Sam S. Rakover, Rani Amit Bar-on, Anna G.,& Asa Kinory

**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 and 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 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.

**Introduction**

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 the 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 (the 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 intact1-7. Thus, while IF processing is part-based (featural), UF processing is principally configural and holis­tic1,2,4,5,8,9.

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 & Gliklich (2022)10 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 orientation6,11-13. 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, with one face in each trial. In a subsequent *Testing* stage, 28 inverted faces were presented: 14 inverted faces that had previously been 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, whether it was old or new. The aim of the second experiment was to empirically test the following two predictions.

According to thevisual-similarityhypothesis, 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 > %FAns14-16.

In contrast, according to themental-rotationhypothesis, there will be no significant differences between %FAs and %FAns. Given that (a) in mental-rotation experiments, the reaction time and number of errors increase as a function of the angular disparity between two presented stimuli17-19 and that (b) the angular disparity was held constant in experiment 2 (IF in both *similar* and *non-similar* groups must 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. The first was to provide additional empirical support to the construction of the *similarity* groups by using a different technique, similarity ranking, and the second was to test whether the distinction between the *similar* and the *non-similar* groups was confined to the UI pairs only or whether it could be generalised to the other UU, IU and II pairs.

The main results of Rakover, Bar-on & Gliklich’s (2022)10 second experiment are shown in Figure 2a.

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Insert Figure 2 about here

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As can be seen from Figure 2a, while false alarms in the similarity group [%FAs (55.0%)] are 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 supports the visual-similarity hypothesis and not the mental-rotation hypothesis, as 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, was as follows. The similarity ranking of the UI pairs in the similarity group was higher than the similarity ranking of the UI pairs in the non-similarity group. Similar results were obtained for all three of the other pairs of orientation, UU, IU and II. We refer to this finding as the “face-similarity invariance”, a discovery that can be 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); these elements 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 asked the following question: will the FA-difference effect (%FAs > %FAns) only be obtained in the UI group or will it also be obtained in the UU, IU and II groups? This is an important question, because many researchers have found that the transformation of face orientation by 180° (e.g. from an upright to an inverted orientation) dramatically reduces face recognition15,20-23. A positive answer to this question would mean that in addition to the above described face-similarity invariance, a face-recognition invariance will be discovered.

To address this question, we established an appropriate research programme. However, as a result of the COVID-19 pandemic, for Rakover, Bar-on & Gliklich’s (2022)10 report we only succeeded in completing the UU experiment. This experiment was identical to Experiment 2 (Part A – Similarity) except that in the *Test* stageall faces were presented in the upright orientation. The results were similar to those of Experiment 2 (compare Figure 2a with Figure 2b). An FA-difference effect was found: %FAs (38.9%) was significantly higher than %FAns (23.4%). However, it was also found that %Hns (77.7%) was significantly higher than %Hs (65.1%). (We will address this last finding within the framework of the discussion of the entire study.)

The present study completes the research programme regarding the crucial question of whether an FA-difference effect will also be obtained 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)10 study, except that in the *Study* stage all oval faces were presented in the inverted orientation, whereas in the *Test* stage the 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 3 seconds at intervals of 1 second between faces. These faces were taken from both the *similar* and *non-similar* groups, presented in the inverted 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 newfaces 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 a randomised order for both groups. Twenty-five new participants (experiment II: 21 females and 4 males; average age 24.8 years) and 21 new participants (experiment IU: 13 females and 8 males; average age 23.0 years) were recruited and shown a series of pictures of oval faces on a computer screen, with one face per trial.

The instructions for each experiment were read prior to 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 28 old and new inverted faces (experiment II) or upright faces (experiment IU), one at a time, and were asked to decide whether they were old or new. They had 10 seconds to make their decision. After 5 seconds, a whistle sounded to expedite their decision. Based on our experience with previous experiments, we selected a reasonably long decision time to relieve the participants of any time pressure.

**Results**

The main results of experiments IU and II are shown in Figure 2c and 2d. Experiment IU (Figure 2c) showed that %FAs (47.6%) was significantly higher than %FAns (26.6%), but there was no significant difference between %Hs and %Hns: F(1,20) = 8.54 p < .008 η2=.30. An LSD test revealed a significant difference between %FAs and %FAns (p <. 001) but not between %Hs and %Hns.

Experiment II (Figure 2d) showed that the FA-difference effect was obtained. The %FAs (54.9%) was significantly higher than %FAns (26.3%), whereas there ws no significant difference between %Hs and %Hns: F(1,24) = 26.79 p < .001 η2=.53. An LSD test revealed a significant difference between %FAs and %FAns (p < .007) but not between %Hs and %Hns.

**Discussion**

The main results of the present study and those included in Rakover et al. (2022)10 are as follows. Face-recognition invariance, i.e. the same type of FA-difference effect, was obtained in each of the four orientation groups, UU, UI, II and IU. This is a remarkable finding, as in the vast majority of previous studies into face recognition, the transformation of inversion reduced recognition to a considerable extent. In contrast, the present findings show that the FA-difference effect resists the transformation of inversion. The phenomena of face-recognition invariance as well as face-similarity invariance can both be explained by 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 the two faces and other elements that differentiate between them14-16. These elements resist the transformation of inversion (a 180° transformation) and may therefore be considered as symmetrical or salient components of a face, such as round eyes, thick lips or bushy eyebrows. Given these elements, one may suggest that they play an important role in evaluating similarity in each of the four orientation groups, UU, UI, II and 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 difficulty by the visual-similarity hypothesis.

Furthermore, given this interpretation of the visual-similarity hypothesis, we can propose an eloquent explanation of face-recognition invariance. As the similarity ranking generalises to all orientation groups, it is reasonable to propose the following. The similarity between UF and IF is represented in the 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 that belongs to a pair of faces from 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 chance of the %FAs being greater than that of %FAns is high, i.e. the chance of obtaining face-recognition invariance is high. Thus, the visual-similarity hypothesis can explain the results with the four orientation groups by invoking the process of direct evaluation of the similarity between two faces, irrespective of their orientation (upright or inverted).

Can this explanation also account for the significant difference between Hns and Hs in the UU group? The answer is yes, and this depends on the following possibility: the difference (Hns – Hs) can be caused either by an increase in Hns or a decrease in Hs (or both). The following finding suggests the increase in Hns as an answer: Hns (77.7%) in the UU group was higher than in the other three orientation groups, UI, IU and II [F(3,87) = 3.77 p < .014 η2 = .115], whereas there was no significant difference in Hs among the four orientation groups (65.1%). This result means that the difference (Hns – Hs) is based on an increase in Hns, which can be explained by invoking the theoretical approach and empirical findings described above, that the processing of an upright face involves all kinds of facial information1-7. Of course, one may argue that Hs is reduced in all 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 this explanation is satisfactory.

In contrast, the mental-rotation hypothesis encounters great difficulties when used to explain these results. This hypothesis cannot explain the face-similarity invariance as it lacks a mechanism for evaluating degrees of similarity between a pair of faces17-19, and it predicts non-significant differences between %FAs and %FAns in the four orientation groups, UU, UI, IU and II. The reason for this is as follows: in all groups, the angular disparity between the two faces (the remembered and the presented) either does not exist (the UU group) or is kept constant (a transformation of 180° from IF to UF in the UI, IU and II orientation groups).

Furthermore, even the “combined hypothesis”, a combination of the mental-rotation process followed by the 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 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 effort involved in two orientation groups: II and UU.

II: 1) *Representation*: The presented-IF must be represented in the cognitive system; 2) *rotation*: the represented-IFmust be rotated to the upright orientation, and the remembered-IF must also be rotated to the upright orientation; 3) *discovery and retrieval*: given the represented-rotated-IF, the appropriate remembered-rotated-IF must be discovered and retrieved from memory; 4) *similarity estimation*: the two rotated-IF faces must be compared to estimate their similarity.

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

Clearly, the mental effort involved in UU is much less than in II,for the following reasons. First, with UU there is no need for mental rotation. Second, it is easier to carry out the processes of *discovery* and *retrieval* with a represented-UFthan with a rotated-IF, which requires extra effort to keep holding it in the rotated orientation12,13. Third, in a similar way to the second reason, the performance of the *similarity estimation* is easier for UU than for II.

Given these explanations, it seems clear that the mental effort invested in II is greater than that required for UU. Now, if one adds to this the reasonable assumption that the greater the mental effort, the greater the probability of making errors when discriminating between faces, then one can predict that the difference between %FAs and %FAns (%FAs – %FAns) with IIwill be smaller than with 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 to a greater degree in IIthan in UU. The results, however, do not support this prediction: (%FAs – %FAns) for IIandUU were 28.6% and 15.5%, respectively. The question is how may the visual-similarity hypothesis handle these results?

The theoretical answer depends on an evaluation of mutual and differentiating elements of similarity in the II pairs compared with those in the UU pairs. A possible indication for this evaluation can be obtained by the similarity-rankings mentioned above (see Rakover, Bar-on & Gliklich, 202210): it was 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 IIwill be higher than in UU, in accordance with the above reported results.

In sum, although the present study suggests that the face-recognition invariance and the face-similarity invariance cannot be explained by the mental-rotation hypothesis but are accounted for by the visual-similarity hypothesis, which is interpreted as based on mutual and differentiating elements14-16, the following must be pointed out. 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 (a Yes/No procedure measured by hits and false alarms)6,17-19. However, further research will be necessary to confirm this.

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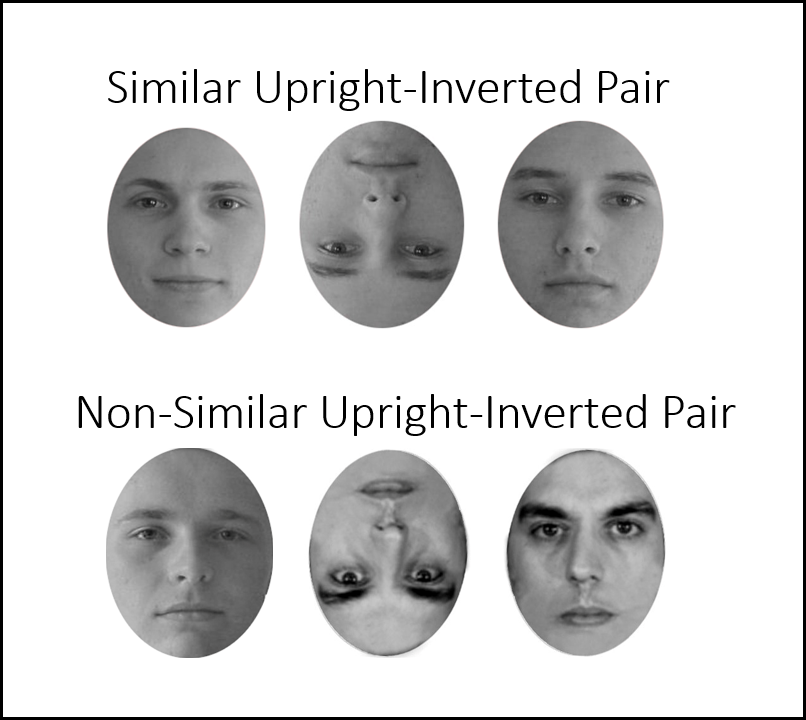
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**Figure 1.** Examples of similar and non-similar pairs of oval faces. The left face was presented in the upright orientation and the middle face in the inverted orientation. The upright face on the right is the same as the inverted one. It is presented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