Multiple paths to holistic processing: Holistic processing of Gestalt stimuli do not overlap with holistic face processing in the same manner as do objects of expertise

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Abstract

Holistic processing is often considered to be limited to faces and non-face objects of expertise, with previous studies revealing a specific mechanistic overlap between the holistic processing of these stimuli. However, more recently holistic processing has been demonstrated for untrained, novel stimuli containing salient Gestalt perceptual grouping cues. The relationship between the holistic processing of these novel stimuli and of faces is unclear. Here we examine whether there is a mechanistic overlap between the holistic processing of these two stimulus categories. To do this we used the same two-back interleaved part-matching task previously used to examine the mechanistic overlap between the processing of faces and of objects of expertise. Concurrent holistic processing of these salient Gestalt stimuli did not impact (Experiment 1), nor was it impacted by (Experiment 2), holistic processing of face stimuli. This suggests that the nature of the overlap between holistic processing of faces and of salient Gestalt stimuli may be distinct from that between objects of expertise and faces. We discuss potential mechanistic accounts of this difference.

Keywords Holistic processing · Gestalt grouping cues · Face processing · Perceptual expertise

Introduction

Faces are perceived holistically, which appears to be unlike the perception of other types of stimuli. This has led to suggestions that holistic face processing is supported by specialised mechanisms distinct from those that support the processing of non-face stimuli (e.g., Farah, 1996; Kanwisher, 2000). However, similar markers of holistic processing are seen for objects of expertise, with evidence that there is a functional overlap in the mechanisms supporting holistic processing of face and non-face objects of expertise (Boggan, Bartlett, & Krawczyk, 2012; Curby & Gauthier, 2014; Gauthier, Curran, Curby, & Collins, 2003). More recently, face-like holistic processing has been reported for novel stimuli with salient Gestalt perceptual grouping cues, suggesting

that holistic perception may be supported, at least in part, by domain-general visual processing mechanisms (Zhao, Bulthoff, & Bulthoff, 2016). However, it is unclear whether the mechanisms supporting the holistic perception of these stimuli are distinct or overlapping with those supporting holistic face processing. Here we examine whether the holistic processing of these salient Gestalt stimuli overlaps with holistic processing of faces in a similar manner as does the processing of objects of expertise.

A robust and widely used task for indexing holistic face perception is the composite face paradigm. In this paradigm, participants make identification or matching judgments about the top or bottom half of chimeric faces made by combining the top and bottom face halves from different individuals (Curby & Gauthier, 2014; Gauthier et al., 2003; Young, Hellawell, & Hay, 1987). Participants are slower and less accurate on judgments about the task-relevant part when it is aligned, compared to misaligned (disrupting the meaningful configuration of the face), with the other, task-irrelevant, face part. This is referred to as the composite effect (Young et al., 1987). Participant's judgments are also influenced by whether the task-irrelevant parts of the faces have the same (congruent) or different (incongruent) relationship relative to that of the task-relevant parts (congruency effect; e.g., Gauthier et al.,

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2003). That is, performance is better when both the task-relevant and -irrelevant parts are the same or both are different (i.e., congruent) across the to-be-matched faces, compared to when one part is different and the other is the same. This pattern of performance suggests that participants are unable to selectively attend to only one part of the face without interference from the task-irrelevant part, and has led to holistic processing being described as a failure of selective attention (Richler, Tanaka, Brown, & Gauthier, 2008). The magnitude of the congruency effect is also modulated by alignment, with the effect attenuated when the stimuli are misaligned. The congruency effect, and its interaction with part alignment, have both been used as indices of holistic processing (e.g., Curby, Goldstein, & Blacker, 2013; Gauthier et al., 2003; Richler, Bukach, & Gauthier, 2009).

These hallmarks of holistic processing indexed via the composite paradigm have also been documented for non-face objects of expertise, including cars and chess configurations (Boggan et al., 2012; Curby & Gauthier, 2014; Gauthier et al., 2003). In previous studies, a modified composite paradigm was employed to assess whether there is interference between the holistic processing of faces and objects of expertise when the two categories are concurrently processed by dual experts (Curby & Gauthier, 2014; Gauthier et al., 2003). Notably, this interference would be expected if there is a functional overlap in the mechanisms supporting holistic perception of face and non-face objects of expertise. In this task, car experts and car novices made two-back part-judgments about interleaved (alternating) face and car stimuli. The faces were interleaved with either cars with an intact configuration, which should be holistically processed by car experts, or cars in a transformed configuration (with an inverted top half), which car experts should no longer process holistically. Notably, while making the face judgment, observers had to keep the car stimuli in mind and vice versa. Not only did car experts experience more difficulty selectively attending to the task-relevant part of the intact cars than did car novices (as indexed by their larger congruency effect), but their performance on face trials also differed depending on the car context. Specifically, with increasing car expertise, faces were processed less holistically in the context of normal (intact) cars than in the context of transformed cars. Thus, there was a trade-off in holistic processing between the face and car stimuli that was related to expertise with cars. This interference effect has also been replicated in a study with chess experts, which revealed interference between holistic processing of faces and chessboards amongst chess experts (Boggan et al., 2012).

Not unlike the holistic processing documented for faces and objects of expertise, Gestalt grouping mechanisms that guide perceptual organisation can also produce unitised, indecomposable representations that make it difficult for observers to attend to isolated parts of a stimulus. A number of recent

studies have explored the relationship between Gestalt perceptual grouping mechanisms and those supporting holistic face perception (Curby & Entenman, 2016; Curby, Entenman, & Fleming, 2016; Curby et al., 2013; Zhao, Bulthoff, & Bulthoff, 2015; Zhao et al., 2016). For example, in a previous study, we found that holistic processing, as indexed via the congruency effect in the composite task, was reduced following disruption of perceptual grouping of the face parts. This occurred despite the configuration of the face stimuli remaining intact. In fact, the magnitude of this reduction in holistic processing was similar to that which occurred when the actual configuration of the facial parts was disrupted via misalignment (Curby & Entenman, 2016). These findings suggest that Gestalt grouping mechanisms may play a role in supporting holistic face processing.

Others have suggested a related, information-based account of holistic perception (Zhao et al., 2015). Specifically, it has been suggested that if certain types of physical information conveyed in faces underlies holistic processing, such as strong Gestalt perceptual grouping cues, then when the same information is present in objects it will also elicit holistic processing. Thereby, holistic processing will occur for objects beyond faces and other objects of expertise. Consistent with this possibility, novel line patterns conveying strong Gestalt cues such as continuity and connectedness, elicited face-like holistic processing, and moreover a weakening in these Gestalt cues attenuated holistic processing (Zhao et al., 2016). Although it has been shown that these stimuli with strong Gestalt cues elicit face-like holistic processing (Zhao et al., 2016), it remains unclear whether the mechanisms supporting holistic processing of these stimuli overlap with those supporting holistic face processing in a similar manner as has been demonstrated for objects of expertise. This would suggest that holistic processing is unitary with stimulus-based and experience-based contributions to holistic processing arising via the same mechanisms.

A recently proposed dual route account of holistic processing suggests that holistic processing is not a unitary phenomenon (Zhao et al., 2016). This account proposes that there is a bottom-up, stimulus-based, and a top-down, experience-based pathway to holistic processing. Thus, this account would predict that the stimulus-driven holistic processing of the novel line pattern stimuli would not overlap with holistic processing of faces in the same manner as does the experience-driven holistic processing of objects of expertise.

In the present study, we test whether there is an overlap in the mechanisms underlying the processing of faces and novel line patterns. We use a task where faces and novel line patterns are processed simultaneously, while alignment is used to manipulate the degree of interference or resource competition between the categories. In Experiment 1, we compared holistic processing of faces under high interference/resource competition, where line stimuli are processed holistically,

compared to low interference/resource competition, where holistic processing of the line stimuli is attenuated. In Experiment 2, we compared holistic processing of line stimuli under high compared to low interference/resource competition from the face stimuli. To preview our main findings, simultaneous holistic processing of the line stimuli did not impact holistic processing of face stimuli (Experiment 1), and vice versa (Experiment 2).

Experiment 1

The present study utilised the same two-back interleaved composite paradigm used in previous studies with face and non-face objects of expertise, but with faces and the line pattern stimuli from Zhao et al. (2016). If the processing of faces and these line patterns with salient Gestalt information draw on common processing mechanisms, then it should manifest as interference, specifically in terms of a trade-off in holistic processing when the two stimulus categories are concurrently processed, similar to that previously demonstrated for faces and cars among car experts. Therefore, the more participants process the line patterns holistically, the more it should interfere with concurrent face processing. Thus, faces should be processed less holistically among aligned line patterns, which are also processed holistically, than when processed among misaligned line patterns, for which holistically processing is attenuated. This trade-off in holistic processing between faces and lines should emerge as a reduction in the size of the congruency effect for faces when they are processed in the context of intact lines relative to when they are processed in the context of misaligned line stimuli that should no longer be processed holistically.

Method

Participants Forty-nine psychology undergraduate students (11 males and 38 females, mean age = 19.88 years, $SD = 2.21$) with normal or corrected-to-normal vision received course credit for participation. Sample size was determined by a power analysis assuming a small to medium effect size ($f = .25$). This power analysis revealed that a sample size of 44 participants would be required to achieve a power level of 0.90 (α error probability = .05). Additional participants were recruited to compensate for the expected loss of participants due to poor performance.

Stimuli The line patterns from Zhao et al. (2016) were used as stimuli. These stimuli are organised into 24 pairs (48 total stimuli). The stimulus pairs are created so the tops and bottoms of the stimuli within each pair can be interchanged and the stimuli still form intact line patterns. Each line pattern was divided into a top and bottom half (270×135 pixels each). The tops and bottoms within each pair were recombined by the experimental program to form composite images ($270 \times$

270 pixels). The parts were recombined so that they were either aligned or misaligned. For misaligned stimuli, the bottom half was shifted horizontally to the left by 33 pixels while the top half was shifted to the right by 33 pixels (for a total misalignment of 66 pixels). A 1-pixel black line separated the top and bottom halves.

Matched face stimuli were also created from the Max-Planck Institute for Biological Cybernetics face database (Troje & Bülthoff, 1996). Each face was cropped in an oval shape to remove the hair and ears. The faces and frames were then divided into top and bottom halves (270×135 pixels each) just above the nostrils. Twenty-four pairs of front-view Caucasian faces (12 males, 12 females) with two tops and two bottoms in each were created. Four different faces were used to make the tops and bottoms within each pair (i.e. none of the tops originally matched the bottoms). This was to ensure that no combination of the parts within the pairs was more natural (e.g., had perfectly matched skin tone etc.). Tops and bottoms within each pair were recombined using the same procedure as that used for the line patterns. Again, a 1-pixel black line separated the top and bottom halves. Note that the face halves were always aligned, whereas the line patterns halves were either aligned or misaligned.

Design, procedure, and analysis Participants performed a modified two-back sequential part matching task (Curby & Gauthier, 2014; Gauthier et al., 2003). They viewed interleaved faces and line patterns and for each image they pressed a key indicating whether the bottom half of the current face or line pattern was the same or different to the preceding image of the same category, with the top half always irrelevant throughout the task (see Fig. 1). Thus, participants were always required to make a response to stimuli from both categories. To successfully perform this task, participants had to simultaneously keep in visual working memory both a face and a line pattern, while they also processed the currently presented face or line pattern. Each stimulus was presented for 2,500 ms or until a key-press response was made. After each response, a fixation cross was shown for 500 ms and then the next image in the series was presented. The task consisted of 16 blocks of 50 trials (images), half faces and half line patterns. With this design, a two-back matching judgment could not be made for the first face or line pattern in each block as no image of the same category preceded it, thus data was collected from 768 trials (48 trials/block). For half of the blocks, faces were interspersed with aligned line patterns, and for the other half, faces were interspersed with misaligned line patterns. The blocks with aligned line patterns constituted the high interference condition, as the aligned lines are processed holistically, while the blocks with misaligned line patterns constituted our low interference condition, as holistic processing of the misaligned line patterns is attenuated. ‘Aligned’ and ‘misaligned’ blocks alternated, with the alignment condition

Fig. 1 Composite faces and line patterns were presented alternately. Normal upright faces were interspersed with either (a) aligned or (b) misaligned line patterns. Participants made sequential judgments on whether the bottom half of each face and line image was the same or

different to that of the image from the same category that preceded it. Each image was presented on the screen for 2,500 ms or until the participant entered a response. A fixation cross (not shown) was presented during a 500-ms inter-trial interval

of the first block counterbalanced over participants. Notably, while the alignment of the line pattern stimuli varied across blocks providing the high and low holistic processing interference conditions, the faces always appeared aligned. Participants completed 36 practice trials with performance feedback before they started the experiment. Participants then completed 384 face trials and 384 line pattern trials, consisting of 192 face trials presented in the context of aligned lines, and 192 face trials presented in the context of misaligned lines. No feedback was given in the experiment, except when participants failed to respond within 2,500 ms.

Within each block, in half of the trials the relationship between the two task-relevant (bottom) and the two task-irrelevant (top) parts was “congruent” and in the other half this relationship was “incongruent.” For congruent trials, the task-irrelevant top part of the image was consistent with the correct response for the bottom part (i.e., if the bottoms were the same, then the tops were the same; or if the bottoms were different, then the tops were different). For incongruent trials, the task-irrelevant top part was inconsistent with the correct response for the bottom part (i.e., if the bottoms were the same, then the tops were different and vice versa). There was a total of 96 congruent trials and 96 incongruent trials in each of the aligned and misaligned context conditions. The order of trials was randomised within each block. Accuracy and response time were recorded. Analysis of response time only included trials where the response was correct. Trials with a response time less than 200 ms or greater than 2000 ms were also excluded from this analysis (< 2% trials).

Results and discussion

Sensitivity analysis A $2(\text{category}) \times 2(\text{alignment}) \times 2(\text{congruency})$ ANOVA performed on the sensitivity (d') data revealed

a significant three way interaction, $F(1, 48) = 11.19, p = .002, \eta_p^2 = .189$, between the effects of congruency, category, and alignment. To probe the basis of the three-way interaction, separate $2(\text{alignment}) \times 2(\text{congruency})$ analyses were performed on the sensitivity (d') data from the line pattern and face (category) conditions.

The $2(\text{line alignment}) \times 2(\text{line congruency})$ ANOVA performed on the sensitivity scores (d') for the line part judgments revealed a main effect of congruency, $F(1, 48) = 90.38, p < .001, \eta_p^2 = .653$, with the expected higher sensitivity for congruent trials than incongruent trials, suggesting a failure to selectively attend to the task-relevant (bottom) parts of the stimuli (Fig. 2a). There was also a main effect of alignment, $F(1, 48) = 9.02, p = .004, \eta_p^2 = .158$, with better part-matching sensitivity when the lines were misaligned than when aligned. In addition, there was a significant interaction between congruency and alignment, $F(1, 48) = 28.18, p < .001, \eta_p^2 = .370$, with misalignment reducing the size of the congruency effect for line patterns. Scheffé tests revealed that there was a significant effect of congruency for both the aligned and misaligned line stimuli (both $ps < .001$). However, while the alignment of the line stimuli did not impact performance in the congruent trials ($p = .58$), sensitivity for the incongruent trials was significantly higher when the lines were misaligned, compared to aligned ($p < .0001$). In summary, processing of the line stimuli demonstrated the established hallmarks of holistic processing with both a significant effect of congruency and a congruency by alignment interaction.

The $2(\text{line alignment}) \times 2(\text{face congruency})$ repeated measures ANOVA performed on the sensitivity scores (d') for the face part judgments also revealed a main effect of congruency,

Fig. 2 Mean sensitivity (d') for the congruent (diamonds) and incongruent (circles) conditions, and the resulting index of holistic perception (congruency effect, filled bars, reflecting the difference between the congruency conditions) for the line pattern (a) and face (b) stimuli in Experiment 1. While the alignment manipulation

impacted holistic perception of the line patterns directly as indexed via the impact of alignment on the congruency effect (a), it did not impact holistic processing of the concurrently processed faces (b), as the congruency effect was unaffected by the alignment of the lines. Error bars represent standard error values

$F(1, 48) = 257.65, p < .001, \eta_p^2 = .843$, with higher sensitivity for congruent trials than incongruent trials (Fig. 2b). However, there was no main effect of, or interaction with, line alignment (both $F_s < 1$). Thus, despite the alignment manipulation significantly impacting holistic processing of the line stimuli, holistic processing of faces processed in the context of aligned lines, as indexed via the congruency effect, did not vary significantly from that for faces processed in the context of misaligned lines.

Response time analysis The holistic processing markers of interest, that is the congruency effect and the congruency by alignment interaction, have been reported in sensitivity and/or response-time data across different studies. Thus, the same analysis was conducted on participants' response times on the correct trials. Consistent with the analysis of the sensitivity data, the $2(\text{line alignment}) \times 2(\text{line congruency})$ repeated measures ANOVA performed on the response-time data for the line part judgments revealed a main effect of congruency, $F(1, 48) = 11.09, p = .002, \eta_p^2 = .188$ (Fig. 3a). As expected, response time was shorter for congruent trials than incongruent trials, suggesting a failure to selectively attend to the task-relevant (bottom) parts of the stimuli. There was also a main effect of alignment, $F(1, 48) = 13.11, p = .001, \eta_p^2 = .215$. Response time was shorter when the lines were misaligned than when aligned, suggesting that misaligning the line patterns facilitated part judgment performance. In addition, there was a significant interaction between congruency and

alignment, $F(1, 48) = 4.87, p = .032, \eta_p^2 = .092$. Scheffé tests revealed that there was a significant effect of congruency for the aligned ($p < .001$), but not the misaligned, line stimuli ($p = .537$). In summary, processing of the line stimuli demonstrated the same established hallmarks of holistic processing with both a significant effect of congruency and a congruency by alignment interaction as was observed in the sensitivity data.

The $2(\text{line alignment}) \times 2(\text{face congruency})$ repeated measures ANOVA performed on the response-time data for the face part judgments also revealed a main effect of congruency, $F(1, 48) = 44.99, p < .001, \eta_p^2 = .484$ (Fig. 3b). As expected, the response time was shorter for congruent trials than for incongruent trials, again indexing the failure of selective attention to the task-relevant (bottom) part. The data also revealed a main effect of line alignment, $F(1, 48) = 8.63, p = .005, \eta_p^2 = .152$. Response time was shorter when faces were processed in the context of misaligned lines than when processed in the context of aligned lines. In addition, the interaction between congruency and alignment was marginally significant, $F(1, 48) = 3.59, p = .064, \eta_p^2 = .070$. Scheffé tests revealed that there was a significant effect of congruency for the face processed in the aligned ($p < .0001$) and misaligned line stimuli contexts ($p < .0001$). However, while the alignment of the line stimuli did not impact performance on the congruent trials ($p = .22$), response times for the incongruent trials were significantly faster when the lines were misaligned, compared to aligned ($p < .0005$). This suggests that face

Fig. 3 Mean response time (ms) for the congruent (diamonds) and incongruent (circles) conditions, and the resulting index of holistic perception (congruency effect, filled bars, reflecting the difference between the congruency conditions) for the line pattern (a) and face (b) stimuli in Experiment 1. The alignment manipulation impacted holistic perception of the line patterns directly as indexed via the impact of alignment on the

congruency effect (a). There was also a trend for it to impact holistic processing of the concurrently processed faces, with faces processed in the context of aligned line patterns processed more holistically than those processed in the context of misaligned line patterns (b). Error bars represent standard error values

processing was somewhat influenced by the line-task context. However, this is the opposite pattern to what would be expected if there was competition between the holistic processing of the line and face stimuli.

Notably, the greater congruency effect for face stimuli processed in the context of aligned, compared to misaligned, line patterns is consistent with a priming effect of the line task on the face task, with the face stimuli being primed to be processed in a manner consistent with the line stimuli (i.e., more or less holistically depending on whether they are processed in the context of the holistically processed aligned lines or the non-holistically processed misaligned lines, respectively). Notably, this priming effect has also been observed previously with this paradigm where holistic processing of one stimulus, in this case a face, primed holistic processing of another stimulus, a car, amongst novice observers (Curby & Gauthier, 2014; see also Gao, Flevaris, Robertson, & Bentin, 2011; Weston & Perfect, 2005, for other related effects).

In summary, consistent with Zhao et al. (2016), these results reveal that both face and line stimuli were processed holistically, indexed by significant congruency effects and a congruency by alignment interaction. There was also weak evidence in the response-time data of a disruptive effect of the misaligned processing context on holistic processing of the face stimuli. However, there was no evidence of competitive interference between the holistic processing of the two stimulus categories, as holistic processing of the face stimuli was not reduced in the high interference (aligned line)

processing context compared to the low interference (misaligned line) context.¹

It is possible that the line stimuli do recruit mechanisms that overlap with those that process faces in a similar manner to objects of expertise, but that they did not place sufficient demands on these mechanisms to impact the concurrent holistic processing of the faces. Consistent with this possibility, the magnitude of the congruency effect was considerably larger for faces than for line stimuli, indicating stronger holistic processing for faces than for line stimuli. In addition, the stimuli that have been shown to interfere with holistic processing of faces in previous studies adopting this task, e.g., chess configurations and cars, also demonstrated numerically larger effects of congruency than did the line stimuli. These previous findings also reported that interference increased with participants' expertise with the non-face stimuli (Curby & Gauthier, 2014; Gauthier et al., 2003). Therefore, it is possible that the line patterns used in this study did not sufficiently drive holistic processing to produce detectable interference with the holistic processing of the faces.

¹ The congruency effect for faces processed concurrently with the aligned line patterns and for those processed concurrently with the misaligned line pattern was also examined by estimating a Bayes Factor (JASP, 2018) comparing the fit of the data under the null hypothesis and the alternative hypothesis. An estimated Bayes factor suggested that the data were 5.3:1 in favor of the null hypothesis, or rather, 5.3 times more likely to occur under a model without including an interference effect of the concurrent (aligned) line pattern task, rather than a model with it.

Experiment 2

Experiment 2 directly addressed the possibility that the line stimuli in Experiment 1 did recruit overlapping mechanisms with those responsible for the holistic processing of faces, but they did not do so sufficiently to impact the robust, and much larger, holistic processing effects observed for the face stimuli. This was achieved by using the same interleaved composite part-judgment task as in Experiment 1, except the roles of the face and line stimuli were reversed. Part judgment about aligned faces (high interference) and misaligned faces (low interference) now provided the context within which holistic processing of the line stimuli would be measured. This provided a stronger manipulation as not only do faces more robustly, and to a larger degree, recruit holistic processing mechanisms, but also misalignment more effectively disrupts holistic processing of faces.

Method

Participants 48 psychology undergraduate students (7 males and 41 females, mean age = 19.33 years, SD = 2.37) with normal or corrected-to-normal vision received course credit for participation in the study.

Stimuli The stimuli were the same as those used in Experiment 1. Except part misaligned versions of the face, instead of the line, stimuli were used.

Design, Procedure, and Analysis Participants performed the same modified two-back sequential part matching task as in Experiment 1 except that the lines were always aligned and the faces were either aligned or misaligned across different blocks. Thus, the roles of the lines and faces were reversed with the faces, either aligned or misaligned, providing the contextual manipulation to explore the impact of a potential trade-off in holistic processing capacity between faces and lines. The analysis was the same as in Experiment 1. Data from two participants were excluded from the analyses due to poor performance (mean $d' < 0$). Analysis of response time only included trials where the response was correct. Trials with a response time less than 200 ms or greater than 2000 ms were also excluded from this analysis ($< 1.5\%$ trials).

Results and discussion

Sensitivity analysis A $2(\text{category}) \times 2(\text{alignment}) \times 2(\text{congruency})$ ANOVA revealed a significant three way interaction $F(1, 45) = 29.86, p \leq .0001, \eta_p^2 = .399$, between congruency, category and alignment. To probe the basis of this interaction, separate $2(\text{alignment}) \times 2(\text{congruency})$ ANOVAs were

performed on the sensitivity (d') data from the line pattern and the face (category) conditions.

The $2(\text{face alignment}) \times 2(\text{face congruency})$ ANOVA performed on the sensitivity scores (d') for the face part judgments revealed a main effect of congruency, $F(1, 45) = 168.93, p \leq .0001, \eta_p^2 = .790$. Sensitivity was higher for congruent trials than incongruent trials, indicating a failure of selectively attend to task-relevant (bottom) parts of the stimuli (Fig. 4a). There was also a main effect of alignment, $F(1, 45) = 15.19, p = .0003, \eta_p^2 = .252$, with better sensitivity when the faces were misaligned than when aligned, suggesting that misaligning the line patterns attenuated holistic processing, facilitating the part judgment task. In addition, there was a significant interaction between congruency and alignment, $F(1, 45) = 46.12, p \leq .0001, \eta_p^2 = .506$, with misalignment reducing the size of the congruency effect for face patterns. Scheffé tests again revealed that there was a significant effect of congruency for both the aligned and misaligned face stimuli ($ps < .0001$). However, numerically, the congruency effect was approximately twice as large in the aligned ($\Delta d' = 1.66$), compared to the misaligned ($\Delta d' = 0.86$), condition. Thus, processing of the face stimuli demonstrated the established hallmarks of holistic processing with both a significant effect of congruency and a congruency by alignment interaction.

The $2(\text{face alignment}) \times 2(\text{line congruency})$ repeated measures ANOVA performed on the sensitivity scores (d') for the line part judgments also revealed a main effect of congruency, $F(1, 45) = 103.46, p \leq .0001, \eta_p^2 = .700$, with higher sensitivity for congruent trials than incongruent trials (Fig. 4b). However, there was no main effect of, or interaction with, face alignment (both $F_s < 1$). Thus, despite the alignment manipulation significantly impacting holistic processing of the face stimuli, holistic processing of lines processed in the context of aligned faces, as indexed via the congruency effect, did not vary significantly from that for lines processed in the context of misaligned faces.

Response time analysis As for Experiment 1, the same analysis was conducted on participants' response times on correct trials. Consistent with the analysis of the sensitivity data, the $2(\text{face alignment}) \times 2(\text{face congruency})$ repeated measures ANOVA performed on the response-time data for the face part judgments revealed a main effect of congruency, $F(1, 45) = 19.92, p \leq .0001, \eta_p^2 = .307$ (Fig. 5a). As expected, response times were shorter for congruent trials than incongruent trials, suggesting a failure to selectively attend to the task-relevant (bottom) parts of the stimuli. There was also a main effect of alignment, $F(1, 45) = 20.85, p \leq .0001, \eta_p^2 = .317$. Response times were also shorter when the faces were misaligned than when aligned, suggesting that misaligning the faces facilitated part judgment performance. In addition, there was a significant

Fig. 4 Mean sensitivity (d') for the congruent (diamonds) and incongruent (circles) conditions, and the resulting index of holistic perception (congruency effect, filled bars, reflecting the difference between the congruency conditions) for the face (a) and line pattern (b) stimuli in Experiment 2. While the alignment manipulation

impacted holistic perception of the faces directly as indexed via the impact of alignment on the congruency effect (a), it did not impact holistic processing of the concurrently processed line patterns (b). Error bars represent standard error values

interaction between congruency and alignment, $F(1, 45) = 18.13$, $p = .0001$, $\eta_p^2 = .801$. Scheffé tests revealed that there was a significant effect of congruency for the aligned ($p < .0001$) and misaligned line stimuli ($p = .017$). However, while the effect of alignment failed to significantly impact performance on congruent trials ($p = .085$),

misalignment resulted in a response time advantage for incongruent trials ($p < .0001$).

The $2(\text{face alignment}) \times 2(\text{line congruency})$ ANOVA performed on the response-time data for the line part judgments also revealed a main effect of congruency, $F(1, 45) = 8.71$, $p = .005$, $\eta_p^2 = .162$ (Fig. 5b). As

Fig. 5 Mean response time (ms) for the congruent (diamonds) and incongruent (circles) conditions, and the resulting index of holistic perception (congruency effect, filled bars, reflecting the difference between the congruency conditions) for the face (a) and line pattern (b) stimuli in Experiment 2. The alignment manipulation impacted holistic perception of the faces directly as indexed via the impact of

alignment on the congruency effect (a). There was also a weak trend for it to impact holistic processing of the concurrently processed line patterns, with line patterns processed in the context of aligned faces processed more holistically than those processed in the context of misaligned faces (b). Error bars represent standard error values

expected, the response time was shorter for congruent trials than for incongruent trials, which again indexed a failure of selective attention to the task-relevant part. The data also revealed a main effect of face alignment, $F(1, 45) = 9.05$, $p = .004$, $\eta_p^2 = .167$. Response time was shorter when lines were processed in the context of misaligned faces than when processed in the context of aligned faces. This again suggested that face processing was somewhat influenced by the alignment context (i.e., the line task). However, there was no interaction between congruency and alignment, $F < 1$. Although this interaction was not significant, to aid comparison with the analysis from Experiment 1, the Scheffé comparisons were conducted and also revealed that while there was a congruency effect for line stimuli processed in the context of aligned faces ($p = .017$), this congruency effect was no longer present for line stimuli processed in the context of misaligned faces ($p = .181$). Notably, this is again the opposite pattern to what would be expected if there was resource competition between the holistic processing of the line and face stimuli and again is consistent with previous demonstrations of the ability of holistically, or globally, processed stimuli to prime greater holistic, or global, processing of other subsequently processed stimuli (e.g., Curby & Gauthier, 2014; Gao et al., 2011; Weston & Perfect, 2005).

In summary, consistent with Experiment 1 and Zhao et al. (2016), both face and line stimuli demonstrated the expected hallmarks of holistic processing. Again, there was weak evidence in the response-time data of a disruptive effect of the misaligned processing context on holistic processing of the line stimuli. However, as in Experiment 1, there was no evidence of competitive interference between the holistic processing of the two stimulus categories, as holistic processing of the line stimuli was not reduced in the high interference (aligned face) processing context compared to the low interference (misaligned face) context².

General discussion

The present study aimed to investigate whether there is a functional overlap in the mechanisms underlying holistic perception of faces and novel stimuli containing salient perceptual grouping cues that is similar to that between the holistic

processing of faces and of objects of expertise. Consistent with previous findings, the novel line pattern stimuli containing salient perceptual grouping cues produced face-like patterns of holistic perception (Zhao et al., 2016). Notably, mimicking established hallmarks of face processing, these holistic effects were modulated by the alignment of the top and bottom parts of the line patterns, with reduced holistic perception when they were misaligned. However, there was no evidence of competitive interferences between the holistic perception of the face and line stimuli. Notably, this finding is in contrast with previous findings comparing the holistic perception of face and non-face objects of expertise (Boggan et al., 2012; Curby & Gauthier, 2014; Gauthier et al., 2003). These findings suggest that, despite the same markers of holistic perception being present, the processing of stimuli with salient Gestalt cues do not overlap with the processing of faces in the same manner as does the holistic processing of faces and of objects of expertise.

Intriguingly, while the sensitivity data failed to reveal evidence of interference between the holistic processing of faces and of lines, the response-time data revealed evidence of a disruptive effect of the *misaligned* task context on holistic processing of concurrently processed aligned stimuli. That is, instead of the faces (Experiment 1) or lines (Experiment 2) being processed *more* holistically when processed in the context of misaligned, compared to aligned, stimuli from the other category, there was a trend for them to be processed *less* holistically. Given that the misaligned stimuli were also processed less holistically, this finding is in direct contrast with predictions based on a proposed competitive trade-off in holistic processing capacity between the two categories. Notably, a similar task context effect was found previously in terms of the impact of concurrent holistic face processing on holistic processing of cars amongst car novices (Curby & Gauthier, 2014). In addition, others have also demonstrated the ability of holistically, or globally, processed stimuli to prime greater holistic, or global, processing of other, subsequently processed stimuli (e.g., Gao et al., 2011; Weston & Perfect, 2005). Notably, these task context effects on holistic processing are also similar to the effects of concurrently presented (contextual) perceptual grouping cues on holistic processing; contextual perceptual cues discouraging grouping of face parts attenuate holistic processing (Curby et al., 2016; Curby et al., 2013). Thus, rather than a trade-off between holistic processing of the line and face stimuli, there was instead evidence of a convergence of processing styles for the stimuli from the two categories when they are processed concurrently.

Despite holistic processing of the line patterns resembling that observed for faces, it may be underpinned by distinct, independent mechanisms. That is, although line patterns with strong Gestalt information show hallmarks of holistic processing, it is possible that this similarity is at a surface or output level only. However, the presence of a congruency effect for

² The congruency effect for lines processed concurrently with the aligned faces and for those processed concurrently with misaligned faces was also examined by estimating a Bayes factor (JASP, 2018) comparing the fit of the data under the null hypothesis and the alternative hypothesis. An estimated Bayes factor suggested that the data were 10.2:1 in favor of the null hypothesis, or rather, 10.2 times more likely to occur under a model without including an interference effect of the concurrent (aligned) face task, rather than a model with it.

these novel stimuli, and moreover the attenuation of this effect when the configuration or form is disrupted, is striking given this is considered a hallmark of face- and expertise-specific holistic processing (Richler et al., 2009). To our knowledge, this pattern has not been shown for any other stimuli, beyond faces and objects of expertise. Thus, the possibility of a relationship between the holistic processing of these stimuli and of faces should not be discarded prematurely.

It is important to note that the prediction of a trade-off in holistic processing between faces and other objects assumes, at least to some degree, that holistic processing is supported by capacity-limited mechanisms. Thus, when the two categories of stimuli are processed concurrently, they should compete for a common holistic processing capacity. However, it is possible that holistic processing functions as a mechanism that is not capacity limited, but rather it is an ability to perceptually group different parts of an object together that varies across stimuli, individuals, and potentially with experience. Such grouping ability might be driven by perceptual grouping cues (Curby et al., 2013; Zhao et al., 2016) as well as by a learned attentional strategy that facilitates attention to the object as a whole (Chua, Richler, & Gauthier, 2014, 2015). Thus, if holistic processing is not supported by a limited, shared capacity, then no interference between the holistic processing of the face and novel line stimulus would be expected. However, it is unclear how this account can explain previous findings from both behavioral and neural levels revealing patterns of interference consistent with a trade-off in holistic processing capacity between face and non-face objects of expertise (Bogdan et al., 2012; Curby & Gauthier, 2014; Gauthier et al., 2003).

One possibility is that the holistic processing of stimuli strong in Gestalt cues *does* overlap with that for faces, but in a manner different to that for non-face objects of expertise. Thus, although the line stimuli fail to show evidence of interference with holistic face processing in the same task that has demonstrated such interference by non-face object of expertise, it is possible that an overlap may occur at a different stage, untapped by this task. Notably, the predominate overlap between the processing of stimuli from the different categories in the two-back interleaved composite task occurs via visual working memory. That is, the face and line stimuli are never presented simultaneously, but instead the perceptual processing of stimuli from one category occurs while an item from the other category, as well as one from the same category, are held in visual working memory. Thus, it is possible that there is a functional overlap between the holistic processing of faces and these line pattern stimuli, but it occurs at an earlier processing stage than does the overlap between the processing of face and non-face objects of expertise. That is, there may be multiple factors that drive holistic processing. This possibility is consistent with the dual route account of holistic processing (Zhao et al., 2016). Some factors may be related to an

observer's experience or expertise with the stimulus category (e.g., Chua et al., 2015; Curby & Gauthier, 2014; Gauthier et al., 2003), while others may stem from the structural aspects of the stimuli, such as the presence of strong Gestalt grouping cues (Zhao et al., 2015, 2016). Alternatively, it is possible that holistic processing is instead just one aspect of Gestalt processing, and thus the failure of the line pattern stimuli to demonstrate the same mechanistic overlap with face processing as has been observed for objects of expertise, may reflect the diversity and complexity of Gestalt properties and laws at play within different types of stimuli.³ Future studies will probe the possibility of an overlap using tasks tapping other stages of processing to further examine whether the mechanisms supporting holistic processing for faces and those for line patterns are overlapping or distinct.

Consistent with the above possibility, recent studies have suggested that structural aspects of face stimuli, such as the presence of strong perceptual grouping cues, may work in conjunction with experience to support holistic processing (Curby et al., 2013, 2016). We have previously proposed that this occurs via its role supporting strong object-based selection, which produces the apparent failure of selective attention to parts that characterizes performance in the composite face task (Curby et al., 2016; Curby & Entenman, 2016). Strong perceptual grouping between face parts appears crucial for holistic processing to occur; when perceptual grouping of the face parts is disrupted so too is holistic processing (e.g., Curby & Entenman, 2016; Curby et al., 2016). Notably, holistic processing of faces is influenced by not only the physical configuration of faces, but also by the perceived perceptual grouping of the face parts (e.g., Curby et al., 2013, 2016). For example, the same face stimuli are processed more or less holistically depending on whether contextual cues facilitate or disrupt perceptual grouping of the face parts (Curby et al., 2013). Experience impacting the interpretation of these contextual cues and thus the perceived perceptual grouping of the face parts has also been shown to modulate holistic face processing (Curby et al., 2016). These findings suggest that holistic processing may reflect, at least in part, strong, stimulus-based and experience-based, perceptual grouping within faces.

Other studies have demonstrated the influence of past experience on perceptual grouping more broadly, with evidence that stimulus familiarity facilitates grouping and contour integration (Kimchi & Hadad, 2002; Noudoost, Adibi, Moeeny, & Esteky, 2005; Zemel, Mozer, Behrmann, & Bavelier, 2002). Taken together, it can be postulated that face holistic processing is supported by the interplay of experience-related factors and the Gestalt information embedded within stimuli. If this is the case, then it also provides a potential explanation as to why

³ We thank an anonymous reviewer for bringing this possibility to our attention.

the magnitude of holistic processing is smaller for line patterns than for faces. Faces, which represent a category of expertise for many, would presumably benefit from both stimulus- and experience-based contributions to holistic processing. In addition, markers of holistic processing of objects of expertise are also typically smaller than those for faces. This has often been thought to be a result of the reduced expertise and/or experience we have for non-face objects, compared to faces, but in addition it may also be a result of a reduced contribution of other, stimulus-based factors in supporting holistic processing, for example the perceptual grouping cues within the stimuli.

In conclusion, while we replicate previous findings of face-like holistic processing of stimuli with salient Gestalt information, such stimuli do not appear to recruit the specific mechanisms that faces share with objects of expertise. Further, processing of the line patterns produced smaller indices of holistic processing as compared to that for the face stimuli. Thus, these findings suggest that Gestalt information alone may not be sufficient to support the level of holistic processing observed for faces. In light of previous literature, we suggest that experience likely operates in addition to the perceptual information in faces to enhance holistic processing. Therefore, holistic processing may be influenced by the interplay between the presence of strong Gestalt properties and extensive experience with a stimulus class. Future research is needed to better untangle and establish the mechanistic basis of these different contributions to the holistic processing of face and non-face stimuli. Regardless, the absence of a trade-off in holistic processing between faces and stimuli with salient Gestalt cues, in the context of previous results demonstrating such a trade-off between faces and objects of expertise, suggest that there are multiple paths to holistic processing.

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