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Original Communication

When Faces Are Heads: View-Dependent Recognition of Faces Altered Relationally or Componentially

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When faces are viewed from different angles the appearance of facial features undergoes dramatic changes. We investigated two types of 3D-head models in frontal and three-quarter views, varying either in componential information such as different eyes, mouths and noses, or in relational information. Variations of the latter can only be investigated using 3D-head versions. Experiment 1 revealed high costs of transfer in recognition performance when views change, that were similar for both componentially and relationally altered faces. In Experiment 2, whole-to-part superiority was investigated by presenting isolated parts of critical features in addition to the whole face. Recognition of the whole face was only superior when views were identical. The results support the hypothesis of picture-based and view-dependent processing. Thus, there seems to be no efficient view-independent representation, at least for relatively unfamiliar faces.

Keywords: holistic processing, face perception, configural and componential processing, relational information, view dependence, 3D, 3-dimensional representation, learn-test compatibility

Faces can be recognized very fast (Carbon, Schweinberger, Kaufmann, & Leder, 2005) and extremely accurately under very delimited presentation conditions (Carbon & Leder, 2005). Moreover, faces can even be recognized despite a number of changes such as modified viewing conditions (Bruce, 1994) and configural alterations (Carbon & Leder, 2006). This flexibility is impressive when taking into account that faces appear very different when seen from different views. For example, when faces turn from frontal to three-quarter views, the nose changes from a "U"-shape to a "<"-shape, and one eye might even be completely concealed. By turning faces, other valuable identification information is also lost such as the symmetry line of the face and the ear that is turned away. Most importantly, the entire configural arrangement of facial features is dramatically altered.

There has been a long-lasting debate regarding theories of object and face processing on whether identification is based on either view-dependent or view-independent processing. Some researchers have proposed that all object recognition proceeds on the basis of so-called structural descriptions which consist of some sort of three-dimensional (3D) representation. Once established, structural descriptions facilitate the recognition of objects relatively independent of view (Marr, 1982). Biederman and Kalocsai (1997) proposed a model of object recognition in which an object is defined by the essential and characteristic qualitative components and the spatial arrangement of these components. According to their model, object recognition is relatively view-independent because the appearance of qualitative parts (non-accidental properties) does not change substantially when objects are rotated. In contrast, as faces have the same parts in approximately the same relations, it is essential to process the second-level relationship between these parts (Diamond & Carey, 1986; Leder & Carbon, 2006). However, this type of information is strongly distorted when faces are rotated horizontally. Moreover, face processing is mainly based on what is called holistic processing (Leder & Carbon, 2005; Tanaka & Farah, 1993), however, the processing of a whole face seems to be rather difficult when a face is turned away.

With face recognition, it was assumed that recognition is mediated via structural representations which "capture those aspects of the structure of a face essential to distin-

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guish it from other faces" (Bruce & Young, 1986, p307). In face identification tasks, modifying the type of presentation, for example, the clipping size, between learning phase and test phase has proved to reduce the probability of recognition (Leder & Carbon, 2004, 2005). Similarly, this was also found for changes in view between learning and test conditions (Bruce, 1982; Bruce, Valentine, & Baddeley, 1987; Krouse, 1981), particularly when participants were not familiar with the faces (Valentin, Abdi, & Edelman, 1997).

These findings support the hypotheses that two-dimensional (2D) views play an important role in object and face recognition and that view-dependent processing might be predominant (Biederman & Kalocsai, 1997; Hill, Schyns, & Akamatsu, 1997; Schyns & Bülthoff, 1993; Tarr & Pinker, 1990). Schyns and Bülthoff (1993) investigated which facial attributes determine the recognition of a face upon a single view. Using 3D-laser scans of faces, they found that there was no viewpoint preference for recognition when all views had been encountered during the learning phase of a recognition experiment. In a second experiment, they found evidence for the three-quarter view to be preferred over the full view because the former presumably allowed for better face encoding and recognition. A three-quarter view superiority in face recognition was also found in the recognition of unfamiliar faces (Bruce et al., 1987) and particularly for left three-quarter views (Sieroff, 2001).

In many face recognition studies facial components such as eyes, noses and mouths are often replaced between learning and test phase, in order to create locally distinct changes (Rhodes, Brake, & Atkinson, 1993; Tanaka & Farah, 1993). This procedure, however, confounds two types of information as not only new shapes and textures of components are introduced, but presumably the microstructure of relations in a face is also changed (Leder & Carbon, 2006). Therefore, exchanging components affects configural processing locally, sometimes producing inversion effects (Rhodes, 1993). It seems impossible to completely separate componential alterations to faces from relational changes. Therefore, we compared the processing of faces that differ in their individual components to faces differing only in terms of their relational properties. Importantly, the amount of configural processing required for faces differing in componential aspects is much smaller than that required for faces that differ only in relational aspects (Leder & Carbon, 2006).

If faces are special in that their processing particularly relies on second-order relational properties compared to other classes of stimuli (e.g., Diamond & Carey, 1986; Leder & Carbon, 2006), then we need to know whether this type of information can be inferred over different views or not. This is essential to the way we recognize faces despite changes in view. Testing different views of distinctive relational properties can only be achieved by using real heads or 3D-head models. 3D-head models allow for keeping all other dimensions constant across different stimuli, and producing faces which only have one distinctive facial component or one distinctive relationship between the facial components. Therefore, we used pictures of 3D-face models from the MPI face database (Blanz & Vetter, 1999).

In the present study, we used 3D-head models derived from laser scans to test the effects of changes in view between learning and test phase in order to better understand what type of information in faces is encoded in a view-dependent manner. Moreover, we tested faces that differed only with respect to components such as eyes, noses and mouths, or with respect to the spatial relationship between these components such as nose-mouth distances.

In Experiment 2, we addressed another important question in face perception research. There is an ongoing debate concerning holistic versus featural processing of faces. The superiority of holistic processing has often been demonstrated by enhanced processing of critical features presented as part of complete faces in comparison to presenting the same critical facial features as parts isolated from the overall context of the face (Tanaka & Farah, 1993). We tested (a) whether processing of componential and relational facial information is similarly influenced by the clipping size of the presentation (*Full* vs. *Part*) and (b) whether both types of information are based on view-dependent processing or not.

In sum, Experiment 1 investigated how changes of view between learning and test phase affect the recognition of faces that differ from each other only with respect to componential or relational information. In Experiment 2, additionally whole-to-part effects were tested, and, again, whether or not they are influenced by view changes.

Experiment 1

In Experiment 1, the identities of two sets of faces were learned. Within one set the faces differed from each other with respect to components, whilst in the other set they differed with respect to relational information. All versions were generated from one starting face and differed from one another in only one critical feature (either one distinctive facial component or one distinctive spatial relationship between components). Participants learned the faces in either the frontal or three-quarter (3/4) view and later had to recall the stimuli including both views.

Method

Participants

32 graduate students and undergraduates (30 female, mean age 23.4 years) from the Freie Universität Berlin received course credit for their participation in this study. All participants were tested individually.

Materials

Two sets of stimuli were created. Each set contained six faces and names. The faces were based on faces from the MPI face database using the morphable model for 3D faces by Blanz and Vetter (1999). This technique allows changes to relational aspects to be made without altering facial components, which is ideal for the aim of this study. Figure 1 shows three versions of the componential (frontal and ¾ view, produced by a 30-degree change) and three versions of the relational set[1]. Distinct relational versions were created by changing the distance between two facial features (e.g., eyes-nose, nose-mouth). Similarly, to create distinct componential versions, the eye region, mouth or nose were replaced by components from different head models. The resulting heads contained no textures, but were Lambertian shaded to increase their realism. With Lambertian shading, the brightness of each point in the image is proportional to the cosine of the angle between the surface normal and the incident light at each point. The size of each image of the face approximated 8.5 cm in height and 6 cm in width, with participants sitting circa 60 cm away from the screen, thus resulting in a visual angle of 8.1° × 5.6°.

Twelve four to five-letter names were selected, which were randomly assigned to one of the two sets: Moni, Anne, Paula, Gerda, Maria, Rita, Ruth, Ulla, Uschi, Beate, Petra, and Nina.

The experiment was conducted on a Macintosh computer using a 15 inch CRT color monitor with a screen resolution of 1024×768 pixels, 32 768 colors, and a refresh rate of 72 Hz.

1 A colored version of the stimuli is available on the web site http://www.experimental-psychology.com.

Procedure and Design

Participants were tested individually on either the componential or the relational face set. The allocation of names to faces was counterbalanced across the two sets so that each face was learned with two different names (by different participants). The order of trials was randomized within each series by an experimental program.

Pre-tests revealed that participants had difficulty noticing that the faces in the relational versions differed from one another when they were presented in successive order. As we did not intend to inform the participants about which dimensions the faces differed in, all faces in each set were simultaneously shown on the screen at the beginning of the experiment. The instruction during this pre-exposure stressed that a set of similar faces would be used in this experiment. The faces were presented for 20 seconds.

In the learning phase, five learning series followed, in which each of the six stimuli were presented individually on the screen for eight seconds, accompanied by an explanation stating "This is" along with the corresponding name. Within each of these series the stimuli were presented in a randomized order. Half of the participants saw the ¾ views in the learning phase; the other half saw the frontal faces. Half the participants learned the relationally altered faces in the learning phase; the other half learned the componentially altered ones. Both between-subjects factors were fully balanced. All participants had to reach a learning criterion of 100% correct responses in a subsequent criterion test series, which was analogous to the test phase. If they failed, three further learning sessions followed, lasting until they fulfilled the criterion.

The test phase was identical to Leder and Bruce (2000) in that a cued name recall task was used. Leder and col-

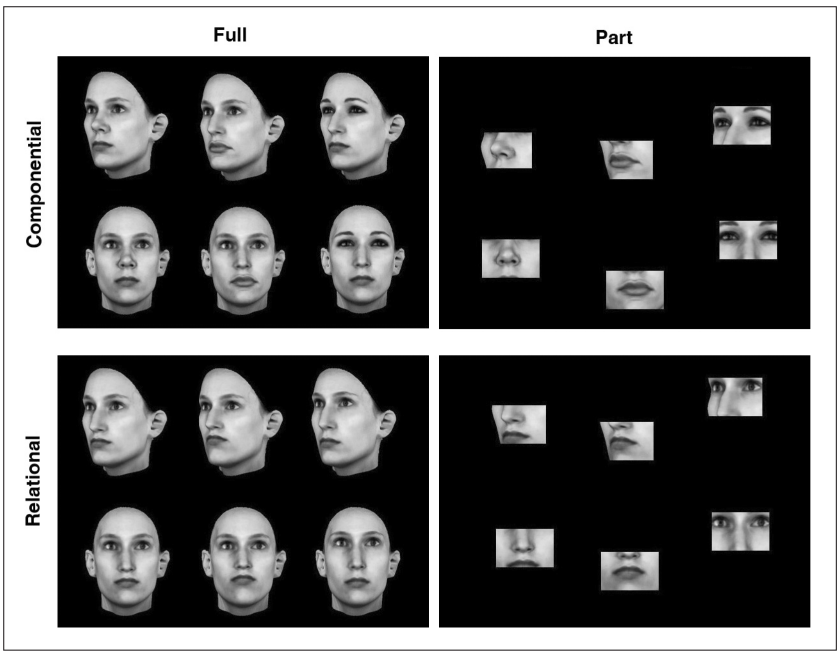

Figure 1: On the left side, a selection of three stimuli used in the study is shown. In the upper box componential faces are shown, in the lower box corresponding relational faces. On the right side, additional Part faces used in Experiment 2 are shown by using the part-based versions of the left faces.

leagues (e.g., Leder & Bruce, 2000; Leder & Carbon, 2006) demonstrated that this task is suitable for detecting subtle differences in the recognition of rather similar faces. The memory load for the names is reduced in this approach, as all names are shown with the stimulus and do not require memory search.

The test series began after a short break. During the test phase, all six names were shown together with a number between 1 and 6 shown underneath. The numbers assigned were added to indicate which number was to be selected on the keyboard for each name. In each trial, one test face was presented for an unlimited presentation time along with the list of names. Participants were instructed to identify the number assigned to the name they thought was the stimulus person's name (name selection task). After the decision was made, the next trial started automatically. Each face was presented twice at every view (frontal and ¾ view) yielding a total of twenty-four trials at test for each session plus two preceding practice trials that were excluded from further analyses. The order of presentation of the stimuli at test was randomized for each participant.

Results and Discussion

The mean percentage of correctly recognized faces was used as dependent variable. Table 1 shows the main results of Experiment 1.

The data were analyzed with a repeated measure ANOVA using *Learnview* (view in the learning phase: frontal vs. ¾ view) and *Version* (relational vs. componential) as between-subjects factors, and *Testview* (view in the test phase: frontal vs. ¾ view) as within-subject factor.

There was a main effect of *Version*, $F(1, 28) = 7.471$, $p = .0107$, $\eta_p^2 = .211$. Although there were no further main effects of *Learnview* or *Testview*, there was a significant interaction between *Learnview* and *Testview*, $F(1, 28) = 71.944$, $p < .0001$, $\eta_p^2 = .719$, illustrated in Figure 2. No other effects were significant.

Table 1
Mean results of correct recognition in Experiment 1 for all conditions at test, for both learning views and both learning versions. Data is given as percentage correct, SDs *are in parentheses*

	LEARN			
	Frontal Relational	3/4 Relational	Frontal Componential	3/4 Componential
Testview				
Frontal	83.3 [14.8]	63.6 [18.4]	96.9 [4.3]	72.9 [14.6]
3/4	66.7 [12.6]	79.2 [17.8]	78.1 [9.9]	92.7 [12.1]

The lack of a main effect of the learning view indicates that both views used here enabled recognition in a comparable way. Another explanation for this insignificant main effect could be that the specific selection of facial changes covered possible advantages for one specific view, for instance, the ¾-view advantage effect described by Bruce et al. (1987). Furthermore, the componential versions were better recognized than the relational versions (rate of correct trials for componential: 85.2%, relational: 73.2%). This is not unexpected as the pure relational information in reality hardly ever distinguishes more than two faces, and such identical twin faces are encountered extremely rarely (Stevenage, 1998). However, the accuracy level in the recognition of relationally altered faces was still high enough to compare with that of componentially altered faces in a reasonable way, although we cannot exclude the possibility that relationally altered faces, as operationalized here, were simply less distinctive per se.

Most interestingly, the congruence of views in the learning phase and the test phase (learn-test compatibility) showed a clear effect. Both facial versions were more difficult to recognize in the "altered view" of the test phase. This result indicates that unfamiliar faces, after having been familiarized in the learning procedure, are not processed in a view-independent way. This in turn, leads to transfer costs due to changing views for both componential *and* relation-

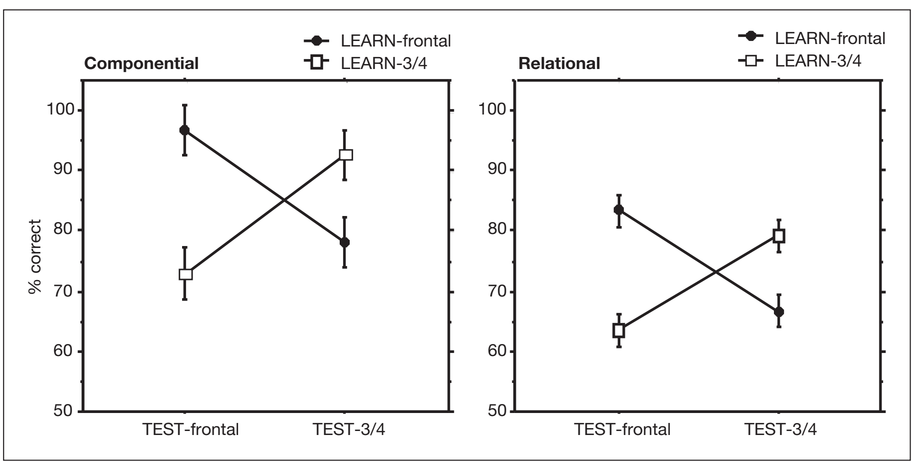

Figure 2: Interaction between factor *Learnview* and *Testview* found in Experiment 1, separately for both *Versions* (relational and componential). Error bars show 95% confidence intervals according to the calculation proposed by Loftus and Masson (1994) for repeated measures.

al information. We further analyzed this interaction by testing the simple main effects of *Testview* under both *Learnview* conditions. This analysis revealed that *Testview* was significant for the frontal *Learnview*, $F(1, 28) = 35.997$, $p < .0001$, $\eta_p^2 = .562$, as well as for the ¾ *Learnview*, $F(1, 28) = 35.946$, $p < .0001$, $\eta_p^2 = .562$.

However, the participants might have used an artificial strategy to learn these faces as the stimuli are relatively hard to distinguish from one other. The task requires distinguishing faces that vary in componential or relational information, whereby both performances are thought to represent the needs of everyday face processing. However, in everyday life faces can be differentiated by simultaneous changes of componential *and* relational aspects.

The question of view dependence of critical features is addressed further in Experiment 2. Here, it was investigated whether changes of view affect the recognition of whole versus part face information. Therefore, an additional presentation condition at test was introduced, in which only parts of faces were shown. If the participants focus on the critical parts, then there should be no differences between wholes (full faces) and parts. As in Experiment 1, relational and componential information were used to test these hypotheses. Apart from whole-to-part effects, Experiment 2 also provides a replication of the view effects found in Experiment 1.

Experiment 2

Experiment 2 used a whole-to-part comparison to investigate the role of holistic processing in 3D heads, differing in either componential or relational information.

Method

Participants

24 graduate students and undergraduates (20 female, mean age 27.8 years) from the Freie Universität Berlin received course credit for participation in this study. All participants were tested individually.

Materials

The same stimuli as in Experiment 1 were used. For each face, an additional part version was created, which included the critical part in both views. This was done for all six faces of each version. Twelve three to five-letter names were selected and randomly assigned to one of the two sets. The following names were used: Maria, Anna, Susi, Gabi, Moni, Sarah, Petra, Ute, Sandra, Ulla, Sonja and Anne.

Procedure and design

Participants were tested with only one of the two sets (relational or componential face stimuli). Again, the order of testing and allocation of names to faces were counterbalanced across the two sets. The experiment was conducted on a Macintosh computer with a 17-inch CRT monitor. Other technical details were identical to those in Experiment 1.

The procedure of the learning phase were the same as in Experiment 1. The first trial of the test phase served the purpose of a practice trial. This was a randomly selected extra trial that was not included in any further analysis. At test, all full and part versions of each face were shown in both views (frontal and ¾).

Results and Discussion

The percentage of correctly recognized faces was calculated for each participant and condition as a dependent variable (Table 2). The whole-to-part-superiority, calculated as the performance for full faces minus the corresponding part version, indicates higher recognition rates for the full face over its individual parts.

The data were analyzed with a repeated measure ANOVA using *Learnview* condition (view in the learning phase;

Table 2
Mean results of Experiment 2 for all conditions at test, for both learning conditions (REL or COMP). Whole-to-part superiority effects (WPS) are also shown. Data is given as percentage correct, SD*s are in parentheses*

		LEARN			
		Frontal Relational	3/4 Relational	Frontal Componential	3/4 Componential
Test Frontal	Full	72.2 [27.2]	47.2 [19.5]	80.5 [24.5]	55.6 [34.4]
	Part	58.3 [25.3]	38.9 [20.2]	55.6 [29.2]	52.8 [28.7]
	WPS	*13.9*	*8.3*	*24.9*	*2.8*
Test 3/4	Full	47.2 [16.4]	63.9 [24.5]	75.0 [9.0]	88.9 [13.6]
	Part	36.1 [22.2]	41.7 [20.4]	69.5 [19.5]	77.8 [17.2]
	WPS	*11.1*	*22.2*	*5.5*	*11.1*

frontal vs. ¾ view) and *Version* (relational vs. componential) as between-subjects factors. *Testview* (view in the test phase; frontal vs. ¾ view) and *Testsize* (size in the test phase; Part vs. Full face) were used as within-subject factors.

The analysis revealed a significant main effect of *Version,* $F(1, 20) = 7.645$, $p < .02$, $\eta_p^2 = .276$ (proportion correct of componential: .694, relational: .507), and a main effect of *Testsize,* $F(1, 20) = 7.774$, $p < .05$, $\eta_p^2 = .280$ (Full: .663, Part: .538). Additionally, there was an interaction between *Learnview* and *Testview* with $F(1, 20)=16.857$, $p < .001$, $\eta_p^2 = .457$. No other effects were significant, although there was a trend for a three-way interaction between *Learnview, Testview* and *Testsize,* $F(1, 20) = 3.713$, $p = .068$, *ns.*

We further analyzed this interaction by testing the simple main effects of *Testview* under both *Learnview* conditions. This analysis again revealed that *Testview* was significant for the frontal *Learnview,* $F(1, 20) = 12.922$, $p = .0018$, $\eta_p^2 = .392$, as well as for the ¾ *Learnview,* $F(1, 20) = 4.892$, $p = .0388$, $\eta_p^2 = .197$. The interaction between *Learnview* and *Testview* indicates compatibility effects for both views in this experiment, which were similar to the findings of Leder and Carbon (2005) where whole and part presentations were varied between learning and test phase (cf. Leder & Carbon, 2004). As in Experiment 1, after participants had learned the ¾-view faces, they were strongly impaired in correctly identifying the frontal views and vice versa. This supports a view-dependent representation of the (pre-experimentally) unfamiliar faces used here. As in Experiment 1, main effects of view were not found, which indicates that the two views facilitate recognition in a similar way.

The main goal of Experiment 2 was to investigate whole-to-part superiority in the context of the view-dependent processing debate. Overall, the data revealed a superiority of whole-to-part conditions indicated by a significant effect of the *Testsize* factor. However, Table 2 reveals another interesting effect: Whole-to-part-superiority was particularly strong in conditions in which the view of the face had not been altered between learning and test phase.

For a better understanding of this effect, we performed an additional repeated measure ANOVA. A new variable was constructed as the within-subject factor *Compatibility* (compatible vs. incompatible view). In the compatible view condition, the view in the learning phase was the same as in the test phase, whereas in the incompatible view condition the view changed between both phases. Additionally, *Version* (componential vs. relational) was used as between-subjects factor, and *Testsize* (Full vs. Part) as within-subject factor. This ANOVA yielded a main effect of *Version,* $F(1, 22) = 7.145$, $p = .014$, $\eta_p^2 = .245$, *Testsize,* $F(1, 22) = 8.391$, $p = .008$, $\eta_p^2 = .276$, and *Compatibility,* $F(1, 22) = 17.411$, $p < .0001$, $\eta_p^2 = .442$ (compatible: .674, incompatible: .528). The interaction between *Compatibility* and *Testsize* was only found as a trend, $F(1, 22) = 3.861$, $p = .0622$, *ns.* However, concerning this trend, the simple main effects of *Testsize* under both *Compatibility* conditions revealed that there was whole-to-part superiority for compatible trials, $F(1, 22) = 10.347$, $p = .004$, $\eta_p^2 = .320$, but not for incompatible trials, $F(1, 22) = 2.219$, $p = .092$, *ns.* Figure 3 illustrates these differential effects of *Compatibility.*

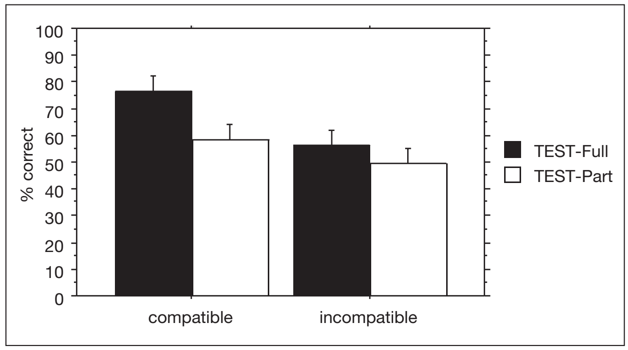

Figure 3: Whole-to-part effects (percentage of correct recognition) for compatible and incompatible trials in Experiment 2. Error bars show 95% confidence intervals according to the calculation proposed by Loftus and Masson (1994) for repeated measures.

Thus, the whole-to-part superiority nearly disappeared when the view was changed. In the face perception literature, whole-to-part superiority is often used to support the hypothesis of holistic processing. With respect to this type of processing, Experiment 2 has shown that whole-to-part superiority can be severely disrupted when the important dimension of view is changed.

However, an alternative explanation for the learn-test compatibility effects observed cannot be ruled out by the current data: According to the rationale of view compatibility, we could also explain the high recognition rate for full faces in the compatible view condition by the fact that in this condition the facial clippings shown in the learning and test phases were also highly compatible. In contrast, part-based faces shown at test were not identical to full faces in the learning phase.

General Discussion

This study demonstrates that the processing of unfamiliar faces is severely disrupted when the view is changed between learning phase and test phase. This was shown in two cued name recall experiments with 3D-head models based on face stimuli from the MPI face database (Blanz & Vetter, 1999). Importantly, when recognition performance was contrasted between faces that had been initially learned in a frontal view and faces that had been learned in a ¾ view there was no specific advantage for either of these views. Thus, the often proposed three-quarter view advantage (Bruce et al., 1987; Sieroff, 2001) was not found here. This corresponds with the recent review of Liu and Chaudhuri (2002) who claimed that there is no rigid advantage of one view, for example, a general ¾ view advantage. Rather, and this is also the conclusion of our experimental work, the compatibility between the views at learning and test was the essential variable for a successful recognition. These findings of encoding specificity, as observed by Tulving and Thomson (1973), are also in accordance with recent findings of face perception research with compatibility of facial context between learning and test (e.g., Leder & Carbon, 2004, 2005) but are probably not limited to face-specific processing.

Moreover, the faces used in the study varied in terms of relational or componential aspects. As we used technically advanced morphable 3D heads, both types of manipulations were implemented without changing other properties. For example, when componential information was modified, the position of the components was left untouched.

Experiment 1 revealed that manipulation of view compatibility had a comparable effect on both relationally altered and componentially altered faces. Although recognition scores for relationally manipulated faces were generally lower, this finding is probably best explained by our specific relational manipulations (only one relation altered), which might be less distinctive than our componential manipulations, and/or by the fact that relational manipulations are less salient in general. Despite these lower scores, no floor effects were observed, thus we were able to compare the influence of view compatibility on recognition performance for both types of face manipulation. As we obtained similar data patterns, we conclude that similar cognitive processes are likely to underlie processing of both types of faces. The lack of an effect of recognition performance of faces differing in relational and componential aspects is in accordance with the findings of Valentin, Abdi, Edelman, and Posamentier (2001). These authors demonstrated that, within a range of 30 degrees, configural (relational) as well as specific local (componential) information might be interpolated.

Experiment 2 investigated whole-to-part effects by using the same paradigm as in Experiment 1, while expanding the design by varying the clipping size of presentations at test between full and part-based faces. This was done in order to address two important issues. First, we were interested in whether participants in Experiment 1 used an artificial feature learning strategy, which is characterized by local processing of simple features but not by a holistic face processing strategy. Second, we tested whole-to-part effects in dependence of view changes between learning and test. Regarding the first issue, we found clear whole-to-part effects indicating a more holistic processing of the stimuli. This could be interpreted as an indication that the faces used here had been learned in a way that includes information beyond the critical parts. Alternatively, these results can also be interpreted as additional learn-test compatibility effects. When the clipping size changed between learning and test, recognition performance dropped significantly (cf. Leder & Carbon, 2004, 2005). Additionally, Experiment 2 demonstrated that there were clear costs of transfer due to an unfamiliar view, although the recognition rates for faces in altered views were still better than chance. Thus, both aspects, deficits as a result of unfamiliar views and the capacity to extrapolate from uncommon views, were found here.

The present experiments have shown that the use of 3D heads versus two-dimensional pictures of a face reveal the sensitivity of the face recognition system to changes in view. Relational as well as componential facial information, both of which can only be view-manipulated using 3D-head models, contribute to these effects. To summarize our findings, when faces turn into heads, a number of additional processing requirements become relevant and may override other effects. For instance, changing the view from learning to test seems to decrease the recognition performance drastically. Based on our everyday experience, it is clear that these effects decrease with increasing familiarity. How view independence is attained with increasing familiarization will be the challenging question of further research in this field.

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