Two faces of holistic face processing: Facilitation and interference underlying part-whole and composite effects

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Holistic processing, a strong tendency to process multiple features together, is regarded as a hallmark of face perception. Holistic effects can be revealed by several tasks, including the part-whole task, standard composite task, and complete composite task. Although holistic effects are readily observed using these tasks, the lack of correlations among these effects and the mixed findings across these tasks when examining the effects among various populations or manipulations pose questions about how these effects should be understood. We distinguished facilitation and interference effects within the holistic effects in the complete composite task and found that the holistic effect in the part-whole task appeared to be correlated with facilitation but not interference in the complete composite task, whereas the holistic effect in the standard composite task was correlated with interference but not facilitation in the complete composite task. These findings suggest that clarifying the roles of facilitation and interference is critical for understanding holistic face processing.

Introduction

Faces are highly similar to each other, yet most observers are efficient in recognizing hundreds of faces and effortlessly extracting useful details about each one. Such efficiency is likely facilitated by holistic processing—a hallmark of face perception that distinguishes it from object perception—which reflects a strong tendency to process multiple facial parts together (e.g., Farah, Wilson, Drain, & Tanaka, 1998; Tanaka & Farah, 1993; Young, Hellawell, & Hay, 1987). Corroborating evidence on holistic face processing has been accumulated from numerous studies using a variety of paradigms (for reviews, Behrmann, Richler, Avidan, & Kimchi, 2015; Richler & Gauthier, 2014; Rossion, 2013; Tanaka & Simonyi, 2016). It would be expected that if multiple tasks measured the same theoretical construct, performance on them should be correlated. However, among the popular tasks used to study holistic face processing (e.g., Rezlescu, Susilo, Wilmer, & Caramazza, 2017; Richler & Gauthier, 2014; Tanaka & Simonyi, 2016), performance was often found to be poorly correlated between tasks. Therefore a unified account of holistic processing is lacking.

This study focused on three popular tasks used to measure holistic processing: the part-whole task, the standard composite task,[1] and the complete composite task (Figure 1). In the part-whole task (Tanaka & Farah, 1993), participants study a whole face and then are asked to identify one feature (e.g., eyes) between two choices: the correct feature along with a foil presented either in isolation or in the context of the whole face. Although the context is identical between the two whole

Citation: Jin, H., Hayward, W. G., & Cheung, O. S. (2024). Two faces of holistic face processing: Facilitation and interference underlying part-whole and composite effects. *Journal of Vision*, *24*(11):13, 1–17, https://doi.org/10.1167/jov.24.11.13.

https://doi.org/10.1167/jov.24.11.13 Received February 20, 2024; published October 17, 2024 ISSN 1534-7362 Copyright 2024 The Authors

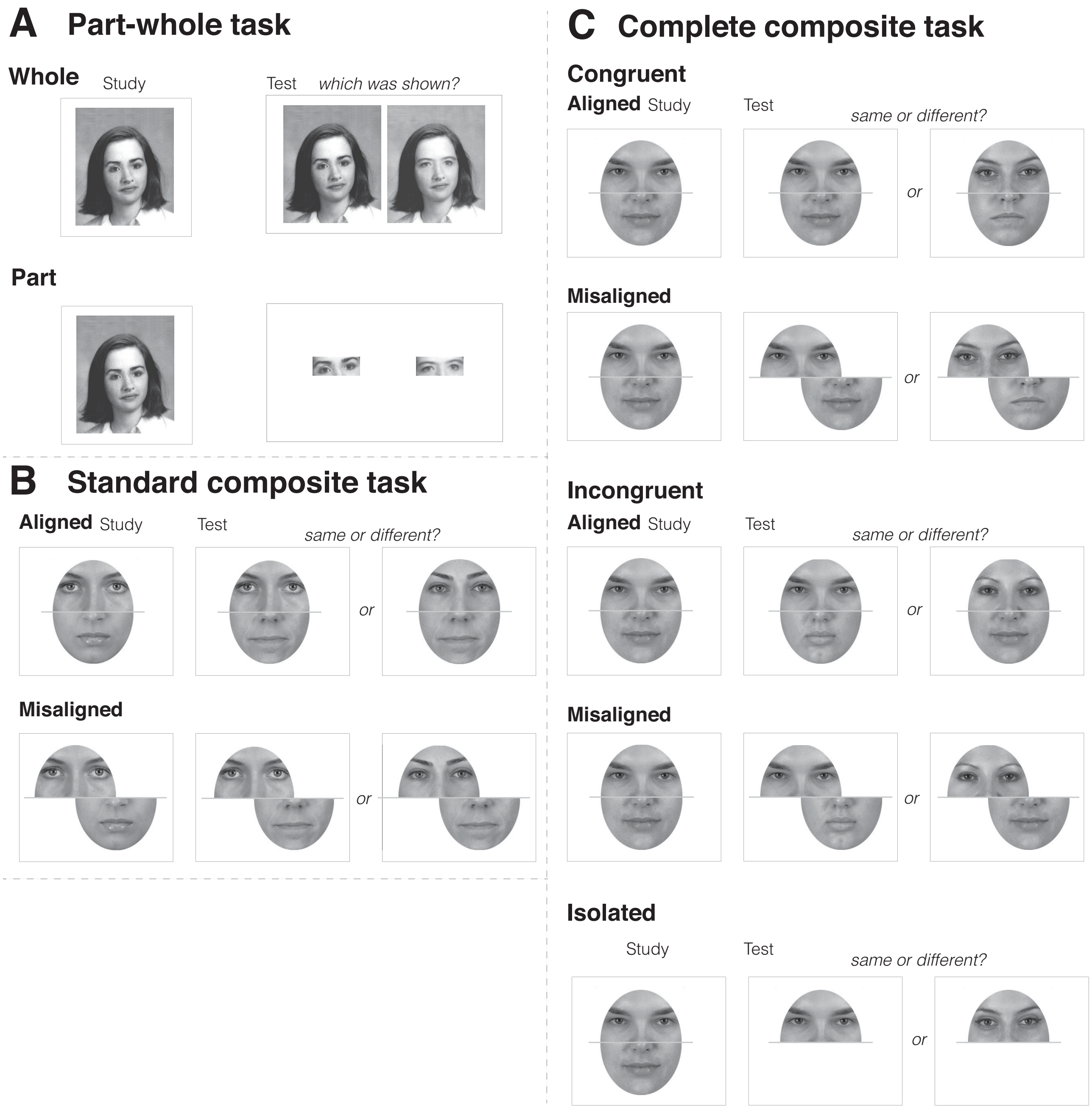

Figure 1. Designs and trial sequences of the three tasks: (**A**) the part-whole task, (**B**) the standard composite task, and (**C**) the complete composite task. In this illustration of the complete composite task, the top halves are the target halves. It should be noted that each of the three tasks in this study used face stimuli from different databases (part-whole: Tanaka et al., 2004; standard: Ge et al., 2009; complete: Ma et al., 2015). Due to copyright issues, the illustration of the standard composite task in B also uses the face images from Ma et al., 2015.

faces, holistic processing is revealed by the part-whole effect—better performance in the whole relative to the isolated conditions. In the standard composite task (Hole, 1994; Young et al., 1987), participants are instructed to judge whether the top halves of two sequentially presented face composites are identical, while ignoring the bottom halves. Because the bottom halves of the two composites are always different, holistic processing is revealed by worse performance in identifying the same top halves when the top and bottom halves are aligned, compared with when they are misaligned. In the complete composite task (Farah et al., 1998; Richler, Tanaka, Brown, & Gauthier, 2008), participants are asked to judge whether either the top or bottom halves are identical between two sequentially presented face composites. Notably, the top and bottom halves of composites in this task are either identical or different, and thus the relationship between the top and bottom halves can be congruent (both are identical, or both are different) or incongruent (identical top halves and different bottom halves, or identical bottom halves and different top halves). Holistic processing is revealed by better performance for congruent than incongruent trials when the top and bottom halves are aligned; such difference is reduced when the halves are misaligned. In the complete composite task, the target halves are sometimes presented alone, serving as a baseline to evaluate whether facilitation or interference occurs by comparing performance between congruent and isolated trials, and between incongruent and isolated trials, respectively (e.g., Cheung & Gauthier, 2010; Richler et al., 2008).

The holistic effects in all three tasks are consistently demonstrated, and these tasks have been used extensively to study various topics related to face perception. However, these tasks also produce conflicting results. For instance, for inverted faces or other-race faces, holistic effects were reduced or minimized in the part-whole task and the standard composite task but remain robust in the complete composite task (e.g., in ethnically White samples, Rossion, 2013; Richler, Mack, Palmeri, & Gauthier, 2011; Tanaka & Simonyi, 2016). Mixed findings across these tasks were also found regarding the extent that holistic processing contributes to face recognition ability (DeGutis, Wilmer, Mercado, & Cohan, 2013; Konar, Bennett, & Sekuler, 2010; Richler, Cheung, & Gauthier, 2011; Wang, Li, Fang, Tian, & Liu, 2012), whether perceptual expertise increases holistic processing for non-face objects (e.g., Gauthier & Tarr, 2002; Robbins & McKone, 2007), or the extent that young children or individuals with autism show holistic processing (e.g., Crookes & McKone, 2009; de Heering, Houthuys, & Rossion, 2007; Gauthier, Klaiman, & Schultz, 2009; Joseph & Tanaka, 2003; Nishimura, Rutherford, & Maurer, 2008; Pellicano & Rhodes, 2003). Critically, the holistic effects measured in these three tasks do not appear to be related: specifically, no significant correlations were found between the holistic effects in the part-whole task and the standard composite task (Boutet et al., 2021; Rezlescu et al., 2017; Wang et al., 2012, but see DeGutis et al., 2013), or between the effect sizes of the standard composite task and the complete composite task (Richler & Gauthier, 2014). These findings pose serious questions about how these holistic effects should be understood to advance the understanding of face perception.

We proposed that these tasks might measure two aspects of holistic face processing—facilitation and interference (Jin, Ji, Cheung, & Hayward, 2024). Facilitation and interference can be quantified in the complete composite task by comparing performance in congruent or incongruent trials with the isolated trials (e.g., Richler et al., 2008), with facilitation being revealed by better performance for congruent trials than the isolated trials, whereas interference being revealed by worse performance for incongruent trials than the isolated trials, indicating that the processing of the target face halves is influenced by the processing of the task-irrelevant face halves. Depending on the nature of the task-irrelevant facial information, we suggest that the whole face context in the part-whole task provides congruent information to aid identification of the target facial feature, whereas the different bottom halves in the standard composite task produces incongruent information to impair the matching of the identical top halves. Here we investigated whether the holistic effects measured in the part-whole task and the standard composite task were specifically related to the facilitation and interference effects in the complete composite task, respectively.

Methods

Transparency and openness

Below we report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study, and we follow JARS (Kazak, 2018). The preregistrations, data and analysis codes are available on https://osf.io/pnrwk.

Participants

The experiment was approved by New York University Abu Dhabi Institutional Review Board (Identification code: 053-2015). All procedures performed were in accordance with the Declaration of Helsinki. A total of 480 self-identified White adult participants completed the online study on Prolific (www.prolific.co) using Google Chrome. Because only White faces were used as stimuli in the experiment, an all-White sample was used to minimize potential other-race effects. All participants were between 18 to 45 years of age and reported normal or corrected-to-normal vision. There were no geographical constraints, and there were approximately 40,000 eligible participants from all available countries. In the current sample, most participants (>93%) reported to be from Europe (including Poland, Portugal, Italy, Greece, the United Kingdom, Hungary, etc.), <2% were from the United States or Canada, <1% were from Australia or New Zealand, and approximately 5% of the participants reported to be from other countries. It is important to note that all participants reported to be fluent in English and had a 100% approval rate on the Prolific platform. Note that participants recruited from this platform have consistently produced high-quality data (Douglas, Well, & Brauer, 2023), and the participants in the current study also performed satisfactorily, with all participants showing higher than 60% overall accuracy across all tasks and only five participants showing overall accuracy below 70%.

Following the preregistered plan, participants with RT outliers (<200 ms or >5000 ms) in ≥10% of one of the tasks were excluded. The remaining data from 455 participants (mean age = 26.20 ± 5.92; *N* female = 227; *N* male = 228), excluding the trials with RT outliers (<200 ms or 3 *SD*s of the condition; <2.2% in each task), were analyzed.

Stimuli

Figure 1 illustrates sample stimuli and trial sequences of the tasks. All faces were ethnically White. To minimize the possibility that the observed correlations among tasks were due to any overlap of stimuli, the three tasks used stimuli from three separate stimulus sources. Specifically, the part-whole task used stimuli from Tanaka, Kiefer, and Bukach (2004) with one female face and one male face as the base templates, and the final set of six individual female faces and six individual male faces were created by combining eyes, noses, and mouths from different individuals on the templates. Composite faces for the standard composite task and the complete composite task were created using top and bottom halves from 20 female and 20 male faces from Ge et al. (2009), and Chicago Face Database (Ma, Correll, & Wittenbrink, 2015), respectively. Isolated face halves were also included in the complete composite task.

Procedure

The experiment was programmed using jsPsych (de Leeuw, 2015) and hosted on www.pavlovia.org. All participants completed three tasks: the part-whole, standard composite, and complete composite tasks. The presentation order of the tasks and the assigned response keys for "same" and "different" in the standard composite task and the complete composite task were counterbalanced across participants. Practice trials with feedback were given before each task using line-drawing stimuli. All tasks followed the typical procedures in the literature.

In the part-whole task, participants studied a whole face and then chose from one of the two whole faces ("whole" trials) or two facial features ("part" trials) that matched the original feature. There were a total of 144 trials, with 24 trials each condition: Format: whole/part × Features: eyes/nose/mouth. On each trial, a fixation (500 ms) was followed by a study face (1000 ms), then by a mask (500 ms), then a pair of test stimuli.

In the standard composite task, participants judged whether two sequentially presented face composites showed the same top half. The top halves were cued with a bracket on both composites. The face halves were either aligned or misaligned. The top halves were identical in half of the trials and were different in the rest of the trials. The bottom halves were always different. There were a total of 160 trials, with 40 trials in each of the Alignment (aligned/misaligned) by Correct Response (same/different) condition. On each trial, a fixation was followed by a study composite (500 ms), then by a mask (500 ms), and then by a test composite.

In the complete composite task, participants judged whether the cued halves (top or bottom) of two sequentially presented face composites were identical. The relationship between top and bottom halves were either congruent (both halves were identical, or both were different) or incongruent (e.g., same top halves and different bottom halves, or vice versa). The face halves were either aligned or misaligned; the target halves were also presented in isolation as the baseline. There were a total of 400 trials, with 20 trials in each condition with full composites (Cue: top/bottom; Congruency: congruent/incongruent; Alignment: aligned/misaligned; Correct response: same/different) and for isolated halves (Cue × Correct Response). On each trial, a fixation was followed by a study composite (500 ms), then by a mask (500 ms), and then a test stimulus (composite or isolated half, with the target half cued by a bracket).

Analysis

Analyses were conducted using R (v4.1.3). As preregistered, reliability of the measures was first conducted prior to examining the relationship among the effects (https://osf.io/5sjxa, section 3.2.4). Following previous literature (DeGutis et al., 2013; Rezlescu et al., 2017; Ross, Richler, & Gauthier, 2015), reliability was estimated using Guttaman's λ^2, because it is more appropriate than Cronbach's alpha when measures include multiple factors (Callender & Osburn, 1979). Specifically, following Ross et al. (2015), reliability of the holistic effects based on the difference score was calculated using the formula from Rogosa, Brandt, and Zimowski (1982); reliability of the holistic effects based on regression was calculated using the formula from Malgady & Colon-Malgady (1991).

For the main analyses, as pre-registered (https://osf.io/5sjxa, section 3), analyses on accuracy/choice and RT data with generalized linear mixed-effects models (GLMM) with one-sided tests.[2] We first tested GLMM with the maximal random-effect structure (i.e., the maximal model) (Barr, Levy, Scheepers, & Tily, 2013), which included all by-subject and by-stimulus random intercepts and random slopes. Since such maximal models usually do not converge, we subsequently built the random effect structures in GLMM following the recommended steps suggested by Bates, Kliegl, Vasishth, and Baayen (2015) and Matuschek, Kliegl, Vasishth, Baayen, and Bates (2017). The details of the maximal models and the corresponding final models used for the analyses are included in Appendix B. All results are reported with corrections of multiple comparisons applied, except otherwise noted.

First, to replicate the holistic effects observed in each task and examine the correlations among the holistic effects across tasks, we examined (1) the part-whole effect comparing performance between wholes and parts (eyes/mouth only, Crookes, Favelle, & Hayward, 2013; Joseph & Tanaka, 2003); (2) the standard composite effect comparing performance in the *same* trials between aligned and misaligned composites (Boutet et al., 2021; Rezlescu et al., 2017); (3) the complete composite effect comparing performance using all trials in alignment and congruency conditions (Jin, Oxner, Corballis, & Hayward, 2022; Richler, Mack, et al., 2011). The holistic effects were computed by subtracting or regressing out performance of a condition that was expected to engage less or minimal holistic processing from another condition that was expected to engage holistic processing: part trials from whole trials for the part-whole task, misaligned trials from aligned trials for the standard composite task, and congruency effects in misaligned trials from congruency effects in aligned trials for the complete composite task (DeGutis et al., 2013; Rezlescu et al., 2017). Correlations were then performed on the holistic effects without multiple comparison corrections (Boutet et al., 2021; DeGutis et al., 2013; Rezlescu et al., 2017; Wang et al., 2012).

Second, facilitation and interference in the complete composite task was revealed by differences in performance between isolated trials (baseline) and congruent trials for aligned composites, and between isolated trials and incongruent trials for aligned composites, respectively (Gregory, Tanaka, & Liu, 2021; Richler, Bukach, & Gauthier, 2009; Richler, Cheung, Wong, & Gauthier, 2009; Richler et al., 2008; Cheung & Gauthier, 2010). Correlations were performed between the facilitation effect in the complete composite task and the holistic effect in the part-whole task, and between the interference effect in the complete composite task and the holistic effect in the standard composite task.

Moreover, non-preregistered analyses were also conducted to examine the specificity of the relationship: correlations were compared among the holistic effects in the part-whole task and the standard composite task, with the facilitation and interference effects in the complete composite task, and correlations were also performed between the interference effect in the complete composite task and the holistic effect in the part-whole task and between the facilitation effect in the complete composite task and the holistic effect in the standard composite task. Additionally, we also examined any relationship between the facilitation and interference effects in the complete composite task. For reference, Appendix A shows the complete list of non-preregistered analyses.

Results

Reliability of the holistic measures

All reliability results are reported in Table 1. Reliability in all separate conditions in the part-whole, standard composite, and complete composite tasks was generally high (Guttman's $\lambda^2 = 0.71$ to 0.96). As expected, reliability was reduced for the holistic effects measured using either the difference scores or regression residuals (Guttman's $\lambda^2 = 0.19$ to 0.70). These results were consistent with those reported in previous studies (DeGutis et al., 2013; Rezlescu et al., 2017; Ross et al., 2015).

Holistic effects across tasks and their relationships

Holistic effects were observed in all tasks (Figure 2; Table 2). In the part-whole task, performance was better ($z = 12.02$, $p < 0.001$) and faster ($z = -2.81$, $p = 0.003$) for wholes than parts. In the standard composite task, performance was worse ($z = -9.93$, $p < 0.001$) and slower ($z = 7.93$, $p < 0.001$) for aligned than misaligned composites. In the complete composite task, the congruency effect was found for aligned composites, with higher d' ($z = 31.95$, $p < 0.001$) and shorter RT ($z = -15.62$, $p < 0.001$) for congruent than incongruent trials, and larger congruency effects for aligned than misaligned composites, as indicated by the interaction between Congruency and Alignment in d' ($z = 18.97$, $p < 0.001$) and RT ($z = -9.41$, $p < 0.001$).

Table 3 shows all the correlation results among the effects, and we highlight the main findings in the text. No significant correlations were observed between the part-whole effect and the standard composite effect ($|r| < .06$, $p > 0.21$), or between the part-whole effect and the complete composite effect (except a marginal effect in d'/accuracy with regression without corrections,

Task	DV	Condition/Effect	Method	Reliability
PW	Accuracy	Whole	Guttman's λ_2	0.81
	Accuracy	Part	Guttman's λ_2	0.72
	RT	Whole	Guttman's λ_2	0.94
	RT	Part	Guttman's λ_2	0.94
	Accuracy	Holistic effect: whole - part	Subtraction	0.27
	Accuracy	Holistic effect: whole ∼ part	Regression	0.41
	RT	Holistic effect: whole - part	Subtraction	0.77
	RT	Holistic effect: whole ∼ part	Regression	0.79
SC	Accuracy	Aligned	Guttman's λ_2	0.84
	Accuracy	Misaligned	Guttman's λ_2	0.89
	RT	Aligned	Guttman's λ_2	0.93
	RT	Misaligned	Guttman's λ_2	0.95
	Accuracy	Holistic effect: ali - mis	Subtraction	0.47
	Accuracy	Holistic effect: ali, ∼ mis	Regression	0.50
	RT	Holistic effect: ali - mis	Subtraction	0.62
	RT	Holistic effect: ali ∼ mis	Regression	0.63
CC	d'	con_ali	Guttman's λ_2	0.77
	d'	inc_ali	Guttman's λ_2	0.71
	d'	con_mis	Guttman's λ_2	0.74
	d'	inc_mis	Guttman's λ_2	0.75
	d'	isolated	Guttman's λ_2	0.77
	RT	con_ali	Guttman's λ_2	0.96
	RT	inc_ali	Guttman's λ_2	0.96
	RT	con_mis	Guttman's λ_2	0.96
	RT	inc_mis	Guttman's λ_2	0.96
	RT	isolated	Guttman's λ_2	0.96
	d'	Holistic effect: (con_ali - inc_ali) - (con_mis - inc_mis)	Subtraction	0.19
	d'	Holistic effect: (con_ali - inc_ali) ∼ (con_mis - inc_mis)	Regression	0.42
	RT	Holistic effect: (con_ali - inc_ali) - (con_mis - inc_mis)	Subtraction	0.49
	RT	Holistic effect: (con_ali - inc_ali) ∼ (con_mis - inc_mis)	Regression	0.59
Facilitation in CC	d'	con_ali - isolated	Subtraction	0.18
	d'	con_ali ∼ isolated	Regression	0.28
	RT	con_ali - isolated	Subtraction	0.61
	RT	con_ali ∼ isolated	Regression	0.60
Interference in CC	d'	inc_ali - isolated	Subtraction	0.35
	d'	inc_ali ∼ isolated	Regression	0.37
	RT	inc_ali - isolated	Subtraction	0.70
	RT	inc_ali ∼ isolated	Regression	0.67

Table 1. Reliability of each condition in the part-whole task, the standard composite task, and the complete composite task, and reliability of the holistic effects in the three tasks and the facilitation and interference effects in the complete composite task calculated using difference scores or regression residuals. *Notes:* PW = part-whole task; SC = standard composite task; CC = complete composite task; DV = dependent variables; RT = response times; Condition/Effect = the condition or effect for which the reliability was calculated; con = congruent; inc = incongruent; ali = aligned; mis = misaligned; - = the difference scores between the conditions; ∼ = regression residuals; Method = the method used to calculate the reliability using either the difference scores ("subtraction", Rogosa et al., 1982) or regression residuals ("regression", Malgady & Colon-Malgady, 1991).

$r(453) = 0.08$, $p = 0.07$, all others: $|r| < 0.04$, $p > 0.46$) (see Table 3, Figure 3A). Nonetheless, significant correlations were observed between the standard composite effect and the complete composite effect for choices using either subtraction: $r(453) = 0.12$, $p = 0.013$ or regression: $r(453) = 0.15$, $p = 0.001$, though not for RT ($|r| < 0.08$, $p > 0.13$) (see Table 3, Figure 4A).

Facilitation and interference in the complete composite task and their relationships with holistic effects in the part-whole task and the standard composite task

Facilitation and interference were observed in the complete composite task (Figure 2; Table 2): Facilitation

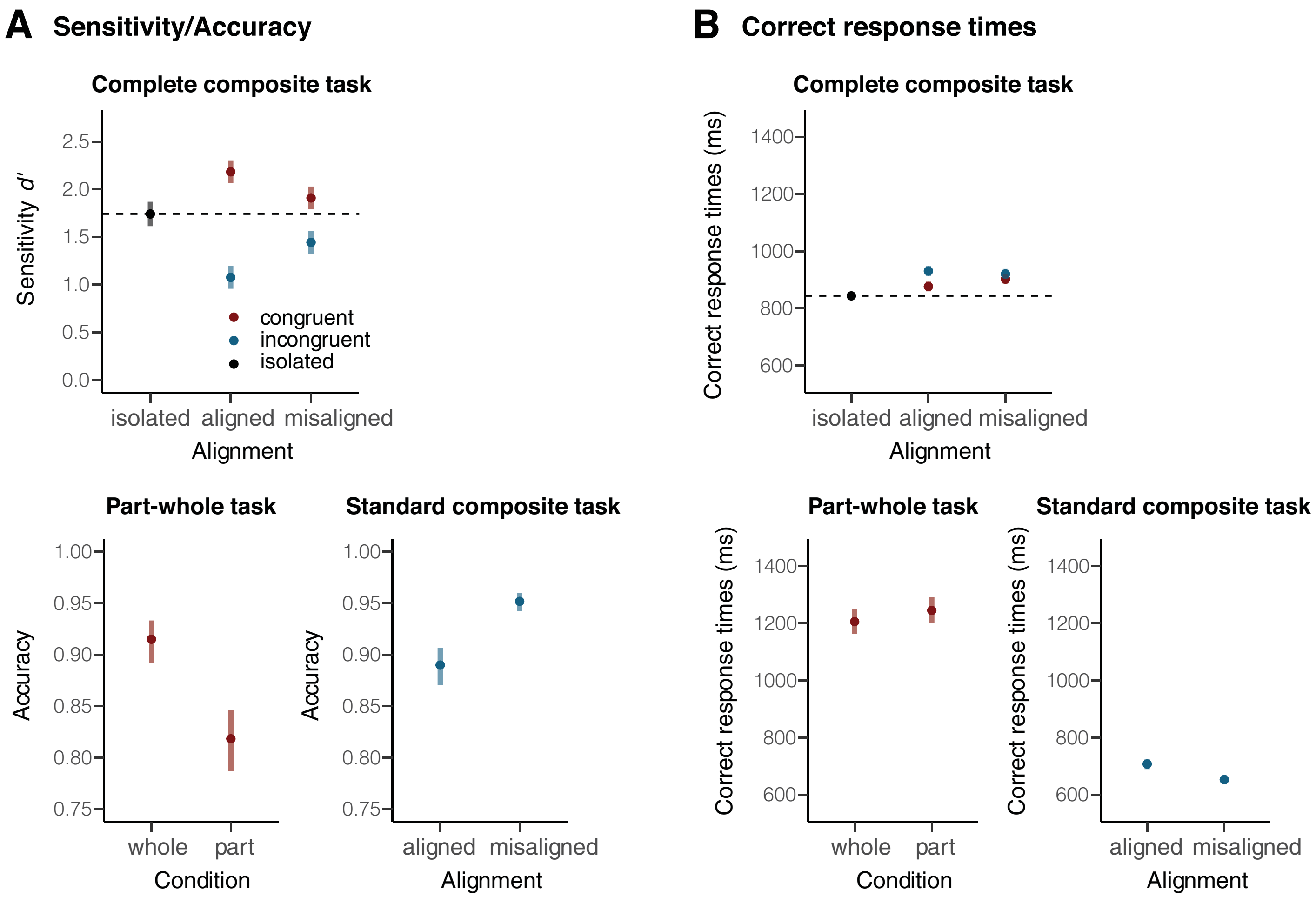

Figure 2. Holistic effects in the three tasks, and facilitation and interference effects in the complete composite task (facilitation: aligned-congruent minus isolated; interference: aligned-misaligned minus isolated). (**A**) illustrates the results on choice (d' for the complete composite task, and accuracy for the part-whole task and the standard composite task), and (**B**) illustrates the results in correct response times. Error bars denote the 95% confidence intervals.

was revealed by higher d' for aligned-congruent than isolated trials ($z = 10.17$, $p < 0.001$), although not significantly faster in RT ($z = 9.86$, $p > 0.99$). Interference was observed with lower d' ($z = -20.33$, $p < 0.001$) and longer RT ($z = 21.91$, $p < 0.001$) for aligned-incongruent than isolated trials.

Correlation analyses (Table 3; Figure 3B) revealed a significant correlation between facilitation in the complete composite task in d' and the part-whole effect in accuracy using regression, when no correction for multiple comparisons was applied, $r(453) = 0.09$, $p = 0.035$, but not when Holm corrections for 4 tests was applied: $p_{\text{adjusted}} = 0.14$; no other correlations were found $|r| < 0.05$, $p > 0.15$. Conversely, interference in the complete composite task in d' (Table 3; Figure 4B) was significantly correlated with the standard composite effect in accuracy using either subtraction, $r(453) = 0.16$, $p < 0.001$, $p_{\text{adjusted}} < 0.001$ or regression, $r(453) = 0.24$, $p < 0.001$, $p_{\text{adjusted}} < 0.001$; no significant results were observed in RT (subtraction: $r(453) = 0.08$, $p = 0.055$, $p_{\text{adjusted}} = 0.11$; regression: $r(453) = 0.05$, $p = 0.14$).

The non-preregistered analyses focused on examining strong evidence for the relations among the part-whole and standard composite effects with the facilitation and interference effects measured in the complete composite task. Specifically, facilitation should be more strongly related to the part-whole effect than the standard composite effect, whereas interference should be more strongly related to the standard composite effect than the part-whole effect. Therefore we tested whether the correlation between the part-whole effect and facilitation was significantly larger than both (1) the correlation between the part-whole effect and interference and (2) the correlation between the standard composite effect and facilitation. Moreover, we also tested whether the correlation between the standard composite effect and interference was

Effects	DV	EMM	Inferential statistics
Holistic effects in PW	accuracy	whole = 91.5%	$z = 12.02$, $p < 0.001$
		part = 81.8%	Odds Ratio = 2.39, 95% CI = [2.12 Inf]
	RT	whole = 1206	$z = -2.81$, $p = 0.003$
		part = 1245	Ratio = 0.97, 95% CI = [0 0.99]
Holistic effects in SC	accuracy	ali = 89.0%	$z = -9.93$, $p < 0.001$
		mis = 95.2%	Odds Ratio = 0.41, 95% CI = [0 0.47]
	RT	ali = 708	$z = 7.93$, $p < 0.001$
		mis = 653	Ratio = 1.08, 95% CI = [1.07 Inf]
Holistic effects in CC	d'	ali_con = 2.18	(1) $z = 31.95$, $p < 0.001$
		ali_inc = 1.08	$\beta = 1.11$, 95% CI = [1.05 Inf]
		mis_con = 1.91	(2)$z = 18.97$, $p < 0.001$
		mis_inc = 1.44	$\beta = 0.64$, 95% CI = [0.59 Inf]
	RT	ali_con = 877	(1) $z = -15.62$, $p < 0.001$
		ali_inc = 931	Ratio = 0.94, 95% CI = [0 0.95]
		mis_con = 903	(2) $z = -9.41$, $p < 0.001$
		mis_inc = 920	Ratio = 0.96, 95% CI = [0 0.97]
Facilitation in CC	d'	ali_con = 2.19	$z = 10.17$, $p < 0.001$
		isolated = 1.74	$\beta = 0.45$, 95% CI = [0.38 Inf]
	RT	ali_con = 877	$z = 9.86$, $p > 0.99$
		isolated = 844	Ratio = 1.04, 95% CI = [0 1.05]
Interference in CC	d'	ali_inc = 1.08	$z = -20.33$, $p < 0.001$
		isolated = 1.74	$\beta = -0.66$, 95% CI = [−Inf −0.61]
	RT	ali_inc = 930	$z = 21.91$, $p < 0.001$
		isolated = 844	Ratio = 1.10, 95% CI = [1.09 Inf]

Table 2. Inferential statistics on the holistic effects in the part-whole task, the standard composite task, and the complete design task, and the facilitation and interference effects in the complete composite task. *Notes:* PW = part-whole task; SC = standard composite task; CC = complete composite task; DV = dependent variables; RT = response times; EMM = estimated marginal means for each condition; ali = aligned; mis = misaligned; con = congruent; inc = incongruent; CI = confidence intervals. For odds ratio or ratio, the null value in the statistical null hypothesis is 1. For the complete composite results, (1) show the congruency effect (i.e., differences between congruent and incongruent trials) for aligned composites, and (2) show the interaction between Congruency and Alignment. As preregistered, one-sided tests were used in these analyses (https://osf.io/pnrwk).

significantly larger than both (3) the correlation between the standard composite effect and facilitation and (4) the correlation between the part-whole effect and interference. Following the established tests to compare correlation effects (Steiger, 1980, with the toolbox implemented by Diedenhofen & Musch, 2015), we found that among the four tests, significant results were observed in one of the two tests related to facilitation, and in both of the tests related to interference. For facilitation, 1) the correlation between the holistic effect in the part-whole task (in accuracy using regression) and facilitation in the complete composite task (in d') was significantly greater than its correlation with interference in the complete composite task ($z = 2.28$, $p = 0.02$). However, (2) the correlation between part-whole effect and facilitation was not significantly different from the correlation between standard composite effect and facilitation ($z = 0.58$, $p = 0.57$). For interference, (3) the correlation between the holistic effect in the standard composite task (in accuracy using regression) and the interference in the complete composite task (in d') was significantly greater than its correlation with the facilitation in the complete composite task (in d') ($z = 2.96$, $p = 0.003$). Moreover, (4) the correlation between the standard composite effect and interference was also larger than the correlation between part-whole effect and interference ($z = 4.72$, $p < 0.0001$).

Because facilitation was not expected to be related to the holistic effect in the standard composite task, and interference was not expected to be related to the part-whole effect, further non-preregistered correlation analyses were conducted to show that there were indeed no significant correlations between facilitation in the complete composite task and the holistic effect in the standard composite task, $|r| < 0.07$, $p > 0.15$, or between interference in the complete composite task and holistic effects in the part-whole task, $|r| < 0.07$, $p > 0.15$.

If facilitation and interference are both aspects of holistic processing, it is possible that the two measures might be correlated. Indeed, in additional non-preregistered analyses, we found that the facilitation

Effects	Method	DV	r	95% *CI*	p Value	p Holm	Upper Bound for r
Holistic effects in PW vs. SC	Subtraction	Accuracy	0.06	[−0.03 0.15]	0.22	—	0.36
	Subtraction	RT	−0.01	[−0.10 0.08]	0.80	—	0.69
	Regression	Accuracy	0.01	[−0.08 0.10]	0.88	—	0.45
	Regression	RT	−0.04	[−0.13 0.06]	0.45	—	0.70
Holistic effects in CC vs. PW	Subtraction	d'/accuracy	0.03	[−0.06 0.13]	0.47	—	0.23
	Subtraction	RT	0.03	[−0.06 0.13]	0.47	—	0.61
	Regression	d'/accuracy	0.08	[−0.01 0.18]	0.071	—	0.42
	Regression	RT	−0.005	[−0.10 0.09]	0.94	—	0.68
Holistic effects in CC vs. SC	Subtraction	d'/accuracy	0.12	[0.02 0.21]	0.013*	—	0.30
	Subtraction	RT	−0.005	[−0.09 0.09]	0.96	—	0.55
	Regression	d'/accuracy	0.15	[0.06 0.24]	0.0011**	—	0.46
	Regression	RT	0.07	[−0.02 0.16]	0.13	—	0.61
Facilitation in CC vs. Holistic effect in PW	Subtraction	d'/accuracy	0.05	[−0.03 1.00]	0.16	0.47	0.22
	Subtraction	RT	−0.01	[−0.09 1.00]	0.38	0.75	0.68
	Regression	d'/accuracy	0.09	[0.01 1.00]	0.035*	0.14	0.34
	Regression	RT	0.01	[−0.07 1.00]	0.40	0.75	0.69
Interference in CC vs. Holistic effect in SC	Subtraction	d'/accuracy	0.16	[0.09 1.00]	<0.001***	<0.001***	0.41
	Subtraction	RT	0.08	[0.00 1.00]	0.055	0.11	0.66
	Regression	d'/accuracy	0.24	[0.17 1.00]	<0.001***	<0.001***	0.43
	Regression	RT	0.05	[−0.03 1.00]	0.14	0.14	0.65
Facilitation in CC vs. Holistic effect in SC	Subtraction	d'/accuracy	0.07	[−0.02 0.16]	0.15	0.60	0.29
	Subtraction	RT	0.01	[−0.09 0.10]	0.89	0.99	0.61
	Regression	d'/accuracy	0.05	[−0.05 0.14]	0.32	0.95	0.37
	Regression	RT	−0.01	[−0.11 0.08]	0.77	0.99	0.61
Interference in CC vs. Holistic effect in PW	Subtraction	d'/accuracy	−0.06	[−0.15 0.03]	0.22	0.65	0.31
	Subtraction	RT	0.03	[−0.06 0.12]	0.48	0.97	0.74
	Regression	d'/accuracy	−0.07	[−0.16 0.02]	0.15	0.61	0.39
	Regression	RT	−0.002	[−0.09 0.09]	0.98	0.98	0.73

Table 3. Correlations among the holistic effects, and correlations among the facilitation and interference in complete composite task and the holistic effects in the part-whole task and the standard composite task. *Notes:* PW = part-whole task; SC = standard composite task; CC = complete composite task; Method = the method used to calculate the holistic effects; DV = dependent variables; RT = response times; r = Pearson's correlation coefficient; 95% *CI* = lower and upper boundaries of the 95% confidence intervals; p value = p value without corrections; p Holm = p value with Holm corrections (for four tests); Upper bound for r = the potential ceiling of the correlation, which is the square root of the product of the two measurements' reliabilities; $^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

and interference effects in the complete composite task (using regression residuals) was negatively correlated in RT ($r = -0.52$, $p < 0.001$), although not in accuracy/d' ($r = -0.01$, $p = 0.76$).

Discussion

As expected, robust holistic effects were found in all three tasks: the part-whole, standard composite, and complete composite tasks. Replicating previous findings, we found no significant correlations between the holistic effects in the part-whole task and those in either the standard or complete composite tasks (Boutet et al., 2021; Rezlescu et al., 2017; Wang et al., 2012; but see DeGutis et al., 2013), despite a large sample being used. Nonetheless, when directly comparing the holistic effects measured in the standard and complete composite tasks, this study was the first to show significant correlations between these effects.

Although all three tasks are designed to measure holistic processing, the lack of significant correlations among the part-whole task with either the standard or complete composite tasks might not be surprising since the part-whole task is more different than the standard composite task and the complete composite task on both stimulus manipulations (e.g., whole-part vs. halves) and task requirements (e.g., two-alternative forced choice vs. sequential matching). However, note that the correlations we observed between the standard composite task and the complete composite task were unlikely simply because of any stimulus or task characteristics that these two tasks might share.

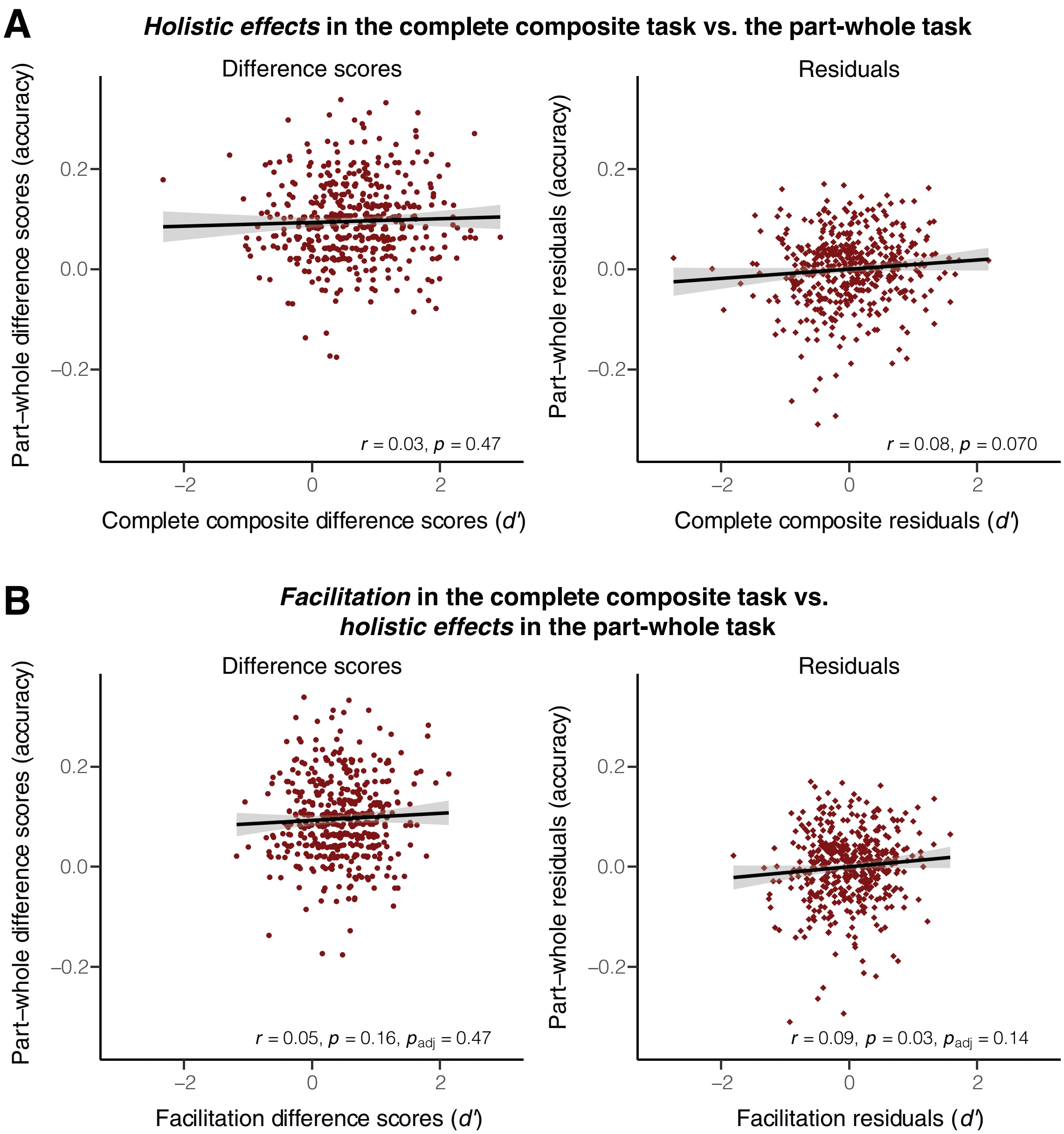

Figure 3. (**A**) Correlation results between the holistic effects in the complete composite task (d') and the part-whole task (accuracy). (**B**) Correlation results between the facilitation effects in the complete composite task (d') and the holistic effects in the part-whole task (accuracy). The gray regions indicate the 95% confidence intervals of the fitted line.

Specifically, the standard and complete composite tasks in this study were blocked and the data was collected independently for the two tasks, with each task using face stimuli from a separate database and slightly different task instructions (i.e., attending to only the top halves in the standard composite task vs. both halves in the complete composite task). Importantly, we found that the holistic effect in the part-whole task was only correlated with the facilitation, but not interference, effect measured in the complete composite task, in the likely most robust condition with d'/accuracy (Richler & Gauthier, 2014) using regression (DeGutis et al., 2013; but see Ross et al., 2015). Note, however, that the correlation between the facilitation effect in the complete composite task and the holistic effect in the part-whole task and was not significantly different from that with the holistic effect in the standard composite task, thus the results did not reflect the strongest evidence for a unique relationship between the part-whole task and facilitation. Conversely, the holistic effect in the standard composite task was only correlated with the interference, but not facilitation, effect measured in the complete composite task. This correlation was significantly larger than that between the interference effect and the holistic effect in the part-whole task. These findings suggest that the two

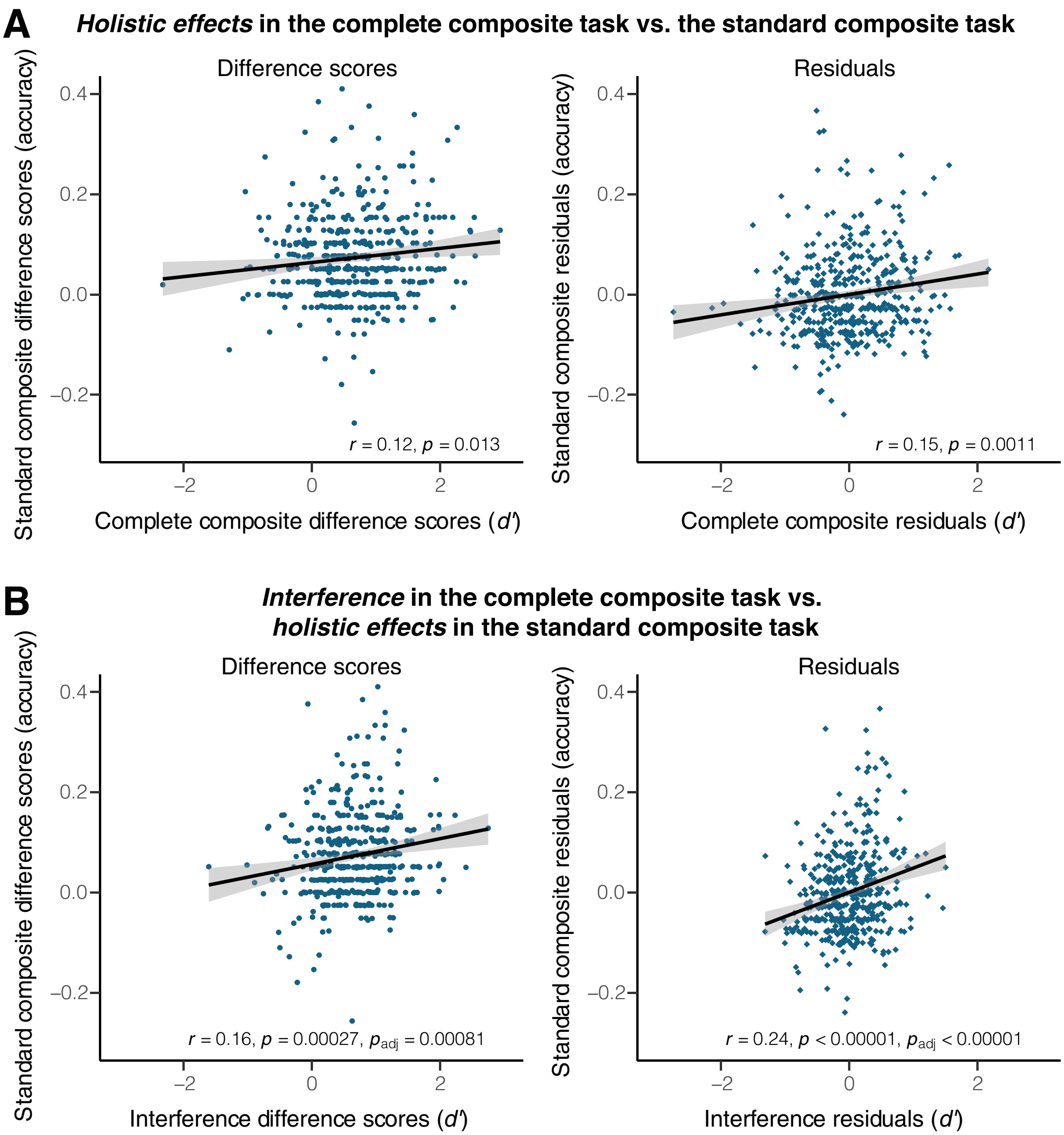

Figure 4. (**A**) Correlation results between the holistic effects in the complete composite task (d') and the standard composite task (accuracy). (**B**) Correlation results between the interference effects in the complete composite task (d') and the holistic effects in the standard composite task (accuracy). The gray regions indicate the 95% confidence intervals of the fitted line.

components of holistic processing measured in the complete composite task, facilitation and particularly interference, are likely differentially related to the holistic effects measured in the widely used versions of the part-whole and standard composite tasks.

It is notable that the correlations among the effects were not very high, even though the sample size was quite large in the study. These findings are consistent with previous studies that suggested these widely used measures of holistic processing indeed reveal heterogenous nature of the holistic effect (e.g., Rezlescu et al., 2017). The low correlations were unlikely due to a relatively small holistic effect in the standard composite task (Figure 1), since the lack of a correlation between the holistic effects in the part-whole task and in the standard composite task was also reported in previous studies (Boutet et al., 2021; Rezlescu et al., 2017; but see DeGutis et al., 2013). More importantly, we found that the holistic effect in the standard composite task was nonetheless correlated with the holistic effect in the complete composite task, and was specifically correlated with the interference, though not facilitation, effect in the complete composite task.

Extending from previous literature on the heterogeneous nature of holistic processing, our results suggest that it is crucial to understand holistic processing in terms of facilitation and interference across these widely used tasks. Facilitation and interference have been discussed as the two sides of a coin for holistic processing (Tanaka & Simonyi, 2016) and the two components can be readily distinguished in the congruency effect measured in the complete composite task (Cheung & Gauthier, 2010; Richler et al., 2008). Naturally, facial features co-vary and consistent information on faces is almost always expected in our daily life. For instance, when seeing a big smile on someone's face, scrunched eyes or dimples are often expected. Inconsistent information, such as a combination of eyes filled with sadness and a big smile, or facial features from different individuals, is highly unexpected. As observers learn such regularities among facial features throughout their lifetime, holistic processing—an efficient way to process as much information as possible on a face—is highly useful for face recognition. Thus it is conceivable that congruent facial information in the part-whole task and complete composite task generally facilitates recognition. Moreover, the experimental manipulations with incongruent face halves in the complete composite task and the standard composite task are robust demonstrations of the strong tendency of processing all facial information together, because the unexpected inconsistencies greatly impair recognition.

Consistent with recent findings that facilitation and interference in holistic face processing may operate somewhat independently (Jin et al., 2024), here we found that the facilitation and interference effects measured in the complete composite task could be negatively correlated. While the underlying mechanisms that support facilitation and interference will need to be further examined, our current results suggest that the separate contributions from facilitation or interference in the part-whole, standard composite, and complete composite tasks might have resulted in the mixed findings in the literature. Because both facilitation and interference that contribute to the holistic effect can be measured by the congruency effect in the complete composite task, we suggest that the complete composite task may be a more complete measure of holistic processing than the other tasks if both components of holistic processing are of interest. Note also that facilitation and interference could also potentially be measured by additional conditions in other versions of the part-whole task or the standard composite task. For example, interference may be measured in the part-whole task, with a condition where participants first learn the facial features in isolation and are later instructed to match the features in a whole context (e.g., Tanaka & Farah, 1993). For the standard composite task, adding trials of isolated target top halves during matching might be useful to separate any facilitation or interference effects in that task.

To examine the nature of holistic face processing and the relationships among the holistic processing measures, this study examined recognition performance of White faces by self-identified White participants. The primary reason to utilize stimuli and participants of only one race is because holistic processing of faces has been consistently observed for own-race faces across all three tasks, whereas the extent of holistic processing for other-race faces remains inconsistent across the tasks (Crookes et al., 2013; Hayward, Crookes, & Rhodes, 2013; Horry, Cheong, & Brewer, 2015; Mondloch et al., 2010; Tanaka et al., 2004; Wang et al., 2019; Wong, Estudillo, Stephen, & Keeble, 2021). Because holistic processing of own-race faces has been observed for participants across several races (e.g., White: Crookes et al., 2013; Horry et al., 2015; Mondloch et al., 2010; Tanaka et al., 2004, Black: Bukach, Cottle, Ubiwa, & Miller, 2012, East Asian: Crookes et al., 2013; Mondloch et al., 2010; Tanaka et al., 2004; Wang et al., 2019, Wang et al., 2023, Southeast/Malaysian Asian: Horry et al., 2015; Wong et al., 2021), it is likely that the current findings will generalize to other non-White populations. For instance, a recent study found that facilitation and interference effects could operate independently in the complete composite task when Chinese participants viewed Chinese faces (Jin et al., 2024), suggesting potential separate contributions of facilitation and interference to holistic processing. Nonetheless, future studies should investigate whether and how the relationship among the holistic effects and their components in these tasks might be affected when further manipulations are introduced (e.g., own- vs. other-race faces) or when diverse or clinical populations are tested. Note also that while this study compared these tasks in their most widely used formats, these tasks were originally designed to measure group-level results. Although the reliability of our measures was improved following previous recommendations (Ross et al., 2015), future studies may consider adopting versions of these tasks optimized to study individual differences (Richler, Floyd, & Gauthier, 2015; but see Sunday, Richler, & Gauthier, 2017).

Conclusions

In sum, this study shows the importance of studying holistic processing of faces in terms of facilitation from consistent information and interference from inconsistent information. Both effects are readily measured in the complete composite task, and these components are differentially related to the holistic effects in the part-whole and standard composite tasks. Our findings help clarify the relationship among these widely used tasks for studying holistic processing and have a great potential for resolving some mixed findings in the literature and for advancing the field to elucidate the nature of holistic processing.

Keywords: holistic processing, part-whole, composite faces, facilitation, interference

Acknowledgments

The authors wish to acknowledge the use of New York University Abu Dhabi high-performance computing facilities and consulting support for part of this research.

Supported by a New York University Abu Dhabi faculty grant (AD174) and a Tamkeen New York University Abu Dhabi Research Institute grant (CG012) to O.S.C. and by a grant (LU13605523) from the General Research Fund of the Hong Kong Research Grants Council to W.G.H.

Data available: The pre-registrations, data and analysis codes are available on https://osf.io/pnrwk/.

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Footnotes

[1]We adopted the name “the standard composite task” following Rossion (2013). It has also been known as the partial design of the composite task (e.g., Richler & Gauthier, 2014).
[2]Note that following Rossion (2013), one of the dependent measures of the standard composite effect used here was the accuracy of the same trials, where different trials were not used. The calculation of sensitivity (d′) might not be suitable to interpret the composite illusion (Rossion, 2013), and also was not necessarily useful for addressing potential concerns of response bias (Cheung, Richler, Palmeri, & Gauthier, 2008; Konar et al., 2010; Richler, Cheung, et al., 2011).

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Appendix A: List of non-preregistered analyses

In addition to reporting all the preregistered analyses (https://osf.io/pnrwk/), further analyses that were not included in the preregistration were conducted. To investigate the specificity of part-whole and standard composite effects in relations to the facilitation and interference effects in the complete composite effect, six comparisons were conducted. We examined whether the correlation between the part-whole effect and facilitation was significantly larger than both (1) the correlation between part-whole effect and interference and (2) the correlation between standard composite effect and facilitation. Moreover, we also tested whether the correlation between the standard composite effect and interference was significantly larger than both (3) the correlation between the standard composite effect and facilitation and (4) the correlation between part-whole effect and interference. Moreover, we compared correlations between (5) the interference effect in the complete composite task and the holistic effect in the part-whole task and between (6) the facilitation effect in the complete composite task and the holistic effect in the standard composite task.

Additionally, to examine any relationship between facilitation and interference, we calculated (7) the correlations between the facilitation and interference effects in the complete composite task.

Appendix B: Details of the generalized linear mixed-effects models used in the analyses

The maximal and final models used in the generalized linear-mixed effect model analyses on the accuracy/choice and RT data in the part-whole task, the standard composite task, and the complete composite task are presented below using lme4 syntax with back-difference contrast coding.

Part-whole task: Accuracy

The maximal model included all by-subject and by-stimulus random intercepts and random slopes:

$$\begin{aligned}&\text{isCorrect} \sim \text{PW} * \text{Feature} + (\text{PW} * \text{Feature}|\text{Subject})\\&\quad + (\text{PW} * \text{Feature}|\text{StimGroup})\end{aligned}$$

where “isCorrect” refers to whether the response was correct on that trial; “PW * Feature” refers to the independent variables PW (whole vs. part) and Feature (eye vs. mouth), as well as their interaction; “Subject” and “StimGroup” refer to the by-subject and by-stimulus-group random effects, respectively.

The maximal model was submitted to the pre-registered steps to obtain the final model:

$$\begin{aligned}&\text{isCorrect} \sim \text{PW} * \text{Feature}\\&\quad + (\text{PW\_C} + \text{Feature\_C}|\text{Subject})\\&\quad + (\text{PW\_C} + \text{Feature\_C} + \text{PW\_Feature}|\text{StimGroup})\end{aligned}$$

where “PW_C”, “Feature_C”, and “PW_Feature” refer to the random slopes of PW, Feature, and their interaction, respectively. Denotations of other terms were the same as those in the maximal model for accuracy.

Part-whole task: Correct response times

The maximal model included all by-subject and by-stimulus random intercepts and random slopes:

$$\begin{aligned}&\log(\text{RT}) \sim \text{PW} * \text{Feature}\\&\quad + (\text{PW} * \text{Feature}|\text{Subject})\\&\quad + (\text{PW} * \text{Feature}|\text{StimGroup})\end{aligned}$$

where “log(RT)” refers to the log-transformed correct response times; the denotations of other terms were the same as the maximal model for accuracy in the part-whole task.

The maximal model was submitted to the pre-registered steps to obtain the final model:

$$\begin{aligned}&\log(\text{RT}) \sim \text{PW} * \text{Feature}\\&\quad + (\text{PW\_C} + \text{Feature\_C} + \text{PW\_Feature}|\text{Subject})\\&\quad + (\text{PW\_C} + \text{Feature\_C} + \text{PW\_Feature}|\text{StimGroup})\end{aligned}$$

where “log(RT)” refers to the log-transformed correct response times; the denotations of terms were the same as the final model for accuracy in the part-whole task.

Standard composite task: Accuracy (in the “same” trials)

The maximal model included all by-subject and by-stimulus random intercepts and random slopes:

$$\begin{aligned}&\text{isCorrect} \sim \text{Alignment} + (\text{Alignment}|\text{Subject})\\&\quad + (\text{Alignment}|\text{StimGroup})\end{aligned}$$

where “isCorrect” refers to whether the response was correct on that trial; “Alignment” refers to the independent variable Alignment (aligned vs.

misaligned); "Subject" and "StimGroup" refer to the by-subject and by-stimulus-group random effects, respectively.

The maximal model was submitted to the pre-registered steps to obtain the final model:

$$\text{isCorrect} \sim \text{Alignment} + (\text{Ali\_C}||\text{Subject}) + (\text{Ali\_C}||\text{StimGroup})$$

where "Ali_C" refers to the random slope of Alignment; the denotations of other terms were the same as the maximal model for accuracy in the standard composite task.

Standard composite task: Correct response times (in the "same" trials)

The maximal model included all by-subject and by-stimulus random intercepts and random slopes:

$$\log(\text{RT}) \sim \text{Alignment} + (\text{Alignment}|\text{Subject}) + (\text{Alignment}|\text{StimGroup})$$

where "log(RT)" refers to the log-transformed correct response time and the denotations of other terms were the same as the maximal model for accuracy in the standard composite task.

The maximal model was submitted to the pre-registered steps to obtain the final model:

$$\log(\text{RT}) \sim \text{Alignment} + (\text{Ali\_C}|\text{Subject}) + (\text{Ali\_C}|\text{StimGroup})$$

where "log(RT)" refers to the log-transformed correct response time; the denotations of other terms were the same as the final model for accuracy in the standard composite task.

Complete composite task: Sensitivity (*d′*)

The maximal model included all by-subject and by-stimulus random intercepts and random slopes:

$$\text{isSame} \sim \text{Congruency} * \text{Alignment} * \text{CorrectResponse} + \text{Cue} + (\text{Congruency} * \text{Alignment} * \text{CorrectResponse}|\text{Subject}) + (\text{Congruency} * \text{Alignment} * \text{CorrectResponse}|\text{StimGroup})$$

where "isSame" refers to whether that participant reported "same" (i.e., the signal) on that trial; "Congruency * Alignment * CorrectResponse" refers to the independent variables Congruency (congruent vs. incongruent), Alignment (aligned vs. misaligned) and CorrectResponse (same vs. different), as well as their interactions; "Cue" refers to the control variable Cue (top vs. bottom); "Subject" and "StimGroup" refer to the by-subject and by-stimulus-group random effects, respectively.

The maximal model was submitted to the pre-registered steps to obtain the final model:

$$\text{isSame} \sim \text{Congruency} * \text{Alignment} * \text{CorrectResponse} + \text{Cue} + (\text{Ali\_C} + \text{CR\_C} + \text{Con\_CR} + \text{Con\_Ali\_CR}||\text{Subject}) + (\text{Con\_C} + \text{Ali\_C} + \text{CR\_C} + \text{Con\_Ali} + \text{Con\_CR} + \text{Ali\_CR}||\text{StimGroup})$$

where "Con_C", "Ali_C", "CR_C" refers to the random slopes of Congruency, Alignment, and CorrectResponse, respectively. "Con_Ali", "Con_CR", "Con_Ali" refer to the random slopes of the corresponding two-way interactions, and "Con_Ali_CR" refers to the random slope of the three-way interaction. The denotations of other terms were the same as the maximal model for sensitivity *d′* in the complete composite task.

Complete composite task: Correct response times

The maximal model included all by-subject and by-stimulus random intercepts and random slopes:

$$\log(\text{RT}) \sim \text{Congruency} * \text{Alignment} + \text{CorrectResponse} + \text{Cue} + (\text{Congruency} * \text{Alignment}|\text{Subject}) + (\text{Congruency} * \text{Alignment}|\text{StimGroup})$$

where "log(RT)" refers to the log-transformed correct response time; "Congruency * Alignment" refers to the independent variables Congruency (congruent vs. incongruent), Alignment (aligned vs. misaligned), as well as their interactions; "CorrectResponse" and "Cue" refers to the control variable CorrectResponse (same vs. different) and Cue (top vs. bottom); "Subject" and "StimGroup" refer to the by-subject and by-stimulus-group random effects, respectively.

The maximal model was submitted to the pre-registered steps to obtain the final model:

$$\log(\text{RT}) \sim \text{Congruency} * \text{Alignment} + \text{CorrectResponse} + \text{Cue} + (\text{Con\_C} + \text{Ali\_C} + \text{Con\_Ali}||\text{Subject}) + (\text{Con\_C} + \text{Ali\_C}||\text{StimGroup})$$

where "log(RT)" refers to the log-transformed correct response time and the denotations of other terms were the same as the final model for sensitivity *d′* in the complete composite task.