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Recognition, Classification and Inversion of Faces in the Multidimensional Space

Or Catz¹, Michal Kampf², Israel Nachson¹ and Harvey Babkoff¹

¹Bar-Ilan University (Now at Ashkelon Academic College)

²Ashkelon Academic College
Israel

1. Introduction

1.1 The multidimensional space

One of the leading models of face recognition is the multidimensional space (MDS) model proposed by Valentine (1991a) which suggests that faces are encoded as points in a metaphoric multidimensional space, and that any characteristic which differentiates among faces can serve as a dimension in that space (Bruce, Burton, & Dench, 1994; Valentine, 1991a; Valentine & Endo, 1992).

According to the model, faces are normally distributed along each of the dimensions which share a common center (Bruce et al., 1994; Johnston, Milne, Williams, & Hosie, 1997; Lewis & Johnston, 1999b). Most faces that one encounters are typical, and as such are distributed around the center of the MDS. Distinctive faces, on the other hand, are located far from the center. Therefore, the more typical a face is on the various dimensions, the closer it is to the center of the MDS and to other faces, and consequently the smaller is its representation space (Lewis & Johnston, 1999a; Tanaka, Giles, Kremen, & Simon, 1998). Thus, the greater the similarity among the faces, the more densely they are located and hence their recognition is more difficult (Busey, 1998; Johnston, Milne et al., 1997; Lewis & Johnston, 1999a; Tanaka et al, 1998; Valentine, 1991a,b, 2001; Valentine & Bruce, 1986a,c). As the MDS model suggests, distinctive faces are indeed recognized faster and more accurately than typical ones (Lewis & Johnston, 1997; Valentine, 1991a, 2001; Valentine & Bruce, 1986a,c; Valentine & Ferrara, 1991; Wickham, Morris, & Fritz, 2000).

1.2 The inversion effect

A similar phenomenon is observed regarding faces presented in the upright or in the inverted position: Inverted faces are more difficult to recognize than upright faces (Yin, 1969). The greater decline in the recognition of inverted faces than in that of other visual stimuli is known as the inversion effect (Valentine, 1988; Yin, 1969, 1978). Encoding of inverted faces is assumed to involve mental rotation to the upright position (Collishaw & Hole, 2000; Rakover & Teucher, 1997; Valentine & Bruce, 1988; Yin, 1969) - a procedure which is likely to be erroneous. Therefore, recognition of inverted faces, regardless of whether they are typical or distinctive, is more error prone than that of upright faces (Valentine & Bruce, 1986b). But since typical faces are more densely located in the MDS than

distinctive faces, the potential for their erroneous recognition is greater than that of distinctive faces, and consequently the inversion effect is larger for typical than for distinctive faces (Byatt & Rhodes, 1998; Valentine, 1991a,b, 2001; Valentine & Endo, 1992).

According to the MDS model, the difference between upright and inverted face recognition is quantitative since it reflects the task's relative difficulty (Kanwisher, Tong, & Nakayama, 1998; Nachson & Shechory, 2002; Rakover & Teucher, 1997; Valentine, 1988, 1991a; Valentine & Bruce, 1988). For example, Collishaw and Hole (2000) found a linear decline in face recognition according to the angle of inversion from upright to totally inverted faces.

Yet, other researchers (Bartlett & Searcy, 1993; Carey & Diamond, 1977; Farah, Tanaka, & Drain, 1995; Farah, Wilson, Drain, & Tanaka, 1998; Leder & Bruce, 1998; Rossion, 2008; Sergent, 1984) have argued that processing of inverted faces is qualitatively different from that of upright faces as recognition of upright faces is both holistic and featural, whereas that of inverted faces is only featural. For example, Farah et al. (1995) showed that while faces and dot-aggregates showed inversion effects when learned as whole stimuli (holistic processing), no inversion effect appeared when the stimuli were learned part-by-part (featural processing).

1.3 Classification versus recognition

Unlike recognition which requires differentiation among individuals (Valentine, 1991a), classification (face/non-face judgment) requires differentiation between groups. Thus, in contrast to recognition that is easier for distinctive faces, classification is easier for typical faces due to their proximity to the center of the MDS (Valentine, 1991a; Valentine & Bruce, 1986c; Valentine & Endo, 1992). Inversion affects face recognition, and as such it requires a within-group judgment which presumably interacts with face distinctiveness. However, classification requires differentiation among categories (between-group judgment), and it is not expected to yield interactive effects between distinctiveness and inversion (Levin, 1996; Valentine, 1991a; Valentine & Endo, 1992).

1.4 Empirically testing the MDS model

The previous findings (e.g. Bruce et al., 1994; Byatt & Rhodes, 1998; Tanaka et al., 1998; Valentine & Endo, 1992; Wickham et al., 2000) have been explained in reference to an MDS metaphorical model (Valentine, 1991a, 2001). One of the problems with this model is its ability to explain different phenomena using opposite arguments. As Levin (1996) pointed out, by changing the estimated weight of different dimensions or the relative density of the theoretical faces, one can explain different phenomena. Thus, although many studies have referred to the MDS metaphoric model (e.g., Bruce et al., 1994; Burton & Vokey, 1998; Busey, 1998; Byatt & Rhodes, 1998; Johnston, Kanazawa, Kato, & Oda, 1997; Lewis & Johnston, 1997, 1999a,b; Tanaka et al., 1998; Valentine, Chiroro, & Dixon, 1995; Valentine & Endo, 1992; Wickham et al., 2000), it is necessary to test its predictions on an empirically defined MDS.

Recently, an attempt was made (Catz, Kampf, Nachson, & Babkoff, 2009) to construct an operational MDS that included 200 faces which were each rated on 21 dimensions. A factor analysis enabled the empirical establishment of six factors that distinguished among the faces. Three of the factors were holistic (configural): Size (of the face, the chin, the forehead, and the eyebrows), Form (the size of the cheeks, face length, and shapes of the cheeks, the chin and the face) and Nose through Eyebrows (a combination of centrally located internal

features: Nose shape and size, distance between the eyes, and the shape of the eyebrows); and three were featural: Mouth (thickness, shape and size), Eyes (size and shape), and Face Appearance (eyes and facial color and marks). An overall index referring to the faces' distance from the center of the MDS was also calculated on the basis of the 21 facial dimensions. This index was based on the relative distance of the faces on each of the MDS dimensions (for further details, see Catz et al., 2009).

The purpose of the present study was to utilize an empirically based MDS, in which faces are located relative to six face-defining factors, to test predictions regarding both face recognition and classification. Experiment 1 was designed to measure the relative contribution of the six factors to the recognition of upright and inverted faces. According to the quantitative approach, spelled out above, no difference was expected between the relative importance of holistic and featural factors to face recognition. Significant differences between the two would support the notion that the difference between upright and inverted face recognition is qualitative.

In Experiment 2 the effects of distinctiveness and inversion on face recognition and classification were tested. According to the MDS model, typical (as opposed to distinctive) faces are difficult to recognize (due to their relatively dense distribution) but easy to classify (due to their proximity to the MDS center). Inversion was expected to enhance these differences in face recognition (by interrupting the encoding of typical faces), but not in classification (which does not require differentiation among faces).

2. Experiment I

The main purpose of Experiment 1 was to measure the efficacy of the MDS model in accounting for the speed and accuracy of upright and inverted face recognition. Upright faces were expected to be better (faster and more accurately) recognized than inverted faces. Similarly, distinctive faces were expected to be better recognized than typical faces. Furthermore, the inversion effect was expected to be larger for the typical than for distinctive faces.

In addition, since the distance from the center of the MDS is defined by all facial dimensions, it was reasonable to assume that it would better predict the speed and accuracy of face recognition than each of the 21 dimensions alone. Finally, as noted above, comparison of the relative importance of the factors for the recognition of upright and inverted faces was expected to distinguish between the quantitative and qualitative approaches to the facial inversion effect.

2.1 Method

2.1.1 Participants

Forty students (half females and half males) participated in the experiment. Participants' ages ranged between 20 and 32 years (M: 23.95, SD: 2.60).

2.1.2 Stimuli and material

Two hundred frontal photos of faces were used as stimuli. The faces were all with neutral expression, without glasses, beards or moustaches, and with hair and ears removed (by Adobe Photoshop 6.0 ME; see Figure 1). The faces which were placed on a white background were about 16 x 11 cm (thus preserving the faces' original proportions), with a

resolution of 72 pixels. The faces were presented by a Pentium 2 computer on a 17" screen with SuperLab Pro for Windows.



Fig. 1. Fig. 1. Example of a female face (right) and a male face (left)

The faces were ranked for distinctiveness in a previous study (Catz et al., 2009) by assessing the relative ease of spotting them in a crowd (Chiroro & Valentine, 1995; Tanaka et al., 1998; Valentine & Bruce, 1986a,c; Valentine et al., 1995; Valentine & Endo, 1992). On the basis of these rankings, faces above the median were considered typical, and those below the median were considered distinctive. The 200 faces were then subdivided into five groups of 40 faces; half distinctive and half typical.

2.1.3 Procedure

The experiment consisted of two stages: learning and testing. In the learning stage the participants were asked to remember 20 faces (10 distinctive and 10 typical). The faces were randomly presented for 3s each with 1s interstimulus interval during which a blank white screen appeared.

In the test stage, which began one minute after the conclusion of the learning stage, the participants were presented with 40 faces; half typical and half distinctive. In each category of faces, half were familiar (presented in the first stage) and half were unfamiliar (new faces). Following the presentation of each face the participants pressed, as quickly as they could, the "M" key, marked "yes", when they considered the face to be familiar, and the "C" key, marked "no", when they considered it to be unfamiliar. The faces were presented for an unlimited duration, and once a response was made, a blank white screen appeared for 1s before the next face was shown. Both reaction time (RT) and accuracy were recorded.

The 20 faces which were familiar to half of the participants were unfamiliar to the other half, and vice versa. Half of the familiar faces and half of the unfamiliar faces were presented in

the upright position, and half were inverted. For each half of the participants the inverted and upright faces were interchanged.

Since the 200 faces were subdivided into 5 subgroups of 40 faces each, 30 seconds after the termination of the test stage, another session began with new faces from another subgroup and so forth. The first six pictures served as practice trials and were not included in data analysis.

2.2 Results

Mean RTs and the number of hits, misses, false alarms and correct rejections were calculated for both upright and inverted faces. RTs above 5000ms were considered errors, and RTs deviating more than 2 SD from each participant's mean RT were adjusted to fit his or her minimal or maximal RT. Hit rate was calculated by adding 0.5 to the number of hits and dividing it by the number of hits plus the number of misses plus 1. Similarly, false alarm rate was calculated by adding 0.5 to the number of false alarms and dividing it by the number of false alarms plus the number of correct rejections plus 1. This procedure produced a Z-score range of -1.86 to +1.86 rather than $-\infty$ through $+\infty$ (Snodgrass & Corwin, 1988; Wright, Boyd, & Tredoux, 2003). d' was calculated by deducting the false alarm Z-score from the hit Z-score.

In order to test trade-off effects between the RT and d' , Pearson correlations for upright and inverted faces were calculated. No significant correlations were found; $r(198)=-.07$, $p>.05$ and $r(198)=-.04$, $p>.05$, respectively.

2.2.1 Predicting face recognition by the MDS

Four stepwise regressions, two for the upright and two for the inverted faces, were administered for d' (regressions for RTs were discarded due to low betas and negligible explained variance). For two of the regressions (one for upright- and one for inverted-faces) the predicting variables were distance from the center and the six MDS factors mentioned above: Size, Form, Mouth, Eyes, Face Appearance and Nose through Eyebrows. In the other two regressions the predicting variables were the six MDS factors only.

For the upright faces, Distance and Nose through Eyebrows had a significant contribution to the explained variance. However, for the inverted faces, Eyes and Face Appearance significantly contributed to the explained variance (Table 1).

Step	Variables	B	SE B	β	ΔR^2	R^2
d' - Upright faces						
1	Distance	.160	.036	.302***	.080***	.080***
2	Nose through Eyebrows	-.100	.043	-.157*	.024*	.104***
d' - Inverted faces						
1	Eyes	.092	.030	.213**	.049**	.049**
2	Face Appearance	.063	.026	.165*	.027*	.076**

* $p < .05$ ** $p < .01$ *** $p < .001$

Table 1. Stepwise regressions for predicting d' by the distance from the center and the six MDS factors

When distance was excluded from the regressions, Eyes and Face Appearance had a significant contribution to the explained variance for the recognition of both upright and inverted faces (Table 2).

Step	Variables	B	SE B	β	ΔR^2	R ²
d' - Upright faces						
1	Eyes	.068	.030	.157*	.028*	.028*
2	Face Appearance	.059	.027	.155*	.023*	.051**
d' - Inverted faces						
1	Eyes	.092	.030	.213**	.049**	.049**
2	Face Appearance	.063	.026	.165*	.027*	.076***

* p<.05 ** p<.01 *** p<.001

Table 2. Stepwise regressions for predicting d' by the six MDS factors

Stepwise regression is a computer-generated analysis in which the computer enters variables, one by one, according to their contribution to the explained variance. The variable entered first is the one with the highest correlation with the predicted variable. The variable entered on the next step is the one with the largest partial correlation with the predicted variable, which reflects the variable's contribution to the remaining unexplained variance. Further steps are carried out by the computer until no more variables have significant contributions for explaining the variance and are therefore left out of the regression. Thus, even slight differences between the correlations of predicting variables with the predicted one might alter the course of the regression. Therefore, correlations between the predicted variable (d') and the predicting variables (the factors and the distance) were carried out. As Table 3 shows, for upright faces, the correlation between d' and Distance, which was entered first, is considerably higher than those between it and the other variables. For inverted faces, although the correlations between d' and Eyes was a bit higher, Distance and Face Appearance were similarly high.

Predicting variables	d' for Upright Faces	d' for Inverted Faces
Distance	0.28**	0.21**
Size	0.04	-0.10
Form	0.05	0.07
Mouth	0.03	-0.01
Eyes	0.17*	0.22**
Appearance	0.16*	0.18*
Nose Through Eyebrows	-0.12	-0.06

* p<.05 ** p<.01

Table 3. Correlations between d', distance from the center, and the six MDS factors

In order to account for the relative contributions of all variables, four simultaneous regressions, similar to those described above, were carried out. For upright faces, Distance, Size, Form, Mouth, and Nose through Eyebrows had significant contributions to the explained variance. For inverted faces, Distance and Size significantly contributed to the explained variance (Table 4).

Distance is a measure based on all six factors. Evaluation of the relative contributions of each factor alone was done by two additional regressions (one for the upright and one for the inverted faces) with Distance excluded. Table 5 shows, Face Appearance and Eyes had significant contributions to the explained variance.

	Variables	B	SE B	β	R ²
d' - Upright faces	Distance	.302	.069	.569***	
	Size	-.053	.027	-.162*	
	Form	-.064	.028	-.212*	
	Mouth	-.068	.029	-.184*	
	Eyes	-.010	.034	-.023	
	Appearance	-.019	.032	-.050	
d' - Inverted faces	Nose through Eyebrows	-.131	.045	-.205**	.151***
	Distance	.195	.069	.370**	
	Size	-.076	.027	-.235**	
	Form	-.029	.028	-.096	
	Mouth	-.054	.030	-.147	
	Eyes	.047	.034	.109	
	Appearance	.013	.032	.034	
Nose through Eyebrows	-.062	.046	-.097	.133***	

* $p < .05$ ** $p < .01$ *** $p < .001$

Table 4. Simultaneous regressions for predicting d' by the distance from the center and the six MDS factors

	Variables	B	SE B	β	R ²
d' - Upright faces	Size	.013	.023	.041	
	Form	.018	.021	.060	
	Mouth	-.001	.026	-.002	
	Eyes	.062	.031	.143*	
	Appearance	.061	.027	.160*	
	Nose through Eyebrows	-.064	.045	-.100	.066*
d' - Inverted faces	Size	-.033	.023	-.103	
	Form	.024	.021	.081	
	Mouth	-.011	.026	-.029	
	Eyes	.093	.030	.216**	
	Appearance	.065	.026	.171*	
	Nose through Eyebrows	-.018	.044	-.029	.097**

* $p < .05$ ** $p < .01$

Table 5. Simultaneous regressions for predicting d' by the six MDS factors

2.2.2 Inversion effects and distinctiveness

Two ANOVAs with repeated measurements were carried out in order to test the interactive effect of inversion and distinctiveness on face recognition. In order to make the dichotomy between distinctive and typical faces clear-cut, the 40 highest ranking faces on the distinctiveness scale were considered typical, and the 40 lowest ranking faces were considered distinctive.

As Table 6 shows, recognition of upright faces was significantly faster than that of inverted faces, $F(1,78)=28.86$, $p < .001$, $\eta^2=0.270$, and recognition of distinctive faces was significantly

faster than that of typical faces, $F(1,78)=15.07$, $p<.001$, $\eta^2=0.162$. There was no significant interaction between the two, $F(1,78)=0.17$, n.s., $\eta^2=0.002$.

Accuracy of face recognition was significantly higher for upright than for inverted faces, $F(1,78)=53.09$, $p<.001$, $\eta^2=0.405$, and accuracy for distinctive faces was significantly higher than that for typical faces, $F(1,78)=29.52$, $p<.001$, $\eta^2=0.275$. There was no significant interaction between the two, $F(1,78)=1.58$, n.s., $\eta^2=0.020$.

Measure		Upright		Inverted		Overall	
		M	SD	M	SD	M	SD
Distinctiveness							
RT	distinctive	1277.96	220.22	1509.99	297.54	1393.97	202.09
	typical	1446.11	308.48	1716.53	359.37	1581.32	228.79
	overall	1362.03	279.42	1613.26	343.89	1487.65	234.28
d'	distinctive	1.83	0.75	1.00	0.81	1.41	0.62
	typical	1.04	0.67	0.45	0.56	0.74	0.47
	overall	1.43	0.81	0.72	0.74	1.08	0.64
Distance from the center							
RT	distant	1246.10	177.18	1543.69	327.30	1394.90	206.76
	near	1410.78	318.30	1555.53	293.68	1483.15	229.50
	overall	1328.44	269.03	1549.61	309.03	1439.03	221.54
d'	distant	1.75	0.79	0.81	0.77	1.28	0.69
	near	1.19	0.71	0.42	0.67	0.80	0.52
	overall	1.47	0.80	0.61	0.74	1.04	0.65

Table 6. Means and SDs for RT and accuracy of face recognition of upright and inverted faces by distinctiveness, distance from the center and density

2.2.3 Inversion effects and distance from the center

Two ANOVAs with repeated measurements were carried out in order to test the interactive effect of inversion and distance from the center of the MDS on face recognition. In order to make the dichotomy between the near and the distant faces clear-cut, the 40 lowest ranking faces on the distance index were considered "near" the center of the MDS, and the 40 highest ranking faces on that index were considered "distant" from the center.

As Table 6 shows, recognition of upright faces was significantly faster than that of inverted faces, $F(1,78)=28.93$, $p<.001$, $\eta^2=0.271$, but recognition of distant faces was not significantly faster than that of faces near the center, $F(1,78)=3.27$, n.s., $\eta^2=0.040$. There was no significant interaction between the two, $F(1,78)=3.46$, n.s., $\eta^2=0.042$.

Accuracy of face recognition was significantly higher for upright than for inverted faces, $F(1,78)=84.66$, $p<.001$, $\eta^2=0.520$, and accuracy for distant faces was significantly higher than that for faces near the center of the MDS, $F(1,78)=12.23$, $p<.001$, $\eta^2=0.136$. There was no significant interaction between the two, $F(1,78)=0.82$, n.s., $\eta^2=0.010$.

2.3 Discussion

The purpose of Experiment 1 was to test which of the MDS facial characteristics best predict recognition speed and accuracy of upright and inverted faces. When the distance from the center of the MDS and the six MDS factors were included as predictors, in three of four regressions, distance contributed significantly more than the other factors. However, when

only the six MDS factors were included as predicting variables, for all regressions (simultaneous and stepwise), and for the two facial orientations (upright and inverted), only Eyes and Face Appearance had significant contributions to recognition. Thus, when the MDS factors are considered alone, face recognition seems to rely on featural characteristics. However, when distance is introduced, face recognition seems to be better accounted for, thus supporting the notion that face recognition is a holistic process (Bartlett & Searcy, 1993; Carey & Diamond, 1977; Diamond & Carey, 1986; Farah et al., 1995; Farah et al., 1998; Leder & Bruce, 1998). Distance may be considered a holistic measure since it is a mathematically derived aggregate of the distances of all 21 dimensions from a prototypical face. In other words, unlike distinctiveness which may rely on a single feature, distance relies on all dimensions and is therefore a holistic measure (Catz et al., 2009).

Most researchers agree that recognition of upright faces is holistic in nature, yet a controversy exists as to whether inverted faces are similarly processed holistically (Collishaw & Hole, 2000; Kanwisher et al., 1998; Nachson & Shechory, 2002; Rakover & Teucher, 1997; Valentine, 1988, 1991a; Valentine & Bruce, 1988) or feature-by-feature (Bartlett & Searcy, 1993; Carey & Diamond, 1977; Farah et al., 1995; Farah et al., 1998; Leder & Bruce, 1998; Sergent, 1984). The data of Experiment 1 seem to be relevant to this controversy. When implementing a stepwise regression with Distance and the six MDS factors to upright and inverted face recognition, the variables which emerged as significant in the upright condition were holistic or configural - Distance and Nose through Eyebrows, whereas the variables which emerged as significant in the inverted condition were featural - Eyes and Face Appearance. This difference may suggest that recognitions of upright and of inverted faces are qualitatively different from each other. Yet, when implementing a simultaneous regression for both upright and inverted faces, the variables which emerged as significant were holistic, thus supporting the idea of a quantitative difference between the two processes.

This apparent contradiction may be resolved by considering the correlations between d' for face recognition and its predicting variables. The correlations showed that on one hand, the same three characteristics - Distance, Eyes and Face Appearance - are significantly correlated with both upright and inverted d' for face recognition. However, the correlation between Distance and d' for upright faces is higher than that for inverted faces. It therefore seems that recognition of both upright and inverted faces relies on holistic as well as on featural properties. However, whereas for upright faces the holistic component may be stronger than the featural components, for inverted faces all components, holistic as well as featural, are about equally strong.

As predicted by the MDS model, upright and distinctive faces were consistently recognized faster and more accurately than inverted and typical faces. Similarly, faces located far from the center were recognized more accurately (though not significantly faster) than faces located near the center (Johnston, Milne et al., 1997; Lewis & Johnston, 1997, 1999a; Tanaka et al., 1998; Valentine, 1991a,b, 2001; Valentine & Bruce, 1986a,b,c; Valentine & Ferrara, 1991; Wickham et al., 2000).

However, contrary to expectation, no interaction was found between inversion and facial properties (distinctiveness and distance from the center). This finding clearly does not support the notion that the harder the face recognition, the greater the inversion effect (Valentine, 1991a), but it is in line with the results of the present experiment which demonstrate a quantitative rather than a qualitative difference between the recognitions of upright and of inverted faces.

3. Experiment II

The purpose of Experiment 2 was to test the effects of inversion and distinctiveness on face recognition and classification. According to the MDS model (Valentine, 1991a), upright faces are expected to be recognized and classified faster and more accurately than inverted faces. Since distinctive faces are located more sparsely and farther away from the center than typical faces, they should be easier to recognize but harder to classify. Finally, though not supported by the results of Experiment 1, it made sense to assume that since recognition is affected by density, inversion effect would be greater for face recognition of typical than of distinctive faces. Unlike face recognition, classification is based on differentiation between classes of stimuli and not between individuals, and consequently inversion effect is not supposed to be influenced by traits that differentiate among faces. Therefore, inversion effects for classification of typical and distinctive faces were expected to be similar.

3.1 Method

3.1.1 Participants

Thirty two students (half females and half males) participated in the experiment. Participants' ages ranged between 18 and 30 years (M: 24.13, SD: 2.90).

3.1.2 Stimuli and material

Recognition task: 40 of the highest ranking (typical) and 40 of the lowest ranking (distinctive) photos of faces used in Experiment 1 served as stimuli for the recognition task.

Classification task: The 80 faces, modified by Adobe Photoshop 6.0 ME so that the eyes, nose, and mouth were each surrounded by a rectangle, were considered "faces". "Non-faces" were created by jumbling the internal features of these stimuli (Figure 2).



Fig. 2. Example of a "face" stimulus (right) and a "non-face" stimulus (left)

3.1.3 Procedure

All participants performed both, the recognition and the classification tasks in that order to avoid possible bias on the recognition task due to pre-exposure of the faces in the classification task.

Recognition task: The procedure of the recognition task was the same as in Experiment 1, except that in the learning stage 40 faces (20 distinctive and 20 typical) were presented, and in the test stage 80 faces were presented (half of which were familiar and half unfamiliar).

Classification task: A total of 320 stimuli, 160 "faces" and 160 "non-faces" (in each category, half upright and half inverted) were randomly presented to the participants as described in Experiment 1. Following the presentation of each face the participants pressed, as quickly as they could, the "M" key, marked "yes", when they considered the stimuli to be "face", and the "C" key, marked "no", when they considered it to be "non-face". Exposure duration and response pattern were the same as in Experiment 1.

3.2 Results

Mean RTs and d' s were calculated for "face" recognition and classification. RT above 5000ms were considered errors, and RTs deviating more than 2 SD from each participant's mean were adjusted to fit his or her minimal or maximal RT. ANOVA with repeated measurements revealed no gender effects (of both participants and facial stimuli). Therefore, all responses were pooled together for analysis across gender.

3.2.1 Recognition

In order to test the effects of inversion and distinctiveness on face recognition, two ANOVAs with repeated measurements were conducted, one for RT and one for accuracy (d'). Pearson correlations between the measures revealed no trade-off effect, $r(30) = -.01$, $p > .05$.

RT for distinctive faces was significantly faster than for typical faces, $F(1,31)=5.42$, $p < .05$, $\eta^2=0.149$, and RT for upright faces was significantly faster than for inverted faces, $F(1,31)=21.83$, $p < .001$, $\eta^2=0.413$. There was no significant interaction between inversion and distinctiveness, $F(1,31)=0.01$, n.s., $\eta^2=0.001$ (Table 7).

Accuracy of face recognition was significantly higher for distinctive than for typical faces, $F(1,31)=8.31$, $p < .005$, $\eta^2=0.211$, and accuracy for upright faces was significantly higher than that for inverted faces, $F(1,31)=80.25$, $p < .001$, $\eta^2=0.721$. The interaction between inversion and distinctiveness, $F(1,31)=4.05$, $p = .05$, $\eta^2=0.115$ was marginal (Table 7). As a paired t -test ($\alpha = .05$) showed, accuracy for upright faces was greater than that for inverted faces for both typical and distinctive faces, but the inversion effect was larger for distinctive than for typical faces. Thus, the difference in accuracy between distinctive and typical faces was for upright faces only.

3.2.2 Classification

In order to test the effect of inversion and distinctiveness on face classification, an ANOVA with repeated measurements was performed on the RT data. Accuracy was not analyzed because of a ceiling effect: Classifications of upright and of inverted faces were 98.87% and 97.63% correct, respectively.

RT for upright faces was significantly faster than for inverted faces, $F(1,31)=28.16$, $p < .001$, $\eta^2=0.476$. Neither the main effect for distinctiveness, $F(1,31)=0.68$, n.s., $\eta^2=0.021$, nor its interactive effect with inversion, $F(1,31)=0.27$, n.s., $\eta^2=0.009$, were significant (Table 7).

Measure		Upright		Inverted		Overall	
		M	SD	M	SD	M	SD
Recognition							
RT	distinctive	1360.87	534.50	1627.38	458.99	1494.12	460.96
	typical	1497.50	564.19	1762.98	578.96	1630.24	522.63
	overall	1429.18	511.79	1695.18	470.63	1562.18	464.18
d'	distinctive	1.49	0.59	0.55	0.62	1.02	0.47
	typical	0.94	0.74	0.40	0.52	0.67	0.54
	overall	1.21	0.48	0.47	0.39	0.84	0.37
Classification							
RT	distinctive	667.97	126.30	719.01	159.48	693.49	140.99
	typical	666.55	141.34	711.23	154.44	688.89	144.34
	overall	667.26	131.80	715.12	155.37	691.19	141.79

Table 7. RT and accuracy of face recognition and RT for classification of upright and inverted faces by distinctiveness

3.3 Discussion

According to the MDS model, distinctive faces should be easier to recognize and more difficult to classify than typical faces. The results of Experiment 2 supported the prediction for recognition but not for classification: Distinctive faces were easier to recognize than typical faces, but the latter were not easier to classify than distinctive faces. A ceiling effect in the classification task, perhaps due to very short RTs, might account for these results.

The existence of an inversion effect was indicated by the easier recognition and classification of upright relative to inverted faces. Due to their greater density, typical faces were expected to be more influenced by the inversion effect than distinctive faces. However, the interaction that was found for recognition accuracy revealed the opposite pattern: The inversion effect was greater for distinctive faces than for typical faces. Inspection of the data raises the possibility that this is a result of a floor effect (very small d') for accuracy of recognition of inverted faces: As expected, accuracy of typical inverted faces was lower than for distinctive inverted faces, but d' was very low and consequently the difference between the accuracy of upright and of inverted faces was small.

4. Conclusion

The present study constitutes a pioneering attempt to systematically explore face recognition, classification, distinctiveness and inversion within the framework of the MDS model.

The MDS model, which began as a metaphor for mental representations of faces (Valentine, 1991a), and has been extensively investigated ever since its conceptualization (e.g. Bruce et al., 1994; Burton & Vokey, 1998; Busey, 1998; Byatt & Rhodes, 1998; Johnston, Kanazawa et al., 1997; Lewis & Johnston, 1997, 1999a,b; Tanaka et al., 1998; Valentine, 2001; Valentine et al., 1995; Valentine & Endo, 1992; Wickham et al., 2000), was only recently empirically validated (Catz et al., 2009). Once validated, it was possible to test some of the model's predictions.

Consistent with previous studies (Lewis & Johnston, 1997; Valentine, 1991a, 2001; Valentine & Bruce, 1986a,c; Valentine & Ferrara, 1991; Wickham et al., 2000), faces which were

distinctive and distant from the center of the MDS were recognized faster and more accurately than those which were typical and close to the center. As well, corroborating earlier studies (e.g., Diamond & Carey, 1986; Valentine, 1988; Yin, 1969, 1978), upright faces were recognized faster and more accurately than inverted faces.

4.1 The inversion effect: Holistic and featural factors

Analysis of the factors that contributed to accurate recognition showed that for both, upright and inverted faces, it is based upon holistic as well as featural factors. However, for upright faces the holistic or configural factor is predominant. As our data show, this distinction is relative rather than absolute. A stepwise regression suggested that recognitions of upright and inverted faces are qualitatively different from each other (Bartlett & Searcy, 1993; Carey & Diamond, 1977; Diamond & Carey, 1986; Farah et al., 1995; Farah et al., 1998; Leder & Bruce, 1998). Yet, a simultaneous regression suggested the idea of a quantitative difference between the two processes (Collishaw & Hole, 2000; Kanwisher et al., 1998; Nachson & Shechory, 2002; Rakover & Teucher, 1997; Valentine, 1988, 1991a; Valentine & Bruce, 1988). Further examination of the correlations between the variables suggested that although both upright and inverted face recognition may rely on holistic as well as on featural properties, upright face recognition is based primarily on holistic components, while inverted face processing relies on both holistic and featural ones.

4.2 The interaction between inversion and distinctiveness

One purpose of the present study was to explore the difference between upright and inverted face recognition in conjunction with distinctiveness. However, five out of six pertinent interactions were insignificant, and the only interaction that was marginally significant yielded a bigger inversion effect for distinctive than for typical faces. Similar findings have been found regarding inversion effect in recognition of other-race faces. Similarly to typical faces, it is difficult to distinguish among other-race faces which are densely located in the MDS. Therefore, recognition of other-race faces is expected to be impaired relative to that of own-race faces in a manner similar to the recognition of typical versus distinctive faces (Valentine et al., 1995; Valentine & Endo, 1992). In the past, some studies have reported greater inversion effects for other-race than for own-race faces (Valentine & Bruce, 1986b), but others have reported the opposite effect (Nachson & Catz, 2003; Rhodes, Brake, Taylor, & Tan, 1989; Sangrigoli & de Schonen, 2004). Still others have found no differences between the two (Buckhout & Regan, 1988; James, Johnstone, & Hayward, 2001; Rhodes, Hayward, & Winkler, 2006). Indeed, the few studies which have uncovered race differences have also reported some insignificant results.

Presumably, inversion requires mental rotation which impairs face encoding regardless of its specific features (Collishaw & Hole, 2000; Rakover & Teucher, 1997; Valentine & Bruce, 1988; Yin, 1969). Therefore, regardless of the facial distinctiveness, distance from the center and other properties, upright faces are always better recognized than inverted faces.

The contradictory findings raise the question of whether they are genuine or a methodological artifact. Hopefully, this question will be answered by further research on the inversion effect of faces varying in terms of distinctiveness and race.

In conclusion, the MDS model enhances our understanding of face recognition and classification. Specifically, the model which began as a metaphor, finally became a tangible entity uncovering the differential processes that underlie the recognition of upright and inverted faces.

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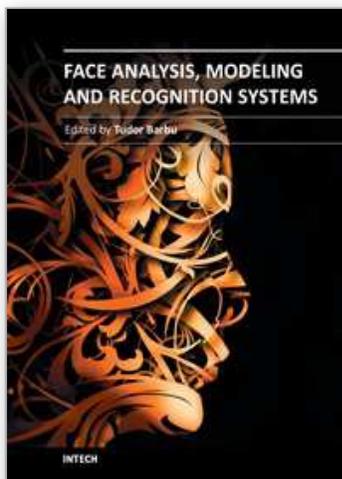
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The purpose of this book, entitled Face Analysis, Modeling and Recognition Systems is to provide a concise and comprehensive coverage of artificial face recognition domain across four major areas of interest: biometrics, robotics, image databases and cognitive models. Our book aims to provide the reader with current state-of-the-art in these domains. The book is composed of 12 chapters which are grouped in four sections. The chapters in this book describe numerous novel face analysis techniques and approach many unsolved issues. The authors who contributed to this book work as professors and researchers at important institutions across the globe, and are recognized experts in the scientific fields approached here. The topics in this book cover a wide range of issues related to face analysis and here are offered many solutions to open issues. We anticipate that this book will be of special interest to researchers and academics interested in computer vision, biometrics, image processing, pattern recognition and medical diagnosis.

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Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China

Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

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