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**Face-recognition invariance in four upright and inverted facial orientations**

**A 180° transformation in face orientation from the *Study* stage to the *Test* stage in an experimental design, such as a Yes/No procedure, reduces face recognition. Recognition of an upright face in the *Study* and *Test* stages (UU condition) is better than in any other conditions (UI, IU, and II) (e.g. Civile, McLearn & McLearn, 2014; McKone & Yovel, 2009; Rakover & Cahlon, 2001; Rakover & Teucher, 1977; Raskin, Tweedy & Borod, 1990). In contrast to these findings, we report a phenomenon wherein the same pattern of face recognition is obtained in all four conditions (UI, UU, IU, II), which we term “face-recognition invariance”. This can be explained by the hypothesis of “visual similarity” between an inverted face (IF) and an upright face (UF), not by the hypothesis of “mental rotation” from IF to UF.** **Visual similarity is based on certain elements that are mutual to the two faces and elements that differentiate them. These mutual and differentiating elements resist the transformation of inversion (a 180° transformation) and can therefore be considered as symmetrical or salient components of the face, such as round eyes or thick lips.**

Research into the face inversion effect (FIE), according to which an upright face (UF) is much more easily recognised than an inverted face (IF), has led to two hypotheses—the configural processing and holistic hypotheses—that can successfully explain FIE. Accordingly, for a UF, four types of informa­tion, i.e. featural (eyes, nose, mouth), relational (eyes above the nose, nose above the mouth), configural (space between the eyes, nose and mouth), and holistic (face is perceived as an entire whole unit) undergo appropriate processing. For an IF, however, configural and holistic information are greatly impaired, but featural information processing remains intact (Maurer et al., 2002; Rakover, 2002, 2013; Rossion, 2008, 2009; Valentine, 1988; Yin, 1969). Thus, while IF processing is part-based (featural), UF processing is principally configurally and holis­tically based (Maurer et al., 2002; McKone, 2010; Piepers & Robbins, 2012; Rakover, 2013; Rossion, 2008, 2009).

Nevertheless, there is an important problem with understanding the FIE, which was an important consideration for this study and which has not been appropriately dealt with in previous research. The question is this: how does the cognitive system compare IF with UF? Rakover, Bar-on and Gliklich (2022) attempted to answer this question and suggested the comparison between IF and UF is made on the basis of visual similarity between these two faces and not on the basis of the mental rotation of IF to an upright orientation (e.g. Rakover, 2015; Rock, 1973, 1974; Valentine & Bruce, 1988). This answer is based on three experiments, described briefly here. In the first experiment, the *preparatory experiment*, two different groups of upright and inverted pairs of different faces, UI-pairs, were empirically established (the participants had to indicate at least one IF from five that were similar to the target UF). The *similarity group* consisted of seven UI-pairs of different faces, wherein each pair had one UF and another IF, with a high degree of similarity between them. The *non-similarity group* also consisted of seven UI-pairs of different faces, but the degree of similarity between each pair was low (see Figure 1).

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In the second experiment, *similarity*, a variation of the Yes/No recognition procedure was used. In the *Study* stage, 14 upright faces taken from both the *similar* and *non-similar* groups were presented, one face at each trial. In a subsequent *Testing* stage, 28 inverted faces were presented: 14 old inverted faces, which were previously viewed in the *Study* stage, and 14 new faces. The 14 new inverted faces included seven inverted faces from the *similar* group and seven from the *non-similar* group. The participant’s task was to decide for each inverted face if it was old or new. The aim of the second experiment was to test the following two predictions empirically.

According to the **visual-similarity** hypothesis, the percentage of false alarms of the seven new-similar inverted faces (%FAs) will be significantly greater than the percentage of false alarms of the seven new non-similar inverted faces (%FAns). That is, when the visual similarity between UF and IF is high, there is a greater likelihood of believing that a new face is an old one; thus, %FAs > %FAns (e.g., Rakover & Cahlon, 1989, 2001; Tversky, 1977).

In contrast, according to the **mental-rotation** hypothesis, there will be no significant differences between %FAs and %Fans. Given that (a) in mental-rotation experiments, reaction time and number of errors increase as a function of the angular disparity between two presented stimuli (e.g., Cheung et al., 2009; Cooper, 1975; Shepard & Metzler, 1971), and that (b) the angular disparity was held constant in experiment 2 (IF in both *similar* and *non-similar* groups have to be rotated to the upright orientation, a 180° rotation), one may predict that there will be no significant differences between %FAs and %Fans.

The third experiment, *orientation*, had two goals. First, to give additional empirical support to the construction of the *similarity* groups by using a different technique, similarity ranking, and the second goal, to test whether the distinction between the *similar* and the *non-similar* groups was confined only to the UI-pairs or whether it could be generalised to the other UU-, IU- and II-pairs.

The main results of Rakover, Bar-on & Gliklich’s (2022) second experiment appear in Figure 2a.

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As can be seen from Figure 2a, while false alarms in the similarity group [%FAs (55.0%)] is significantly greater than false alarms in the non-similarity group [%FAns (35.7%)] (let us call this difference the “FA-Difference Effect”) there is no significant difference between percent hits in the similarity group (%Hs) and the non-similarity group (%Hns). This finding support the visual-similarity hypothesis and not the mental-rotation hypothesis, since the latter predicts non-significant differences between %FAs and %FAns.

The main finding of the third experiment, which became the major motivation for the present study, is as follows. The similarity ranking of the UI-pairs of the similarity group was higher than the similarity ranking of the UI-pairs in the non-similarity group. Similar results were obtained in all the other three pairs of orientation UU, IU and II. We call this finding the “Face-Similarity Invariance”, a discovery that is explained by assuming that visual-similarity evaluation is based on certain mutual and differentiating elements (elements that are mutual to both faces and elements that differentiate between them), elements which are symmetrical or salient components of the face, such as round eyes or thick lips.

In view of the finding of Face-Similarity Invariance, we raised the following question: will the FA-Difference Effect (%FAs > %FAns) be obtained only in the group of the UI-group or will it be obtained also in the UU, IU, and II groups? This is an important question, because many researchers found that the transformation of a face orientation in 180° (e.g., from upright to inverted orientation), reduces face recognition dramatically (e. g., **Civile, McLearn & McLearn, 2014; McKone & Yovel, 2008; Rakover & Cahlon, 2001; Rakover & Teucher, 1977; Raskin, Tweedy & Borod, 1990**). A positive answer to that question means that in addition to the above Face-Similarity Invariance, a Face-Recognition Invariance will be discovered.

We began testing the above question by running the appropriate research programme. However, as a result of the COVID-19 pandemic, we succeeded in completing for Rakover, Bar-on & Gliklich’s (2022) report only the UU experiment. This experiment was identical to Experiment 2 (Part A – Similarity) except that in the *Test* stageall the faces were presented in the upright orientation. The results were similar to those of experiment 2 (compare Figure 2a to Figure 2b). The FA-Difference Effect has been found: %FAs (38.9%) was significantly greater than %FAns (23.4%), however it was also found that %Hns (77.7%) was significantly greater than %Hs (65.1%). (Note that we will deal with the last finding within the framework of the discussion of the whole study.)

The present study completes the research programme regarding the crucial question whether a FA-Difference Effect will be obtained also in the IU and II groups.

Methods

Experiments II and IU

*Participants, Design, and Procedure*: These two experiments were identical to experiment 2 (Part A – Similarity) in Rakover, Bar-on & Gliklich’s (2022) except that in the *Study* stage all oval faces were presented in the inverted orientation, wherein in the *Test* stage all faces were presented either in the inverted orientation (experiment II) or in the upright orientation (experiment IU) (see Figure 1). Each experiment consisted of two stages: *Study* and *Test* and was a variation of the common Yes/No recognition procedure. In the *Study* stage of experiment II, participants were shown 14 oval inverted faces, each exposed for 3s at intervals of 1s between faces. These faces were taken from both the *similar* and *non-similar* groups and presented in the inversion orientation and in a randomised order. In the *Test* stage of experiment II, participants were shown 28 inverted faces including 14 *old* faces that appeared in the *Study* stage and 14 *new* faces taken from both the *similar* and *non-similar* groups. Experiment IU was similar to experiment II, except that in the *Test* stage the 28 oval faces were presented in the upright orientation. The faces in this stage were also presented in randomised order for both groups. Twenty-five new participants (experiment II: 21 females and 4 males; average age 24.8) and 21new participants (experiment IU: 13 females and 8 males; average age 23.0) were recruited and were shown a series of oval facial pictures on a computer screen, one face at each trial.

 The instructions for each experiment were read before the beginning of each experiment. For the *Study* stage, participants were told to concentrate on the inverted oval faces and attempt to remember them. In the *Test* stage, they were presented with *old* and *new* 28 inverted faces (experiment II) or upright faces (experiment IU) one at a time, and had to decide whether they were *old* or *new*. They had 10s to make their decision. After 5s, a whistle sounded to expedite their decision. Based on previous experiments, a lengthy decision time was utilised to relieve the participants from time pressure.

Results

The main results of experiments IU and II appear in Figure 2c and 2d. *Experiment IU* (see Figure 2c): %FAs (47.6%) is significantly greater than %Fans (26.6%) and there is no significant difference between %Hs and %Hns: F(1,20) = 8.54 p < .008 η2=.30; A LSD test revealed a significant difference between %FAs and %FAns p <. 001 but not between %Hs and %Hns.

*Experiment II* (see Figure 2d): The FA-Difference Effect has been obtained. %FAs (54.9%) is significantly greater than %FAns (26.3%) whereas there is no significant difference between %Hs and %Hns: F(1,24) = 26.79 p < .001 η2=.53; A LSD test revealed a significant difference between %FAs and %FAns (p < .007) but not between %Hs and %Hns.

General discussion

The main results of the present study and those included in Rakover et al., 2022, are as follows. The Face-Recognition Invariance, i.e., the same type of FA-Difference Effect, has been obtained in all the four orientation groups: UU, UI, II, IU. This is a remarkable finding, since in the vast majority of studies on face recognition the transformation of inversion reduces recognition to a great extent. In contrast, the present findings show that FA-Difference Effect resists the transformation of inversion. The phenomenon of Face-Recognition Invariance as well as the Face-Similarity Invariance can both be explained by appeal to the visual-similarity hypothesis. One may reasonably assume that visual similarity between two different faces is carried out on the basis of certain elements that are mutual to these faces and elements that differentiate between them (e.g., Rakover & Cahlon, 1989, 2001; Tversky, 1977). These elements resist the transformation of inversion (a 180° transformation) and therefore may be considered as symmetrical or salient components of a face, such as round eyes, thick lips and bushy eyebrows. Given these elements, one may suggest that they are playing an important role in evaluating similarity in each of the four orientation groups: UU, UI, II, IU. As a result, similarity ranking was significantly greater in the *similarity* group than in the *non-similarity* group in each of these four orientation groups. Thus, Face-Similarity Invariance can be accounted for without difficulties by the visual-similarity hypothesis.

Furthermore, given this interpretation of the visual-similarity hypothesis, one may propose a fluent explanation of the Face-Recognition Invariance. Since the similarity ranking generalises to all orientation groups, it is reasonable to propose the following. The similarity between UF and IF is represented in memory and is activated by the presentation of an old or new-similar IF or UF in the *Test* stage. That is, when a face, which belongs to a pair of faces of the *similarity* group, is presented in the *Test* stage, it arouses in the cognitive system its associate similar face. This means that in all orientation groups the chances of %FAs to be greater than of %FAns are high, i.e., the chances for obtaining the Face-Recognition Invariance are high. Thus, the visual-similarity hypothesis can explain the results in the four orientation groups by appeal to the process of direct evaluation of the similarity between two faces irrespective of their orientations (upright or inverted).

Can this explanation handle the significant difference between Hns and Hs in the UU group? The answer is yes and it depends on the following possibility: the difference (Hns – Hs) can be caused either by increase in Hns or decrease in Hs (or both). The following finding suggests the increase in Hns as an answer: Hns (77.7%) in the UU group is higher than in the other three orientation groups: UI, IU, II [F(3,87) = 3.77 p < .014 η2 = .115], whereas there are no significant difference among the four orientation groups in Hs (65.1%). This result means that difference (Hns – Hs) is based on the increase in Hns, which is explained by appeal to the theoretical approach and empirical findings mentioned above that the processing of an upright face involves all kinds of facial information (e.g., Maurer et al., 2002; Rakover, 2002, 2013; Rossion, 2008, 2009; Valentine, 1988; Yin, 1969). [Of course one may argue that Hs is reduced in all the four groups by interference aroused by the *similar* pairs of faces, but if one adheres to the methodological value of parsimony (Ockham’s razor) then the above explanation is satisfactory.]

In contrast, the mental-rotation hypothesis encounters great difficulties to explain these results. It cannot explain the Face-Similarity Invariance since it lacks a mechanism for evaluating degrees of similarity between a pair of faces (e.g., Cheung et al., 2009; Cooper, 1975; Shepard & Metzler, 1971) and it predicts non-significant differences between %FAs and %FAns in the four orientation groups: UU, UI, IU, II. The reason for this is as follows: in all groups the angular disparity between the two faces (the remembered and the presented) is either not exists (UU group) or is kept constant (a transformation of 180° from IF to UF in the UI, IU or II orientation groups).

Furthermore, even the “combined hypothesis”, a combination of mental-rotation process followed by visual-similarity process, according to which an inverted face is rotated to the upright orientation and followed by the process of visual similarity, cannot properly account for the Face-Recognition Invariance. One possible reason for this is that the combined hypothesis involves a huge mental effort; one has to rotate the perceived or remembered inverted face to the upright orientation and then compare it with the upright face to evaluate their visual similarity. Here are hypothetical rough estimations of the mental efforts involved in two orientation groups: II and UU.

**II:** 1) *representation*: The presented-IF have to be represented in the cognitive system; 2) *rotation*: the represented-IFhas to be rotated to the upright orientation and also the remembered-IF has to be rotated to the upright orientation; 3) *discovery and retrieval*: given the represented-rotated-IF, the appropriate remembered-rotated-IF have to discovered and retrieved from memory; 4) *similarity estimation*: these two rotated-IF have to be compared for estimating their similarity.

**UU:** 1) *representation*: The presented-UFhave to be represented in the cognitive system; 2) *discovery and retrieval*: given the represented-UF, the appropriate remembered-UFhave to discovered and retrieved from memory; 3) *similarity estimation*: the represented-UFhave to be compared to the remembered-UFto estimate their similarity.

Clearly, the mental effort involved in **UU** is much less than in **II** for the following reasons. First reason, there is no need for mental rotation. Second reason, it is more easy to carry out the processes of *discovery* and *retrieval* with a represented-UFthan with a rotated-IF, which needs extra effort to keep holding it in the rotated orientation (e.g., Rock, 1973, 1974). And finally, in a way similar to the second reason, the performance of the *similarity estimation* is easier for **UU** than for **II**.

Given these estimations, it seems that the mental effort invested in **II** is greater than **UU**. Now, if one adds to this the reasonable assumption that the greater the mental effort, the greater is the probability of making errors in discriminating between faces, then one may predict that the difference between %FAs and %FAns (%FAs - %FAns) in the **II** will be smaller than in the **UU.** That is,the differences between the seven new faces of the *similarity* group and the seven new faces of the *non-similarity* group will be blurred in **II** to a greater degree than in the **UU**. The results, however, do not support this prediction: (%FAs - %FAns) for **II** is 28.6% and for **UU** is 15.5%! The question is how may the visual-similarity handle these results?

The theoretical answer depends on an evaluation of mutual and differentiating elements of similarity in the II-pairs compared to those in the UU-pairs. Nonetheless, a possible indication for this evaluation can be obtained by the similarity-rankings mentioned above (see Rakover, Bar-on & Gliklich, 2022): it has been found that the similarity ranking for **II** (average 4.07, where 1 signifies low similarity and 5 high similarity) was greater than for **UU** (average 3.17). Given these rankings, the visual-similarity hypothesis predicts that (%FAs - %FAns) in the **II** will be higher than in the **UU** – in accordance with the above reported results.

In sum, although the present paper suggests that the Face-Recognition Invariance and the Face-Similarity Invariance cannot be explained by the mental-rotation hypothesis, but is accounted for by the visual-similarity hypothesis, which is interpreted as based on mutual and differentiating elements (e.g., Rakover & Cahlon, 1989, 2001; Tversky, 1977), the following remark has to be made. One may propose the possibility that the process of mental rotation is confined to an identity-judgement task (measured by reaction time), whereas visual similarity is limited to a recognition task (Yes/No procedure measured by hits and false alarms) (e.g., Cheung et al., 2009; Cooper, 1975; Shepard & Metzler, 1971; Valentine & Bruce, 1988). Clearly, this comment deserves an additional research.

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**Figure 1** depicts examples of similar and non-similar pairs of oval faces. The left face was presented in the upright orientation and the middle one in the inverted orientation. The upright face on the right is the same as the inverted one. It is presented here for the sake of comparison.