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Holistic processing of faces happens at a glance

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ABSTRACT

Holistic processing (HP) of faces can be inferred from failure to selectively attend to part of a face. We explored how encoding time affects HP of faces by manipulating exposure duration of the study or test face in a sequential matching composite task. HP was observed for exposure as rapid as 50 ms, and was unaffected by whether exposure of the study or test face was limited. Holistic effects emerge as soon as performance is above chance, and are not larger at rapid exposure durations. Limiting exposure at study vs. test did have differential effects on response biases at the fastest exposure durations. These findings provide key constraints for understanding mechanisms of face recognition. These results are first to demonstrate that HP of faces emerges for very briefly presented faces, and that limited perceptual encoding time affects response biases and overall level of performance but not whether faces are processed holistically.

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1. Introduction

Because faces are made from common features (eyes, nose, mouth, etc.) arranged in the same general configuration, subtle differences in spatial relations between face features being encoded is particularly useful for successful recognition of a given face (Diamond & Carey, 1986; Le Grand, Mondloch, Maurer, & Brent, 2004; Leder & Bruce, 2000; Maurer, Le Grand, & Mondloch, 2002; Maurer et al., 2002; Searcy & Bartlett, 1996). As such, faces are said to be processed holistically – as a whole – rather than as a collection of individual face features. One consequence of such holistic processing is an inability to selectively attend to one part of a face, even when instructed to do so and even when it is advantageous for that instructed task (e.g., Farah, Wilson, Drain, & Tanaka, 1998; Richler, Tanaka, Brown, & Gauthier, 2008). In this article, we investigate how such failures of selective attention are influenced by perceptual encoding time through manipulations of the exposure duration of the face.

Failure of selective attention from holistic processing is commonly demonstrated using composite face stimuli, made by combining the top half of one face with the bottom half of another face (Young, Hellawell, & Hay, 1987). In the sequential matching version of the composite task, participants study one novel composite face and after a brief delay are tested on another novel composite face. Specifically, they are asked to judge whether one part of the test composite (e.g., top) is the same or different from the studied composite while ignoring the other part (e.g., bottom). Holistic processing is inferred from an inability to ignore the irrelevant face part – the irrelevant face part affects performance because the face is processed as a whole.

In one version of this paradigm (*partial design*; Gauthier & Bukach, 2007), the irrelevant face part is always "different", and face parts at test are either aligned or misaligned. Holistic processing is inferred from an *alignment effect*, where performance on "same" trials is better when face parts are misaligned (e.g., Goffaux & Rossion, 2006; Le Grand et al., 2004; Michel, Rossion, Han, Chung, & Caldara, 2006). However, recent work has shown that this paradigm has important limitations. Namely, when only accuracy on "same" trials is analyzed, differences in response bias between aligned and misaligned trials could be misinterpreted as true discriminability differences (see Cheung, Richler, Palmeri, & Gauthier, 2008). In addition, in the parlance of Stroop tasks, all "same" trials in the partial design are incongruent – the correct response to the relevant part is "same", but the response to the irrelevant part would always be "different". Thus, the partial design does not take into account the possible influence of the relationship between the target and distractor parts.

We instead used a version of the composite task (*complete design*; Gauthier & Bukach, 2007) where holistic processing is inferred from a *congruency effect*: Performance is better on *congruent trials* (both parts same, or both parts different) compared to *incongruent trials* (one part same, one part different; Cheung & Gauthier, in press; Cheung et al., 2008; Farah et al., 1998; Gauthier, Curran, Curby, & Collins, 2003; Richler, Gauthier, Wenger, & Palmeri, 2008; Richler, Tanaka, et al., 2008). The congruency effect is larger for faces than other objects (Farah et al., 1998; Gauthier et al., 2003) and does not arise due to response interference

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(Richler, Cheung, Wong, & Gauthier, 2009). One benefit of this complete design paradigm is that it allows us to measure holistic processing for aligned faces directly without requiring a comparison to misaligned faces. Also, because both same and different trials are analyzed, we can measure discriminability independently from response bias.

In a typical sequential composite face task, presentation time of the study face is fixed at around 500–1000 ms, followed by a brief delay, and then the test face is presented until the participant makes a same–different response. We know of one previous study by Hole (1994) that manipulated exposure duration of the faces. With short presentations (80 ms), standard holistic effects were observed. But with long presentation times (2 s), participants appeared to switch to using a part-based, feature-matching strategy. Unfortunately, there are some important limitations in interpreting these results with respect to holistic processing more generally: First, the presentation time manipulation was conducted not only between subjects but between experiments, which may encourage the use of different explicit strategies. Second, holistic processing was inferred using the inversion effect within a partial design, so discriminability and response bias could not be separated. Third, those experiments used simultaneous presentation of face pairs. With long presentation times, when both faces are presented simultaneously, participants have ample opportunity to scan back and forth between the faces, allowing for a feature-matching strategy that is not possible in sequential matching tasks or with short presentation times.

We assessed how holistic processing might be affected by perceptual encoding time within a sequential composite face task by systematically manipulating the exposure duration of one of the two faces to be compared. We were particularly interested in how failure to selectively attend to the target part of the face – the marker of holistic processing in the composite face task – would vary with different perceptual encoding times. We considered three alternatives illustrated in Fig. 1 and discussed in detail below. Holistic processing as marked by a failure of selective attention is indicated when there is a significant difference in performance for congruent versus incongruent trials. In other words, the same–different status of the irrelevant to-be-ignored part of the face nonetheless influences same–different performance for the target part of the face.

Panel A of Fig. 1 illustrates a case where holistic effects emerge only as exposure duration is increased. With short presentations, there is no difference between congruent and incongruent trials, but there is a difference with long presentation times. Existing lines of research suggest that the emergence of holistic effects in the composite task may require longer presentation times. For example, according to the load theory of selective attention, excess processing capacity for targets automatically "spills over" to distractors, especially under conditions of low perceptual load, such as when there is only one target and one distractor (Lavie, 1995; Lavie, Hirst, de Fockert, & Viding, 2004). Although obligatory processing of whole-face distractors within this framework has been investigated (Jenkins, Lavie, & Driver, 2003), whether processing face *parts* as targets and distractors is influenced by the same principles of selective attention put forth by the load theory is unknown. In addition, it is unknown whether and how any such spillover of attention might emerge with longer presentation time of faces. For example, if the spread of excess processing capacity to non-attended parts of a face takes time, with short presentation times there may not be sufficient time for the irrelevant distractor half to be erroneously processed. This would lead to an absence of interference from an irrelevant distractor half when presentation times are short.

Panel B of Fig. 1 illustrates a different possibility, where holistic effects are even larger when exposure duration is limited. Imagine that with rapid presentation, selective attention to one face part is difficult or even impossible, either because selective attention is too slow or because the face is only represented as an undifferentiated gestalt. This could lead to a very large congruency effect under short presentation times, perhaps even larger than for long presentations times when selective attention to part of the face is eventually possible. Research examining global vs. local processing in the perception of hierarchical patterns (e.g., a "Y" made up of small "X"s) suggests that failures of selective attention to parts may be more pronounced under rapid presentation because global information is processed and available more rapidly than local information. For example, Navon (1977) showed that participants are faster to name the global pattern (e.g. "Y") than the local elements (e.g., "X"), and the identity of the global figure interferes more with the identification of the local elements than the other way around (Navon, 1977; Paquet & Merkile, 1984). More recently, Kimchi (1998) examined the time-course of this global dominance effect by asking participants to judge whether a pair of hierarchical figures were the same or different following the presentation of a prime stimulus. Results showed that at short prime durations (40 ms and 90 ms), participants were faster to respond on "same" trials when the prime shared the same global configuration as the test pair, compared to when the prime shared local elements with the test pair. At 190 ms, however, participants were faster on "same" trials sharing local elements with the prime. These results suggest that it may be more difficult to selectively attend to parts when stimuli are presented briefly (shorter than 200 ms) because the representation does not contain information about individual features, only the global gestalt. This is also consistent with the work by Hole (1994) discussed earlier, where more holistic effects emerge under fast but not slow presentations.

Finally, Panel C of Fig. 1 illustrates a case where the emergence of holistic effects does not depend on exposure duration. Face rep-

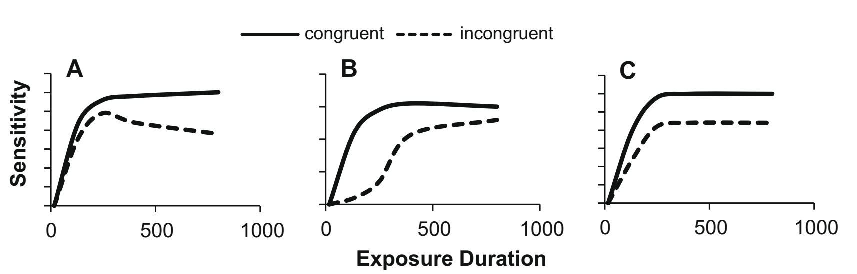

Fig. 1. Three possible outcomes for the time-course of holistic processing. In each case, same–different discriminability (d') is plotted as a function of exposure duration for congruent trials (both parts same or different from study face) versus incongruent trials (one part same, one part different). Holistic processing occurs when there is a significant difference in performance for congruent versus incongruent trials. Panel A: holistic processing only emerges after long exposures, when there is enough time to erroneously process the irrelevant part. Panel B: holistic processing is more pronounced for brief exposure due to global dominance at short presentation times. Panel C: holistic processing is present at all exposure durations, once above-chance performance is possible.

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resentations improve with longer presentation times, which causes the overall increase in d' seen in all three panels. But holistic effects emerge at the same time that above-chance performance is possible. In terms of mechanisms, holistic effects in face recognition need not reflect a rapid holistic bias, nor be the result of a slower spillover of selective attention. They may just be a natural byproduct of how faces are processed and represented, which is distinct from general attentional processes that operate regardless of object category during encoding.

In the present experiment, we assessed how holistic processing is influenced by perceptual encoding time within a sequential composite face task by systematically manipulating the exposure duration of either the study or test face. Previous work has shown that manipulations of the test face but not the study face influence holistic processing; for example, misalignment of the test face reduced holistic processing, whereas misalignment of the study face had no effect (Richler, Tanaka, et al., 2008). In line with this previous work, we may observe different effects depending on whether exposure duration of the study face or test face is limited. One reason this might occur is that the encoding demands differ between the study and test face. In our paradigm, participants are not cued as to whether they need to respond about the same–different status of the top or bottom half of the face until after the offset of the study face (see Fig. 2). Thus, for the study face, both parts need to be encoded since the participant does not know which part they will be tested on. In other words, there are no demands for selective attention during encoding of the study face. For the test face, on the other hand, participants are aware of which part they need to respond to, so presentation time could significantly affect selective attention and the congruency effect. Of course, another viable alternative is that study and test manipulations produce comparable effects since in both cases it is the timing of a presented face that is being systematically manipulated.

2. Methods

2.1. Participants

Forty-two undergraduates from Vanderbilt University participated in exchange for course credit. For 21 participants exposure duration of the study face was limited, and for 21 participants exposure duration of the test face was limited. These conditions were initially run as separate experiments, so group assignment was not randomized. Data from nine participants (4 from the Study group, 5 from the Test group) were discarded for below chance performance.

2.2. Stimuli

Twenty female faces from the Max Planck Institute Database (Troje & Bulthoff, 1996) were converted to gray-scale and cut in half to produce 20 face tops and 20 face bottoms 256 × 128 pixels in size. Face halves were randomly combined on every trial. A white line 3 pixels thick separated the two face halves resulting in faces that were 256 × 259 pixels. The white line was added to make it unambiguous where the top half ends and the bottom half begins, which, if anything, should facilitate selective attention. Faces were cropped within a black rectangle on a gray background to eliminate cues derived from the shape of the head or chin.

2.3. Procedure

For the Test group, on each trial the study face was presented (800 ms), followed by a random pattern mask (500 ms). A square bracket was presented simultaneously either above or below the mask cueing whether the target part would be the top or bottom half of the test face. The cue remained on the screen during the presentation of the test face. The test face was presented at one of eight randomly selected presentation durations (17 ms, 50 ms, 83 ms, 133 ms, 183 ms, 250 ms, 400 ms, 800 ms). A second random pattern mask was presented immediately after the exposure of the test face (see Fig. 2). The participant responded by keypress if the cued part was the same or different as the corresponding part of the study face.

The procedure for the Study group was the same as for the Test group, with the exception that the presentation time of the study face was varied (17 ms, 50 ms, 83 ms, 133 ms, 183 ms, 250 ms, 400 ms, 800 ms). The test face was always displayed for 800 ms. Participants were instructed to wait until the test face was replaced with the mask before responding.

3. Results

Fig. 3 displays sensitivity (d') and response criterion (c) on congruent and incongruent trials as function of exposure duration of the Study or Test face. Reaction times on correct trials, measured from the onset of the test mask, are reported in Table 1.

3.1. Sensitivity (d')

A 2 × 2 × 8 mixed factors ANOVA was conducted with within-subjects factors of congruency (congruent vs. incongruent) and exposure duration (17, 50, 83, 133, 183, 250, 400, 800 ms) and between-subjects factor of the limited face presentation (Study vs.

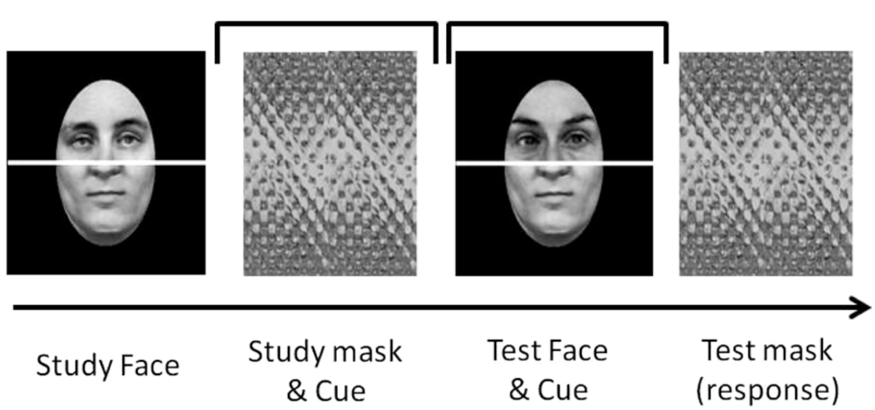

Fig. 2. Illustration of a single trial of the experiment. See text for details.

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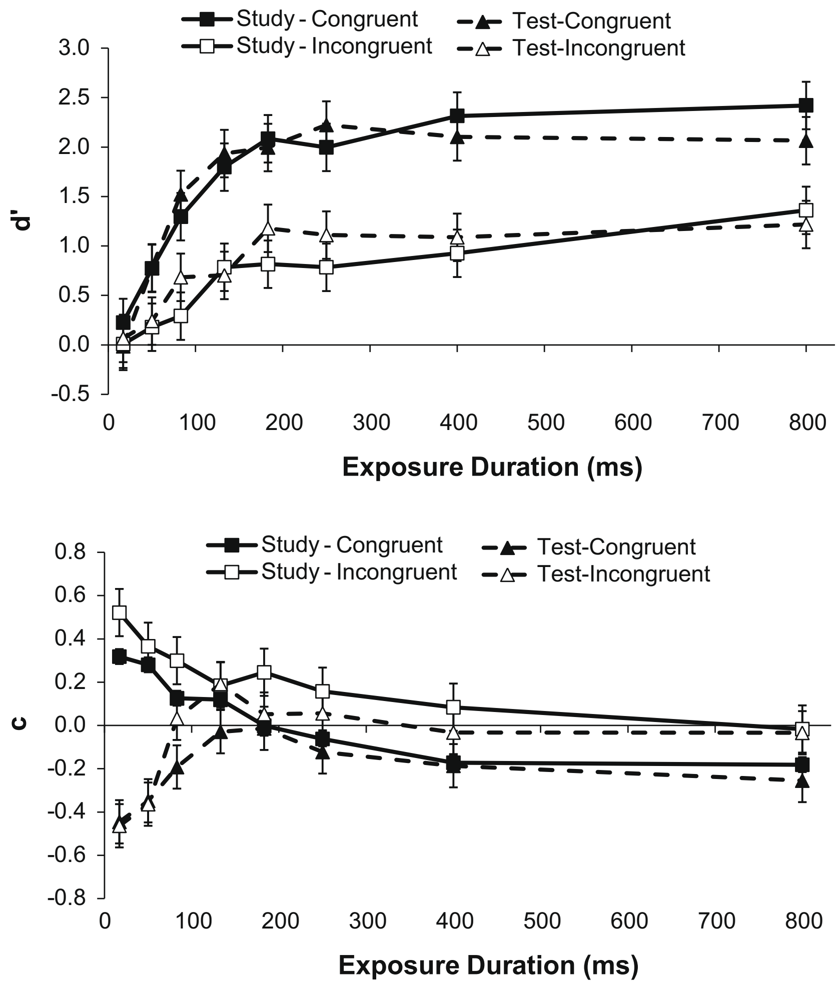

Fig. 3. Sensitivity (*d*′; top panel) and response criterion (*c*; bottom panel) for congruent (filled symbol) and incongruent (open symbol) trials as a function of exposure duration of the study face (square symbol, solid line) and test face (triangle symbol, dashed line). Error bars show 95% confidence intervals of within-subjects effects.

Table 1
Reaction times (ms) of correct responses measured from the onset of the test mask for congruent and incongruent trials for each exposure duration when exposure duration was limited at study and test.

	Exposure duration (ms)							
	17	50	83	133	183	250	400	800
Test								
Congruent	898	831	808	824	854	882	896	1129
Incongruent	898	850	862	882	893	931	961	1164
Study								
Congruent	900	800	781	765	747	743	697	719
Incongruent	891	826	807	800	793	800	814	803

Test). Performance was better on congruent vs. incongruent trials, as reflected in a significant main effect of congruency ($F_{1,31} = 200.738$, $MSE = 0.509$, $p < 0.0001$); there was also a main effect of exposure duration ($F_{7,217} = 121.799$, $MSE = 0.195$, $p < 0.0001$), and a significant congruency × exposure duration interaction ($F_{7,217} = 12.707$, $MSE = 0.191$, $p < 0.0001$).

As can be appreciated from Fig. 3 (top panel), performance did not differ when the limited face was at study versus test. Limited face interacted with exposure duration ($F_{7,217} = 2.907$, $MSE = 0.195$, $p < 0.01$), but did not interact with congruency ($F_{1,31} = 2.102$, $MSE = 0.509$). Critically, there was no significant congruency × exposure duration × limited face interaction observed ($F_{7,217} = 0.947$, $MSE = 0.191$).

According to our first hypothesis, if congruency effects require enough time for attention to spread to the irrelevant part, then there should be at least one time-point where performance is above chance, but where there is no congruency effect (Fig. 1, Panel A). In contrast, our third hypothesis predicts that congruency effects should be evident as soon as above-chance performance is possible (Fig. 1, Panel C). Bonferroni-corrected paired-sample *t*-tests between congruent and incongruent trials at each exposure duration revealed significant congruency effects for all exposure durations beyond 17 ms ($\alpha = 0.00625$, p's < 0.0001). However, average performance at 17 ms – the only exposure duration that does not show a congruency effect – is not significantly different from chance ($t_{32} = 1.319$, $p = 0.197$). Thus, our results do not support our first hypothesis but are consistent with our third hypothesis.

Our second hypothesis was that congruency effects might be larger at shorter exposure durations due to global dominance (Fig. 1, Panel B). To test this, we conducted a 2 × 2 ANOVA comparing performance at 50 ms (the first exposure duration that shows a congruency effect) with performance at 800 ms on congruent and incongruent trials. If congruency effects are larger at 50 ms than 800 ms, we would expect a significant interaction between congruency and exposure duration. However, although the interaction between congruency and exposure duration is significant ($F_{1,32} = 4.383$, $MSE = 0.286$, $p < 0.05$) the nature of this interaction is the opposite of what our second hypothesis predicts; that is, the congruency effect is smaller at 50 ms vs. 800 ms (congruency

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effect at 50 ms = 0.5672, congruency effect at 800 ms = 0.9567). Thus, our data are still most consistent with our third hypothesis.

3.2. Response criterion

A similar 2 × 2 × 8 mixed factors ANOVA was conducted on response criteria. There was a significant main effect of congruency ($F_{1,31} = 59.234$, $MSE = 0.054$, $p < 0.0001$), such that participants were somewhat more likely to respond "different" on incongruent trials. Congruency did not interact with limited face ($F_{1,31} = 1.053$, $MSE = 0.054$) or exposure duration ($F_{7,217} = 1.514$, $MSE = 0.040$). There was also a main effect of exposure duration ($F_{7,217} = 3.232$, $MSE = 0.146$, $p < 0.01$) that was modulated by an interaction with limited face ($F_{7,217} = 13.097$, $MSE = 0.146$, $p < 0.0001$). Most critically, as can be seen in Fig. 3 (bottom panel), this interaction arises because at exposure durations less than 133 ms, participants were more likely to respond "different" if the exposure duration of the study face was limited, but were more likely to respond "same" if the exposure duration of the test face was limited. No significant congruency × exposure duration × limited face interaction was observed ($F_{7,217} = 1.707$, $MSE = 0.040$).

4. Discussion

Faces are said to be perceived holistically. When people judge whether parts of a pair of sequentially presented composite faces are the same or different, holistic processing can be operationalized by the observed failure to selectively attend to one face part; specifically, whether the irrelevant part of a face is the same or different affects how well people are able to judge whether the relevant part is the same or different. This article represents the first attempt to systematically measure how perceptual encoding time influences holistic processing of faces.

Holistic processing of faces happens at a glance. As soon as overall performance was above chance (at 50 ms), we observed significant congruency effects. Holistic effects are not *absent* at rapid exposure durations, a possible prediction from the load theory of selective attention (Lavie, 1995); holistic effects seem not to be a byproduct of a spillover of attentional resources from the attended part to the unattended part, which would likely emerge with additional encoding time. Nor are holistic effects *larger* at rapid exposure durations, as might be suggested by global dominance (e.g., Kimchi, 1998). It is clear that holistic effects are seen when faces are only briefly presented, and do not need to wait for successful local encoding of individual face parts; but holistic effects are not especially large when presentation time is short, nor are they attenuated when there is more time to process the face with longer presentation times (cf. Hole, 1994). Thus the failures of selective attention observed with faces do not arise due to the same mechanisms that can sometimes reduce selective attention in novice object perception.

While our work may represent the first systematic attempt to assess how perceptual encoding time influences holistic processing of faces, some other recent work has also suggested that holistic processing of faces emerges rapidly. For example, experiments that have used the composite task with faces filtered by spatial frequency may provide indirect clues to the relationship between perceptual encoding time and holistic processing (Goffaux & Rossion, 2006) because there is evidence that low-spatial frequency information may be extracted at more rapid presentations compared to high-spatial frequency information (Coin, Versace, & Tiberghien, 1992; Ginsburg, 1986; Parker, Lishman, & Hughes, 1997; Sergent, 1986; but see Schyns & Oliva, 1999). Goffaux and Rossion (2006) found larger holistic effects for faces containing only low spatial frequencies compared to those containing only high spatial frequencies or full spectrum faces. They argued that holistic perception occurs at an early stage of face processing and is supported by low-spatial frequency information. We should note that Goffaux and Rossion used the partial design version of the composite task, where holistic processing is inferred from an alignment effect and only performance on "same" trials is considered. A follow-up study by Cheung et al. (2008) that measured holistic processing in terms of a congruency effect (as used in the present paper) found no difference in the magnitude of holistic processing for faces containing only low-spatial frequency information compared with full-spectrum or high-spatial frequency faces (but see Goffaux, 2009). Instead, Cheung et al. found significant differences in response biases between spatial frequency conditions. Our results are consistent with those of Cheung et al. (2008): we found no difference in the amount of holistic processing when exposure duration was very short, conducive to the extraction of low-spatial frequency information, or quite long, allowing more spatial frequency channels to become available.

We observed the same pattern of congruency effects across exposure durations regardless of whether exposure duration was limited at study or test. In a sequential matching composite task, there are different task demands for the study and test face. At study, subjects do not know which part of the face will be relevant, so the whole face needs to be encoded. By contrast, at test the cue has already appeared during the brief delay interval signaling which part of the face needs to be judged as same or different, so selective attention can be deployed. If the relationship between exposure duration and the congruency effect was influenced by strategic factors, we might have expected different patterns of results depending on whether exposure duration was limited at study versus test. We found none.

Instead, we found that limiting exposure duration did have differential effects at study and test in terms of response biases. When exposure duration was limited at study, participants had a bias to judge faces as more different, especially at the shortest exposure duration. The opposite was found when exposure duration was limited at test, with participants showing a bias to judge faces as the same. Significant response biases have been previously reported using the composite task (Cheung et al., 2008; Richler, Bukach, & Gauthier, 2009; Richler, Gauthier, et al., 2008; Richler, Tanaka, et al., 2008). There is not yet a comprehensive account on how these biases are best interpreted, but we can still speculate on the biases observed here. When exposure duration is manipulated at study, participants have a degraded representation of that face. The face viewed at test may look very different from the degraded representation of the study face, resulting in an overall bias to respond "different". When exposure duration is limited at test, on the other hand, participants may only be able to encode global configuration, consistent with the global dominance hypothesis. Because all faces share the same global configuration (eyes, nose, mouth in a particular configuration), the test face may appear similar to the study face, resulting in a bias to respond "same". Of course these are post hoc explanations of an unexpected result, and there are likely other possible explanations. What is important to emphasize here is that differences in response biases were observed without differences in discriminability, providing yet another demonstration of the importance of assessing holistic processing with tasks that can measure both discriminability and bias: looking at accuracy (hits) alone confounds these effects (see also Cheung et al., 2008; Gauthier & Bukach, 2007). Indeed, the alignment effect in the partial design may show a different dependence on presentation time than what we observed here with the congruency effect because that measure of holistic processing

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could combine both our sensitivity effect and our bias effect. Future work that makes a priori predictions about response biases in the composite task will be important to understanding what factors influence face recognition and holistic processing.

In summary, our work shows that even briefly presented faces are processed holistically, and that holistic processing is not influenced by manipulations of encoding time that can affect selective attention in novice object perception. Observing holistic processing effects for rapidly presented or perceptually degraded faces has been used to argue that holistic processing of faces arises during early perceptual processes (e.g., Goffaux & Rossion, 2006). However, we have shown that a manipulation of perceptual encoding time does not affect the presence or the magnitude of holistic processing. One possibility is that holistic effects do not arise during perceptual encoding *per se* but rather emerge later in processing, such that face parts are initially represented independently but are integrated when decisions are made about them (Richler, Gauthier, et al., 2008; Richler, Tanaka, et al., 2008).

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