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# Learning facilitates dual-process face recognition regardless of holistic processing

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## Abstract

Much evidence suggests that faces are recognized based on their global familiarity in a signal-detection manner. However, experiments drawing this conclusion typically present study lists of faces only once or twice, and the nature of face recognition at higher levels of learning remains unclear. Here, three experiments are reported in which participants studied some faces eight times and others twice and then took a recognition test containing previously viewed faces, entirely new faces, and faces which recombined the parts of previously viewed faces. Three measures converged to suggest that study list repetition increased the likelihood of participants rejecting recombined faces as *new* by recollecting that their parts were studied but in a different combination, and that manipulating holistic or Gestalt-like processing—a hallmark of face perception—qualitatively preserved its effect on how memory judgments are made. This suggests that face learning causes a shift from the use of a signal-detection strategy to the use of a dual-process strategy of face recognition regardless of holistic processing.

**Keywords** Face recognition · Holistic processing · Conjunction paradigm · Signal-detection model · Dual-process model

The signal-detection model of recognition memory holds that participants accept any test item as *old* when its familiarity meets or exceeds an *old–new* decision criterion (see Wixted, 2007; Yonelinas et al., 1996, for a review), while the dual-process model proposes that they use an item's familiarity as well as recollection of contextual elements of a previous encounter to make recognition judgments (see Jones, 2005; Jones & Jacoby, 2001; Lampinen et al., 2004; Light et al., 2004). Thus, one can test these competing models by attempting to elicit recollection, and this is frequently done using "conjunction items" that recombine parts of previously viewed stimuli (e.g., Jones & Jacoby, 2001; Jones & Bartlett, 2009; Lampinen et al., 2004). If participants correctly reject conjunction items as *new* by recollecting that their parts were studied *but not together*, this supports the dual-process model of recognition memory, and if they reject them because they perceive them to be wholly novel stimuli, this supports the signal-detection model of recognition memory.

With face stimuli, conjunction items typically fail to elicit recollection. For instance, Meltzer and Bartlett (2019) had participants study lists of top-bottom composite faces and then take a recognition test containing "intact" faces they had studied, entirely new faces, and conjunction faces that recombined the top and bottom halves of studied faces. The authors found that participants rarely recognized or recognized with low confidence the halves of the conjunction faces they rejected as *new* whole items, apparently sensing those stimuli to be wholly novel, and this along with other behavioral and neuropsychological data (e.g, Aly et al., 2010; Edmonds et al., 2012; Jones & Bartlett, 2009; Weatherford et al., 2021; Yonelinas et al., 1999) supports a signal-detection model of face recognition. However, participants in most investigations only view study lists of faces once or twice, and findings with verbal stimuli (with which CHECKLIST and NEEDLEPOINT might be recombined to form the conjunction CHECKPOINT) suggest that participants reject conjunction items using recollection primarily at higher levels of learning (e.g, Arndt & Jones, 2008; Jones & Jacoby, 2001; Leding & Lampinen, 2009). Therefore, the present study used conjunction items to examine whether additional learning encourages dual-process face recognition.

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That learning might exert this effect is not without precedent. Having participants verbalize or briefly describe faces at encoding causes them to reject conjunctions using recollection while also improving face memory (Jones et al., 2013; Weatherford et al., 2021), indicating a correspondence between learning and the adoption of a dual-process face recognition strategy. However, the real-world applicability of this finding is limited, and whether learning in the absence of verbalization causes participants to reject conjunction faces using recollection is unclear. Therefore, I examined whether study list repetition alone facilitates dual-process face recognition. This manipulation was chosen partly because it mimics the repeated encounters that produce naturalistic face learning, but also because it facilitates recollection-based rejections of verbal conjunctions (e.g., Jones, 2005; Jones & Jacoby, 2001, 2005; Lampinen et al., 2004) and robustly improves face memory as measured by the conjunction paradigm (see Bartlett et al., 2009; Jones & Bartlett, 2009).

Only one previous investigation has explored whether study list repetition affects conjunction face rejection strategies. Participants in Jones and Bartlett (2009) studied faces either once or eight times and then took a recognition test containing intact faces that were studied eight times, intact faces that were studied once, conjunctions made from faces studied eight times, conjunctions made from faces studied once, and entirely new faces. The test was administered once under *exclusion* instructions, which were to accept only intact items as *old*, and then again (using different faces) under *inclusion* instructions, which were to accept both intact and conjunction items as *old*. Regardless of how many times the faces from which they were made were studied, participants were unable to flexibly respond to conjunction faces in accordance with the varying task demands, suggesting that they were oblivious to the recombined nature of such items. At first blush, this finding supports a signal-detection model of face recognition even at higher levels of learning.

However, two considerations make the Jones and Bartlett (2009) findings difficult to interpret. First, using exclusion instructions, the authors observed near-chance levels of discrimination between intact and conjunction items made from faces studied once. This suggests that little to no associative learning occurred, making it difficult to establish how participants rejected conjunction faces in the absence of study list repetition. Second, and more importantly, the exclusion/inclusion procedure they used only indirectly measures how participants reject conjunction items and also makes assumptions that are difficult to test regarding whether participants employ the same retrieval strategies across instruction conditions (see Jacoby, 1991). Both of these limitations were addressed in Experiment 1.

## Experiment 1

Participants in Experiment 1 viewed the top/bottom composite faces employed by Meltzer and Bartlett (2019) (see Fig. 1) twice or eight times and then took an exclusion recognition test containing intact faces they studied twice, intact faces they studied eight times, conjunction faces that recombined the halves of faces they studied twice, conjunction faces that recombined the halves of faces they studied eight times, and entirely new faces. The lower bound of this presentation schedule was chosen to avoid the low levels of associative learning observed in the Jones and Bartlett (2009) one-presentation data, and the upper bound was chosen because it reliably facilitates recollection-based rejections of verbal conjunction items (see Jones, 2005).

To obtain more direct evidence of study list repetition effects than that provided by the exclusion/inclusion paradigm, Experiment 1 also adopted the Meltzer and Bartlett (2019) strategy of having participants judge whether they had studied each test face as a whole as well as whether they had studied each of its halves as part of any study list face (see Fig. 2). According to the signal-detection model, participants reject conjunction items by sensing them to be wholly unfamiliar. Therefore, support for this model was inferred if participants rarely recognized or recognized with low confidence the halves of the conjunction faces they rejected as *new* wholes. By contrast, given the dual-process model premise that participants reject conjunction items by recollecting that their parts were studied separately, support for this model was inferred if participants frequently recognized with high confidence the halves of conjunctions they rejected as *new* whole faces. Thus, it was predicted that if learning encourages dual-process face recognition, study list repetition would shift participants from rarely recognizing to frequently recognizing with high confidence the halves of the conjunction faces they rejected as *new* whole items.

In addition, an analysis of whole-face judgments provided two supplemental measures of study list repetition effects. The first capitalizes on the verbalization finding that manipulations which facilitate both learning and associative recollection with faces increase hit rates to intact items but not false-alarm rates to conjunctions, presumably because recollection encourages the former but not the latter (Jones et al., 2013; Weatherford et al., 2021), and the second regards the finding that participants tend to make recollection-based memory judgments with more confidence than familiarity-based ones (see Migo et al., 2012, for a review). Collectively, these measures led to the predictions that if learning encourages dual-process face recognition, study list repetition should (1) increase hit rates to intact faces but not false-alarm rates to conjunction faces and (2) increase the frequency of high confidence hits to intact items and high confidence rejections of conjunction faces.

## Method

**Participants** The power-analysis for Experiment 1 was based on previous studies examining study list repetition effects on whether participants reported recognizing as *old* the parts of verbal conjunctions they rejected as *new*. The only two such investigations to report sufficient descriptive statistics for calculating effect size (see Jones, 2005; Lampinen et al., 2004) obtained an average Cohen's $d$ of .38, suggesting that a sample size of 57 participants would provide a minimum acceptable power level of .80 (Cohen, 1988) for a $t$ test comparing rejected conjunction part recognition across repetition conditions. However, to improve sensitivity to meaningful effects, I purposely exceeded this quota by recruiting 67 undergraduates at the University of Texas at Dallas, with normal or corrected-to-normal vision, to participate in the experiment for course credit. The mean age was 20.82 ($SD$ = 3.96), approximately 64% self-identified as female, and 80% self-identified as Caucasian (most of the remainder identified as Hispanic or Asian). All participants gave informed consent, and the institutional review board approved the study.

**Stimuli and study/test lists** The face stimuli were the same as those used by Meltzer and Bartlett (2019). They were created from full-frontal monochromatic photographs of Caucasian students at the University Texas at Dallas taken at least five years prior to the study who were approximately the same age as the experimental participants. First, each photograph was divided horizontally just below the nasal bridge, and the resulting top/bottom face halves were recombined to form a novel set of aligned composite faces. Then, a black line three pixels in diameter was superimposed onto each composite face at the intersection of its top and bottom halves. Finally, each composite face was cropped horizontally at the hairline and the bottom of the chin as well as vertically to remove the ears. Example stimuli are shown in Fig. 1.

Eight study lists were made (stimulus duration = three seconds, interstimulus interval = two seconds). Six "short" lists contained 12 to-be-remembered faces plus two buffer faces at the beginning and end for a total of 16 faces (the to-be-remembered faces were randomly reordered in each list), and two "long" lists contained an additional 12 to-be-remembered faces. The test (stimulus duration = 24 seconds, interstimulus interval = three seconds) contained eight intact faces participants studied eight times (these appeared in all eight study lists), eight intact faces they studied twice (these only appeared in the two long study lists), eight conjunctions made from faces participants studied eight times, eight conjunctions made from faces they studied twice, and eight entirely new faces. Five versions of the study list were used

**Fig. 1** Examples of intact and conjunction well-aligned upright faces (Experiments 1, 2, and 3) and misaligned-inverted faces (Experiments 2 and 3). The left and middle photographs in each row represent study list faces, whereas the right most photograph represents a conjunction face (i.e., a recombination of the top and bottom halves of study list faces)

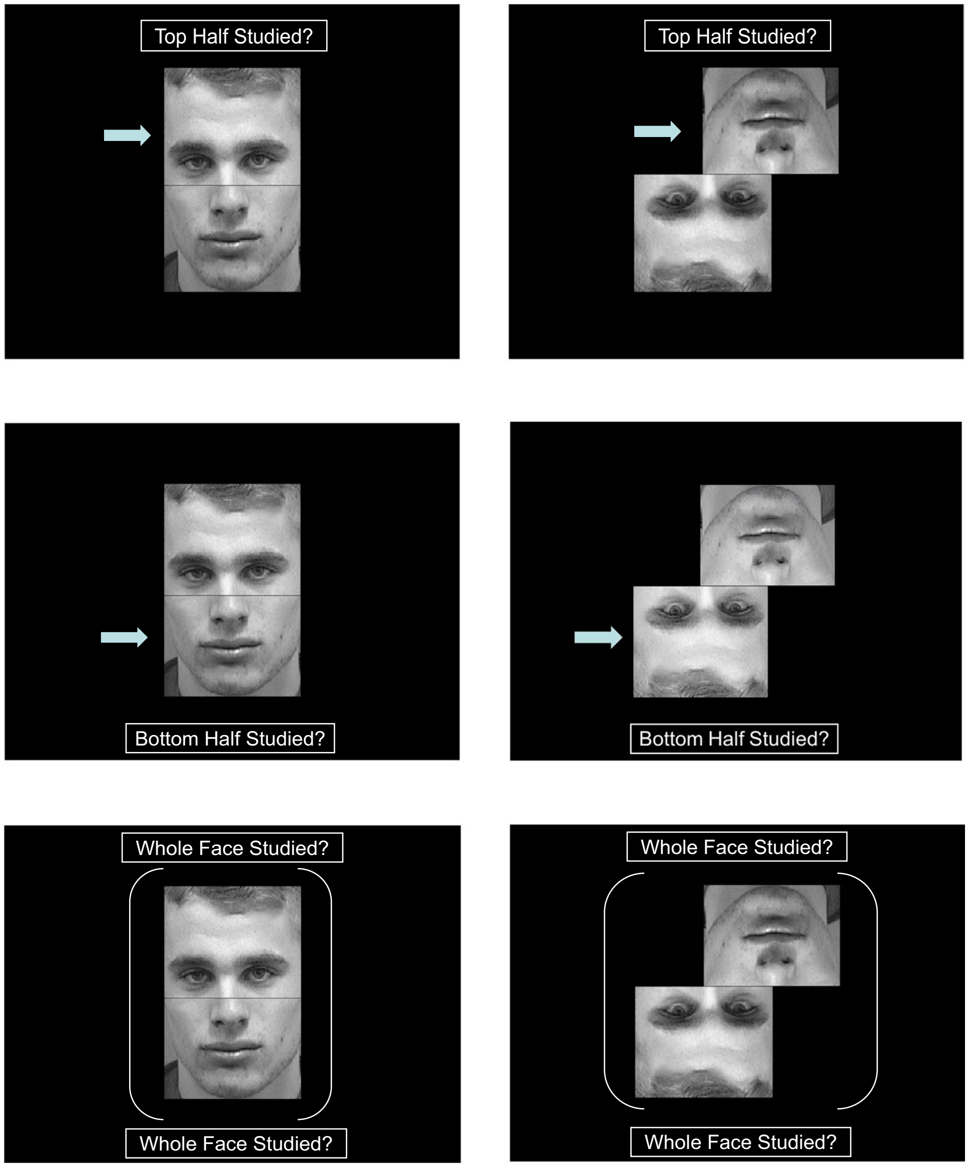


**Fig. 2** Examples of whole-face/half-face judgment test trials with response cues in the well-aligned upright face (left) and misaligned-inverted face (right) conditions. Figure first published in Meltzer and Bartlett (2019)

with five subgroups of participants so that each test face served as each type of test item for approximately one fifth of the participants in each condition.

All stimuli were presented via PowerPoint on a 45.72 cm Gateway VX900 computer monitor, from which participants were seated approximately 60 cm. Face images were 7.60 cm wide and varied from 11.40 cm to 14.00 cm in height (with a horizontal visual angle of 7.30$^{o}$ and a vertical visual angle of between 10.90$^{o}$ and 13.30$^{o}$).

**Procedure** After providing informed consent, participants were told that they would see lists of faces that they should try to remember for purposes of a subsequent test. They then saw eight study lists of faces (described above), filling out a short demographic survey between the fourth and fifth list (the long lists were always presented first and last). Following the last study list, participants were told about the construction of conjunction faces and then took a recognition test containing intact faces, entirely new faces, and conjunction faces under exclusion instructions. For each test face, they made three *old/new* judgments and response confidence ratings (1 = low confidence, 3 = high confidence) regarding (1) whether they had studied the top half of the face, (2) whether they had studied the bottom half of the face, and (3) whether they had studied the face as a whole (see Fig. 2). They had eight seconds to make each judgment, with three

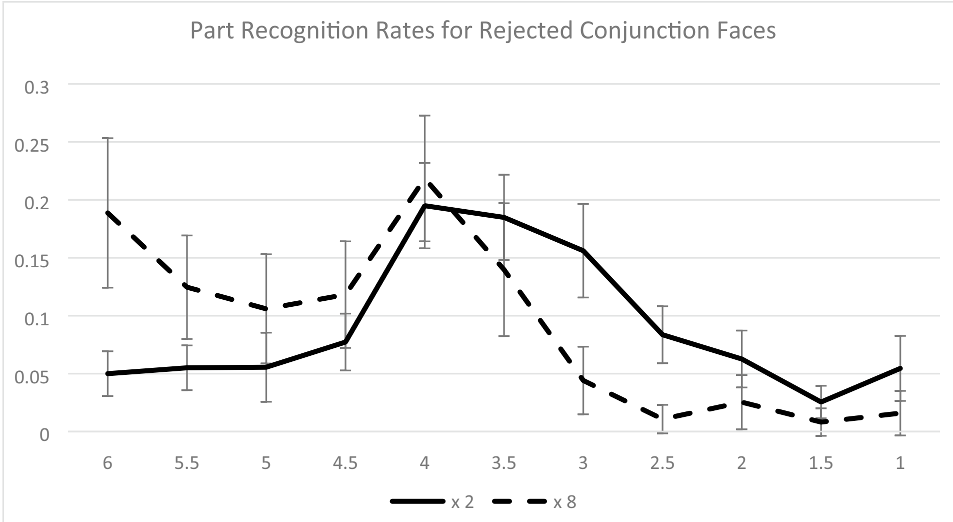


**Fig. 3** Probabilities of average half ratings for conjunction faces participants rejected as *new* wholes in Experiment 1. Error bars represent 95% confidence intervals calculated using the Cousineau–Morey correction for within-subject comparisons (see Cousineau, 2005; Morey, 2008)

**Table 1** Means and standard deviations for proportions of test items participants endorsed as *old* whole faces

| Stimuli | Exp. | Intact × 2 | Intact × 8 | Conj. × 2 | Conj. × 8 | Feat. × 2 | Feat. × 8 | New |
|---|---|---|---|---|---|---|---|---|
| Well-Aligned Upright | 1 | .57 (.26) | .87 (.17) | .35 (.24) | .37 (.22) | — | — | .11 (.17) |
| Well-Aligned Upright | 2 | .56 (.24) | .85 (.22) | .34 (.20) | .38 (.27) | — | — | .09 (.17) |
| Misaligned-Inverted | 2 | .34 (.21) | .62 (.24) | .32 (.19) | .44 (.23) | — | — | .22 (.21) |
| Well-Aligned Upright | 3 | .60 (.29) | .89 (.17) | — | — | .20 (.18) | .22 (.23) | .09 (.16) |
| Misaligned-Inverted | 3 | .43 (.24) | .61 (.23) | — | — | .30 (.26) | .29 (.23) | .20 (.21) |

*Note.* Exp. = experiment; Intact × 2 = intact items studied twice; Conj. × 2 = conjunctions made from faces studied twice; Feat. × 2 = feature-faces made from faces studied twice; *M*(*SD*)

practice trials immediately preceding the actual test. The sequence of memory judgments was counterbalanced such that approximately one-fourth of the participants in each stimulus condition made their judgments in each of the following orders: Whole Face/Top Half/Bottom Half, Whole Face/Bottom Half/Top Half, Top Half/Bottom Half/Whole Face, and Bottom Half/Top Half/Whole Face. Participants were then thanked for their time and dismissed.

## Results

Judgments participants made to the halves of conjunction faces they rejected as *new* were examined by first converting the *old/new* and three-point confidence ratings for half-face judgments to a 1–6 scale (1 = *high confidence "new judgment"* to 6 = *high confidence "old" judgment*). Then, to quantify the overall sense of oldness participants detected for the parts of conjunctions they rejected as new wholes, I calculated the average face half rating they made to each item. For instance, if they gave the top half a rating of 6 and the bottom half a rating of 5, the average half rating for that face was recorded as 5.5.

Figure 3 shows the probability of each possible average half rating being given to a rejected conjunction face. The distribution of average half ratings in the two-presentation condition is unimodal with most participants either failing to recognize or recognizing with low confidence the halves of conjunction faces they rejected as *new* wholes. By contrast, for conjunctions made from faces studied eight times, a second mode emerged corresponding to an average face half rating of "6." Providing quantitative support for this observation, *t* tests revealed a significant effect of study list repetition on the probability of average half ratings of 6, $t(63) = 4.43$, $p < .001$, $d = 1.29$, and 5.5, $t(63) = 2.61$, $p = .011$, $d = 1.10$, being made to a rejected conjunction face.

Turning to the whole-face hit rate and false-alarm rate data, Table 1 presents the mean proportions of intact faces, conjunction faces, and entirely new faces participants in Experiment 1 accepted *old*. Crucially, a 2 × 2 (Item Type [Intact, Conjunction] × Repetition [Two, Eight]) repeated-measures

**Table 2** Main effects and interactions on proportions of items endorsed as *old* whole faces

| Effect/Interaction | *F* | *MSE* | Significance | Partial Eta Squared |
|---|---|---|---|---|
| Experiment 1 | *df*: 1, 66 | | | |
| A. Item Type | 227.89 | 8.54 | $p < .001$ | .78 |
| B. Repetition | 38.35 | 1.67 | $p < .001$ | .37 |
| A × B | 45.42 | 1.23 | $p < .001$ | .41 |
| Experiment 2 | *df*: 1, 128 | | | |
| A. Item Type | 182.01 | 6.15 | $p < .001$ | .59 |
| B. Repetition | 110.75 | 4.41 | $p < .001$ | .46 |
| C. Stimulus Type | 16.62 | 1.42 | $p < .001$ | .12 |
| A × B | 30.85 | 1.24 | $p < .001$ | .19 |
| B × C | 1.23 | .05 | $p = .269$ | .01 |
| A × C | 63.26 | 2.14 | $p < .001$ | .33 |
| A × B × C | 1.90 | .08 | $p = .170$ | .02 |
| Experiment 3 | *df*: 1, 127 | | | |
| A. Item Type | 312.56 | 18.58 | $p < .001$ | .71 |
| B. Repetition | 63.10 | 1.89 | $p < .001$ | .33 |
| C. Stimulus Type | 7.15 | .63 | $p = .008$ | .05 |
| A × B | 45.83 | 1.68 | $p < .001$ | .27 |
| B × C | 6.12 | .18 | $p = .015$ | .05 |
| A × C | 51.98 | 3.09 | $p < .001$ | .29 |
| A × B × C | .85 | .03 | $p = .357$ | .01 |

analysis of variance (RMANOVA) revealed a significant Item Type × Repetition interaction, $F(1, 66) = 45.42$, $MSE = 1.23$, $p < .001$, $\eta_p^2 = .41$. Simple effects analyses revealed that study list repetition significantly increased hit rates to intact faces, $t(66) = 9.14$, $p < .001$, $d = 1.12$, but not false-alarm rates to conjunction faces, $t(66) = .68$, $p = .499$, $d = .08$. All effects and interactions are presented in Table 2.

Finally, Fig. 4 shows the aggregate frequencies of whole-face intact face hits (top panel) and conjunction rejections (bottom panel) made with high, moderate, or low confidence for faces studied eight versus two times. Notably, in both cases, study list repetition selectively increased the frequency of high confidence responses. Consistent with this observation, a chi-square test of goodness-of-fit confirmed that the distribution of aggregate frequencies of high, moderate, and low confidence whole-face responses significantly differed across repetition conditions for intact item hits, $\chi^2(2, N = 353) = 77.05$, $p < .001$, and conjunction rejections, $\chi^2(2, N = 252) = 10.13$, $p = .006$.[1]

[1] The two-presentation and eight-presentation conditions provided the expected and observed data, respectively, for all of the chi-square analyses reported in this study.

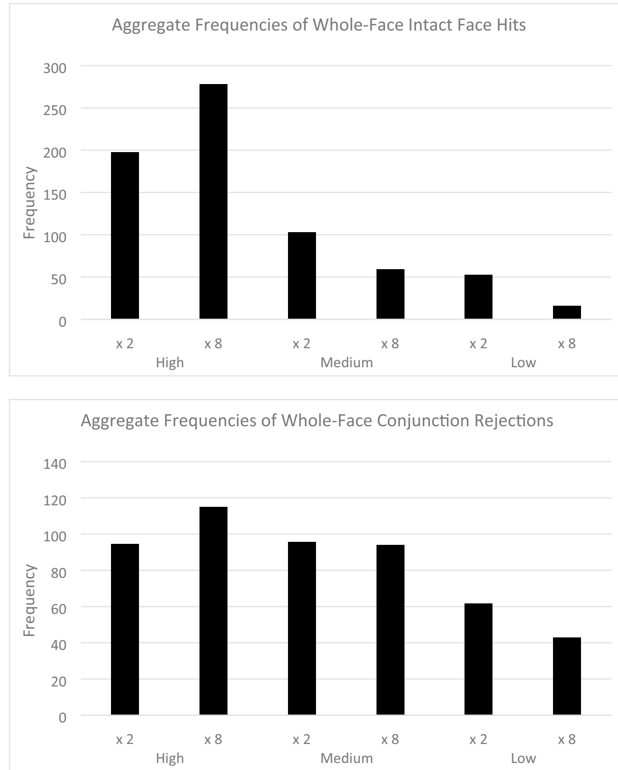


**Fig. 4** Aggregate frequencies of whole-face intact face hits (top panel) and conjunction rejections (bottom panel) as a function of repetition condition and confidence level in Experiment 1. The frequencies for the two-presentation condition are the expected frequencies and those for the eight-presentation condition are the observed frequencies from the analysis

## Discussion—Experiment 1

In the two-presentation condition, participants in Experiment 1 rarely recognized or recognized with low confidence the parts of the conjunction faces they rejected as *new* wholes. Consistent with previous findings (e.g., Jones & Bartlett, 2009; Meltzer & Bartlett, 2019; Weatherford et al., 2021), this supports a signal-detection model of face recognition at low levels of learning. By contrast, in the eight-presentation condition, participants often recognized the halves of rejected conjunction faces with high confidence just as predicted by the dual-process model. Consistent with this signal-detection/dual-process shift in face recognition strategies, study list repetition also selectively increased whole-face hit rates to intact faces as well as the relative frequency with which participants accepted intact faces as *old* and rejected conjunctions as *new* whole-faces with high confidence.

Yet, questions remain. For instance, Meltzer and Bartlett (2019) administered the whole-face/half-face judgment paradigm employed here using the well-aligned upright faces from Experiment 1 with some participants and the same composite faces inverted and with their halves horizontally misaligned with others (as shown in Fig. 1). Having matched memory performance (defined as the degree to which participants endorsed more intact faces than conjunction faces as *old* whole faces) across stimulus conditions by presenting the well-aligned upright faces twice but the misaligned-inverted faces eight times, the authors found that participants who viewed misaligned-inverted faces at study and test were better at recognizing the parts of rejected conjunction faces than those who viewed well-aligned upright faces at study and test. Given that both inversion and composite face half misalignment disrupt holistic or Gestalt-like processing of faces—a hallmark of face perception and recognition (Hole et al., 1999; Tanaka & Farah, 1993; Young et al., 1987)—this finding along with other data led Meltzer and Bartlett to propose a "holistic-unitization hypothesis" according to which holistic processing favors a signal-detection strategy of face recognition at a given level of memory performance. Therefore, although the Experiment 1 findings suggest that holistic processing permits dual-process face recognition, might it nonetheless limit the degree or rate of its adoption? Or, do learning effects encouraging such recognition occur independent of holistic processing?

To answer these questions, Experiment 2 used the same design as Experiment 1 except that participants were randomly assigned to view either the face stimuli from Experiment 1 at study and test, which receive holistic processing, or the misaligned-inverted faces used by Meltzer and Bartlett (2019) at study and test, which do not. Given the Experiment 1 results, it was predicted that study list repetition of well-aligned upright faces would increase high confidence recognition of the parts of rejected conjunction faces, whole-face hit rates to intact faces but not false-alarm rates to conjunction faces, and the relative frequency of high confidence whole-face intact item hits and conjunction item rejections. Further, it was reasoned that if holistic processing impairs the adoption of a dual-process strategy of face recognition, study list repetition effects on associative recollection would be larger with misaligned-inverted faces than with well-aligned upright faces.

## Experiment 2

### Methods

**Participants** The power analysis for Experiment 2 was based on the effect size for the smallest significant repetition effect on rejected conjunction part recognition in Experiment 1 (mean face half ratings of 5.5, $d$ = .32). While this revealed that employing a total of 62 participants would supply a minimum acceptable power level of .80 (see Cohen, 1988) for detecting repetition effects with well-aligned upright faces, I intentionally exceeded this quota in Experiment 2 by randomly assigning 130 participants to view either well-aligned upright faces ($n$ = 67) or misaligned-inverted faces ($n$ = 63). The mean age of the participants was 20.23 ($SD$ = 2.12), approximately 65% self-identified as female, and 75% self-identified as Caucasian (most of the remainder identified as Hispanic or Asian). All of them were undergraduates at the University of Texas at Dallas, with normal or corrected-to-normal vision, who participated in the experiment for course credit. They each gave informed consent, and the institutional review board approved the study.

**Stimuli and study/test lists** The stimuli, study lists, and test lists were the same used in Experiment 1 except that misaligned-inverted faces were used in addition to well-aligned upright faces. These were created by first turning each face stimulus from Experiment 1 upside down and then misaligning its top and bottom halves such that the left side of the top half of the face fell at the midpoint of the bottom half of the face (see Fig. 1). Images of misaligned-inverted faces were 11.40 cm wide and varied from 11.40 cm to 14.00 cm in height (with a horizontal visual angle of 10.90$^{o}$ and a vertical visual angle of between 10.90$^{o}$ and 17.40$^{o}$).

**Procedure** The procedure was the same as in Experiment 1.

### Results

**Well-aligned upright faces studied twice versus misaligned-inverted faces studied eight times** Given its relevance to the research question at hand, it was important to first replicate the Meltzer and Bartlett (2019) finding that holistic processing favors a signal-detection strategy of face recognition at a given level of memory performance. Therefore, I examined whether participants would be better at recognizing with high confidence the halves of rejected conjunction faces made from misaligned-inverted faces studied eight times than the halves of those made from well-aligned upright faces studied twice despite intact/conjunction discrimination being similar across stimulus conditions. To verify that such discrimination was matched across stimuli, I subtracted whole-face false-alarm rates to conjunction faces from whole-face hit rates to intact faces for each participant, and a $t$ test confirmed that these difference scores were statistically similar across stimulus conditions (well-aligned upright × 2: $M$ = .24, $SD$ = .26; misaligned-inverted × 8: $M$ = .17, $SD$ = .24), $t(128)$ = 1.46, $p$ = .147, $d$ = .26. Next, the same approach employed in Experiment 1 was used to calculate the probability of participants giving different average face half ratings to

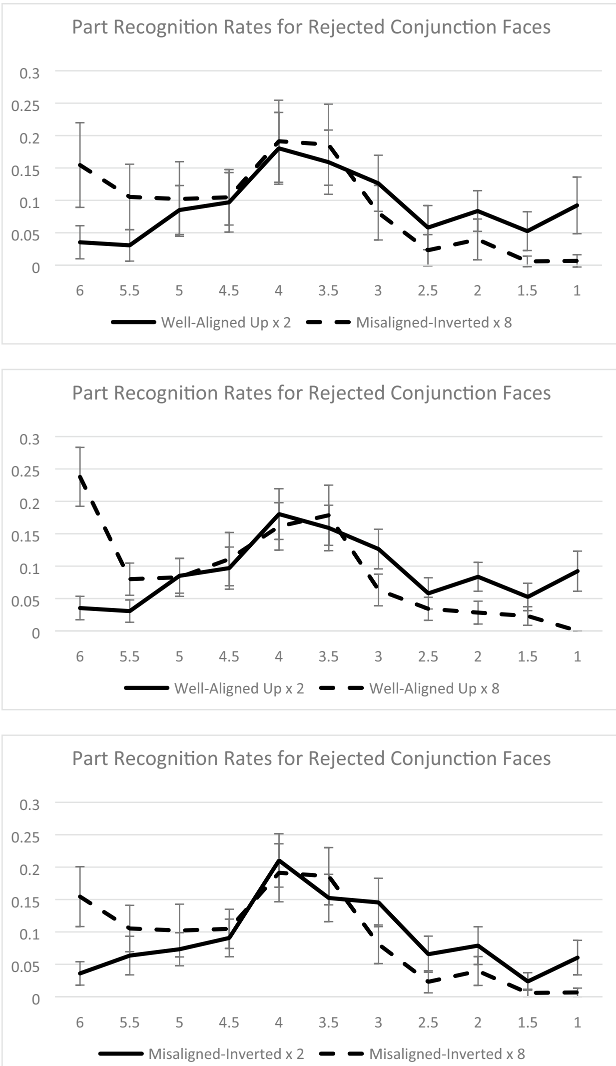


**Fig. 5** Probabilities of average half ratings for conjunction faces participants rejected as *new* wholes in Experiment 2. Error bars represent 95% confidence intervals and these were calculated using the Cousineau–Morey correction for within-subject comparisons in the middle and bottom panels (see Cousineau, 2005; Morey, 2008)

the conjunctions they rejected as *new* in each stimulus and study list repetition condition.

Replicating the Meltzer and Bartlett (2019) findings, Fig. 5 (top panel) shows that participants were more likely to recognize with high confidence both parts of rejected conjunction items (average half rating of 6) when they were made from misaligned-inverted faces studied eight times than when they were made from well-aligned upright faces studied twice, and a similar trend emerged for an average half rating of 5.5. Providing quantitative support for this observation, *t* tests revealed a statistically significant misaligned-inverted > well-aligned upright part recognition advantage for both average half ratings (6: $t(64.59) = 5.59$, $p < .001$, $d = 1.01$; 5.5: $t(88.03) = 2.68$, $p = .009$, $d = .48$).[2]

**Study list repetition effects** Having found support for the holistic-unitization hypothesis, I next examined whether holistic processing influences study list repetition effects on associative recollection. Just as in Experiment 1, Fig. 5 (middle panel) shows a slightly left-skewed unimodal distribution of average half rating probabilities for conjunctions made from well-aligned upright faces studied twice, with participants either failing to recognize or recognizing with low confidence the halves of the conjunctions they rejected as *new*. By contrast, with conjunctions made from well-aligned upright faces studied eight times, an additional mode emerged reflecting a repetition advantage in average half ratings of 6 and 5.5. Crucially, as shown in Fig. 5 (bottom panel), this pattern of repetition effects was closely mirrored in the misaligned-inverted face condition. Offering quantitative support for these observations, a pair of 2 × 2 (Repetition [Two, Eight] × Stimulus Type [Well-Aligned Upright, Misaligned-Inverted) mixed ANOVAs found significant main effects of Repetition on the probability of average half ratings of 6, $F(1, 124) = 47.78$, $MSE = 1.60$, $p < .001$, $\eta_\rho^2 = .28$, and 5.5, $F(1, 124) = 7.81$, $MSE = .13$, $p = .006$, $\eta_\rho^2 = .06$, with Stimulus Type moderating neither of these effects ($p > .07$ for both Stimulus Type × Repetition Interactions).[3]

Turning next to the whole-face hit rate and false-alarm rate data, a 2 × 2 × 2 (Item Type [Intact, Conjunction] × Repetition [Two, Eight] × Stimulus Type [Well-Aligned Upright, Misaligned-Inverted) mixed ANOVA revealed a significant Item Type × Repetition interaction, $F(1, 128) = 30.85$, $MSE = 1.24$, $p < .001$, $\eta_\rho^2 = .19$. Consistent with the Experiment 1 findings, study list repetition increased hit rates to intact faces, $t(66) = 9.02$, $p < .001$, $d = 1.10$, but not false-alarm rates to conjunction faces, $t(66) = 1.07$, $p = .291$, $d = .13$, in the well-aligned upright face condition. Further, stimulus type failed to moderate this pattern, $F(1, 128) = 1.90$, $MSE = .05$, $p = .170$, $\eta_\rho^2 = .01$, though repetition did significantly increase false alarms to conjunctions in the misaligned-inverted face condition, $t(62) = 3.76$, $p < .001$, $d = .47$.[4] Descriptive statistics for the whole-face judgments

[2] Degrees of freedom containing decimals indicate an adjustment to correct for a violation of Levene's test of homogeneity of variance.

[3] Consistent with this outcome, a Bayesian analysis provided evidence, albeit weak, for the null hypothesis of a Repetition × Stimulus Type interaction with average face half ratings of 6.0 ($B_{01} = 1.13$) and provided moderate evidence for the null hypothesis of no such interaction with face half ratings of 5.5 ($B_{01} = 5.42$).

[4] Consistent with this outcome, a Bayesian analysis provided moderate evidence for the null hypothesis of no Item Type × Stimulus Type × Repetition interaction on *old* whole-face judgments ($B_{01} = 3.06$).

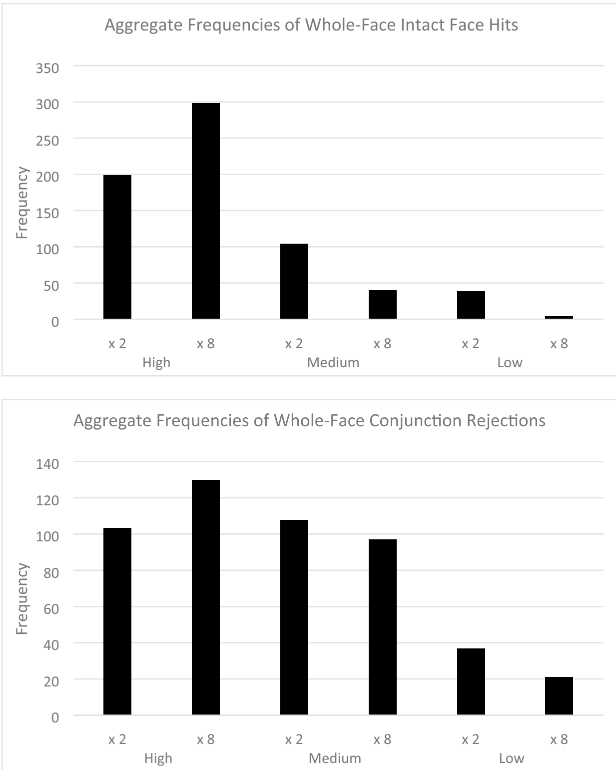


**Fig. 6** Aggregate frequencies of whole-face intact face hits (top panel) and conjunction rejections (bottom panel) as a function of repetition condition and confidence level for well-aligned upright faces in Experiment 2. The frequencies for the two-presentation condition are the expected frequencies and those for the eight-presentation condition are the observed frequencies from the analysis

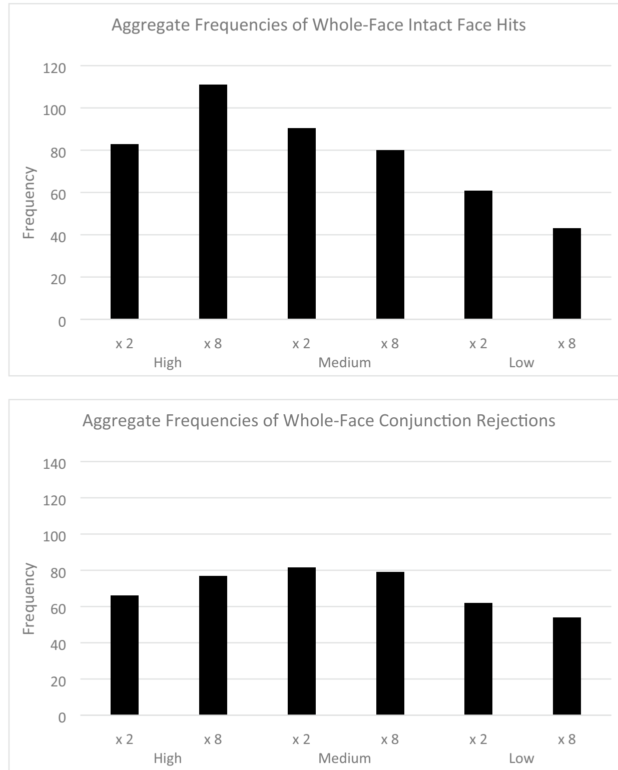


**Fig. 7** Aggregate frequencies of whole-face intact face hits (top panel) and conjunction rejections (bottom panel) as a function of repetition condition and confidence level for misaligned-inverted faces in Experiment 2. The frequencies for the two-presentation condition are the expected frequencies and those for the eight-presentation condition are the observed frequencies from the analysis

are presented in Table 1, and all statistical effects and interactions are shown in Table 2.

Finally, Fig. 6 shows that just as in Experiment 1, study list repetition of well-aligned upright faces selectively increased the aggregate frequency of high confidence whole-face intact item hits (top panel) and conjunction rejections (bottom panel), and chi-square tests of goodness-of-fit quantitatively supported this pattern (intact face hits: $\chi^2(2, N = 342) = 120.802$, $p < .001$; conjunction rejections: $\chi^2(2, N = 248) = 14.86$, $p < .001$). Notably, Fig. 7 shows a similar pattern of effects in the misaligned-inverted face condition, though it only reached significance by chi-square tests of goodness-of-fit for hits to intact items, $\chi^2(2, N = 234) = 15.90$, $p < .001$; $\chi^2(2, N = 210) = 3.81$, $p = .149$, for conjunction item rejections.

## Discussion—Experiment 2

Experiment 2 replicated the Meltzer and Bartlett (2019) finding that holistic processing favors a signal-detection strategy of face recognition at a given level of memory performance. However, it found no evidence for such favoritism when absolute memory performance was *not* of concern. Just as in Experiment 1, with well-aligned upright faces, study list repetition increased the likelihood of participants recognizing as *old* the parts of conjunction faces they rejected as *new* wholes, selectively raised whole-face hits to intact faces, and increased the relative frequency of high confidence intact item hits rates and conjunction item correct rejections. The new finding, though, was that several of these effects were also significant with misaligned-inverted faces. This implies that learning effects on the retrieval processes involved in face recognition are at least moderately independent of holistic processing.

Although these findings are persuasive, Reinitz and Loftus (2017) suggest that participants may experience conjunction faces as unnatural given their perceptual overlap with multiple previously viewed faces. Rather, a much more common real-world experience is to encounter different faces with only partial overlap. Therefore, rather than using conjunction faces, Experiment 3 examined study list repetition effects with "feature-faces" that recombined a studied face half with a nonstudied face half (see Meltzer & Bartlett, 2019). If participants reject feature-faces using recollection as implied by the dual-process model, they should show an ability to recognize with high confidence the studied part of such items while judging the whole items to be *new*.

Based on the Experiment 2 results, it was predicted that study list repetition would increase recollection-based rejections of feature-faces with both well-aligned upright and misaligned-inverted faces. This would be evidenced by an increased likelihood of participants recognizing the parts of rejected feature-faces with high confidence and an increased frequency of whole-face high confidence intact item hits and feature-face rejections in the eight- versus two-presentation conditions. It would also be evidenced by study list repetition increasing whole-face hit rates to intact items (which are encouraged by recollection) but not whole-face false alarms to feature-faces (which are not encouraged by recollection) (see Jones & Jacoby, 2001; Leding & Lampinen, 2009).

## Experiment 3

### Methods

**Participants** The power analysis for Experiment 3 was based on the effect size for the smallest significant repetition effect on rejected conjunction part recognition in Experiment 2 (mean face half ratings of 5.5 with well-aligned upright faces, $d = .39$). While it revealed that employing a total of 53 participants would supply a minimum acceptable power level of .80 (see Cohen, 1988) for detecting repetition effects via $t$ test with well-aligned upright faces, I intentionally exceeded this quota by randomly assigning 129 participants to either a well-aligned upright ($n = 63$) or a misaligned-inverted condition ($n = 66$) to increase sensitivity to meaningful effects. The mean age was 20.50 ($SD = 3.02$), approximately 80% self-identified as female, and 70% self-identified as Caucasian (most of the remainder identified as Hispanic or Asian). All participants were undergraduates at the University of Texas at Dallas, with normal or corrected-to-normal vision, who participated in the experiment for course credit. They each gave informed consent, and the institutional review board approved the study.

**Stimuli and study/test lists** The stimuli were drawn from the same set of faces used in Experiments 1 and 2. As in those experiments, a total of eight study lists were prepared with the interstimulus interval set at three seconds and the stimulus duration set at two seconds on each list. However, to accommodate the construction of the feature-faces, the length of the two “long” lists were reduced to eighteen faces (with two buffer faces at the beginning and end bringing the total to 22 faces) and the length of the two “short” lists was reduced to nine faces (with two buffer faces at the beginning and end bringing the total to 13 faces).

All parameters of the test were the same as in Experiment 2 except that feature-faces were used instead of conjunction faces. Five versions of the study list were used with five subgroups of participants so that each test face served as each type of test item for approximately one-fifth of the participants in each condition. Half of the feature-faces contained a studied top part and the other half contained a studied bottom part, and the studied/nonstudied status of each part was completely counterbalanced across participants.

**Procedure** The procedure was the same as in Experiment 2.

### Results

**Well-aligned upright faces studied twice versus misaligned-inverted faces studied eight times** Given the switch to using feature-faces to examine whether holistic processing influences face learning effects, it was important to first demonstrate its ability to impact how participants reject such items as *new*. Therefore, I tested the holistic-unitization hypothesis prediction that participants would be more likely to recognize with high confidence the studied half of feature-faces made from misaligned-inverted faces studied eight times than the studied half of feature-faces made from well-aligned upright faces studied twice. To confirm that this study list presentation schedule matched memory performance across stimulus conditions (as is assumed by the holistic-unitization hypothesis), I calculated the degree to which each participant endorsed more whole intact faces than whole feature-faces as *old*, and found such intact/feature-face discrimination to be statistically similar for well-aligned upright faces studied twice ($M = .40$, $SD = .31$) and misaligned-inverted faces studied eight times ($M = .32$, $SD = .31$), $t(127) = 1.49$, $p = .137$, $d = .26$.

I next examined the probabilities of participant responses to the halves of feature-faces they rejected as *new* wholes. These were analyzed by first transforming the *old/new* and three-point confidence ratings for half-face judgments to a 1–6 scale (1 = *high confidence “new” judgment* to 6 = *high confidence “old” judgment*) in the same manner used with conjunction faces in Experiments 1 and 2 except that no ratings were averaged. Then, to account for response bias, I calculated “corrected” hit rates to the studied halves of feature-faces for each face half rating corresponding to an *old* judgment (6, 5, and 4). These were derived by subtracting the probability of participants giving that rating to a nonstudied half of a rejected feature-face from the probability of them giving it to a studied half of a rejected feature-face. For instance, if a participant made a high confidence *old* judgment to 50% of the studied halves and 25% of the nonstudied halves of the feature-faces they rejected as *new* wholes, their corrected hit rate for a face half rating of 6 would be .50 minus .25, or .25. As shown in Fig. 8 (top

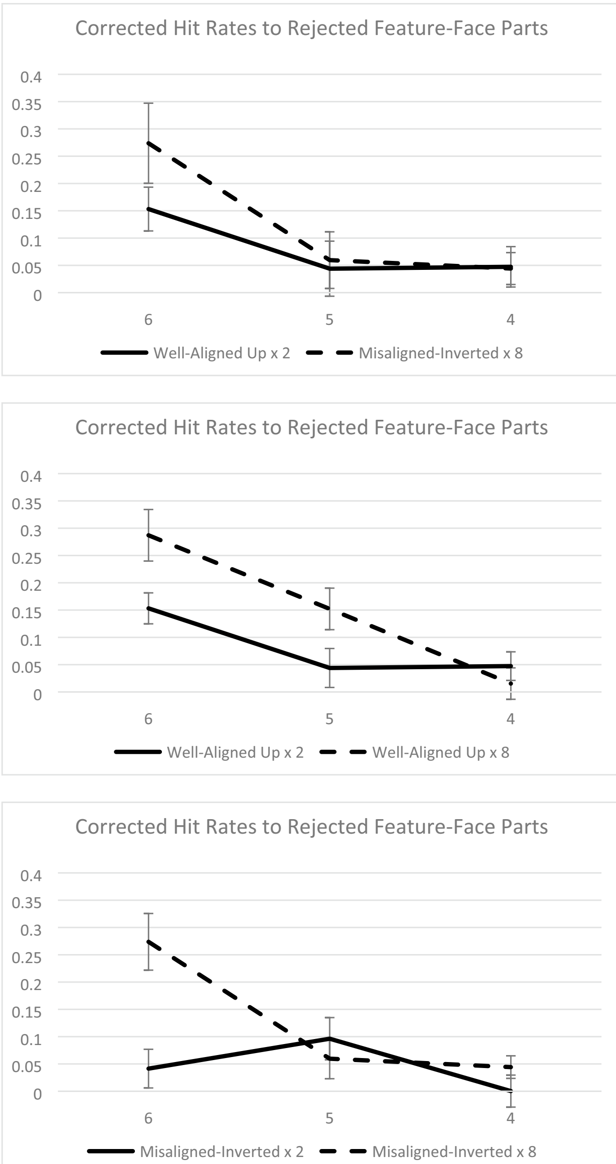


**Fig. 8** Corrected hit rates for the studied parts of feature-faces participants rejected as *new* wholes in Experiment 3. Error bars represent 95% confidence intervals, and these were calculated using the Cousineau–Morey correction for within-subject comparisons in the middle and bottom panels (see Cousineau, 2005; Morey, 2008)

panel), the corrected hit rate corresponding to a rating of 6 (high confidence old) was higher for feature-faces made from misaligned-inverted faces studied eight times than for those made from well-aligned upright faces studied twice. This pattern, which is consistent with the holistic-unitization hypothesis, was quantitatively supported by $t$ test, $t(100.26) = 2.39$, $p = .019$, $d = .42$.

**Study list repetition effects** Having found support for the holistic-unitization hypothesis using feature-faces, I next examined whether holistic processing influences study list repetition effects on how participants reject such items as *new*. The corrected hit rates in the two-versus eight-presentation conditions are shown in Fig. 8 for well-aligned upright faces (middle panel) and misaligned-inverted faces (bottom panel). Given the high confidence with which recollection-based recognition judgments are typically made, of primary interest was that study list repetition increased high confidence corrected hit rates (ratings of 6) with both well-aligned upright faces (top panel) and misaligned-inverted faces (bottom panel). Of lesser interest, study list repetition also increased moderate confidence corrected hit rates (ratings of 5) with well-aligned upright faces. Providing quantitative support for these observations, a 2 × 2 (Repetition [Two, Eight] × Stimulus Type [Well-Aligned Upright, Misaligned-Inverted] mixed ANOVA examining high confidence corrected hit rates revealed only a significant main effect of repetition, $F(1, 125) = 27.95$, $MSE = 2.00$, $p < .001$, $\eta_\rho^2 = .18$, such that they were higher for feature-faces in the eight-presentation condition than in the two-presentation condition for both stimuli.[5] The same analysis examining moderate confidence corrected hit rates revealed only a significant interaction, $F(1, 125) = 5.14$, $MSE = .31$, $p = 025$, $\eta_\rho^2 = .04$, with study list repetition only increasing moderate confidence hit rates with well-aligned upright faces, $t(62) = 2.47$, $p = .016$, $d = .31$.

I next analyzed the whole-face hit rate and false-alarm rate data (see Table 1 for descriptive statistics). A 2 × 2 × 2 (Item Type [Intact, Feature] × Repetition [Two, Eight] × Stimulus Type [Well-Aligned Upright, Misaligned-Inverted) mixed ANOVA revealed a significant Item Type × Repetition interaction, $F(1, 127) = 45.83$, $MSE = 1.68$, $p < .001$, $\eta_\rho^2 = .33$, reflecting an increase in whole-face hit rates to intact faces, $t(128) = 9.76$, $p < .001$, $d = .96$, but not whole-face false-alarm rates to feature-faces, $t(128) = .30$, $p = .77$, $d = .03$, for faces studied eight versus two times, with no moderation by stimulus type ($p = .357$). All main effects and interactions are reported in Table 2.[6]

Finally, Fig. 9 shows the aggregate distribution of whole-face intact face hits (top panel) and feature-face rejections (bottom panel) that participants made with high, moderate, and low confidence in each stimulus/repetition condition. One can see that with well-aligned upright faces, study list repetition selectively increased the frequency of high confidence intact face hits and feature-face rejections, and chi-square tests of goodness-of-fit quantitatively supported this observation (intact face

[5] Consistent with this outcome, a Bayesian analysis found support, albeit weak, for the null hypothesis of no Repetition × Stimulus Type interactions for corrected feature-face part hit rates of 6 ($B_{01} = 1.84$).

[6] Consistent with this outcome, a Bayesian analysis provided moderate evidence for the null hypothesis of no Item Type × Stimulus Type × Repetition interaction on *old* whole-face judgments ($B_{01} = 3.68$).

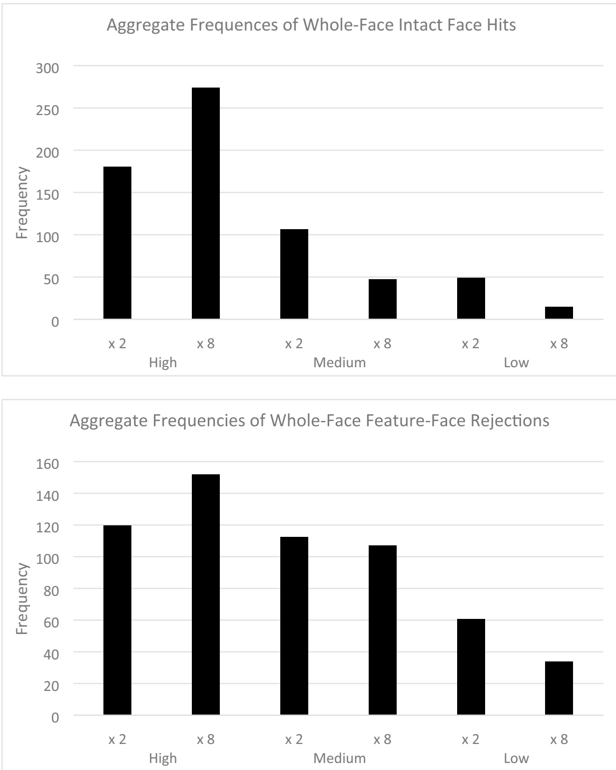


**Fig. 9** Aggregate frequencies of whole-face intact face hits (top panel) and feature-face rejections (bottom panel) as a function of repetition condition and confidence level for well-aligned upright faces in Experiment 3. The frequencies for the two-presentation condition are the expected frequencies and those for the eight-presentation condition are the observed frequencies from the analysis

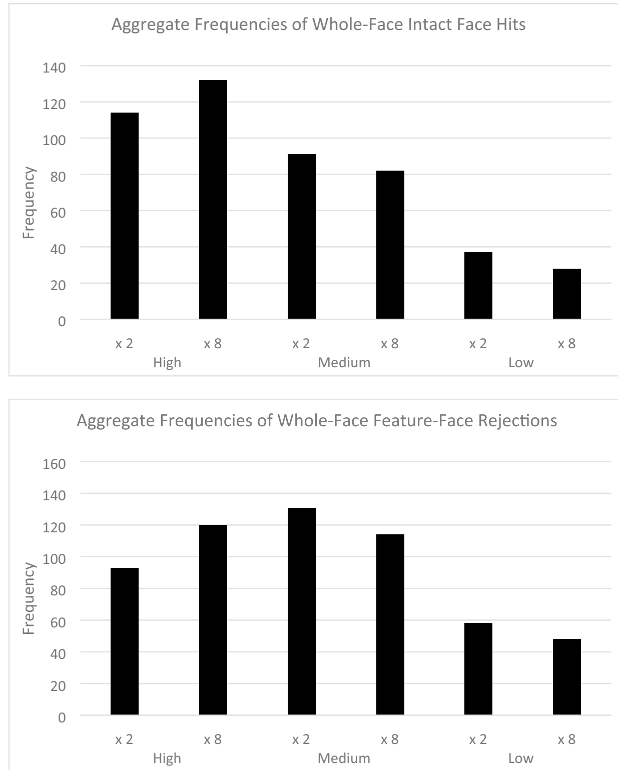


**Fig. 10** Aggregate frequencies of whole-face intact face hits (top panel) and feature-face rejections (bottom panel) as a function of repetition condition and confidence level for misaligned-inverted faces in Experiment 3. The frequencies for the two-presentation condition are the expected frequencies and those for the eight-presentation condition are the observed frequencies from the analysis

hits: $\chi^2(2, N = 336) = 105.08$, $p < .001$; feature-face rejections: $\chi^2(2, N = 293) = 20.87$, $p < .001$). Figure 10 shows that a similar pattern emerged with misaligned-inverted faces which trended towards significance for intact face hits, $\chi^2(2, N = 242) = 5.99$, $p = .050$, and reached significance for feature-face rejections, $\chi^2(2, N = 282) = 11.81$, $p = .003$.

## Discussion—Experiment 3

Employing feature-faces that participants may perceive as more natural in appearance than conjunction faces (see Reinitz & Loftus, 2017), Experiment 3 supported the conclusion that study list repetition increases recollection for specific combinations of face features. Further, although the whole-face hit/false-alarm rate and high confidence part recognition data were more convincing with misaligned-inverted faces, and the response confidence data were more convincing with well-aligned upright faces, a similar pattern of collective study list effects emerged with both stimuli. With an increased degree of ecological validity, this bolsters the notion that learning causes a qualitative shift in how faces are recognized independent of holistic processing.

# General discussion

Using a study list repetition manipulation, three experiments suggested that face learning causes a qualitative shift in how participants recognize faces. At lower levels of learning, the signal-detection model adequately accounted for face recognition as demonstrated by participants rarely recognizing as *old* the studied parts of conjunction and feature-faces they rejected as *new* wholes. At higher levels of learning, however, participants often recognized these parts with high confidence, indicating the use of recollection in rejecting such items. This finding along with others and their qualitative and frequently quantitative similarity with well-aligned upright and misaligned-inverted faces suggests that learning causes the adoption of a dual-process strategy of face recognition regardless of holistic processing.

### Theoretical implications

The finding that learning causes conjunction and feature-face parts to become cues for recollection broadly fits with evidence that familiar faces receive more featural processing than unfamiliar ones (e.g., Mohr et al., 2018; O'Donnell & Bruce, 2001). However, most investigations define familiar faces as those belonging to celebrities (e.g., Buttle & Raymond, 2003; Megreya & Burton, 2006; Mohr et al., 2018) or to personal acquaintances or family members of participants (e.g., Herzmann et al., 2004; Pierce et al., 2004; Platek et al., 2006), and by those standards any familiarity gained by studying a face eight versus two times should not fundamentally affect its recognition. One consideration, though, is that faces of celebrities, family members, and acquaintances become familiar to us as a result of seeing them from multiple angles. Because of this, we may only encode a given image of them once, and identical stimulus repetition might be needed to change how a face is recognized with so few as eight exposures. Further, the present findings are rather *unsurprising* given data obtained with verbal stimuli. Indeed, as few as three study list repetitions can increase the type of associative information supported by recollection with compound words (see Lampinen et al., 2004; Leding & Lampinen, 2009), and as few as four can have this effect with conjunction word pairs (see Light et al., 2004).[7] This cross-stimulus generalization in findings supports a material-general view (see Aly et al., 2010) of study list repetition effects and of dual-process models of recognition memory in general.

Finally, in light of the holistic-unitization hypothesis, one interpretation of the present findings is that learning reduces holistic processing of faces, allowing participants to reject conjunction faces using recollection. However, no such reduction was evidenced here. Indeed, the decrement in whole-face *old/new* discrimination caused by manipulations of holistic processing—a behavioral marker of such processing (see Brace et al., 2001; Diamond & Carey, 1986)—was greater or unchanged for faces studied eight times versus twice in Experiments 2 and 3, as shown in Table 1.

On the one hand, the coexistence of holistic processing with part-cued associative recollection for faces fits nicely with findings emphasizing the role of both holistic and featural information in face recognition (see Cabeza & Kato, 2000). On the other hand, how these findings can be reconciled with the holistic-unitization hypothesis remains unclear. One possibility is that holistic processing delays but does not *prevent* the adoption of a dual-process strategy of face recognition. In other words, holistic processing may merely require that higher levels of learning be achieved with faces than with other stimuli before participants can use part-cued recollection to reject conjunction and feature-item lures.

### Avenues for future research

As mentioned in the introduction, recent findings suggest that verbalizing or briefly describing faces at encoding causes participants to reject conjunction faces using recollection (e.g., Jones et al., 2013; Weatherford et al., 2021). On the one hand, Jones et al. (2013) suggest that verbalization intrinsically exerts this effect by creating contextual information about the encoding event that participants can later recollect. On the other hand, when verbalization increases recollection for faces, it also facilitates face memory in much the same way as study list repetition did in the present experiment. This raises the possibility that verbalization facilitates dual-process face recognition by generically enhancing face learning, nominating an important topic for future research to explore.

Additionally, future research should clarify whether encoding faces from different angles supports the type of learning that facilitates dual-process face recognition. However, using the conjunction paradigm to this end would be challenging if not impossible because participants may never study conjunction/feature-face parts from a perspective replicated at test, limiting the ability of such parts to cue recollection. Therefore, other measures of recollection-based retrieval including event-related potentials (see Rugg & Curran, 2007, for a review) and remember/know data (see Tulving, 1985) may be particularly sensitive to the effects of multi-view encoding on how faces are recognized and better suited for this research.

Finally, the composite faces employed here possess visually segmented top and bottom halves which make them useful for measuring recollection-based responding but somewhat unnatural in appearance. It should be noted that data obtained using composite faces with visually segmented regions has been widely accepted as being applicable to naturalistic face perception in previous studies (e.g., Gauthier, 2020; Kuefner et al., 2010; Laguesse & Rossion, 2013; Meinhardt et al., 2014; Meltzer & Bartlett, 2019; Murphy et al., 2017; Richler et al., 2014). Further, the upright face two-presentation data presented here align well with results obtained using more naturalistic face stimuli at lower levels of learning (see Jones & Bartlett, 2009; Weatherford et al., 2021), suggesting that visual segmentation of parts does not fundamentally alter retrieval processes in face recognition. Nonetheless, future research should test the replicability of the present findings using more naturalistic face stimuli.

[7] Examining verbal memory, Kelley and Wixted (2001) proposed a "some-or-none" model of recognition memory according to which associative retrieval does not require recollection conceptualized as an all-or-none threshold process. For this reason, I distinguish between associative information and recollection regarding study list repetition effects on verbal memory.

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The data and materials for all experiments are available at Open Science Framework.