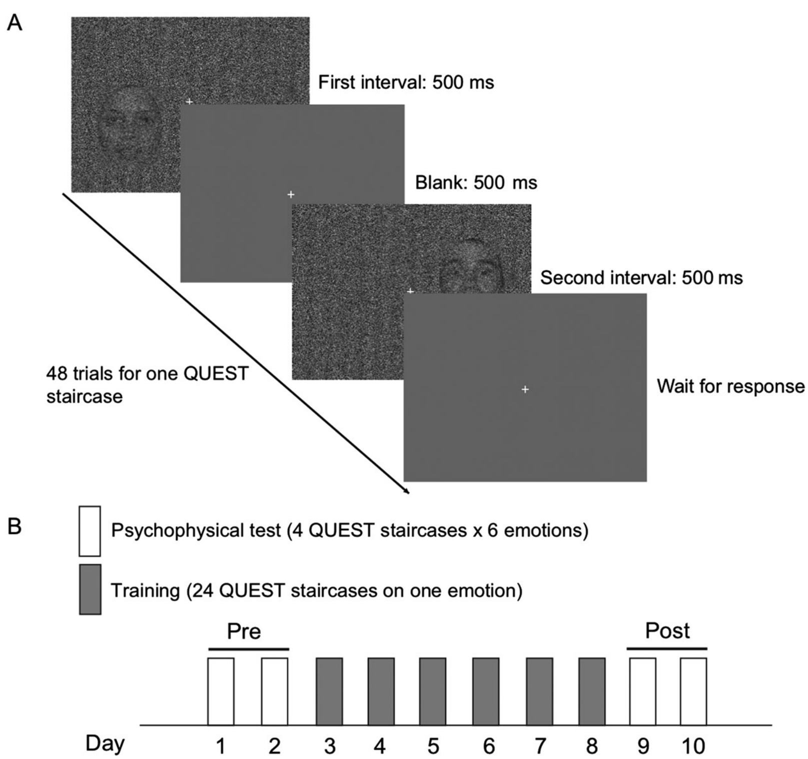

Figure 1. Procedure of Experiment 1. A. Schematic description of a two-alternative forced-choice trial in a QUEST staircase designed to measure emotion detection threshold. Each staircase contained 48 trials. B. Experimental protocol. Each participant underwent six training sessions (Days 3–8) on one emotion. The pre- (Days 1–2) and post-training (Days 9–10) tests took place on the days before and after training on the six emotions. Each session contained 24 staircases.

averaged, and then plotted as a function of training day. The control group received no training.

Procedure for the Post phase was the same as that in the Pre phase.

Data analysis

For each test, detection thresholds from the eight staircases for each of the six emotions were averaged as a measure of subjects' detection performance. The percentage of performance improvement on each emotion was calculated as $(\text{threshold}_{Pre} - \text{threshold}_{Post}) / \text{threshold}_{Pre} \times 100\%$.

Results and discussions

First, we compared participants' emotion detection performance before training on the six basic emotions. We performed a 6 (emotion conditions: the six basic emotions) × 7 (between-group factor, training conditions: six training conditions and one no training condition) repeated measures ANOVA on the emotion detection thresholds at the Pre phase. The main effect of emotion was significant ($F(5,315) = 143.482$, $p < .001$, $\eta^2 = 0.695$), illustrating that the detection sensitivities for the six basic facial expressions were not equal. Further investigations showed that the detection threshold for happy expression was the lowest (Mean ± SEM: 0.726 ± 0.039) and the threshold for sad expression was the highest (Mean ± SEM: 2.720 ± 0.113). Neither the main effect of training ($F(6,63) = 1.061$, $p = .396$, $\eta^2 = 0.092$) nor the interaction between training and emotion ($F(30,315) = 0.927$, $p = .581$, $\eta^2 = 0.081$) was significant, confirming that subject allocation between the conditions was random.

Next, we tested whether and to what extent training could improve facial expression detection. Results showed that, throughout the six training sessions, participants' facial expression detection thresholds for all the six basic emotions reduced steadily (Figure 2(A)). We calculated the percentages of performance improvement from the Pre to the Post phase for the six basic emotions. The improvement was the highest for anger detection (Mean ± SEM: 67.29 ± 3.53%) and the lowest but still significant ($p < .008$ (0.05/6), Bonferroni corrected) for fear (Mean ± SEM: 32.81 ± 5.62%) and surprise (Mean ± SEM: 33.45 ± 8.70%) detection. Therefore, emotion detection could be significantly improved through perceptual learning.

Finally, we tested whether training on detecting one facial expression could improve performance on other expressions (Figure 2(B)). We calculated the percentage of performance improvement on the six basic expressions separately for the six training groups. Bonferroni correction was applied for each training group. Results showed that, disgust training improved detection performance not only on disgust (one-tailed t-test, $t(9) = 6.095$, $p < .001$) but also on anger ($t(9) = 2.924$, one-tailed $p < .008$) expression; in turn, training on anger detection improved performance on both anger ($t(9) = 19.029$, one-tailed $p < .001$) and disgust ($t(9) = 3.781$, one-tailed $p < .008$) expressions. Likewise, training on fear detection improved performance on both fear ($t(9) = 5.839$, one-tailed $p < .001$) and surprise ($t(9) = 2.422$, marginally significant, one-tailed $p = .019$) expressions; and surprise training improved detection performance on both fear ($t(9) = 4.564$, one-tailed $p < .001$) and surprise ($t(9) = 3.844$, one-tailed $p < .008$). Happiness training also improved performance on fear ($t(9) = 3.369$, one-tailed $p < .008$) and surprise ($t(9) = 3.561$, one-tailed $p < .008$) expressions, in addition to happy expression ($t(9) = 7.474$, $p < .001$). Furthermore, we found that training on any expression improved detection performance on happy expression (marginally significant for sadness ($t(9) = 2.183$, one-tailed $p = .029$) and fear detection training ($t(9) = 2.656$, one-tailed $p = .013$); significant for training on other emotions, all one-tailed $ps < .008$). In contrast, sadness detection could only be improved by training on sad expression itself ($t(9) = 3.437$, one-tailed $p < .008$). The null effect ($ps > .05$ for all the six emotions) in the control group where no training was given excluded the possibility that the improvements were caused by practice at the pre-training test. Therefore, the training effect on one basic emotion transferred to other basic emotions, suggesting that the six basic emotions are not independent. Instead, the six basic emotions might share some common, more basic, psychological components.

Experiment 1B: expression detection learning on Chinese affective faces

In Experiment 1A, emotion pictures were expressed by actors from various ethnic groups. Given potential cultural differences in emotion perception (Beaupre & Hess, 2005; Ekman et al., 1987; Jack et al., 2009; Matsumoto, 1992; McAndrew, 1986), we replicated the perceptual learning experiment with emotion pictures

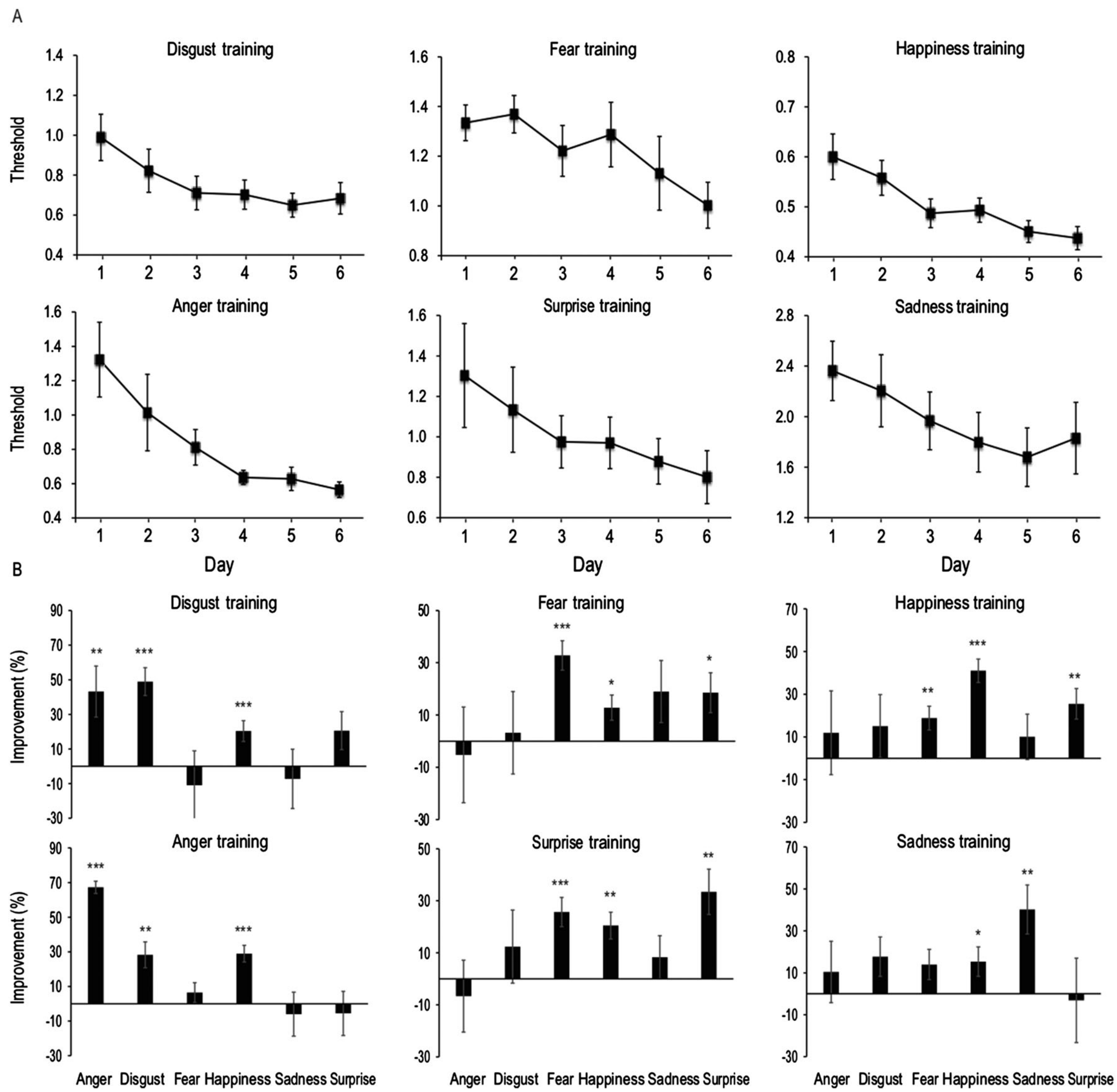

Figure 2. Results of Experiment 1A. A. Group mean learning curves. Emotion detection thresholds, quantified as the reciprocal of the RMS contrast of the noise, are plotted as a function of training day. B. Percentages of emotion detection improvement for each facial expression from different training groups. Asterisks indicate that the improvement is significantly above zero (*$p < 0.03$, **$p < 0.008$, ***$p < 0.001$, one-tailed t-test). Error bars denote 1 SEM calculated across subjects.

expressed by Chinese actors to test whether the observed transfer effects exhibit any cultural difference.

Method

Participants

Forty-two new Chinese participants (27 females, aged 18–27) with normal or corrected-to-normal vision were recruited from Peking University, Beijing, China. All participants were naïve to the purpose of the study and had no known neurological or visual disorders. This work was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). Participants gave written, informed consent in accordance with the procedures and protocols approved by the human subject review committee of Peking University. The participants were randomly assigned to seven groups (six in each group), with each group receiving detection training on angry, disgust, fear, happiness, sadness, surprise, and no training, respectively. Participants were paid for participating in the experiment.

Stimuli

Face images of 24 Chinese adults (12 males and 12 females) depicting the six basic emotions and the neutral expression were selected from the Chinese Facial Affective Picture System (Gong, Huang, Wang, & Luo, 2011). Twenty-four images were used for each emotion condition and were repeated twice in each training and testing session. The picture was converted to grayscale and cropped to show only the face region (mean luminance: 8.50 cd/m^2; RMS contrast: 0.58). Each face subtended a visual angle of 3.6° × 3.3° and was randomly placed within a 9.2° × 9.2° area on a uniform gray background (luminance: 8.50 cd/m^2). Static, white Gaussian noise was added to this area and participants' detection thresholds were defined as the reciprocal of the RMS contrast of the noise.

Procedure

The procedure was the same as that in Experiment 1A.

Results and discussions

Similar results were found as in Experiment 1A. First, a 6 (emotion conditions: the six basic emotions) × 7 (between-group factor, training conditions: six training conditions and the no training condition) repeated measures ANOVA was performed on the emotion detection thresholds at the Pre phase. The interaction effect between the two factors was not significant (F(30,175) = 0.961, $p > .05$, $\eta^2 = 0.141$). The main effect of the training condition was not significant either (F(6,35) = 1.662, $p > .05$, $\eta^2 = 0.222$). Only the main effect of emotion were found to be significant (F(5,175) = 86.046, $p < .001$, $\eta^2 = 0.711$). Emotion detection was most sensitive for happy expression (Mean ± SEM: 0.745 ± 0.046) and least sensitive for sad expression (Mean ± SEM: 2.469 ± 0.155). Meanwhile, training effects were found, with the emotion detection thresholds being reduced steadily throughout the training course (Figure 3(A)).

Finally, we tested the transfer of the training effect (Figure 3(B)). We replicated the results in Experiment 1A by showing that: (1) disgust and anger training improved detection performance on both disgust (disgust training: $t(5) = 4.052$, one-tailed $p < .008$ (0.05/6), Bonferroni corrected; anger training: $t(5) = 7.936$, one-tailed $p < .001$) and anger (disgust training: $t(5) = 3.659$, one-tailed $p < .008$; anger training: $t(5) = 7.478$, one-tailed $p < .001$) expressions; (2) fear and surprise training improved detection performance on both fear (fear training: $t(5) = 4.770$, one-tailed $p < .008$; surprise training: $t(5) = 4.424$, one-tailed $p < .008$) and surprise (fear training: $t(5) = 5.722$, one-tailed $p < .008$; surprise training: $t(5) = 12.043$, one-tailed $p < .001$) expressions. Critically, we found that training on any expression could at least marginally improve the detection on happy expression (all one-tailed $ps < .018$), while detection on sad expression could only be improved by training on sadness itself ($t(5) = 3.380$, marginally significant, one-tailed $p = .010$). No significant improvement was found in the no training control group (all $ps > .05$). These results confirm the transfer effects in Experiment 1A and demonstrate that emotion detection performance can be improved by perceptual learning.

Experiment 2: facial expression recognition

The transfer effect above suggests close relationships among certain basic emotions. In fact, confusions among basic emotions (e.g. fear and surprise, disgust and anger) has been found in previous studies using other behavioural paradigms (e.g. Beaupre & Hess, 2005; Jack et al., 2014; Russell, 1994). To confirm the previous results and to further test whether the transfer effects above are caused solely by perceptual similarity, next we employed the traditional emotion recognition test on a large sample of Chinese participants. To amplify possible confusion effects among emotions, we added white Gaussian noise to face images.

Method

Participants

One thousand, seven hundred and forty-eight participants (85% females, aged 18–24) with normal or corrected-to-normal vision were recruited from Chongqing Medical University in China. This work was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). All participants were naïve to the purpose of the study and had no known neurological or visual disorders. Participants gave written, informed consent in accordance with the procedures and protocols approved by the human subject review

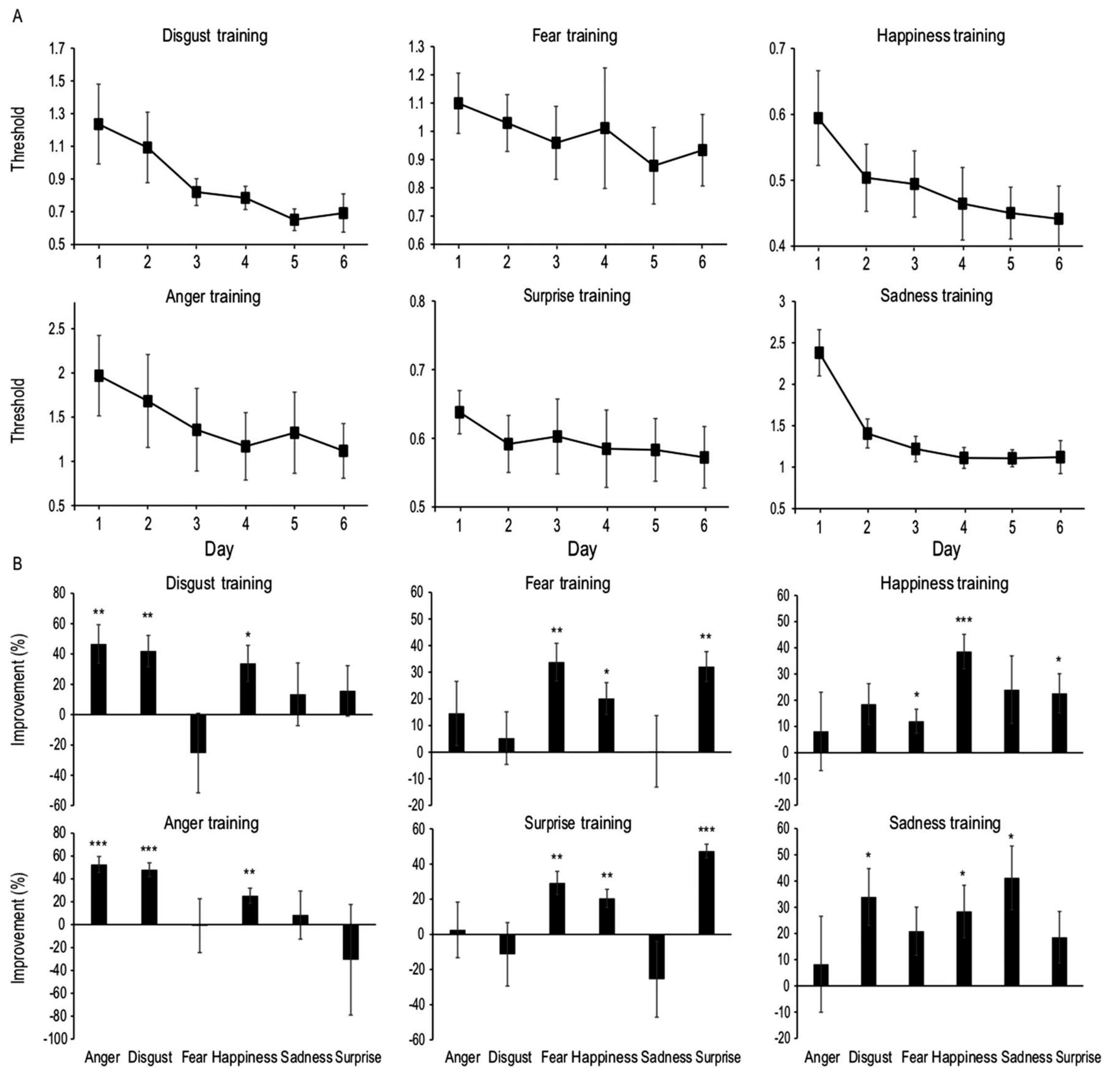

Figure 3. Results of Experiment 1B. A. Learning curves. Emotion detection thresholds, quantified as the reciprocal of the RMS contrast of the noise, are plotted as a function of training day. B. Percentages of emotion detection improvement for each facial expression from different training groups. Asterisks indicate that the improvement is significantly above zero (*$p < 0.02$, **$p < 0.008$, ***$p < 0.001$, one-tailed t-test). Error bars denote 1 SEM calculated across subjects.

committee of Peking University. Participants were paid for participating in the experiment.

Stimuli

The same stimuli as in Experiment 1A were used, except that neutral faces were not included. Each face subtended a visual angle of 3.6° × 3.3° and was randomly placed within a 9.2° × 9.2° area with static, white Gaussian noise added. The noise strength (RMS contrast) was randomly selected, ranging from 0.03 to 1.18 (in steps of 0.05, mean 0.60) for happiness expression and from 0.02 to 0.78 (in steps of 0.033, mean 0.40) for expressions of the other five emotions. Stronger noise was added to pictures depicting happiness in order to get possible confusion effects, because happiness is easier to recognise (Maher, Ekstrom, & Chen, 2014).

Procedure

Participants performed an emotion recognition task. In each trial, a face picture was presented randomly within the 9.2° × 9.2° area for 500 ms. Then the

Table 1. Percentages of responses (%) for each emotion category.

Confusion matrix of facial expression recognition						
	Actual emotional expression (correct answer)					
	Disgust	Anger	Fear	Happiness	Sadness	Surprise
Participants' response						
Disgust	18.47 (8.42)	14.59 (6.27)	8.53 (4.98)	7.00 (4.05)	11.40 (5.64)	6.05 (4.36)
Anger	31.93 (8.94)	44.07 (10.82)	7.58 (4.92)	12.65 (5.96)	11.75 (5.32)	6.93 (4.84)
Fear	12.46 (5.62)	8.94 (4.87)	28.70 (9.16)	6.98 (4.53)	17.49 (6.60)	23.92 (8.80)
Happiness	13.23 (5.75)	8.61 (4.96)	8.85 (4.62)	60.17 (13.60)	8.52 (4.74)	10.35 (5.93)
Sadness	14.77 (6.16)	17.04 (6.04)	21.51 (7.26)	6.98 (4.29)	36.26 (10.77)	10.36 (5.54)
Surprise	8.25 (4.87)	5.84 (3.92)	23.88 (8.85)	5.32 (3.64)	13.63 (6.15)	41.42 (13.51)

Note*:* Values represented the percentages of responses (standard deviation). Percentages of correct responses were shown bold-faced on the diagonal, and above chance false attributions were in italics ($p < .001$).

picture disappeared and six emotion labels appeared at the bottom of the screen. Participants chose the label for the emotion the face expressed. There was no time limit for the response. Each participant completed 288 trials (about 30 min), 48 trials for each emotion.

Data analysis

Percentages of correct response as well as false positive were calculated for each emotion so that a six-by-six confusion matrix was obtained for the six basic emotions. In addition to the confusion matrix, we also inspected the subjective distance between the six emotions using multidimensional scaling (MDS). We first calculated the Euclidean distance between the corresponding vectors in the confusion matrix of each two emotions (i.e. columns in Table 1). We then averaged the distance matrices across the 1748 participants. Next, we computed MDS on the distance matrix to visualise the level of similarity of individual emotions, whereby emotions are automatically assigned coordinates in space so that distances between emotions are preserved (Cichy, Pantazis, & Oliva, 2014).

Results and discussions

We calculated participants' recognition performance. Results (Table 1) showed that participants exhibited above chance (chance level: 16.67%) recognition performance for all the six basic emotions (all *ps* < .001), despite of the added noise. The detection accuracy was the highest for the happiness expression (Mean ± SEM: 60.17 ± 13.60%) (even though it was embedded in stronger noise), replicating previous findings that perceptual sensitivity for happiness is the highest (Calvo, Avero, Fernandez-Martin, & Recio, 2016; Kumar & Srinivasan, 2011; Maher et al., 2014). Detection performance for disgust (Mean ± SEM: 18.47 ± 8.42%) and fear (Mean ± SEM: 28.70 ± 9.16%) was the lowest.

Tremendous confusion was found among the basic emotions. First, disgust was misrecognised as anger (Mean ± SEM: 31.93 ± 8.94%), and the misrecognition percentage was even higher ($t(1751) = 41.776$, $p< .001$) than the percentage of correct response (Mean ± SEM: 18.47 ± 8.42%). Meanwhile, fear was misrecognised as surprise (Mean ± SEM: 23.88 ± 8.85%) and sadness (Mean ± SEM: 21.51 ± 7.26%). Correspondingly, sadness and surprise were misrecognised as fear (Mean ± SEM: 17.49 ± 6.60% and 23.92 ± 8.80%). The percentages of misrecognition were significantly above chance (all *ps*< .001). Therefore, Chinese participants exhibited considerable confusion among negative facial expressions, especially for disgust and anger as well as fear and surprise. This result resonated with previous findings as well as the perceptual learning results above, confirming that the six basic emotions are not entirely independent.

To further illustrate the relative distances between the six basic facial expressions, we performed MDS to place the six emotions in a low-dimensional space for better visualisation. The more similar the two emotions, the closer the two points representing them (Op de Beeck, Brants, Baeck, & Wagemans, 2010). Figure 4 displays the similarities of the six emotions in a two-dimensional space, which is acceptable because the stress value is 0.00 (Kruskal, 1964).

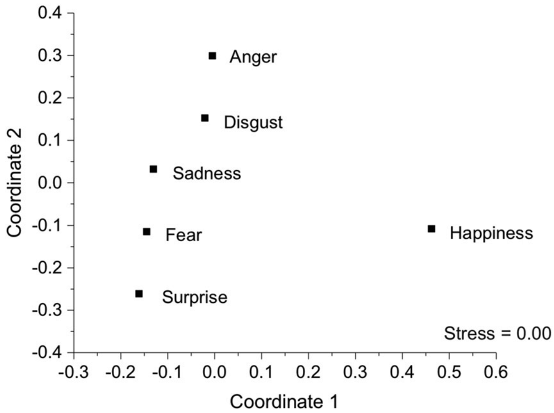

Figure 4. MDS-derived two-dimensional representation space of the six facial expressions based on the similarity measurement calculated from the confusion matrix among these facial expressions. Each point represents one emotion. If two facial expressions are similar, then their points in this spatial representation are close to each other. The "stress" is a measure of lack of fit between the similarity metric and the fitted distances between points.

In this space, happiness was far away from the other emotions. Disgust and anger as well as fear and surprise were close to each other. And both disgust and fear were close to sadness. Based on the measurements of the Euclidean distance between each pair of facial expressions in individuals, two-sample t-tests showed that the distance between disgust and anger was significantly shorter than those between other pairs (all $ps< .001$). The distances between fear and surprise as well as between fear and sadness were also significantly shorter than those between other pairs (all $ps< .001$). Therefore, the six basic emotions are not equally distant from each other at the perceptual level.

Discussion

Our study examined the theory that six basic emotions serve as the primary units of the emotion system. To explore the underlying relationships among the six basic emotions, we employed a perceptual learning procedure to causally change participants' emotion detection ability. We found that performance improvement due to training was not restricted to the trained emotion, but also transferred to other emotions. Such transfer effects were consistently demonstrated between disgust and anger detection as well as between fear and surprise detection in two independent experiments. Notably, we also found that training on detecting any facial expressions would improve happiness detection while sadness detection could only be improved by training on sadness itself. Because training was given only to the trained emotion, it provided compelling evidence that any changes on the tested emotion, namely the transfer effect, was caused by shared component between the tested and the trained emotions. Therefore, the transfer effect suggests shared component between disgust and anger as well as between fear and surprise, and the asymmetric transfer effect also suggests the uniqueness of happiness and sadness. In addition, the emotion recognition performance in a large sample of Chinese participants revealed extensive confusion among the six basic emotions, especially between disgust and anger as well as between fear and surprise. Therefore, our study suggests that the six basic emotions are not discrete categories that are fully independent of each other. Facial expressions for the basic emotions share some common components, indicating that there might be more basic units of the emotion system.

Using the perceptual learning paradigm, our study demonstrated that emotion detection ability could be improved substantially through repetitive training. As a cognitive training approach, perceptual learning has been widely used to study experience-dependent cortical plasticity in adults in a wide range of visual tasks (Sasaki, Nanez, & Watanabe, 2010; Watanabe & Sasaki, 2015). In recent years, much attention has been paid on high-level perceptual learning with visual objects and faces. For example, studies have found that perceptual learning could improve performance of object recognition (Furmanski & Engel, 2000), face identity recognition (Gold, Bennett, & Sekuler, 1999), face gender discrimination (Su, Tan, & Fang, 2013), and face viewpoint discrimination (Bi, Chen, Zhou, He, & Fang, 2014). Recently, Du, Zhang, Wang, Bi, and Qiu (2016) has applied perceptual learning to emotion study. They trained participants on a facial expression discrimination task and found substantial improvement after training. Likewise, perceptual learning significantly improved participants' emotion detection ability in our study. The current study, along with Du et al.'s (2016), provides strong evidence that emotion recognition from facial expressions could be improved through training. Notably, the face stimuli were jittered during the experiment to avoid low-level visual feature learning at a specific location and various facial identities were used in the training and tests. These manipulations ensure that the observed learning effects are not due to plasticity in early visual cortex. Instead, they reflect the plasticity in high-level emotion-related brain areas.

Confusion among the six basic emotions has been established in previous studies. In the early studies, confusions among fear and surprise have been found in people from various cultures, including French Canadians (Beaupre & Hess, 2005) and East Asians (Jack, Garrod, et al., 2012; Matsumoto, 1992; McAndrew, 1986; Russell et al., 1993). Jack and colleagues (2014) examined the dynamic muscle movements during facial expression generation. They analysed the time course of facial muscle movements for the six expressions and found substantial overlaps between the expressions of disgust and anger as well as fear and surprise. Distinction for these emotion expressions occurred only at the end of the expression generation process, suggesting that expressions of these emotions might rely on some common mechanisms. Recently, Jack et al. (2016) modelled the dynamic facial expressions associated with a core set of emotion words in eastern and western cultures and found four basic action unit patterns that are common across cultures. They suggested that the number of basic emotion units might be four rather than six (Jack et al., 2014, 2016). Our results partly support this hypothesis. Using a perceptual learning paradigm, we causally changed the detection performance on one basic emotion and found performance change also on other emotions. Given that manipulation was applied only on the trained emotion, the transfer effect on the untrained emotion suggests shared component between them. In addition, the emotion recognition test reveal confusion between two emotions (e.g. disgust vs. anger, fear vs. surprise). The two pieces of evidence indicate that the basic emotions are not independent of each other.

More than that, perceptual learning task presented novel findings that training on any other facial expressions could improve performance on happiness but not sadness detection. Therefore, in the current training scenario, happiness might share more while sadness might share less components with the other emotions. The asymmetric transfer effect implies that happiness is at a central position of the emotion system or a lower level in the emotion processing hierarchy whereas sadness is at a peripheral position or a higher level. If this is true, refining the neural representation of other emotions through behavioural training would unavoidably improve the representation of happiness in the brain, while leaving the representation of sadness intact. But it is unknown what contributes to the transfer effects between the six facial expressions. Given that random white noise was added to the face images, it is possible that the coarse low-spatial frequency information of the expressions might play a role. Previous studies have established that facial emotion detection relies heavily on the low-spatial frequency information (Langner, Becker, Rinck, & van Knippenberg, 2015; Lojowska, Gladwin, Hermans, & Roelofs, 2015; Pourtois, Dan, Grandjean, Sander, & Vuilleumier, 2005; Vuilleumier, Armony, Driver, & Dolan, 2003; Winston, Vuilleumier, & Dolan, 2003), which is provided by magnocellular inputs to the amygdala through fast subcortical visual pathways. Therefore, we could speculate that disgust and anger expressions share low-spatial frequency information, so do fear and surprise expressions. Moreover, Kumar and Srinivasan (2011) found that perception of happiness and sadness heavily relied on low- and high- spatial frequency information, respectively, which is consistent with the unique roles of these two emotions in the learning effects. Further experiments are needed to test the above assumption. The shared component could also be studied by exploring the brain areas that are modified by perceptual learning.

It is worth noting that major debates exist concerning whether emotion should be divided into discrete categories. Different from the category theory, the dimensional theory propose continuous dimensions that constitute the emotional space. While the categorical theory is supported by emotion recognition and discrimination tasks, the dimensional theory is supported by the finding that rating of morphed facial expressions falls into a circumplex structure that includes valence and arousal dimensions but does not cluster into categories (Takehara & Suzuki, 1997). But recent evidence showed that categorical perception also occurred when people performed a dimensional rating task, suggesting a general existence of categorical representation of facial expressions (Fujimura, Matsuda, Katahira, Okada, & Okanoya, 2012). An fMRI study found dissociative brain areas supporting categorical and dimensional perception of facial expressions respectively (Harris, Young, & Andrews, 2012). Therefore, categorical strategy could co-occur with dimensional strategy in emotion recognition, although it is still unclear how many emotional categories exist. The usage of conceptual knowledge (such as language) as context in the emotion perception might form a basis for the categorical perception of emotion (Barrett, Lindquist, & Gendron, 2007; Fugate, 2013; Lindquist & Gendron, 2013). Investigating the interaction between language and emotion perception might provide further evidence for the categorisation of the basic emotions.

To conclude, although the six basic emotions represent people's general emotion expression and recognition performance, they might not serve as the primary units of the emotion system. Instead, common psychological components exist underlying the basic emotions. Revealing these more basic components could help us get better understanding of the emotion system.

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