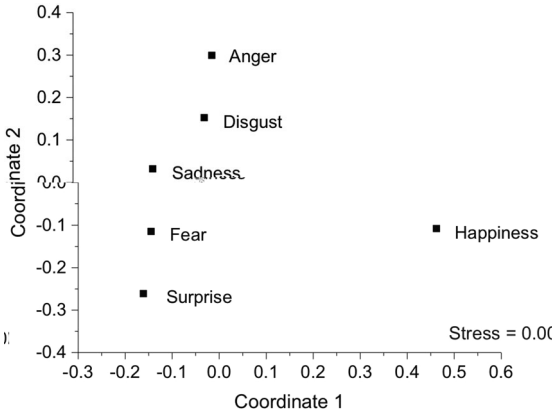

MDS-derived two-dimensional representation space of the six facial expressions based on the similarity measurement calculated from the confusion matrix among these facial expressions. Each point represents one emotion. If two facial expressions are similar, then their points in this spatial representation 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.

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 participant's 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