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Transfer between pose and expression training in face recognition

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ABSTRACT

Prior research has shown that recognition of unfamiliar faces is susceptible to image variations due to pose and expression changes. However, little is known about how these variations on a new face are learnt and handled. We aimed to investigate whether exposures to one type of variation facilitate recognition in the untrained variation. In Experiment 1, faces were trained in multiple or single pose but were tested with a new expression. In Experiment 2, faces were trained in multiple or single expression but were tested in a new pose. We found that higher level of exposure to pose information facilitated recognition of the trained face in a new expression. However, multiple-expression training failed to transfer to a new pose. The findings suggest that generalisation of pose training may be extended to different types of variation whereas generalisation of expression training is largely confined within the trained type of variation.

1. Introduction

The human face transmits rich information such as identity and expressions through a non-rigid 3D shape. Face recognition requires detection of invariant properties of this shape and its reflectance across rigid and non-rigid movements. Despite its complexity in two-dimensional image transformations, our ability to recognise faces often seems surprisingly effortless. However, there is now substantial evidence that recognition is rather fallible for unfamiliar faces (Hancock, Bruce, & Burton, 2000). Bruce (1982) demonstrated that recognition performance can be adversely impaired if a face is learned and tested in different poses or expressions. Since recognition of familiar faces is largely pose and expression invariant, this evidence suggests that image-invariant recognition requires learning or familiarisation. However, exactly how the brain learns to tackle image variations due to pose and expression remains little known.

Brain imaging research has revealed that the fusiform gyrus, a face selective area of the brain, is insensitive to low-level image variations such as size (Kanwisher, McDermott, & Chun, 1997). However, adaptation in this area to repeated presentations of a face is sensitive to variations of pose and facial expressions (Andrews & Ewbank, 2004). Because activities of some face selective neurons are tuned to specific poses (Abbott, Rolls, & Tovee, 1996), there has been a suggestion that pose-invariant representations are formed by converging information from pose-dependent neurons (Booth & Rolls, 1998).

Psychophysical research has also produced evidence for pose-dependent recognition. For example, Edelman and Bülthoff (1992) found that in object recognition, generalisation to novel views from a single trained view falls off with increasing angle of rotation. Hill, Schyns, and Akamatsu (1997) also demonstrated that when subjects learned one pose but tested with different ones, generalisation from the learned front pose was progressively worsened as the angle of rotation increased (see also Troje & Bülthoff, 1996; Wallraven, Schwaninger, Schuhmacher, & Bülthoff, 2002). These studies suggest a viewer-centred encoding that depends on a particular vantage point of the observer relative to the pose of a face.

According to view-based theories, encoding several views of an object or face is necessary for pose-invariant recognition. Psychophysical research has found support for these theories by showing that exposures to multiple views of an object or face can facilitate viewpoint or pose-invariant recognition (Edelman & Bülthoff, 1992; Hill et al., 1997; Wallraven et al., 2002; Watson, Johnston, Hill, & Troje, 2005).

Learning to recognise a face in various expressions may require similar exposures to these expressions. Even for familiar faces where recognition is typically expression invariant, unusual expressions can still slow down or hamper recognition performance (Hay, Young, & Ellis, 1991). This suggests that expression-invariant recognition may require certain level of exposures to all basic expressions.

Assuming that learning a face involves encoding both multiple views and expressions, how does the brain integrate the

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information from these two types of variation? We should note that this question is different from the literature on the relationship between identity and expression processing, which has centred on the issue of whether identity and expression are mediated by a single or a dual route in the brain. The dual-route theory proposes separate modules for identity and expression processing, drawing evidence from brain-damaged patients whose ability to process one type of information is impaired but the ability to process the other is intact (Bruce & Young, 1986). The single-route hypothesis, on the other hand, cites evidence that recognition of identity can be influenced by recognition of facial expression or vice versa (e.g., Ganel & Goshen-Gottstein, 2004). Over the years since the Bruce and Young's (1986) influential model, the main goal of many studies has been to resolve this debate (Martínez, 2003). However, insights from this line of research have no direct relevance to the chief concern of this study. Here we are mainly interested in how pose and expression-invariant identity recognition is achieved by the visual system. As suggested in the literature, agnosic patients suffering from impaired ability for distinguishing facial expressions can nevertheless have intact ability to recognise faces with various facial expressions (Kurucz & Feldmar, 1979). This shows that expression-invariant recognition of identity is separable from classification of facial expressions although both derive information from non-rigid motion or deformations of the face shape. The main focus of this paper is how these image variations are handled in identity recognition. We aim to address the following question: If several pose and facial expressions need to be learned, does the visual system have to be exposed to each expression in different views? The question may be conceptualised as a matter of transfer between pose and expression training. For instance, if a face has been observed from several poses rather than a single pose, can it be recognised more effectively when it is later seen with a different expression? If the answer is yes, it would suggest that pose training can transfer to a new facial expression. The same question can be asked about the transfer from expression training to a new pose. The purpose of this study is to examine whether training in one type of transformation can be transferred to another.

Experiment 1 examined whether seeing several poses of a face assists recognising the face in a new expression, whereas Experiment 2 examined whether seeing several facial expressions of a face facilitates recognising the face in a new pose. Both experiments employed a sequential matching paradigm where the task was to judge whether a pair of faces presented one after the other were of the same person.

2. Experiment 1

To examine the effect of pose training on matching facial identities with different expressions, we compared performance for conditions where the face at learning was either shown in multiple poses or a single pose. The test face in each trial was either shown with the same or a different expression from the learn face.

2.1. Method

2.1.1. Participants

Twenty undergraduate students from Chinese Agricultural University (mean age 22.8 years, $SD = 1.5$) participated in this experiment. All had normal or correct-to-normal vision.

2.1.2. Materials

The face database was obtained from Binghamton University. It contained 100 3D faces and texture maps without facial hair or spectacles. More details about this database can be found in Yin, Wei, Sun, Wang, and Rosato (2006). We used all the 51 Caucasian and 24 Asian models in the database. Nine additional models were used in the practice session. Each face model was rendered against a black background in seven poses ranging from the full frontal (0°) to six left and right poses (±16°, ±35°, and ±60°). Each pose had seven facial expressions (happiness, sadness, disgust, surprise, anger, fear, and neutral). The rendered faces were saved as grey-level bitmap images. An example face in these variations is shown in Fig. 1. To minimise the low-level image cues for the task, the luminance and root–mean–square contrast of the images were scaled to the grand means. The learn face and the test face were also presented in different sizes, with half of these sized 512 by 512 pixels, whereas the other half 384 by 384 pixels.

2.1.3. Design

We employed a within-participant design. Because our stimuli contained Caucasian faces that could be processed differently by participants of a different race (see, for example, Rhodes, Hayward, & Winkler, 2006), we also included face race as a factor. The independent variables were thus face race (own-race vs. other-race), pose training (multiple pose, single pose, and baseline), and expression change (same vs. different).

2.1.4. Procedure

The experiment was run in two blocks. The pair of faces had the same neutral expression in one block but different expressions in another. Each block consisted of six practice trials and 100 experimental trials. The order of the two blocks was counterbalanced.

Each matching trial consisted of a learn face and a test face presented one after the other in the centre of the screen (see Fig. 2). It began with a 500 ms central fixation cross and a 500 ms blank screen. A learn face was then presented for 3 s. The test face appeared after a 500 ms blank screen. Participants were instructed to judge whether the face images presented at learning and test were of the same person. They were told to give their answer as quickly and accurately as possible by pressing one of the two keys labelled 'yes' or 'no'. The test face remained on screen until the participant responded.

The learn face either consisted of a single or multiple poses of the same person, which always had a neutral expression. In the multiple-pose condition, the six left and right poses were shown successively at 500 ms per pose in the centre of the screen. The pose order was shuffled such that no adjacent poses would be shown consecutively. In the single-pose conditions, the learn face was shown in one of the six side poses. Each pose was assigned randomly with equal frequency. In the baseline condition, the learn face was shown in the full frontal pose.

Each participant completed two blocks of trials, one for the same and another for the different expression. The test face was always a single image with the frontal pose. In the same-expression block, the test face was shown in the same neutral expression as the learn face. In the different-expression block, the test face was shown with an emotional expression. Half of the test faces were the same as the learn face (targets), and the remaining half were different from the learn face (distractors).

2.2. Results

We calculated d' scores for each participant based on the hit and false alarm rates. D' is a parametric measure of sensitivity that indicates how well a participant discriminates targets from distractors. To demonstrate how individual participants performed in this experiment, results from an example participant are presented in Table 1.

The mean d' results across all participants are shown in Fig. 3. A three-way repeated-measures analysis of variance (ANOVA) revealed a significant main effects of pose training, $F(2,38) = 5.65$,

Fig. 1. An example face rendered in seven expressions (rows) and seven poses (columns).

$p < 0.01$, $\eta^2 = 0.23$. Post-hoc tests showed impaired matching performance for the single-pose training relative to the multiple-pose training and the baseline conditions, $ps < 0.05$ and 0.01, respectively. The poorer performance of the single-pose condition relative to the baseline was predicted is not surprising because the test face in this condition was always shown in a different pose from the learn face, whereas the test face in the baseline condition was always shown in the same frontal pose as the learn face. Interestingly, however, the performance for the multiple-pose training condition did not differ from the baseline condition although the learn face and test face in this condition were not identical, $p = 0.44$. There were also significant main effects of race of face and expression change, $Fs\ (1,19) = 15.07$ and 75.63, $ps < 0.01$ and 0.001, $\eta^2 = 0.44$ and 0.80, respectively, where own-race faces were matched more accurately than other-race faces, and matching for the same expression was more accurate than for different expressions. There was also a significant two-way interaction between face race and expression change, $F\ (1,19) = 6.66$, $p < 0.05$, $\eta^2 = 0.26$. The remaining two-way and three-way interactions were not significant, $Fs < 1.23$, $ps > 0.30$.

To identify the source of the two-way interaction, we performed simple main effects analyses. This revealed an effect of face race when the facial expression was changed at test, $F\ (1,19) = 18.68$, $p < 0.001$, but not when the expression was identical between learning and test, $F\ (1,19) = 2.48$, $p = 0.13$.

We also calculated c, which is a measure of response bias. A c value of 0 indicates a neutral response criterion. A negative value of c signifies a liberal, whereas a positive value a conservative bias. Results of c are shown in Table 2. ANOVA showed no significant main effects or interactions. Marginally significant main effects were found for pose training, $F\ (2,38) = 2.82$, $p = 0.07$, and face race, $F\ (1,19) = 3.31$, $p = 0.09$. The results suggest limited impact of the experimental variables on the response criterion.

2.3. Discussion

The d' results showed a clear expression-dependence effect, with different-expression pairs producing poorer matching performance than same-expression pairs. However, exposure to multi poses was able to alleviate this effect. There was also a pose-dependence effect, where face pairs with different poses resulted in a poorer performance than the same pose. Here again, multi-pose training could significantly improve this detrimental effect. Overall, the own-race faces were matched more accurately than the other-race faces. This was particularly so for face pairs with different expressions.

The key finding in this experiment was that higher level of exposures to pose variation transferred to face matching with different expressions.

3. Experiment 2

Experiment 1 revealed that pose training can generalise to new facial expressions. We next examined the reverse direction of generalisation, which is whether expression training helps recognition

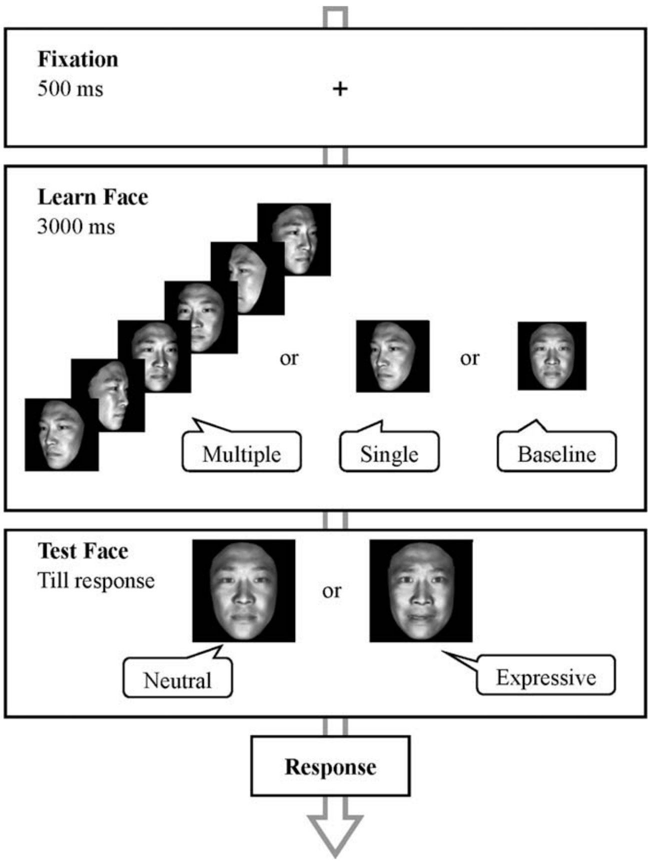

Fig. 2. Illustration of the procedure used in Experiment 1. In the multiple-pose condition, the six side poses were shown in a shuffled order. In the single-pose condition, the face was shown in one of the six poses. In the baseline condition, the face was shown in the frontal pose. The test face was shown in the frontal view, which either had a neutral or an emotional expression. See text for more information.

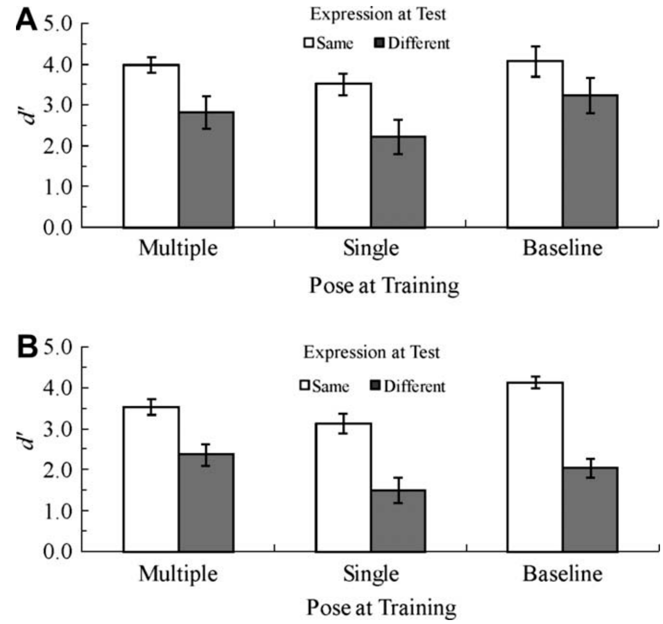

Fig. 3. Mean accuracy results in Experiment 1. Error bars represent one standard error. (A.) Results for own-race faces. (B.) Results for other-race faces.

Table 1
Accuracy results (d') from an example participant in Experiment 1.

Pose at training	Expression at test			
	Same		Different	
	Own-race	Other-race	Own-race	Other-race
Multiple	3.76	3.76	2.76	1.97
Single	3.33	3.65	1.90	1.65
Baseline	4.65	4.46	4.35	2.57

Table 2
Mean criterion results in Experiment 1.

Pose at training	Expression at test			
	Same		Different	
	Own-race	Other-race	Own-race	Other-race
Multiple	−0.04 (0.58)	−0.19 (0.59)	0.08 (0.91)	−0.05 (0.78)
Single	0.10 (0.89)	0.05 (0.74)	0.64 (0.74)	0.28 (0.69)
Baseline	0.17 (0.78)	−0.11 (0.42)	0.20 (0.97)	−0.11 (0.93)

Note: Values in parentheses represent standard deviations.

of the trained face in a new pose. The training conditions here consisted of a single or multiple expressions. The test face always had a neutral expression and was shown either in the same pose or a new pose.

3.1. Method

3.1.1. Participants

A separate group of undergraduate students from Chinese Agricultural University ($N = 22$, mean age 20.6 years, $SD = 1.1$) participated in this experiment. All had normal or correct-to-normal vision.

3.1.2. Materials

We used the same faces as Experiment 1. Each face was rendered in three poses (0° and ±30°), and seven facial expressions (happiness, sadness, disgust, surprise, anger, fear, and neutral). Other aspects of the stimuli were identical to Experiment 1.

3.1.3. Design

This was again a within-participant design. The variables were race of face (own-race vs. other-race), expression training (multiple expressions, single expression, and baseline) and pose change (same vs. different).

3.1.4. Procedure

Procedure was identical to Experiment 1 except the following. The learn face was always shown in a frontal pose for a total of 3000 ms. In the multiple-expression condition, the face was shown in the six non-neutral expressions presented one after the other at 500 ms per expression. The order of the six expressions was completely random. In the single-expression condition, the face was presented with an expression randomly chosen from one of the six non-neutral expressions. In the baseline condition, a single face image was shown with a neutral expression.

Each participant completed two blocks of trials, one for the same and another for the different pose. The test face was always a single image with a neutral expression. In the same-pose block, the test face was shown in the same frontal pose as the learn face. In the different-pose block, it was shown in a side pose (30° to the left or right, assigned randomly).

3.2. Results

Data from two participants were excluded from analysis due to their chance-level performance ($d' = 0.10$ and 0.20). Fig. 4 shows the d' results based on the remaining 20 participants. Results from a single participant are given in Table 3 as an example. ANOVA showed a significant main effect of expression training, $F(2,38) = 13.42$, $p < 0.001$, $\eta^2 = 0.41$. Post-hoc tests showed impaired matching performance for the multiple- and the single-expression training conditions relative to the single neutral expression condition. The results for the multiple- and single-expression training conditions did not differ from each other. There were also significant main effects of pose change and face race, $Fs(1,19) = 27.53$ and 6.09, $p < 0.001$ and 0.05, $\eta^2 = 0.59$ and 0.24, respectively, where matching performance for the same pose was superior to different poses, and the own-race faces were matched more accurately than other-race faces. The interaction between face race and pose change was also significant, $F(1,19) = 4.42$, $p < 0.05$, $\eta^2 = 0.19$. All other two-way and three-way interactions did not reach the level of significance, $Fs = 0.42$–1.21, $ps = 0.31$–0.66.

Simple main effects analyses of the interaction between face race and pose change showed that the own-race faces were matched better than the other-race faces in the same-pose condition, $F(1,19) = 12.76$, $p < 0.01$, but the two types of faces scored equally in the different-pose condition, $F(1,19) = 0.15$, $p = 0.71$.

The criterion results are shown in Table 4. There was a significant main effect of expression training, $F(2,38) = 14.38$, $p < 0.001$, $\eta^2 = 0.43$. Single-expression training produced a more conservative criterion than the multiple-expression training and the baseline conditions. Although neither the main effect of face race nor pose change was significant, $Fs(1,19) = 0.29$ and 0.99, $ps = 0.60$ and 0.33, respectively, there was a significant interaction between these, $F(1,19) = 5.86$, $p < 0.05$, $\eta^2 = 0.24$. Analysis of the interaction showed that pose change created more conservative criterion for the other-race faces, $F(1,19) = 9.03$, $p < 0.01$, but not for the same-race faces, $F(1,19) = 0.67$, $p = 0.42$. Other two-way and three-way interactions were not significant, $Fs = 0.13$–1.26, $ps = 0.30$–0.88.

Because face race and level of training appeared to produce different effects on the sensitivity results in the two experiments, we conducted specific comparisons of interest in Figs. 3 and 4, treating experiments as a between-participant factor. The results showed that the overall performance in Experiment 1 (pose training) was superior to Experiment 2 (expression training), $F(1,38) = 8.28$, $p < 0.01$. There was also a significant three-way interaction among experiment, face race, and image change (pose or expression), $F(1,38) = 9.11$, $p < 0.01$. Simple main effect analyses revealed that the interaction between face race and image change was only significant in Experiment 2, $F(1,38) = 6.86$, $p < 0.01$, but not in Experiment 1, $F(1,38) = 2.72$, $p = 0.11$. The results suggest that matching faces with different expressions is more susceptible to the other-race effect. A significant interactions was also found between experiment and training, $F(2,38) = 3.17$, $p < 0.05$. Simple main effects analyses showed that multiple-pose training in Experiment 1 generated better performance than multiple-expression training in Experiment 2, $F(1,38) = 11.07$, $p < 0.002$, while the single image and baseline conditions in the two experiments produced comparable performance, $Fs(1,38) = 0.12$ and 3.35, $ps = 0.73$ and 0.08, respectively.

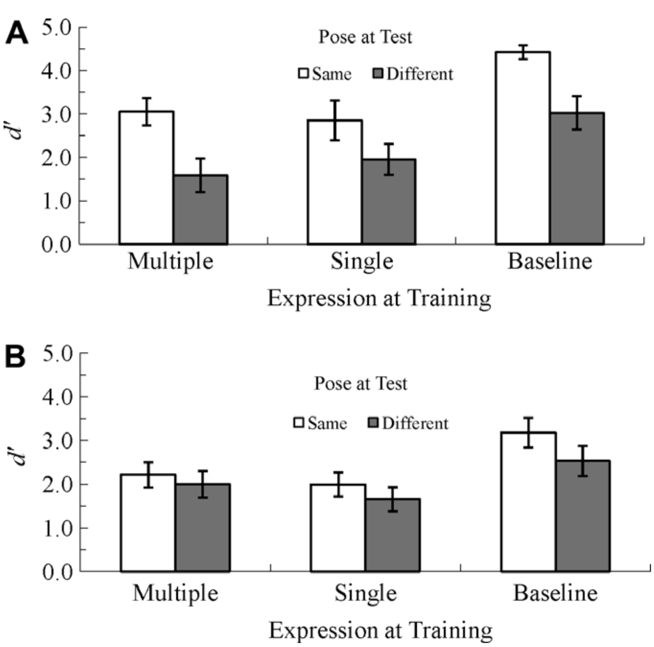

Fig. 4. Mean accuracy results in Experiment 2. Error bars represent one standard error. (A.) Results for own-race faces. (B.) Results for other-race faces.

Table 3
Accuracy results (d') from an example participant in Experiment 2.

Expression at training	Pose at test			
	Same		Different	
	Own-race	Other-race	Own-race	Other-race
Multiple	3.65	3.17	2.33	1.41
Single	3.65	3.39	2.65	1.07
Baseline	4.27	4.65	2.95	1.81

Table 4
Mean criterion results in Experiment 2.

Expression at training	Pose at test			
	Same		Different	
	Own-race	Other-race	Own-race	Other-race
Multiple	−0.23 (0.96)	−0.46 (0.70)	−0.25 (1.16)	−0.07 (0.68)
Single	0.38 (0.93)	0.15 (0.59)	0.37 (1.08)	0.52 (0.53)
Baseline	−0.12 (0.36)	−0.53 (0.60)	−0.47 (1.10)	−0.33 (0.76)

Note: Values in parentheses represent standard deviations.

3.3. Discussion

The matching performance was poorer when the face pair had different expressions than when they both had the same neutral expression. There was also a cost of pose change in face matching. Like Experiment 1, matching own-race faces was more advantageous than matching other-race faces. The fact that the own-face advantage was only found in the same-pose condition is somewhat surprising. This could be explained by the overall poorer performance for different-pose pairs in both conditions.

The most important finding in this experiment, however, was that increased level of exposure to expression variation did little to improve matching performance when the face was tested in a new pose.

It was also found that single-expression training produced more conservative criterion than the multiple-expression or the baseline training condition. Pose change created a more conservative bias for the other-race faces, but not for the own-race faces.

4. General discussion

Both experiments demonstrate pose and expression dependent behaviours in face matching. The results are consistent with Bruce (1982) and the subsequent literature. The key finding in this study, however, is that pose training can transfer to new expressions but expression training cannot transfer to new poses. Experiment 1 showed that matching performance in the multiple-pose training was less impaired than the single-pose training by a change of facial expression. Experiment 2 showed that matching performance after multiple-expression training was equally impaired as single-expression training when the test face was shown in a different pose. The results suggest that transfer between pose and expression is unidirectional, where knowledge of pose variation is more adaptable to another type of image variation, whereas knowledge of expression variations is more strictly confined to the trained type. This finding is consistent with a recent study on the transfer between pose and illumination training (Liu, Bhuiyan, Ward, & Sui, in press). Like pose and expression, illumination on a face is a major source of image variation (Braje, Kersten, Tarr, & Troje, 1998). Liu et al. found that pose training could transfer to a new illumination, although illumination training failed to transfer to a new pose. Their results suggest that pose training can compensate for illumination variation. Illumination training, on the other hand, is only useful for the trained pose. The present study identifies the utility of pose encoding for yet another major image variation caused by facial expressions. Again, the processes for pose and expression variation appear to play uneven roles in face learning, where the output from pose processing produces stronger influence on image-invariant recognition. This implies that pose-invariant recognition is achieved mainly through exposures to pose variations, whereas expression-invariant recognition can be achieved through exposures to both expression and pose variations. To achieve image-invariant face recognition, the visual system may rely on a strategy that focuses on pose encoding. The transfer of pose training to a new expression may be achieved by predicting non-rigid distortion of the facial features from the stored face views.

Although the lack of transfer from expression training to pose may be due to a number of factors, a potential reason may be that negative facial expressions (which were shown more often than positive ones) had a detrimental effect on encoding of facial identities (see D'Argembeau & Van Der Linden, 2007). This hypothesis will require future investigations. Furthermore, encoding expressions on a single pose may have inherent limitations, because it cannot rely on image-based processing strategies such as interpolation and extrapolation to predict the poses other than the stored pose. Finally, multiple expressions of a face may contain less image variance than multiple poses of the same face, which could also be a reason for poorer generalization. Perhaps due to greater image variance, a face learned from multiple poses is more robust from the sort of image pixel changes introduced by facial expressions.

Future research is also called for transfer across different types of image variation. Expression training may be further divided according to emotional categories. Systematic study of transfer within or cross expression is currently lacking. There is also a need to examine the role of facial motion. There has been evidence that image variation due to non-rigid motion may compensate for pose dependence (Watson et al., 2005). However, no research has tested this with emotional expressions.

Our results lend strong support to the idea that image-invariant face recognition requires exposures to most types of image variations. Transferability is likely to be determined by image similarities, which tend to be greater within than across types of image variation. This may underlie the lack of transfer across certain types of image variation. Poor cross-type transfer also consolidates the idea that face recognition is largely image-based, where image similarity between the stored representations of faces and the input determines the matching performance. However, in line with Liu et al. (in press), the results from this study have demonstrated and established that certain kinds of image variations such as pose may play a more important role than others in face learning.

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