Revisiting the Role of Spatial Frequencies in the Holistic Processing of Faces

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Abstract

Goffaux and Rossion (G&R, 2006) argued that holistic processing of faces is largely supported by low spatial frequencies (LSF) but less so by high spatial frequencies (HSF). We addressed this claim using a sequential matching task with face composites. Observers judged whether the top halves of aligned or misaligned composites were identical. We replicated the G&R results, finding a greater alignment effect in accuracy for LSF compared with HSF faces on *same* trials. However, there was also a greater bias for responding "same" for HSF compared with LSF faces, indicating that the alignment effects arose from differential response biases. Importantly, comparable congruency effects found for LSF and HSF suggest that LSF and HSF faces are processed equally holistically. These results demonstrate that it is necessary to use measures that take into account response biases in order to fully understand the holistic nature of face processing.

Faces contain two types of information that may be used for recognition: featural information, such as the shape of the eyes, nose and mouth, and configural information, such as the spatial relationship between those features. Face recognition is thought to rely critically on configural information. For example, recognition of an individual feature (e.g., the nose) within a face context is impaired when the configural information (e.g., spatial relationship between the nose and the eyes) in the study and test faces differs. This effect is not found with scrambled faces, inverted faces, or common objects (e.g., houses), suggesting that processing upright faces is particularly sensitive to configural information (Tanaka & Sengco, 1997). Importantly, faces are also processed more ‘holistically’ – as a gestalt combining individual face features – than other types of stimuli (for a review, see Maurer, Le Grand & Mondloch, 2002).

Different visual spatial frequency information may be used to extract featural and configural information within a face (Sergent, 1986). Sergent suggested that high spatial frequencies (HSF), which reflect local luminance gradients, or fine visual details, are critical for extracting information about face parts, whereas low spatial frequencies (LSF), which reflect large-scale luminance changes or coarse visual information, are critical for extracting configural information from a face. LSF information is extracted and processed rapidly (e.g., Schyns & Oliva, 1994; but see Morrison & Schyns, 2001; Oliva & Schyns, 1999), thus it may be especially important for rapid recognition of human faces (Goffaux, Gauthier, & Rossion, 2003a; Sergent, 1986). Although HSF information may be processed at a slower rate than LSF information, the fine-level details that HSF carry are probably useful for discriminating individual faces from one another because faces are highly visually similar (Goffaux, Jemel, Jacques, Rossion, & Schyns, 2003b; Halit, de Haan, Schyns, & Johnson, 2006; Oliva & Schyns, 1997; Schyns & Oliva, 1999).

Recent work supports the idea that LSF dominate configural processing of faces

(Goffaux, Hault, Michel, Vyong, & Rossion, 2005). When faces in a match-to-sample task varied in terms of featural information, performance was better for HSF faces (with LSF information filtered out) than LSF faces (with HSF information filtered out); when the faces varied in terms of configural information (distance between individual features), performance was better for LSF than HSF faces. Goffaux et al. interpreted these results as suggesting that face recognition depends on HSF for the extraction of featural information but relies on LSF for the extraction of configural information. Importantly, they did point out that configural information can be extracted from faces using both LSF and HSF information, but there appears to be an advantage for processing configural information from LSF.

Extending this earlier work, Goffaux and Rossion (2006) tested whether holistic processing of faces is more readily observed with LSF than HSF faces. They examined two standard tests of holistic face perception. In the *whole-part paradigm*, participants are asked to study a whole face and then recognize facial features either embedded in a whole face or presented in isolation; holistic processing is inferred from better performance when the features are presented within the context of a face than when presented in isolation (Tanaka & Farah, 1993). Goffaux and Rossion found that the whole-face advantage was significantly larger for LSF than HSF faces. But it should be noted that one potential problem with this paradigm is that participants are never instructed *not* to attend to the whole face, so finding an advantage for the whole may not be all that surprising. Indeed, one observes a *part* advantage when parts are studied instead of wholes (Leder & Carbon, 2005). Moreover, a whole advantage can also be found with unfamiliar non-face objects (Gauthier et al., 1998).

In contrast, the *composite face paradigm* leads to effects that are more face specific (McKone, Kanwisher, & Duchaine, 2007) under clear instructions to ignore part of the face. In this task, composite faces are created by combining the top half of one face with the bottom half of a second face. Participants are asked to judge whether the top halves of the study and test composites are identical or not. Holistic processing is often inferred from better performance when the top and bottom halves of the composite faces are misaligned than when they are aligned. This *alignment effect* suggests that when the meaningful configuration of the face is disrupted, holistic processing is disrupted (Goffaux & Rossion, 2006; Hole, 1994; Hole, George, & Dunsmore, 1999; Le Grand, Mondloch, Maurer & Brent, 2004; Michel, Rossion, Han, Chung, & Caldara, 2006; Robbins & McKone, 2007; Young, Hellawell & Hay, 1987). Goffaux and Rossion (2006) found that the alignment effect was stronger for LSF than HSF faces and concluded that holistic processing of faces is primarily supported by LSF information.

Although LSF and HSF information in a face may be processed differently, and observers could rely more on LSF for configural processing and more on HSF for featural processing, this does not necessarily imply that holistic processing of faces is primarily supported by LSF information. Indeed, both configural and featural information can be extracted from both LSF and HSF faces (Goffaux et al., 2005). So, holistic effects in face processing could be observed equally with LSF and HSF faces, as the results of the current study will suggest.

There are two commonly used versions of the composite face paradigm that have been used to test holistic processing of faces (see Figure 1 for schematic illustrations of these two versions). In the version used by Goffaux and Rossion (2006), while the target part of the test face can be the same or different from the study face, the irrelevant part of the test face is *always* different. We refer to this as the *partial design* (Gauthier & Bukach, 2007). As described above, holistic processing in this task is operationally defined by an *alignment effect*. Specifically, the accuracy at judging same tops as “same” is significantly greater when the face parts are misaligned than when they are aligned.

By contrast, in the version called the *complete design* (Gauthier & Bukach, 2007), both the target part and irrelevant part of a test face can be the same or different from the study face. There are two critical trial types. On *congruent trials*, both the top and bottom parts are the same or both parts are different. On *incongruent trials*, one part is the same and the other part is different. Holistic processing is operationally defined as a *congruency effect*: discriminability, as measured by d', is better on congruent than incongruent trials (Farah, Wilson, Drain, & Tanaka, 1998; Gauthier, Curran, Curby, & Collins, 2003a; Richler et al., in press). A misalignment manipulation can be included in an experiment using the complete design, with a significant decrease in the congruency effect observed for misaligned composites (Gauthier et al., 2003b). But misalignment is not a necessary manipulation in the complete design for measuring holistic processing of faces.

The complete design and the partial design share many elemental features, but they differ in some fundamental ways that makes us favor the use of the complete design to understand the nature of holistic processing of faces. First, ever since Young et al. (1987), the most interesting finding from the composite face paradigm is that observers cannot selectively attend to one face part and ignore the other face part. Misalignment is just one transformation of a face composite that reduces this impairment in selective attention. Inversion has a similar effect (e.g., Young et al., 1987; Hole, 1994). And according to Goffaux and Rossion (2006), high spatial frequency filtering may be another. But the use of alignment effects alone roots the operational definition of holistic processing in one specific image transformation – misalignment. We believe this is both empirically and theoretically problematic – why alignment and not inversion? By contrast, the congruency effect provides a single measure of holistic processing without necessitating a misalignment manipulation to measure it. A variety of manipulations, including misalignment, inversion, or spatial frequency filtering, can be used to experimentally influence the magnitude of the congruency effect, but misalignment has no special experimental or theoretical status.

A second problem is that most experiments using the partial design, including Goffaux and Rossion (2006), emphasize the accuracy on same trials and how that accuracy changes with misalignment. In the parlance of signal detection theory, this is the hit rate. It is well known from signal detection theory (Macmillan & Creelman, 1991) that differences in hit rate alone could be caused by differences in discriminability (as measured by d') or differences in response biases (as measured by relative values of c). But in experiments using the partial design, differences in accuracy (hit rate) are typically interpreted as true discriminability differences. In the case of Goffaux and Rossion, it is claimed that LSF faces show a significantly larger alignment effect because LSF faces are perceived more holistically – the irrelevant part of the face cannot be ignored because it is perceptually fused with the relevant part of the face. Although that explanation is possible, without examining the entire set of data, including the false alarm rates, differences in response biases might be lurking as well (see Gauthier & Bukach, 2007, for simulations illustrating this problem). Indeed, regardless of whether the correct answer is same or different, participants are biased to respond "different" to aligned face parts and "same" to misaligned face parts (Gauthier, Tanaka, & Brown 2003b; Richler et al., in press). A bias to respond "same" does not arise because participants are better able to *correctly* identify same top parts when a face is misaligned – they *incorrectly* respond "same" more often as well. Other manipulations also influence response bias, such as inversion (Farah et al., 1998; Wenger & Ingvalson, 2002). We will show the same for spatial frequency filtering in the present study.

If false alarms in the partial design were examined, discriminability and response bias differences could be calculated in ways analogous to what is done typically in the complete design. But a third problem with the partial design is that it confounds the response with congruency and congruency itself has been shown to influence response bias. The response relation between the top and bottom parts on "same" trials is always incongruent; while the top is the same, the bottom is different, and is always different. But the response relation between the top and bottom parts for "different" trials is always congruent; both parts are different. Previous work has shown that participants are more likely to respond "different" on incongruent than congruent trials (Farah et al., 1998; Gauthier, et al., 2003b). This response bias could interact with other factors such as misalignment. Without the full complement of trials from the complete design it is impossible to know if a manipulation affects the ability of observers to selectively attend to a face part (discriminability), whether it affects response biases, or both.

This study extends Goffaux and Rossion (2006) by using the *complete* composite design, comparing performance on LSF and HSF faces that are aligned or misaligned. Like Goffaux and Rossion, we can measure the alignment effect as the accuracy on the same-incongruent trials in the complete design, where the top parts are the same and the bottom parts are different, for aligned versus misaligned faces. Replicating Goffaux and Rossion, we expected to find a significantly larger alignment effect for LSF than HSF faces. If observers truly find it more difficult to selectively attend to a single face part in LSF than HSF (aligned) faces, presumably because LSF faces are more perceptually holistic than HSF faces, then there should also be a significantly larger alignment effect when false alarm rate is also taken into consideration. Moreover, there should be a significantly larger congruency effect for LSF than HSF faces in the complete design. Alternatively, differences in performance could instead be reflected by differences in response bias.

Method

Participants

Twenty-three undergraduate students (mean age=18.9, 6 male) at Vanderbilt University with normal or corrected-to-normal vision participated for course credits. Data from two participants were discarded because of a large (>10%) number of trials without a response.

Stimuli

The twenty face stimuli (10 male, 10 female) from Goffaux and Rossion (2006) were used to form face composites. All faces were approximately 180 pixels wide and 250 pixels high and were fitted onto a 256 x 256 pixel gray background. The faces were Fourier transformed and multiplied by low-pass and high-pass Gaussian filters that preserved either low (< 8 cycles/face width) or high (> 32 cycles/face width) spatial frequencies (see Figure 2), creating *LSF* or *HSF* faces, respectively. Full spectrum (*FS*) faces were also used. In Goffaux and Rossion, the study stimuli were 20 real faces and the test stimuli were 20 composites made by pairing each target top part with a bottom part from another individual of the same sex. Because these are real faces, there is perfect alignment of the top and bottom parts, whereas composite faces never align perfectly; as such, if the original real faces were used in our study, where bottoms can also be the same or different, it would be perceptually obvious when a same-congruent test stimulus was shown because it would be a real faces, not a composite. Therefore, we randomly paired top and bottom parts from different individuals of the same sex to form both the study and test stimuli. Each of the 20 target top parts appeared approximately once in each condition.

Procedure

The experimental procedure was essentially identical to Goffaux and Rossion (2006), except that the additional trial types required by the complete design were included. Participants were instructed to match the top parts of the composites while ignoring the bottom parts. The experiment was run within the Psychophysics Toolbox running in Matlab 5.2 on Macintosh computers with 17" monitors (screen resolution: 1024 x 768, 85Hz refresh rate). A study composite face was shown for 600 ms, followed by a 300 ms blank, followed by a test composite face for 1 s or until a response was made (whichever came first). Participants were seated 110 cm away from the monitor with a chin rest in order to maintain that distance. The aligned faces subtended a visual angle of 4.1° x 3.1° and the misaligned faces were 4.1° x 3.7°. There was a 3 mm (0.15°) gap inserted between the top and bottom parts. Because of a minor programming error, each condition had slightly unequal numbers of trials (mean=17.4 to 21 trials across subjects, SD≤1.6). Study and test faces were presented in the same spatial frequency, either LSF, HSF or full spectrum (FS), were either both aligned or both misaligned and face parts were either congruent or incongruent. Trial presentations were randomized for each subject.

Analyses

We first analyzed data in the same way as Goffaux and Rossion (2006). Two-way repeated measures ANOVAs were applied on accuracy and correct RTs for "same" (incongruent) trials, with spatial frequency (FS vs. LSF vs. HSF) and alignment (aligned vs. misaligned) as factors. We then analyzed the all trials in the partial design on sensitivity [zHit – zFA], response criterion [-0.5 x (zHit + zFA)], and correct RTs with the same factors. Finally, we analyzed data using all trials from the complete design trials in terms of the congruency effect. Three-way repeated measures ANOVAs were applied to sensitivity, response criterion and correct RTs, with spatial frequency, alignment, and congruency (congruent vs. incongruent) as factors. For all analyses, Fisher LSD tests were used for planned comparisons among the spatial frequency conditions and Scheffe's tests were used post hoc. Bonferroni tests corrected for the number of planned comparisons of interest were used when the main effects were not significant.

Results

Hit Rates and Corresponding Correct Response Times in the Partial Design (Alignment Effect with Same-Incongruent Trials). We replicated the basic finding of Goffaux and Rossion (2006) that the alignment effect was larger for LSF than HSF faces (see Figure 3). There was a significant main effect of spatial frequency in accuracy ($F_{2,40}$=4.37, p<.05, $\tilde{\eta}_p^2$=.18, but not significant in RTs, p=.39). Accuracy was poorer for LSF than HSF faces (p<.01), and for LSF than FS faces (p<.05), but there was no significant difference between accuracy for HSF and FS faces (p=.4). There was a significant main effect of alignment in both accuracy ($F_{1,20}$=50.71, p<.0001, $\tilde{\eta}_p^2$=.72), and RTs ($F_{1,20}$=35.41, p<.0001, $\tilde{\eta}_p^2$=.61) with higher accuracy and faster responses on misaligned than aligned trials. Importantly, we observed a significant interaction between spatial frequency and alignment in accuracy ($F_{2,40}$=3.63, p< .05, $\tilde{\eta}_p^2$=.15; but not significant in RTs, p=.23), just like Goffaux and Rossion: The alignment effect was larger for LSF faces than for either HSF or FS faces (p's<.05). Following Goffaux and Rossion, we conducted separate ANOVAs on accuracy for aligned trials and misaligned trials. Similarly, we did not find a significant difference across spatial frequencies for misaligned composites ($F_{2,40}$=1.29, p>.28); differences in spatial frequencies were only observed with aligned composites ($F_{2,40}$=5.74, p < .01, $\tilde{\eta}_p^2$=.22). Critically, accuracy was lowest for aligned LSF composites compared to aligned FS and aligned HSF composites (p's<.05), and there was no significant difference between aligned FS and aligned HSF composites (p=.4).

To summarize, we replicated Goffaux and Rossion (2006) by showing that performance on aligned *same* trials was lower for LSF than HSF faces, whereas there was no difference for misaligned *same* trials. But is this because it is harder to ignore a face part in a LSF than a HSF face? In other words, are LSF faces perceived more holistically than HSF faces? If that's true, then there should also be a difference in sensitivity when all trials in the partial design are examined. Alternatively, there could be differences in response bias for LSF and HSF faces.

Sensitivity and Correct Response Times in the Partial Design (Alignment Effect with Same-Incongruent and Different-Congruent Trials). We obtained a significant main effect of spatial frequency in d' ($F_{2,40}$=4.68, p=.015, $\tilde{\eta}_p^2$=.19; but not in RTs, p>.71), with significantly higher d' for FS than LSF and HSF faces (p's<.02) while there was no difference in d' between LSF and HSF (p>.72). There was a significant effect of alignment (d': $F_{1,20}$= 36.78, p<.0001, $\tilde{\eta}_p^2$=.65, RTs: $F_{1,20}$=26, p<.0001, $\tilde{\eta}_p^2$=.57), with better and faster performance for misaligned than aligned trials. While alignment effects were comparable in RTs across the spatial frequency conditions ($F_{2,40}$=.99, p=.38), there was a significant interaction between spatial frequency and alignment in d' ($F_{2,40}$=6.36, p<.005, $\tilde{\eta}_p^2$=.24). Although the alignment effect was reduced for FS composites compared to LSF and HSF composites (p's<.02), the alignment effects were comparable between LSF and HSF composites (p=.36) (see Figure 4).

Response Criterion (c) in the Partial Design (Alignment Effect with Same-Incongruent and Different-Congruent Trials). While there was no significant difference in the alignment effect between LSF and HSF faces measured in d', there were differential biases between them (see Figure 4). Importantly, a significant main effect of spatial frequency in response criteria ($F_{2,40}$=6.01, p=.005, $\tilde{\eta}_p^2$=.23) revealed that participants were more likely to respond "different" to FS and LSF composites compared to HSF composites (p's<.005) and there was no significant difference between FS and LSF composites (p=.95). As expected, there was a significant effect of alignment ($F_{1,20}$ =37.95, p<.0001, $\tilde{\eta}_p^2$=.65), where participants were more likely to respond “different” to aligned compared to misaligned composites. The interaction between spatial frequency and alignment was significant ($F_{2,40}$=5.27, *p*<.01, $\tilde{\eta}_p^2$=.21). Participants had a larger tendency to respond “different” to aligned compared to misaligned FS and LSF composites than to respond “same” to misaligned vs. aligned HSF composites (*p*’s<.05) while there was no significant difference between FS and LSF (*p*=.39).

When taking into account the false alarm rates with all the partial design trials, we found no discriminability difference between LSF and HSF composites. This result supports the idea that both LSF and HSF faces are processed equally holistically. Instead, there was a significant response bias, suggesting that the alignment effect obtained in hit rates by Goffaux and Rossion might not merely a perceptual effect. As mentioned before, the partial design suffers from a possible confound of response congruency between the task-relevant and irrelevant part. Next, we examined the *congruency* effect with all trials in the complete design.

Sensitivity and Correct Response Times in the Complete Design (Congruency and Alignment Effects with All Trials). We found that LSF faces *do not* lead to stronger holistic effects than HSF faces: The congruency effects are comparable for both face types (see Figure 5). The main effect of spatial frequency was significant in d’ ($F_{2,40}$=11.46, *p*<.0001, $\tilde{\eta}_p^2$=.36; but not significant in RTs, *p*>.45), with d’ significantly higher for FS than LSF or HSF faces (both *p*’s<.005). However, d’ was comparable for both LSF and HSF faces (*p*=.23). Replicating standard findings, performance was better and faster for congruent than incongruent trials, as revealed by a significant main effect of congruency (d’: $F_{1,20}$ = 26.21, *p*<.0001, $\tilde{\eta}_p^2$=.57, RTs: $F_{1,20}$ = 7.13, *p*<.0001, $\tilde{\eta}_p^2$=.29), and d’ was higher for misaligned than aligned composites, as revealed by a significant effect of alignment (d’: $F_{1,20}$=25.45, *p*<.0001, $\tilde{\eta}_p^2$=.56; RTs: $F_{1,20}$=35.41, *p*<.0001, $\tilde{\eta}_p^2$=.64). There was a larger congruency effect for aligned than misaligned composites, as indicated by a significant interaction between alignment and congruency in d' ($F_{1,20}$=28.7, $p \leq .0001$, $\tilde{\eta}_p^2$=.59; marginally significant in RTs, p=.07). There was also a significant interaction between spatial frequency and alignment in d' ($F_{2,40}$=4.34, p<.05, $\tilde{\eta}_p^2$=.18; not significant in RTs, p=.23); there were significant alignment effects for both LSF and HSF faces (p's<.0005), with higher d' for misaligned than aligned trials, and there was no significant difference between aligned and misaligned FS faces (p=.63). But most critically, there was no significant difference in the magnitudes of the congruency effect for aligned FS, LSF faces and HSF faces, and misalignment similarly reduced the congruency effect across all spatial frequency conditions. In fact, neither the interaction between spatial frequency and congruency (d': $F_{2,40}$=1.5, p=.23; RTs: $F_{2,40}$=2.15, p=.13) nor the three-way interaction of spatial frequency, alignment, and congruency (d': $F_{2,40}$= .45, p=.64; RTs: $F_{2,40}$= 1.55, p=.22) reached significance.

Although LSF faces showed a significantly larger *alignment effect* in the partial design (greater accuracy on same-incongruent trials for misaligned than aligned trials) than HSF faces, there was no significant difference in the *congruency effect* in d' (or RTs) for LSF and HSF faces. Faces containing either type of spatial frequency information can be processed holistically.

Response Criterion (c) in the Complete Design (Congruency and Alignment Effects with All Trials). Although there was no differences in d' between LSF and HSF faces, there was a significant difference in response criteria (reflecting response biases) as a function of spatial frequency as well as alignment. Participants were more likely to respond "different" to FS and LSF faces and more likely to respond "same" to HSF faces (see Figure 5). This was confirmed by a significant main effect of spatial frequency ($F_{2,40}$=12.58, $p < .0001$, $\tilde{\eta}_p^2$=.39). Participants were more likely to respond "same" to HSF faces than either LSF or FS faces (p's<.0005) and there was no difference between LSF and FS faces (p=.46). Participants were also more likely to respond “same” to misaligned than aligned composites, as revealed by a significant main effect of alignment ($F_{1,20}$=23.24, p=.0001, $\tilde{\eta}_p^2$=.54). The main effect of congruency approached significance ($F_{1,20}$=3.56, p=.074). Importantly, and as predicted, while Goffaux and Rossion (2006) found little or no difference in hit rates between aligned and misaligned HSF faces, we demonstrated that participants were significantly more biased to respond “same” to HSF faces compared to LSF or FS faces (p’s<.001), and there was no significant difference in the response criteria between aligned and misaligned HSF composites (p=.99). Conversely, we found that participants were more likely to respond “different” to aligned than misaligned faces in FS and LSF conditions (p’s<.001), This was confirmed by a significant interaction between spatial frequency and alignment ($F_{2,40}$=5.85, p<.01, $\tilde{\eta}_p^2$=.23). This interaction suggests that the reduced alignment effect for HSF faces compared with LSF faces in the partial design trials could be accounted for by differences in response criteria between LSF and HSF, not a discriminability difference. The interaction between spatial frequency and congruency was not significant ($F_{2,40}$=2.12, p=.13). There was a significant interaction between alignment and congruency ($F_{1,20}$=8.3, p<.001, $\tilde{\eta}_p^2$=.29): participants were more likely to respond “same” to congruent than incongruent trials with aligned composites (p<.001) but there was no difference between congruent and incongruent trials for misaligned composites (p>.85). This interaction appeared to be modulated by a three-way interaction of spatial frequency, alignment, and congruency that approached significance ($F_{2,40}$=3.05, p=.058). Taken together, these results suggest that the reduced alignment effect in same (incongruent) trials for HSF faces in Goffaux and Rossion may be driven by differences in response biases rather than discriminability.

Discussion

We re-examined the role of spatial frequencies in the holistic processing of faces.

Goffaux and Rossion (2006) reported that accuracy at judging a relevant part of a test face as the same as a study face while ignoring the irrelevant part of that face was significantly lower for aligned LSF faces than aligned HSF faces; this difference was significantly attenuated when the face parts were misaligned. These results suggested that holistic processing of faces is largely supported by LSF's, and significantly less so by HSF's. In other words, for LSF faces, perception is holistic in the sense that the relevant and irrelevant parts of the face are perceptually fused, making it difficult to attend to one part while ignoring the other part. Although we replicated the difference in accuracy on same trials for LSF and HSF faces reported by Goffaux and Rossion, we found that this effect is caused by differential responses biases, not differences in perceptual discriminability, for LSF and HSF faces.

Since both configural and featural information can be extracted from LSF and HSF faces (Goffaux et al., 2005), it is not surprising that holistic processing – combining individual features into a 'gestalt' – occurs equally for both LSF and HSF faces. In particular, given that a critical factor in successful face recognition is the overlap of spatial frequency bands between study and test stimuli (Boutet, Collin, & Faubert, 2003; Collin, Liu, Troje, McMullen, & Chaudhuri, 2004; Kornowski & Petersik, 2003; Liu, Collin, Rainville, & Chaudhuri, 2000), it is possible that holistic processing may occur for HSF only when both study and test faces contain this information. This does not mean that LSF and HSF information are processed by the same mechanisms or have the same relations with neural markers of holistic processing. For instance, while either LSF or HSF faces appear sufficient to evoke selective responses in the FFA compared to other objects (Eger, Schyns, & Kleinschmidt, 2004; Gauthier, Curby, Skudlarski, & Epstein, 2005; Lerner, Hendler, Ben-Bashat, Harel, & Malach, 2001; Malach, Peppas et al., 1995; Winston, Vuilleumier & Dolan, 2003), the FFA responses to LSF and HSF faces have been found to be statistically independent, suggesting partly distinct populations of face cells in different spatial frequency bands (Gauthier et al., 2005). Likewise, ERP recordings also suggest that LSF and HSF are processed differently, even though either of them can support face selective responses under different conditions (Goffaux et al., 2003a,b; Halit et al., 2006).

As in many experimental applications of the partial design version of the composite face paradigm (Le Grand et al., 2004; Michel et al., 2007; Robbins & McKone, 2007), Goffaux and Rossion (2006) emphasized the accuracy on those trials where the relevant part of the study face and the test face were the same; as a partial design, the irrelevant part was always different. In the parlance of signal detection theory, this analysis only looked at the hit rates. What about the false alarms, which in this case would be erroneously saying "same" when the relevant part was different? When we analyzed the partial design trials from our data using signal detection theory, combining both hits and false alarms, we found no significant difference in d' for LSF and HSF faces, but there was a significant difference in criterion, reflecting a differential response bias. Participants were significantly more likely to respond "different" to LSF aligned faces than HSF aligned faces. This is then reflected in the hit rates as lower accuracy on same trials for LSF aligned faces. But this is a bias, not a discriminability difference.

As noted by Gauthier and Bukach (2007), one problem with the partial design is that its same trials are always incongruent (the top is the same but the bottom is different) while its different trials are always congruent (the top is different and the bottom is different). Congruency could affect d' or response bias or both, so it seems experimentally prudent to break this confound. In the complete design, both the relevant and the irrelevant part can be the same or different on every trial. When we analyzed all of our data from the complete design we again found no significant difference in d' for HSF and LSF faces. But again there was a significant response bias. Participants were more likely to respond “different” to LSF faces than HSF faces. In addition, participants were more likely to respond “different” to aligned than misaligned LSF faces. Without taking response bias into account, there is an illusion of being less accurate on same trials, especially for aligned LSF faces.

At the moment, there is no compelling theoretical account of these differential response biases. But we can speculate about possible sources. For instance, there are differences in the perceived visual persistence across spatial frequencies. Specifically, HSF information appears to visually persist longer than LSF information, even when the visual information is presented for the same amount of time (Bowling, Lovegrove, & Mapperson, 1979; Meyer & Maguire, 1981; see also May, Brown, Scott, & Donlon, 1990). Visual persistence of the faces could be misinterpreted as the amount of time or effort expended in searching for differences between the test face and the remembered study face. This could lead to a response bias to say “same” to HSF faces without any real difference in discriminability or response times between LSF and HSF faces.

In addition, differential familiarity with LSF versus HSF faces in the world could produce differential response biases in laboratory. Consider that our everyday experience with LSF and HSF information in faces is asymmetrical. We often see distant faces that are recognized using LSF but not HSF information. But we infrequently encounter a face with HSF information but no LSF information outside the laboratory. Recent face recognition research has found that frequent exposure to faces of a particular race in the laboratory can lead to a bias to respond “different” in post-test compared to pre-test, without necessarily any differences in discriminability (Tanaka & Droucker, submitted). More real-world exposure to LSF than HSF faces could influence response biases in a similar manner. Analogous effects on response bias are observed in the memory domain. In recognition memory tasks, participants sometimes adjust their response criteria because they mistakenly believe that extremely infrequent items are more difficult to remember than more frequent items (Wixted, 1992; Stretch & Wixted, 1998). If participants assume that their memory for highly infrequent faces (in this case, HSF faces) would be poor, they may be inclined to compensate by responding “same” to HSF faces more often, leading to a high false alarm rate. But since these items are well encoded after all, the hit rate is also high (Wixted, 1992). Intriguingly, participants not only showed a bias to respond “same” to HSF compared to LSF faces, they are also more likely to respond “same” to faces in other unusual configurations (e.g., misaligned or inverted) compared to more regular configurations (e.g., aligned or upright, Gauthier et al., 2003; Hole, 1994).

In any case, it is also unclear whether the mechanisms at the origins of the biases may influence responses in other tasks (such as the whole-part task). As a matter of fact, even the locus of the congruency effects obtained in sensitivity measures are controversial, with some arguing for a perceptual effect (Farah et al., 1998) and others suggesting a more decisional locus (Gauthier et al., 2003b; Richler et al., in press). However, what is made clear by our results is that ignoring the possibility of important response biases by using the partial design will lead to an incomplete and likely misguided understanding of the nature of holistic processing of faces.

Acknowledgments

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Figure Captions

Figure 1. Schematic of the trial types used in the *partial* composite face design and the *complete* composite face design. Each panel shows a schematic of the study face and test face on each trial. The task-relevant part is shown in white and the task-irrelevant part is shown in gray. Letters (A, B, C, and D) denote the physical identity of the part; for example, a study face A-over-B and a test face A-over-D have the same top part but different bottom parts. "Same Trials" demand a "same" response, "Different Trials" demand a "different" response.

Figure 2. Examples of a non-filtered full spectrum composite face (FS), low-pass filtered composite face (LSF), and high-pass filtered composite face (HSF) used as stimuli (stimuli adapted from Goffaux & Rossion, 2006).

Figure 3. Performance on same trials in the partial design. Accuracy (hit rates, left panel) and correct response times (ms, right panel) for aligned and misaligned trials as a function of spatial frequency and alignment. The *alignment effect* is the difference in accuracy between aligned and misaligned trials. Error bars show 95% confidence intervals of the 3 x 2 within-subjects interaction effect.

Figure 4. Performance on all trials in the *partial* design. Sensitivity (d'; upper right panel), correct response times (ms; upper left panel) and response criterion (c; lower panel) for aligned versus misaligned faces in each spatial frequency condition (FS, LSF, and HSF). Criterion values above 0 reflect a bias to respond "different" and criterion values below 0 reflect a bias to respond "same". Error bars show 95% confidence intervals of the 3 x 2 within-subjects interaction effect.

Figure 5. Performance in the *complete* design. Sensitivity (d'; upper panel) and response criterion (c; lower panel) on congruent and incongruent trials for aligned versus misaligned faces in each spatial frequency condition (FS, LSF, and HSF). Criterion values above 0 reflect a bias to respond "different" and criterion values below 0 reflect a bias to respond "same". The *congruency effect* is the difference in d' and RTs between congruent and incongruent trials. Error bars show 95% confidence intervals of the 3 x 2 x 2 within-subjects interaction effect.

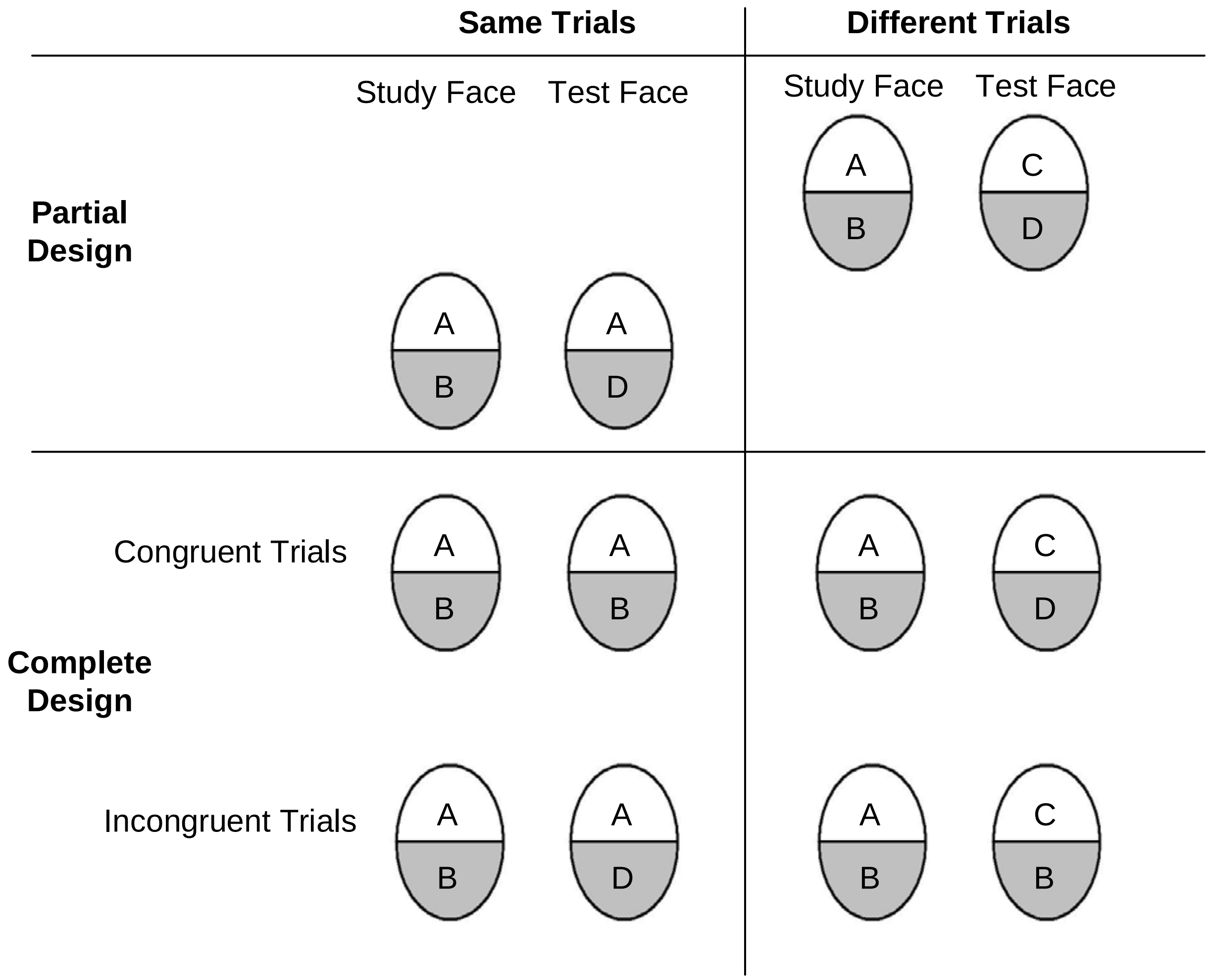
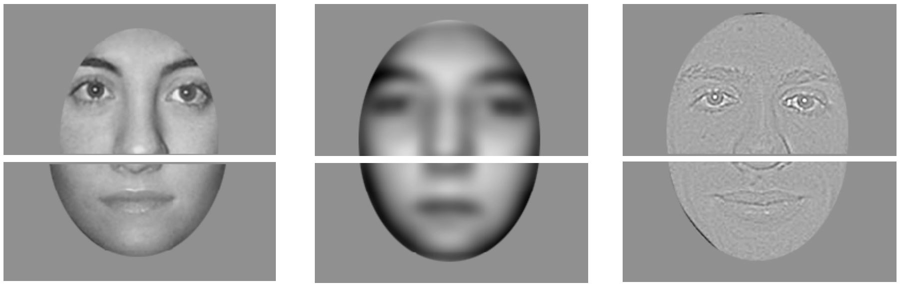

Same Trials
Different Trials
Study Face
Test Face
Study Face
Test Face
Partial Design
A
B
A
D
A
B
C
D
Complete Design
Congruent Trials
A
B
A
B
A
B
C
D
Incongruent Trials
A
B
A
D
A
B
C
B

Figure 1



FS LSF HSF

Figure 2

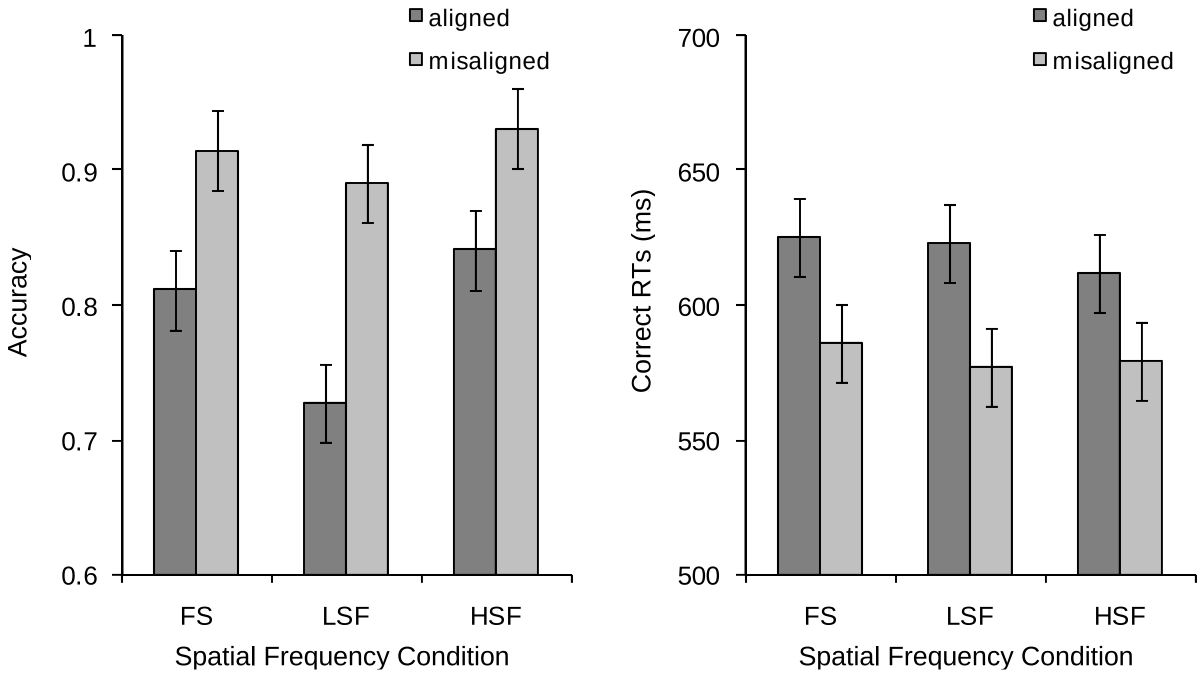

aligned
misaligned
Accuracy
1
0.9
0.8
0.7
0.6
FS
LSF
HSF
Spatial Frequency Condition
aligned
misaligned
Correct RTs (ms)
700
650
600
550
500
FS
LSF
HSF
Spatial Frequency Condition

Figure 3

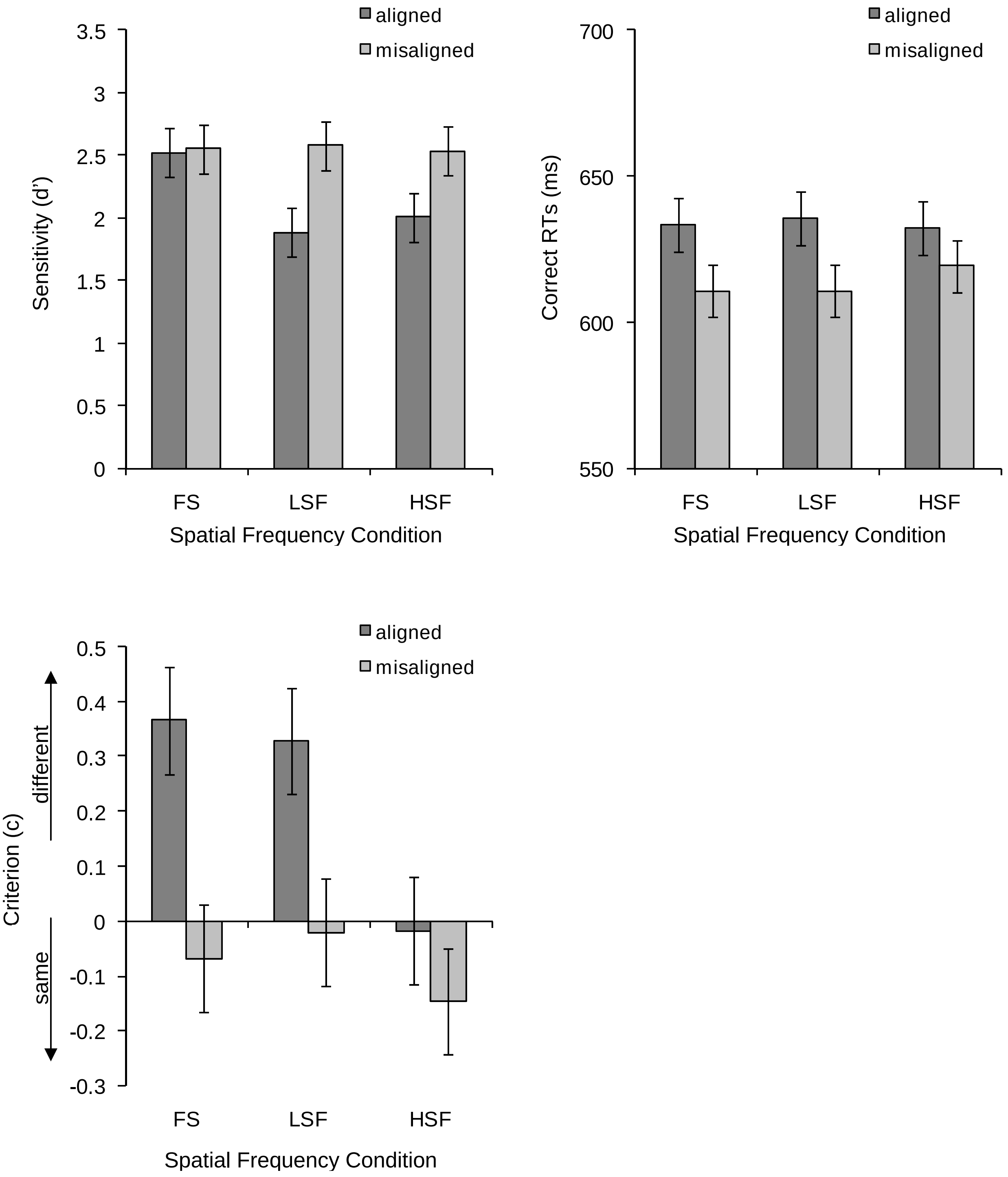

aligned
misaligned
Sensitivity (d')
3.5
3
2.5
2
1.5
1
0.5
0
FS
LSF
HSF
Spatial Frequency Condition
aligned
misaligned
Correct RTs (ms)
700
650
600
550
FS
LSF
HSF
Spatial Frequency Condition
aligned
misaligned
Criterion (c)
different
same
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
FS
LSF
HSF
Spatial Frequency Condition

Figure 4

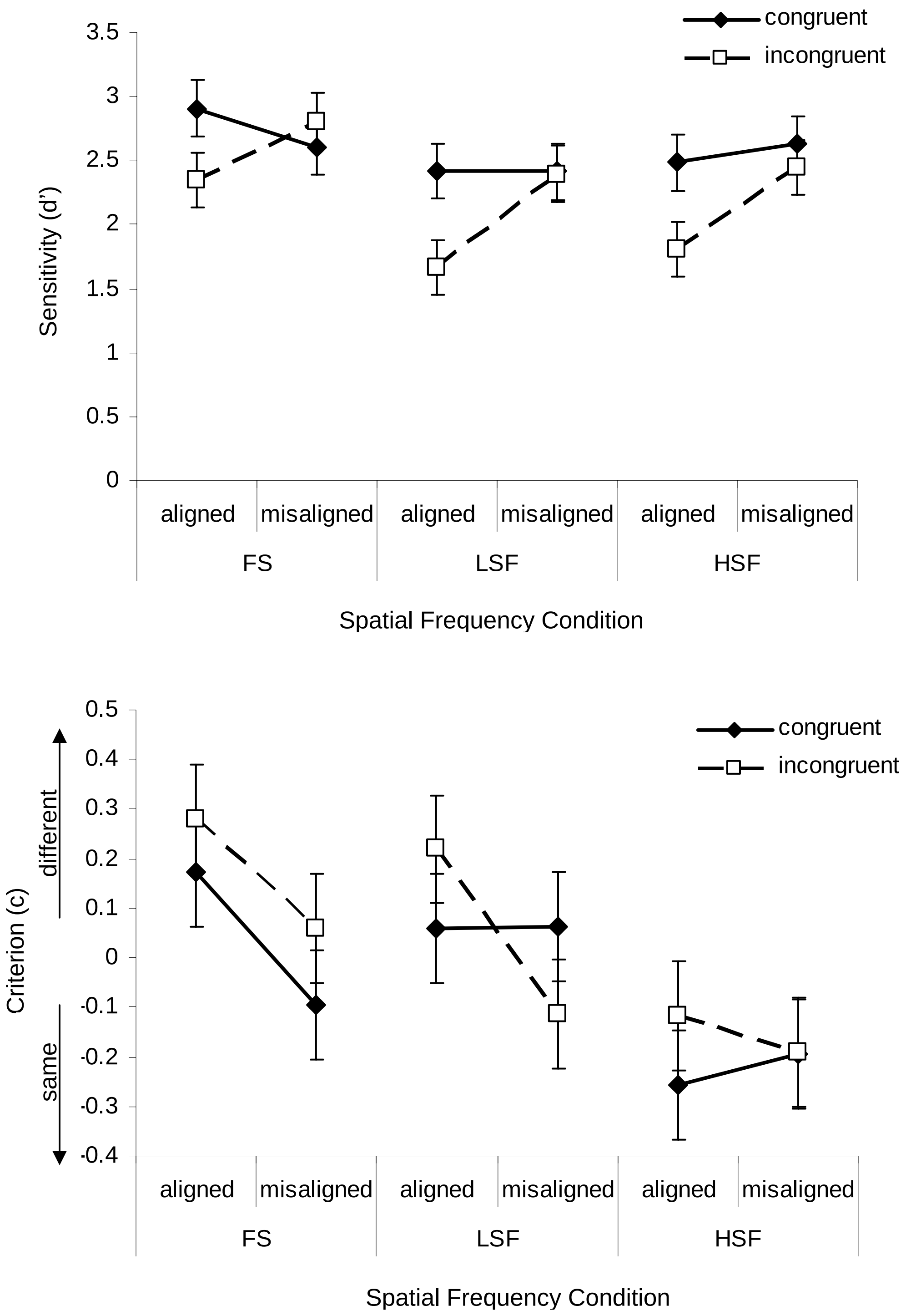
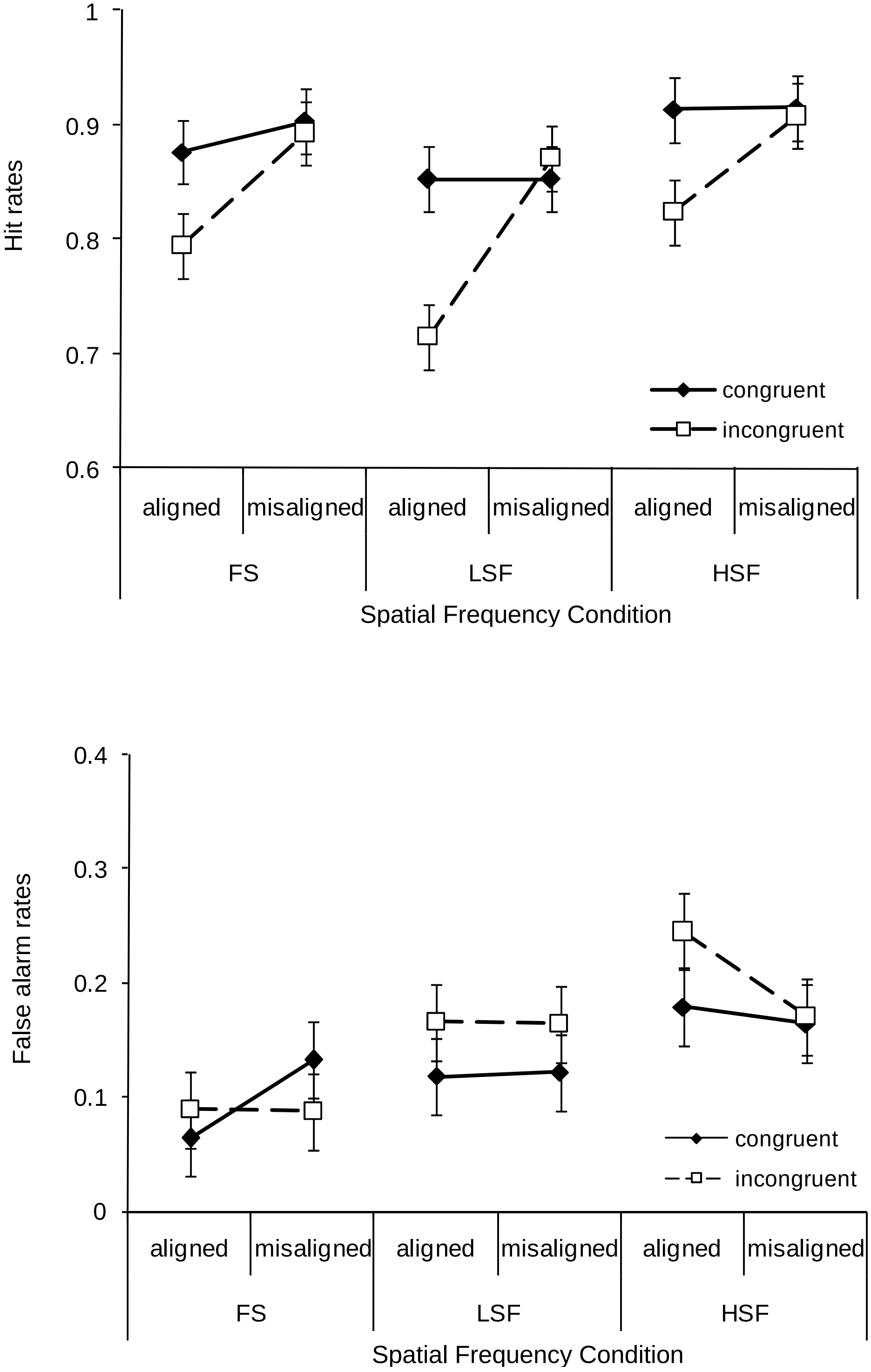
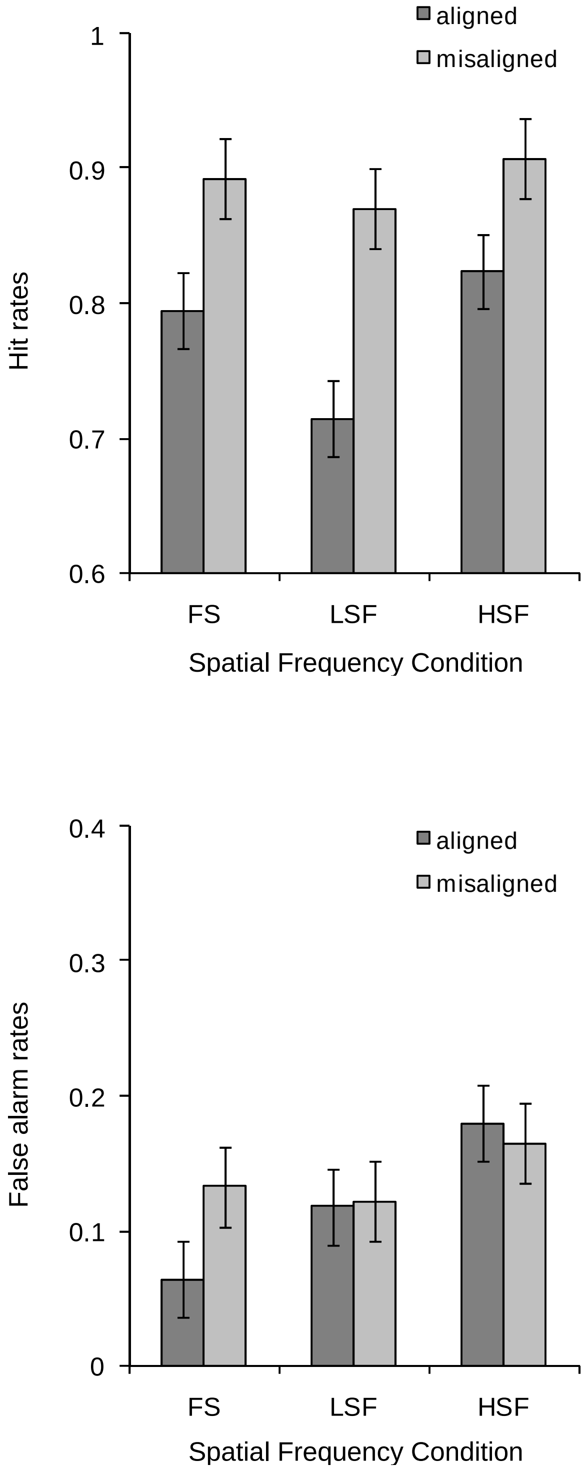

congruent
incongruent
Sensitivity (d')
3.5
3
2.5
2
1.5
1
0.5
0
aligned
misaligned
aligned
misaligned
aligned
misaligned
FS
LSF
HSF
Spatial Frequency Condition
congruent
incongruent
Criterion (c)
different
same
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
aligned
misaligned
aligned
misaligned
aligned
misaligned
FS
LSF
HSF
Spatial Frequency Condition

Figure 5

Appendix A: Hit rates (upper panel) and false alarm rates (lower panel) in the complete design.



Appendix B: Hit rates (upper panel) and false alarm rates (lower panel) in the partial design.



Appendix C. Accuracy for each condition in the *complete design.* The partial design conditions are highlighted.

Spatial Frequency	Alignment	Congruency	Response	Accuracy
FS	Aligned	Congruent	Same	89.52
FS	Aligned	Congruent	Different	96.02
FS	Aligned	Incongruent	Same	81.18
FS	Aligned	Incongruent	Different	93.09
FS	Misaligned	Congruent	Same	92.31
FS	Misaligned	Congruent	Different	89.04
FS	Misaligned	Incongruent	Same	91.49
FS	Misaligned	Incongruent	Different	93.10
LSF	Aligned	Congruent	Same	86.98
LSF	Aligned	Congruent	Different	90.57
LSF	Aligned	Incongruent	Same	72.98
LSF	Aligned	Incongruent	Different	85.14
LSF	Misaligned	Congruent	Same	87.00
LSF	Misaligned	Congruent	Different	89.82
LSF	Misaligned	Incongruent	Same	89.12
LSF	Misaligned	Incongruent	Different	85.22
HSF	Aligned	Congruent	Same	93.36
HSF	Aligned	Congruent	Different	84.46
HSF	Aligned	Incongruent	Same	84.36
HSF	Aligned	Incongruent	Different	76.47
HSF	Misaligned	Congruent	Same	93.38
HSF	Misaligned	Congruent	Different	85.44
HSF	Misaligned	Incongruent	Same	93.15
HSF	Misaligned	Incongruent	Different	84.44