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Selective Interference on the Holistic Processing of Faces in Working Memory

Olivia S. Cheung and Isabel Gauthier
Vanderbilt University

Faces and objects of expertise compete for early perceptual processes and holistic processing resources (Gauthier, Curran, Curby, & Collins, 2003). Here, we examined the nature of interference on holistic face processing in working memory by comparing how various types of loads affect selective attention to parts of face composites. In dual tasks, all loads impaired overall performance on face judgment compared with no load. However, a face load reduced holistic face processing (Experiment 1) whereas an object load did not, regardless of expertise (Experiments 2 and 3). Also, 2 types of faces produced asymmetrical interference on each other (Experiment 4), refuting the hypothesis that any faces would produce equal interference. Thus, the interference on holistic face processing in working memory does not depend on overlap in expertise or face processing, but may be modulated by limitations in encoding or maintenance of highly similar representations.

Keywords: visual working memory, face perception, holistic processing, dual-task interference

Faces are complex stimuli, yet we process all features of a face at a glance and can recognize its identity almost instantly (Jacques & Rossion, 2006a; Rousselet, Mace, & Fabre-Thorpe, 2003). Although faces can be recognized based on their parts, individual face features are better recognized within a face than in isolation (Tanaka & Farah, 1993). In addition, perception of upright faces is particularly sensitive to spatial relations among features compared with nonface objects (Tanaka & Sengco, 1997), suggesting that the processing of facial features is strongly integrative. Indeed, it is very difficult to selectively attend to part of a face (e.g., eyes) even when observers are told to ignore the other parts (e.g., the nose and the mouth), an effect that is often used as evidence for holistic processing (e.g., Cheung, Richler, Palmeri, & Gauthier, 2008; Farah, Wilson, Drain, & Tanaka, 1998; Gauthier & Tarr, 2002; Richler, Bukach, & Gauthier, 2009; Richler, Gauthier, Wenger, & Palmeri, 2008a; Wenger & Ingvalson, 2002). Because observers generally find it harder to selectively attend to face parts than to object parts, it has been argued that face perception is especially holistic (Farah et al., 1998).

On the one hand, holistic processing may facilitate the rapid perception of many properties of a face. On the other hand, there are important limitations to the capacity of face processing and holistic processing. It has been suggested that the capacity of face processing is extremely limited, so that only one face can be identified at a time (Bindemann, Burton, & Jenkins, 2005; Bindemann, Jenkins, & Burton, 2007). Concurrently presented faces compete for neural representations in occipital-temporal cortex shortly after stimulus onset, as event-related potential findings revealed that the magnitude of the N170 potential for a target face was reduced with the presence of other faces compared with its co-occurrence with scrambled faces (Jacques & Rossion, 2004, 2006b).

Direct evidence of perceptual competition for holistic processing of several faces was obtained in a divided attention paradigm (Palermo & Rhodes, 2002). In that study, holistic processing was revealed by a whole-part effect, in which recognition performance was better when the test probe showed a whole face instead of a face part. When observers had to divide attention among a target face and two upright face flankers instead of ignoring the flankers, the whole-part advantage for the target face was reduced. In contrast, divided attention to inverted face flankers or letters did not reduce holistic processing of target faces (Boutet, Gentes-Hawn, & Chaudhuri, 2002; Palermo & Rhodes, 2002), presumably because inverted face or letter perception does not engage holistic processing.

Intriguingly, nonface objects that are processed holistically because of perceptual expertise can also compete with face perception and impact holistic processing (Gauthier, Curran, Curby & Collin, 2003; McKeeff, Tong, & Gauthier, 2007; Rossion, Collins, Goffaux, & Curran, 2007; Rossion, Kung, & Tarr, 2004; Williams, McKeeff, Tong, & Gauthier, 2007). Holistic processing of cars in car experts has been demonstrated by a congruency effect in the composite task (Gauthier et al., 2003), where recognition of a part of a car is influenced by the congruency of the task-irrelevant part

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Olivia S. Cheung and Isabel Gauthier, Department of Psychology, Vanderbilt University.

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Correspondence concerning this article should be addressed to Olivia S. Cheung, Department of Psychology, 301 Wilson Hall, Vanderbilt University, Nashville, TN 37240. E-mail: olivia.cheung@vanderbilt.edu

(e.g., whether both the target and task-irrelevant car parts at test are the same as those at study, or one part is the same but the other is different). As for faces, this composite effect suggests a failure of selective attention to a part in a whole context (cf. Farah et al., 1998; Hole, 1994; Young, Hellawell, & Hay, 1987). In addition, car experts showed an inversion effect for cars while car novices did not (Curby, Glazek, & Gauthier, 2009), revealing the importance of configural information in cars for car experts. When matching faces and cars in an interleaved one-back task, car experts, but not car novices, show a reduction of holistic processing of faces, compared with when they matched faces and distorted cars concurrently in the same task (Gauthier et al., 2003). Thus, normal cars processed holistically by car experts competed with the holistic processing of faces. These results suggest a limited capacity for holistic processing shared by perception of faces and objects of expertise. This does not imply that holistic processing is more limited than nonholistic processing, or that face processing is more limited than object processing, but merely that each process appears to tap into a different pool of resources.

Either faces or objects of expertise can produce perceptual interference on holistic processing of a face (Gauthier et al., 2003; Palermo & Rhodes, 2002; Rossion et al., 2007). However, what is less clear is whether holistic processing of a face can be influenced at relatively late processing stages. It has been suggested that perceptual interference on holistic processing may be strongest when the competing stimulus is still generating ongoing activity in occipital-temporal areas during the processing of a target face (Rossion et al., 2007). Indeed, interference on holistic processing of faces is observed when competing face flankers are presented simultaneously with the target face (Palermo & Rhodes, 2002), or when faces and cars alternate relatively fast (1.5 s per stimulus or until a response) with an interstimulus interval of 0 (Gauthier et al., 2003). Other studies also suggest a temporal bottleneck for using the same perceptual processing strategy (e.g., holistic) (Awh et al., 2004; Bindemann et al., 2005, 2007; McKeeff et al., 2007; Williams et al., 2007). A very brief temporal interval (200 ms) separating the competing face and object of expertise reduces perceptual interference when the object is task-irrelevant (Rossion et al., 2007). However, it is unknown whether holistic face processing could be susceptible to interference from competing items over a longer period, if the competing items are task-relevant and require encoding into working memory. Therefore, in this study we examine whether and how holistic processing is influenced by stimuli that are encoded and maintained in working memory.

The capacity of visual working memory is severely limited so that only three to four objects can be stored at the same time (e.g., Pashler, 1988; Sperling, 1960; Vogel, Woodman, & Luck, 2001). The capacity limitation is even more severe when objects are complex and have to be discriminated from other objects of the same category (Alvarez & Cavanagh, 2004; Awh, Barton, & Vogel, 2007; Eng, Chen, & Jiang, 2005; Olsson & Poom, 2005; Wong, Peterson, & Thompson, 2008). Loading working memory can affect selective attention to objects in a scene (e.g., de Fockert, Rees, Frith, & Lavie, 2001; Kim, Kim, & Chun, 2005; Park, Kim, & Chun, 2007). In particular, Park et al. (2007) used faces and houses, two types of stimuli that engage specialized processing mechanisms in the brain (e.g., Epstein & Kanwisher, 1998; Kanwisher, McDermott, & Chun, 1997), to show dissociable effects of working memory load on selective attention. They found that when matching two target faces placed in the context of two houses, a face working memory load increases interference from house distractors. In contrast, a house working memory load facilitates selective attention to faces in the same context and reduces house distractor processing. Robinson, Manzi, and Triesch (2008) also showed that perceptual judgment of a target is delayed by a visually similar working memory load. For instance, working memory maintenance of a face but not a body selectively slowed perceptual judgments about a target face, whereas maintenance of a body but not a face in working memory selectively slowed perceptual judgments for a target body. While working memory loads influence selective attention and the time course of perceptual judgments, it is unclear how they affect the processing style of the information, such as the extent to which the target faces are processed holistically.

If interference on holistic processing can occur in working memory, there are at least four possible hypotheses regarding the factors that determine which type of stimuli will and will not interfere with the holistic processing of a face. First, interference may occur according to category boundaries. If information from different categories was segregated in working memory, a face working memory load would interfere with the holistic processing of a face, whereas any other object load would not.

Second, interference may occur whenever a sufficient amount of information is encoded in working memory, regardless of stimulus category. Accordingly, in prior work faces or objects of expertise may have interfered with holistic processing only because they were encoded in more detail than noncompeting control stimuli, such as inverted faces or objects in a broken configuration (Curby & Gauthier, 2007; Curby et al., 2009; Gauthier et al., 2003; Palermo & Rhodes, 2002).

Third, interference could be determined by the holistic strategy used to encode the objects. This account suggests that faces and objects of expertise compete with the holistic processing of a face because they are encoded using the same processing strategy. In essence, the bottleneck that has been observed in perceptual encoding (Awh et al., 2004; Gauthier et al., 2003; Rossion et al., 2007, 2004) could also govern how stimuli compete after they are encoded in working memory.

Fourth, the amount of interference may depend on the similarity of the competing objects. Working memory capacity for complex objects is very limited for similar items from the same category (Alvarez & Cavanagh, 2004; Awh et al., 2007; Scolari, Vogel, & Awh, 2008; Wong et al., 2008), and items encoded in working memory may compete for the perceptual processing of other items to the extent that they are visually similar with them (e.g., Robinson et al., 2008). Therefore, although it is possible that competition on holistic processing of faces may occur whenever other faces are stored in working memory simply because all faces engage holistic processing, or because they engage a face module, it is possible that the critical factor influencing holistic processing is the similarity of the items in working memory to those being currently processed. If so, then it should be possible to influence the degree of competition by varying the similarity of the perceived faces with those in working memory.

Four experiments were conducted to distinguish among these possibilities. Experiment 1 investigated the effect of a face working memory load on the holistic processing of a face compared with no load, confirming that interference can be obtained in working memory. Experiment 2 tested whether a demanding working memory load of objects is sufficient to produce interference, when the objects are not processed holistically. Experiment 3 manipulated working memory load with cars in participants with a range of expertise with cars, to test whether an object load can interfere when objects are processed holistically. Finally, Experiment 4 considered whether all faces would produce the same effect by comparing two types of face working memory loads.

All four experiments used a composite task to measure holistic processing (Young et al., 1987) by means of a congruency effect (Cheung et al., 2008; Farah et al., 1998; Gauthier, Klaiman, & Schultz, 2009; Gauthier et al., 2003; Richler et al., 2009; Richler et al., 2008a; Richler, Tanaka, Brown, & Gauthier, 2008b; for a review, see Gauthier & Bukach, 2007). Each of the face composites were made by combining top and bottom halves from two individuals. Participants were instructed to attend to only the *top* part of a study face composite and to judge whether it was identical to the *top* part of a test face composite in a sequential matching paradigm. Because the correct responses for the top and bottom parts were manipulated independently and thus the relations between the top and bottom parts could be congruent or incongruent, a congruency effect (better performance for congruent than incongruent trials) would reflect a failure of selective attention to face parts, indicative of holistic processing.

To examine the effect of working memory load on holistic processing, the composite task was combined with a working memory task. A 3-item array was presented either before a study or test face in the composite task, which was followed by a test probe of the working memory task (see Figure 1 and Method section). Previous work found that dividing attention to stimuli presented around the study face in a composite task did not affect holistic processing (Boutet et al., 2002). Other work suggests that manipulations such as misalignment of the face parts are much more effective when performed on the test face than on the study face (Richler et al., 2008b). Because it is unclear whether competition for holistic face processing in working memory would be governed by the same principles as perceptual and attentional manipulations, we examined the effect of different types of working memory load separately on both study and test faces in Experiments 1 to 3.

In addition to measuring the impact of different types of working memory loads on holistic processing (via the impact on the congruency effect), we also measure the effect of these loads on matching the task-relevant face parts when they are presented in isolation at test. Because no task-irrelevant information is present in this case, this condition provides a useful baseline for the effect of a load on part processing. In addition, the isolated-part trials are also helpful in revealing whether congruency effects are because of facilitation from congruent trials and/or interference from task-irrelevant parts in incongruent trials. It is both theoretically and empirically important to emphasize the effect of interference from task-irrelevant parts. Specifically, facilitation in congruent trials in

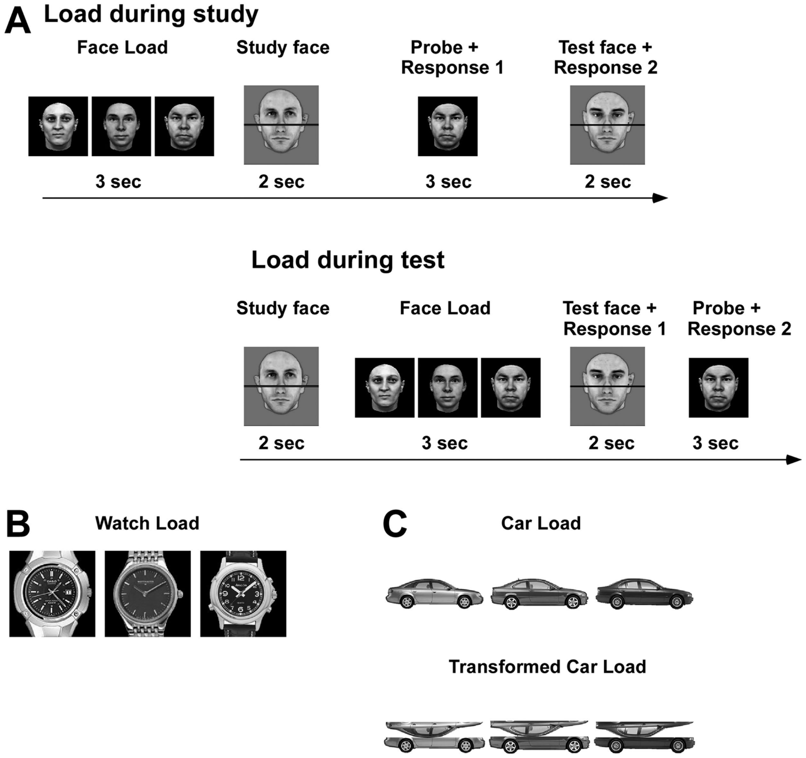

Figure 1. Schematic illustration of the experiment procedure and stimuli in Experiments 1 to 3. Figure 1A shows the sample face load trials in Experiment 1. Figure 1B shows the sample watches used in Experiment 2. Figure 1C shows the sample car stimuli used in Experiment 3. In Experiments 1 to 3, a load was presented either before a study face composite (load during study) or before a test composite (load during test).

selective attention paradigms (e.g., Stroop task) is thought to be difficult to interpret, because it is impossible to distinguish whether the task-relevant or task-irrelevant information gives rise to the response in a given congruent trial (MacLeod, 1991; MacLeod & MacDonald, 2000). Moreover, with an isolated-part baseline, the congruency effect in the composite task reliably reflects interference in incongruent trials, whereas facilitation in congruent trials is less consistent (Richler et al., 2009, 2008b). Therefore, we predict that the reduction of holistic face processing from the working memory loads should be revealed by the elimination of interference from incongruent trials relative to the isolated-part baseline, in addition to a reduction in the congruency effect compared with a no load condition. To anticipate the results, we expect a general working memory load effect on the face composite task compared with a no load condition (Experiments 1 to 3), such that any type of load would impair overall performance in matching parts of the face composites. However, the effect of working memory load on holistic face processing is expected to be more selective.

Experiment 1

Experiment 1 examined whether a face working memory load reduced the congruency effect in the composite task, compared with a no load condition. The face load was either presented before a study face composite (load during study) or in between study and test face composites (load during test).

Method

Participants. Thirty volunteers (23 women, mean age = 19.3 years, *SD* = 2.4) at Vanderbilt University with normal or corrected-to-normal vision participated for course credit or payment.

Stimuli. One hundred ninety-eight male and female frontal-view faces were obtained from the Max-Planck face database (Troje & Bülthoff, 1996). All images were then saved in grayscale. The composites were made from top and bottom parts of 24 male faces (top halves taken from 12 faces and bottom halves taken from the remaining 12 faces). The pairing of top and bottom parts was randomized. Each composite was approximately 180 (w) × 230 (h) pixels in size (4.2° × 5.7°) and was placed on a gray background (245 × 260 pixels in size, 5.8° × 6.7°). The stimuli for the working memory task included the remaining 174 faces (120 × 160 pixels in size, 2.9° × 3.8°). Each of these images was saved in grayscale and was placed on a black background to prevent confusion between the stimuli relevant for the two tasks (180 × 180 pixels in size; 4.3° × 4.3°). Scrambled images for the no load condition were created by dividing these stimuli into 30 × 30 blocks and randomly shuffling these blocks. A pattern mask (600 × 400 pixels in size, 15.2° × 10°) created with the "tiny lens" glass filter in Adobe Photoshop was also used.

Procedure and design. The experiment was conducted on Macintosh computers running OS 9 Matlab. In a dual-task paradigm, the working memory task required participants to remember 3 items and match whether a test probe was one of those items; the composite task required participants to match the top parts of the study and test face composites. As illustrated in Figure 1, the 3 study items for the working memory task were presented either before a study face composite (load during study) or a test face composite (load during test). At the beginning of each trial, a fixation was presented for 500 ms. The presentation times were 2 s for each composite and 3 s for each working memory array/probe to ensure sufficient amount of information was encoded for these complex stimuli (Curby & Gauthier, 2007; Curby et al., 2009; Eng et al., 2005). A pattern mask flashed for 400 ms in between each stimulus display. A response cue was presented on top of each test display. Participants indicated their responses by key press. Response times were measured from the onset of each test display and a trial timed out when the test display was removed from the screen. The response keys were the same for the two tasks: "s" for "same"/"match" and "d" for "different"/"non-match." In the no load condition for both presentation orders (during study vs. test), scrambled images were presented in the 3-item array, and a response was not required. Crucially, participants were explicitly instructed to emphasize accuracy in the working memory task (except for the no load condition). They were also told to attend to the top parts of the face composites while ignoring the bottom parts. In some trials, only the top parts of the face composites were presented. There were a total of 288 trials, with 16 trials in each combination of Locus (no load vs. load during study vs. load during test), Congruency of composites (congruent vs. incongruent vs. isolated part), and Response (same vs. different). The presentation order for Locus was blocked for each participant and was counterbalanced across participants. The presentation order for the other factors was randomized. Eighteen practice trials (6 from each locus condition) were given prior to testing. No feedback was given. The study lasted approximately 75 min.

Analyses. To measure the effects of the working memory loads on the composite task, we analyzed only the data with relatively good performance (≥60%) in the working memory task. Data from participants who failed to respond in over 10% of the trials in either or both the working memory task and the composite task were also excluded. Based on these criteria, data from two participants were removed from analyses. The timed out trials in the remaining data were also excluded from analyses (1.6% in the working memory task, 4% in the composite task).

Sensitivity (d′) was analyzed as the main measure in the composite task [zHit – zFA]. It is important to use a measure that is independent of response bias because differential response biases have been found in the composite task across various manipulations, such as alignment, congruency and spatial frequency filtering (Cheung et al., 2008; Farah et al., 1998; Gauthier et al., 2003; Richler et al., 2008a; Wenger & Ingvalson, 2002). Response times (RT) for correct trials were also analyzed, and the results were generally consistent with the d′ results. The RT results in all experiments are reported in Table 1.

Results

The main focus of our analyses was on the congruency effect in the composite task. The results of the congruency effects (d′) are illustrated in Figure 2, showing the performance on congruent, incongruent and isolated target part trials across the Locus conditions. Two-way analyses of variance (ANOVAs) with within-subjects factors of Locus (no load vs. load during study vs. load during test) and Congruency (congruent vs. incongruent) were conducted on d′ and RT for correct trials in the composite task.

Table 1
Mean Response Times (in ms) in All Conditions

Condition	Congruent	Incongruent	Isolated part
Experiment 1			
No load (study and test)	932.2 (32.7)	988.3 (31.1)	954.7 (30.7)
Face load during study	950.3 (35.2)	997.2 (32.3)	976.4 (35.2)
Face load during test	1,077.3 (31.2)	1,083.6 (33.7)	1,056.1 (33.5)
Experiment 2			
No load (study and test)	908.2 (33.7)	973.4 (36.7)	949.0 (35.3)
Watch load during study	877.1 (30.4)	933.6 (30.3)	954.7 (30.7)
Watch load during test	1,016.6 (31.1)	1,055.0 (29.5)	1,057.0 (31.9)
Experiment 3			
No load during study	851.2 (29.9)	913.8 (31.6)	
Car load during study	873.5 (25.9)	919.4 (26.5)	
Transformed car load during study	854.9 (27.9)	928.3 (28.2)	
No load during test	915.4 (31.7)	985.5 (32.1)	
Car load during test	961.3 (30.8)	1,010.0 (28.6)	
Transformed car load during test	963.1 (30.4)	1,005.3 (29.5)	
Experiment 4			
Adult load on child composite	1,067.4 (20.6)	1,104.9 (25.5)	1,069.6 (20.6)
Child load on child composite	1,093.6 (22.8)	1,091.3 (21.4)	1,096.3 (22.8)
Adult load on adult composite	1,020.8 (25.5)	1,057.0 (28.7)	1,038.4 (24.6)
Child load on adult composite	1,050.5 (24.6)	1,076.4 (26.8)	1,056.1 (24.9)

Note. *SEs* are in parentheses.

There was a main effect of Locus in d′, $F(2, 54) = 24.68$, $p < .0001$, $\tilde{\eta}_p^2 = .48$), with better performance in no load than the two face load conditions ($ps < .0001$). The main effect of Locus was also significant in RT, $F(2, 54) = 19.84$, $p < .0001$, $\tilde{\eta}_p^2 = .42$), with longer RT for face load during test compared with no load and load during study ($ps < .0001$). The main effect of Congruency was significant in both d′ and RT, d′: $F(1, 27) = 24.70$, $p < .0001$, $\tilde{\eta}_p^2 = .48$; RT: $F(1, 27) = 10.48$, $p < .005$, $\tilde{\eta}_p^2 = .28$, revealing better and faster performance for congruent than incongruent trials. Critically, the interaction between Locus and Congruency was significant in both d′ and RT (d′: $F(2, 54) = 4.41$, $p < .02$, $\tilde{\eta}_p^2 = .14$; RT: $F(2, 54) = 3.81$, $p < .03$, $\tilde{\eta}_p^2 = .12$). Planned comparisons showed that the magnitude of the congruency effect was reduced in the two face load conditions compared with no load in d′ ($ps < .05$), and the congruency effect was smaller with load during test than load during study and no load in RT ($ps < .05$).

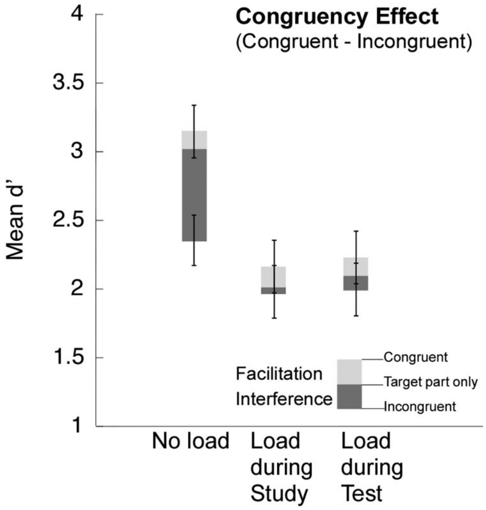

Figure 2. Mean sensitivity (d′) in Experiment 1 as a function of Locus and Congruency. The dark gray area represents the interference from incongruent trials and the light gray area represents the facilitation from congruent trials. Error bars show the 95% confidence intervals of the interaction of Locus and Congruency.

One-way ANOVAs with the factor of Locus was also conducted on d′ and RT for the isolated-part trials in the composite task. It showed impaired sensitivity with the face loads compared with no load, $F(2, 54) = 21.77$, $p < .0001$, $\tilde{\eta}_p^2 = .45$. A significant effect in RT, $F(2, 54) = 11.78$, $p < .0001$, $\tilde{\eta}_p^2 = .30$ showed longer RT with face load during test than no load and face load during study ($ps < .001$). Paired *t*-tests ($\alpha = .05$) conducted on d′ for the isolated-part baseline versus the congruent/incongruent trials revealed significant interference ($p < .0001$) but no facilitation ($p > .30$) in the no load condition. There was no interference or facilitation in either face load conditions ($ps > .31$).

For the working memory task, the mean accuracy was 71.9% and the mean RT was 1,127 ms for the load during study and 73.3% and 1,081 ms for load during test. One-way ANOVAs conducted on d′ and RT showed no statistical difference between load during study and load during test, accuracy: $F(1, 27) = .793$, $p = .38$; RT: $F(1, 27) = 2.52$, $p = .12$.

Discussion

Experiment 1 showed that faces maintained in working memory impaired overall performance in the composite task compared with no load, and more importantly, reduced holistic processing of other faces. Although task-irrelevant items do not compete with face processing after a 200-ms interval (Rossion et al., 2007), competing items that are task-relevant and maintained in working memory do reduce holistic face processing. Also, a face load imposed on either a study or test face resulted in a significant reduction of holistic processing of target faces, with a slightly larger reduction of the congruency effect with a load imposed on a test face. We suggest that the face loads impair maintenance of a study face, and a face load presented before a study or test face may also impair its encoding. The fact that the congruency effect is reduced to a greater extent for the load during test (in RT) provides some support for the important role of the processes taking place during the comparison and decision on the second face in the composite task (Richler et al., 2008b). More importantly, face working memory loads during both study and test increase the ability of participants to ignore the task-irrelevant parts of the composite faces. Interference from the task-irrelevant composite part was eliminated in the face load conditions, a result consistent with the fact that the congruency effect typically reflects interference in incongruent trials rather than facilitation in congruent trials (Richler et al., 2008b).

An obvious question is whether the working memory load needs to consist of faces to reduce the holistic processing in the concurrent composite task. It is possible that to interfere with holistic processing, a certain amount of information needs to be maintained in working memory, or that the information needs to be represented with sufficient resolution (Alvarez & Cavanagh, 2004). The working memory capacity for complex objects from a homogenous category is very limited (Olsson & Poom, 2005) and may reach a limit at about 3 items, given sufficient encoding time (Curby & Gauthier, 2007; Curby et al., 2009; Eng et al., 2005). The goal of Experiment 2 was to examine the effect of a demanding working memory load of three objects on holistic face processing. Watches were used in this experiment because they are complex objects from a homogeneous nonface category.

Experiment 2

Method

Participants. Thirty volunteers (14 women, mean age = 20.3 years, *SD* = 2.9) at Vanderbilt University with normal or corrected-to-normal vision participated for course credit or payment.

Stimuli, procedure, and design. The procedure, design, and stimuli were identical to those in Experiment 1 except that the face stimuli for the working memory task were replaced by 174 watch images (120 × 180 pixels in size, 2.9° × 4.3°). The images were saved in grayscale and placed on a black background (180 × 180 pixels in size; 4.3° × 4.3°). Scrambled images for the no load condition were also created by dividing these stimuli into 30 × 30 blocks and randomly shuffling these blocks.

Analyses. Data from three participants were removed according to the criteria defined in Experiment 1. The timed-out trials were also discarded for analyses in each task (0.8% in the working memory task, 3.8% in the composite task).

Results

The results of the congruency effects (d′) in the composite task are illustrated in Figure 3, showing the performance on congruent, incongruent and isolated target part trials across the locus conditions. Two-way ANOVAs with within-subjects factors Locus (no load vs. load during study vs. load during test) and Congruency (congruent vs. incongruent) conducted on d′ and RT in correct trials for the composite task showed a main effect of Locus on d′, $F(2, 52) = 13.97$, $p < .0001$, $\tilde{\eta}_p^2 = .35$, with better performance in the no load than the two watch load conditions ($ps < .005$). The main effect of Locus was also significant in RT, $F(2, 52) = 19.48$, $p < .0001$, $\tilde{\eta}_p^2 = .43$, where RT was longer with watch load during test than no load and load during study ($ps < .0005$). The main effect of Congruency was significant in both d′ and RT, d′: $F(1, 27) = 49.26$, $p < .0001$, $\tilde{\eta}_p^2 = .65$; RT: $F(1, 26) = 33.77$, $p < .0001$, $\tilde{\eta}_p^2 = .56$, revealing better and faster performance for congruent than incongruent trials. Critically, the interaction between Locus and Congruency was not significant in neither d′ or RT, d′: $F(2, 52) = .76$, $p = .47$; RT: $F(2, 52) = .92$, $p = .41$, with significant congruency effects in all conditions.

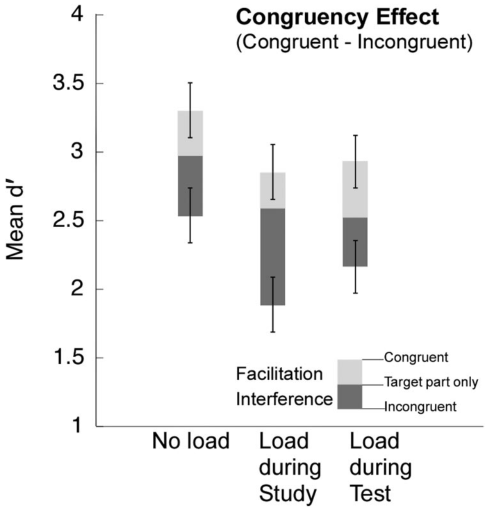

Figure 3. Mean sensitivity (d′) in Experiment 2 as a function of Locus and Congruency. The dark gray area represents the interference from incongruent trials and the light gray area represents the facilitation from congruent trials. Error bars show the 95% confidence intervals of the interaction of Locus and Congruency.

Similar to analyses on the congruency effect, one-way ANOVAs with the factor Locus conducted on the isolated-part trials for d′ and RT in the composite task showed impaired sensitivity with the watch loads compared with no load, $F(2, 52) = 4.28$, $p = .02$, $\tilde{\eta}_p^2 = .14$. A significant effect in RT, $F(2, 52) = 16.99$, $p < .0001$, $\tilde{\eta}_p^2 = .40$ showed longer RT with watch load during test than no load and watch load during study ($ps < .001$). Paired *t*-tests ($\alpha = .05$) conducted on d′ for the isolated-part baseline versus the congruent/incongruent trials revealed significant facilitation and interference in all conditions ($ps < .05$).

For the working memory task, the mean accuracy was 75.8% and the mean RT was 1,141 ms for load during study and 74.6% and 1,052 ms for load during test. One-way within-subjects ANOVA with the factor of Locus conducted on accuracy, and RT showed no statistical difference between load during study and load during test in accuracy, $F(1, 26) = .85$, $p = .37$, but RT was longer for load during study than load during test, $F(1, 26) = 12.26$, $p < .002$, $\tilde{\eta}_p^2 = .32$.

Could a difference in the difficulty of working memory tasks between Experiments 1 and 2 be responsible for the fact that face loads, but not watch loads, interfered with holistic processing? Two-way ANOVAs with a between-subjects factor Load Category (faces vs. watches) and a within-subjects factor Locus were conducted on accuracy and RT across the two Experiments. The main effect of Locus was significant in RT, $F(1, 53) = 12.16$, $p = .001$, $\tilde{\eta}_p^2 = .19$ but not in accuracy, $F(1, 53) = .01$, $p = .92$, with longer RT for load during study compared with load during test. However, there was no significant effect of Load Category, accuracy: $F(1, 53) = 3.07$, $p = .085$; RT: $F(1, 53) = .028$, $p = .87$, or interaction between Load Category and Locus, accuracy: $F(1, 53) = 1.61$, $p = .21$; RT: $F(1, 53) = 1.21$, $p = .28$.

Discussion

The watch working memory load imposed during either the processing of a study or test composite face impaired overall performance in the composite task compared with no load, including performance on isolated-part trials. However, unlike a face load, it did not reduce the magnitude of the congruency effect. In fact, in all conditions, interference from incongruent trials and facilitation from congruent trials compared with the isolated-part baseline were found.

Because of the comparable performance in the face and watch working memory tasks, the effect of the face load is unlikely explained by a difference in the amount or quality of information encoded in working memory. Object and face loads affected performance on the composite task, but in very different ways. An object load did not affect the magnitude of the face congruency effect but still produced a general degradation of performance in the composite task, observed in all trials including on the processing of isolated parts. These are expected costs attributable to dual-task situation, compared with the single-task measure of composite task without a working memory load. Accordingly, overall impairment in the composite task was also observed as a result of the face working memory loads, but in addition, face loads reduced the congruency effect. This was the result of face loads disproportionally affecting the processing of the irrelevant face part, relative to the task-relevant face part.

However, it remains unclear exactly what determines the bottleneck in working memory that results in a reduction of holistic face processing from a face load. In perceptual paradigms investigating competition between faces and objects of expertise (Gauthier et al., 2003; Rossion et al., 2007, 2004), objects of expertise such as cars or novel objects (greebles) interfered with face processing, suggesting that visual similarity or category membership are not critical, while overlap in holistic encoding may have been determinant to produce perceptual interference. Therefore, we next consider the possibility that objects that are encoded holistically because of expertise might interfere with holistic processing of faces in working memory.

In Experiment 3, modeled after a prior study of perceptual competition (Gauthier et al., 2003), we used working memory loads of cars or transformed cars (cars with inverted top parts), as well as a no load baseline. If there is competition between face and expert object processing in working memory, we would expect that for car experts, a load of cars should reduce holistic processing of faces, relative to no load. A car load should also reduce holistic face processing compared with a transformed car load, because car experts do not process transformed cars holistically (Gauthier et al., 2003). By contrast, for car novices, a car load should not affect holistic face processing differently than no load and than a transformed car load. We again placed the working memory load either during the study or test face composites, although based on the results of Experiments 1 and 2, we expected the two loci to have very similar effects.

Following prior work, we measured car expertise in a separate sequential matching task with cars and birds and calculated a car expertise index by taking the difference between d′ of car trials and d′ of bird trials for each participant (Curby et al., 2009; Gauthier et al., 2003, Gauthier, Skudlarski, Gore, & Anderson, 2000; Gauthier, Curby, Skudlarski, & Epstein, 2005; Grill-Spector, Knouf, & Kanwisher, 2004; Rossion et al., 2007, 2004; Xu, 2005). To reveal interference on holistic processing, we calculated face interference indices (Δd′) by subtracting the magnitude of the congruency effect for faces in the context of a car load from the magnitude of the congruency effect in a baseline condition. This was done relative to two different baselines (no load or the transformed car load) with the loads imposed either over the study face or over the test face of the composite task. To test whether interference on holistic processing depends on car expertise, we calculated the correlation between each of these four face interference indices (2 baselines × 2 loci) with the car expertise index. A positive correlation would reveal that a working memory load of cars can affect the holistic processing of faces, as a function of perceptual expertise with cars.

Experiment 3

Method

Participants. Forty-eight volunteers (15 women, mean age = 20.75, *SD* = 4.23) at Vanderbilt University with normal or corrected-to-normal vision participated for payment. Most car experts were recruited through advertisement or invitation.

Stimuli. Eighty side views of car images were obtained from the Web site www.tirerack.com, including two versions of 40 different car models common in North America. All versions were manufactured between the years 1996 to 2006. The images were saved in grayscale and were used in the normal car load condition. The images were approximately 220 × 90 pixels in size (5.2° × 1.5°). For the transformed car load condition, the top halves of the car images were inverted using Adobe Photoshop. For the scrambled images used in the no load condition, the original car images were divided into 20 × 20 blocks and the blocks were randomly shuffled. The composite faces were identical to those used in previous experiments.

Procedure and design. The dual-task procedure was identical to previous experiments except that this experiment was divided into two sessions according to the Locus of loads (load during study vs. load during test). The session order of Locus was counterbalanced across participants. Each participant completed a total of 288 trials in each session, with 24 trials in each combination of Load Category (no load vs. car load vs. transformed car load), Congruency (congruent vs. incongruent), and response (same vs. different). The Load Category conditions were blocked and counterbalanced across participants, while the trials for the other factors were randomized. Eighteen practice trials were given at the beginning of each session and were not analyzed. Each session lasted approximately 75 min.

While a "same" probe in the working memory task was always one of the three studied items, a "different" probe was always a different version of one of the studied cars. This was done to minimize the possibility that car experts would rely on naming the car models to perform the task. All participants were informed about this constraint before the beginning of the study. They were also asked to repeat the word "the" out loud continuously during the experiment to prevent verbal rehearsal.

After the completion of the second session, participants were tested for their perceptual expertise with cars in a sequential matching task (Curby et al., 2009; Gauthier et al., 2003, 2000; Rossion et al., 2007; McGugin & Gauthier, in press; Xu, 2005). Participants judged whether a pair of study and test images showed the same make and model of cars regardless of orientations or manufactory years. As a baseline for motivation and general visual discrimination skills, participants also judged whether pairs of birds were from the same species regardless of orientations. The difference in performance for cars and birds was compared for each individual participant to yield a quantitative measure of car expertise.

Analyses. Data from eight participants were removed according to the criteria described in Experiment 1. The timed-out trials were also discarded for analyses in each task (1% in the working memory task, 4% in the composite task).

Results

There was a wide range of car expertise level in our sample. Nineteen of the 40 participants who obtained a d′ of 2 or higher in the car task can be considered car experts, based on prior work (e.g., Curby et al., 2009; Gauthier et al., 2003, 2000; Grill-Spector et al., 2004; Rossion et al., 2007; Xu, 2005). All the car experts showed much better performance for cars than birds (mean car d′ = 2.56, $SD = .48$ vs. mean bird d′ = .87, $SD = .25$), with a Δd′ (car d′ minus bird d′) of at least 1.08 (mean Δd′ = 1.69, $SD = .47$). The remaining participants were classified as car novices (mean car d′ = .94, $SD = 1.03$ vs. mean bird d′ = .74, $SD = .75$, mean Δd′ = .20, $SD = .28$). However, because expertise is a continuous variable, correlational analyses provide stronger statistical power than dichotomous comparisons of novices and experts. As in previous studies (e.g., Gauthier et al., 2003; Grill-Spector et al., 2004; Rossion et al., 2007; Xu, 2005), a car expertise index (Δd′) was calculated by subtracting the bird d′ from the car d′ for each participant (Δd′ range for all participants = −.73 to 2.56, $M = .93$, $SD = .93$) for correlation analyses with the face interference indices.

As illustrated in Figure 4A and 4B, the car expertise index showed no significant correlations with any of the four Face Interference Indices (no load minus car load during study, $r = .01$, $p = .95$; no load minus car load during test, $r = -.05$, $p = .75$; transformed car load minus car load during study, $r = .22$, $p = .17$, and transformed car load minus car load during test, $r = -.28$, $p = .08$).

Because of the absence of an expertise effect, we also report the within-subjects effects in the composite task collapsed over all participants. The results of the congruency effects (d′) are illustrated in Figure 4C, showing the performance on congruent and incongruent trials across the load conditions for the two loci. Three-way ANOVAs with within-subjects factors Locus (load during study vs. load during test), Load Category (no load vs. car load vs. transformed car load), and Congruency (congruent vs. incongruent) conducted on d′ and RT in correct trials for the composite task showed a main effect of Locus in RT, $F(1, 39) = 33.38$, $p < .0001$, $\tilde{\eta}_p^2 = .46$, but not in d′, $F(1, 39) = .045$, $p = .83$, with longer RT for load during test than load during study. The main effect of Load Category was significant in both d′ and RT, d′: $F(2, 78) = 112.17$, $p < .0001$, $\tilde{\eta}_p^2 = .74$; RT: $F(2, 78) = 3.20$, $p < .05$, $\tilde{\eta}_p^2 = .076$, with better and faster performance with no load compared with performance with either car load. The main effect of Congruency was significant in both d′ and RT, d′: $F(1, 39) = 101.69$, $p < .0001$, $\tilde{\eta}_p^2 = .72$; RT: $F(1, 39) = 86.40$, $p < .0001$, $\tilde{\eta}_p^2 = .69$), revealing better and faster performance on congruent than incongruent trials. The interaction between Load Category and Congruency was significant in d′, $F(2, 78) = 4.06$, $p = .02$, $\tilde{\eta}_p^2 = .094$, but not in RT, $F(2, 78) = 1.61$, $p = .21$, with a larger congruency effect with the transformed car load than no load ($p < .01$). It is important to note that there was no significant difference in the magnitude of the congruency effect with car load vs. no load ($p = .15$) or with car load vs. transformed car load ($p = .17$).

For the working memory task, the mean accuracy was 68.4% and the mean RT was 1,156 ms for car load during study, 69.3% and 1,169 ms for car load during test, 66.3% and 1,203 ms for transformed car load during study and 66.3% and 1,220 ms for transformed car load during test. Two-way ANOVAs conducted on d′, and RT showed a significant effect of Load Category, accuracy: $F(1, 39) = 10.60$, $p < .003$, $\tilde{\eta}_p^2 = .21$; RT: $F(1, 39) = 10.51$, $p < .003$, $\tilde{\eta}_p^2 = .21$, with better and faster performance for the car task than the transformed car task. There was no statistical difference between load during study and load during test, accuracy: $F(1, 39) = .22$, $p = .64$; RT: $F(1, 39) = .50$, $p = .48$, or interaction between Locus and Load Category, accuracy: $F(1, 39) = .39$, $p = .53$; RT: $F(1, 39) = .04$, $p = .84$.

Discussion

Experiment 3 showed no evidence that working memory maintenance of objects of expertise has any differential impact on holistic face processing compared with other object loads, although the two car loads imposed during the processing of a study or test face composite impaired overall performance in the composite task, compared with no load. This suggests that the overlap of holistic processing strategy between faces and objects of expertise is not the source of interference on holistic face processing in working memory. This conclusion, although based on a null effect of expertise, is bolstered by the fact that cars have been found to interfere with the holistic processing of faces in the same composite task, as a function of car expertise defined with the same measure as used here, when the task allows for perceptual competition (Gauthier et al., 2003). This finding therefore provides more direct evidence for the conjecture by both Gauthier et al. (2003) and Rossion et al. (2007) that competition between faces and objects of expertise for holistic processing resources does not occur in working memory but rather has a perceptual locus.

These results refute the hypothesis that objects of expertise processed holistically can reduce holistic processing of faces in working memory. Holistic processing may influence the manner in

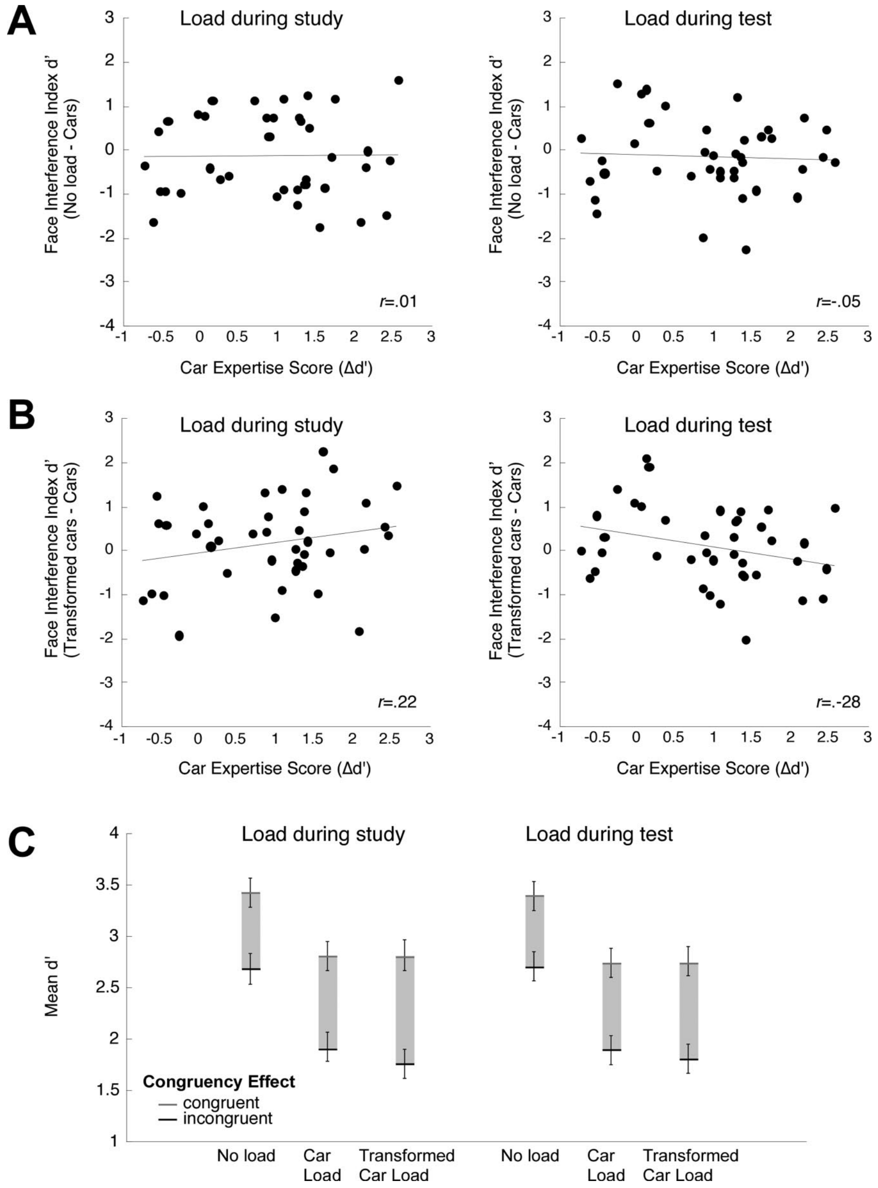

Figure 4. Correlation measures between the behavioral index of car expertise and the face interference indices with the face congruency effect (d′) of car load subtracted from the face congruency effect of no load during study and test (Figure 4A) and the face interference indices with the face congruency effect (d′) of car load subtracted from the face congruency effect of transformed car load (Figure 4B). Figure 4C shows the mean sensitivity (d′) of all participants in Experiment 3 as a function of Locus, Load Category and Congruency. Error bars show the 95% confidence intervals of the interaction of Locus, Load Category, and Congruency.

which an object of expertise is stored in working memory and even provide an advantage in working memory capacity because these items, like faces, are more efficiently encoded (Curby & Gauthier, 2007; Curby et al., 2009). But once a holistically encoded object of expertise is in working memory, we find little evidence that it interferes with face processing more than any other object does. Representations in working memory can compete, thereby reducing holistic processing, but this competition does not occur on the basis of holistic processing strategy.

Interestingly, Experiment 3 showed that nonface objects stored in working memory could influence holistic face processing in an opposite way from a face load, if the objects were in a distorted configuration. This unexpected finding may reflect the fact that the distorted objects impose a larger cognitive demand in working memory than normal objects or faces, because of their unusual form, or simply to the fact that the gestalt of whole objects is broken to result in more parts. For instance, participants might have to attempt different strategies to remember the distorted items. Indeed, our results showed that matching transformed cars was more difficult than matching normal cars. The additional cognitive demand could explain the increase in holistic face processing, because complex cognitive processes that result in or require higher prefrontal activity have been found to impair the ability to ignore task-irrelevant information (de Fockert et al., 2001; Lavie, 2005; Lavie, Hirst, de Fockert & Viding, 2004). Crucially, this effect appears to be qualitatively different from the effect of a face load, which selectively reduces holistic processing of a face, presumably because of competition in visual processing between the target and load faces (Park et al., 2007; Robinson et al., 2008). Later studies could test the hypothesis that a working memory load of distorted objects would reduce selective attention in a noncategory selective manner, i.e., for objects just as for faces. This prediction is supported by the recent report that the encoding of distorted objects can result in failures of selective attention that are similar to holistic processing in some ways, although such effects are not sensitive to stimulus configuration (Richler et al, 2009).

In an attempt to account for the results from our first three experiments, it is important to note that several researchers have suggested a "special" status for face processing (e.g., Kanwisher, 2000; McKone, Kanwisher, & Duchaine, 2007), and it may be that only faces can produce interference on holistic processing in working memory. The interference may be attributable to a particularly severe limitation in the encoding or matching of stimuli that are all categorized as "faces" because they share the same first-order configuration of parts and therefore would be predicted to engage a domain-specific system for face processing. Alternatively, the limitation may be because of similarity rather than category membership, because better resolution of representations is necessary to retain the ability to distinguish each object when they are highly similar to each other (Alvarez & Cavanagh, 2004; Awh et al., 2007; Scolari et al., 2008).

To examine whether interference on holistic face processing is influenced by the similarity of the stimuli, in Experiment 4 we use two visually distinct categories of faces that are both processed holistically. Faces from different age groups are visually dissimilar, but adult participants process both adult (Tanaka & Farah, 1993; Young et al., 1987) and young children faces holistically (de Heering, Houthuys, & Rossion, 2007; Kuefner, Macchi Cassia, Picozzi, & Bricolo, 2008; Pellicano & Rhodes, 2003; but see Anastasi & Rhodes, 2005). If the face-selective interference on holistic processing of faces in working memory depends on categorization of stimuli as faces, or if a only a coarse degree of visual similarity is necessary for interference, we would not expect a difference between holding adult vs. child faces in working memory. Alternatively, if the impact of a face load on a target face is sensitive to the differences between adult and child faces (we are simply assuming on average a greater degree of similarity between faces of the same age group than between age groups), we would expect more interference on holistic processing when the faces in the composite task and working memory load are from the same age group than from different age groups.

Experiment 4

Method

Participants. Eighty volunteers (49 women, mean age = 19.63 years, $SD = 1.81$) at Vanderbilt University with normal or corrected-to-normal vision participated for course credit or payment. They were randomly assigned to either the child composite group ($n = 40$) or the adult composite group ($n = 40$).

Stimuli. Seventy-two frontal views of Caucasian child faces (approximately 1–24 months of age) obtained from the Internet were standardized in upright orientation. The child faces showed either neutral or happy expressions. The stimuli for the working memory tasks included 48 child faces and 48 adult faces randomly selected from the larger set used in the working memory task in Experiment 1. The remaining 24 child faces were used to form composites (12 top parts and 12 bottom parts) and the adult composites used were identical to those in Experiments 1–3. Because of the relatively low resolution of the child face images, all composites were resized to approximately 140 × 70 pixels (3° × 3.8°), and the stimuli for the working memory tasks were rescaled to 120 × 90 pixels in size (2.3° × 2.9°).

Procedure and design. Because we found qualitatively similar effects for face loads during the processing of study and test face composites in Experiment 1, only larger when the face loads were held during test, Experiment 4 only required participants to encode working memory loads during test. Depending on the group assigned, a participant matched the top parts of either child or adult face composites. Each participant completed a total of 192 trials, with 16 trials in each combination of Load Category (adult vs. child face load), Congruency (congruent vs. incongruent vs. isolated part), and Response (same vs. different). The presentation order for Load Category was blocked and counterbalanced across participants, whereas the trials for the other factors were randomized. Eighteen practice trials were given prior to testing and were not analyzed. The experiment lasted approximately 50 min.

Analyses. Data from 5 participants in the child composite group and 4 in the adult composite group were removed according to the criteria defined in Experiment 1. The timed-out trials were also discarded for analyses in each task (1.1% in the working memory task, 3.7% in the composite task).

Results

The congruency effects (d') in the composite task are illustrated in Figure 5, showing the performance on congruent, incongruent and isolated target part trials across the Load conditions for child and adult composites. Three-way ANOVAs with a between-subject factor Composite Type (child composites vs. adult composites) and two within-subjects factors Load Category (child face load vs. adult face load) and Congruency (congruent vs. incongruent) conducted on d' and RT in the composite task showed no significant main effect of Composite Type, d': $F(1, 69) = .14$, $p = .71$; RT: $F(1, 69) = 1.47$, $p = .29$, and no significant main effect of Load Category, d': $F(1, 69) = .25$, $p = .62$; RT: $F(1, 69) = 1.82$, $p = .18$. The effect of Congruency was significant, d': $F(1, 69) = 87.69$, $p < .0001$, $\tilde{\eta}_p^2 = .56$; RT: $F(1, 69) = 11.34$, $p = .001$, $\tilde{\eta}_p^2 = .14$, revealing better and faster performance for congruent than incongruent trials. The interaction between Composite Type and Congruency was not significant, d': $F(1, 69) = .40$, $p = .53$; RT: $F(1, 69) = .86$, $p = .36$. However, there was a significant interaction between Load Category and Congruency in d', $F(1, 69) = 8.12$, $p = .006$, $\tilde{\eta}_p^2 = .11$; not in RT: $F(1, 69) = 3.13$, $p = .08$, revealing a smaller congruency effect with a child face load compared with an adult face load. Moreover, the 3-way interaction between Composite Type, Load Category, and Congruency was

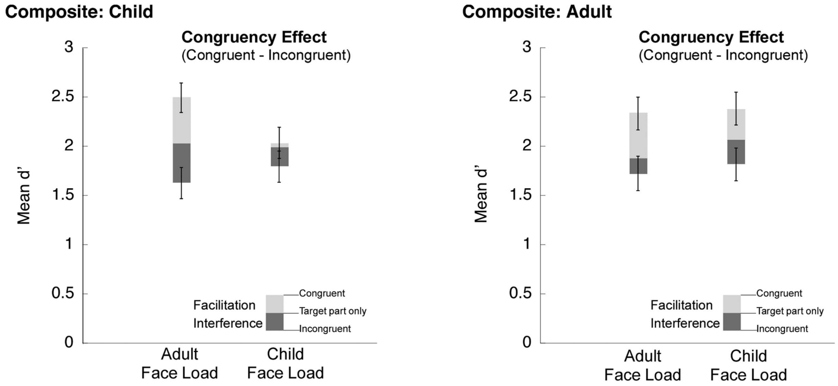

Figure 5. Mean sensitivity (d′) in Experiment 4 as a function of Load Category and Congruency for the child composite group (left) and the adult composite group (right). The dark gray area represents the interference from incongruent trials and the light gray area represents the facilitation from congruent trials. Error bars show the 95% confidence intervals of the interaction of Load Category and Congruency for each composite group.

significant in d′, $F(1, 69) = 6.27$, $p = .015$, $\tilde{\eta}_p^2 = .083$, but not in RT: $F(1, 69) = 1.08$, $p = .30$.

We conducted two separate within-subject ANOVAs to examine performance within the child composite group and the adult composite group. In both groups, there was no significant main effect of Load Category (d′: Fs < 2.81, ps $> .10$; RT: Fs < 1.95, ps $> .17$). The main effect of Congruency was significant in d′ for both the adult and child composites (Fs > 35.11, ps $< .0001$, $\tilde{\eta}_p^2 > .51$) and was significant in RT for the adult composites, $F(1, 35) = 9.54$, $p < .005$, $\tilde{\eta}_p^2 = .21$, but not for the child composites, $F(1, 34) = 2.88$, $p = .10$. In the child composite group, the interaction between Load Category and Congruency was significant in d′, $F(1, 34) = 12.98$, $p = .001$, $\tilde{\eta}_p^2 = .28$; not in RT: $F(1, 34) = 3.37$, $p = .075$, with a reduced congruency effect by a child face load than an adult face load, revealing asymmetrical influences of the two face loads on child composites. In the adult composite group, the interaction between Load Category and Congruency was not significant, d′: $F(1, 35) = .067$, $p = .80$; RT: $F(1, 35) = .32$, $p = .58$.

For the isolated-part trials, two-way ANOVAs with the between-subjects factor Composite Type and the within-subjects factor Load Category conducted on d′ and RT showed no significant main effect of either factor, Composite Type: d′: $F(1, 69) = .07$, $p = .79$; RT: $F(1, 69) = 1.41$, $p = .24$; Load Category: d′: $F(1, 69) = .79$, $p = .38$; RT: $F(1, 69) = 2.68$, $p = .11$, and no significant interaction, d′: $F(1, 69) = 1.50$, $p = .22$; RT: $F(1, 69) = .11$, $p = .74$. Critically, paired t-tests ($\alpha = .05$) conducted on d′ for the isolated-part baseline versus the congruent/incongruent trials revealed that in the child composite group, there was significant facilitation and interference with an adult face load (ps $< .006$) but no significant facilitation or interference was found with a child face load (ps $> .14$). In the adult composite group, the congruency effect found with both face loads reflected facilitation in congruent trials (ps $< .02$), and interference in incongruent trials was only found with a child face load ($p < .04$) but not with an adult face load ($p = .14$), suggesting that an adult face load disproportionally reduced holistic processing of adult faces compared with a child face load.

Here, an adult face load eliminated the interference from task-irrelevant parts in incongruent trials for adult composites, but there was significant facilitation in congruent trials. It may be a concern that the face load effect obtained here was different from those in Experiment 1, where a face load resulted in no significant facilitation or interference for the congruency effect. Thus, we compared the magnitude of the congruency effects for adult face composites with an adult face load in this experiment and that in Experiment 1, and found no statistical difference between the congruency effects in the two experiments, d: $F(1, 62) = 3.75$, $p = .06$; RT: $F(1, 62) = 2.13$, $p = .15$. More importantly, the elimination of the interference in incongruent trials in both experiments suggests that holistic face processing in both cases was affected by the face load from the same subordinate-level category.

For the working memory task, the child composite group showed a mean accuracy of 73.4% and a mean RT of 1,080 ms in the child face task and 69.1% and 1,095 ms in the adult face task. The adult composite group showed a mean accuracy of 75.1% and a mean RT of 1,045 ms in the child face task and 69.3% and 1,017 ms in the adult face task. Two-way ANOVAs with the factors of Composite Type and Load Category conducted on accuracy and RT showed a significant effect of Load Category, accuracy: $F(1, 69) = 29.65$, $p < .0001$, $\tilde{\eta}_p^2 = .30$; not in RT: $F(1, 69) = .27$, $p = .61$, revealing better performance for matching child faces than adult faces. The main effect of Composite Type approached significance in RT, $F(1, 69) = 3.86$, $p = .053$; not in accuracy: $F(1, 69) = .37$, $p > .54$, with longer RT in the child face group than the adult face group. There was no significant interaction, accuracy: $F(1, 69) = .56$, $p = .46$; RT: $F(1, 69) = 3.01$, $p = .09$. Because working memory performance for the child face task was better than that for the adult face task in both composite groups, this enhancement in performance cannot explain the asymmetrical result pattern of the load effects on the two composite types.

Discussion

The child and adult face working memory loads had similar impact on the overall performance in the composite tasks, but exerted different effects on holistic processing on each face type. For the child composites, no congruency effect was observed when other child faces were held in working memory. In contrast, a congruency effect was found when an adult face load was maintained, with facilitation from congruent trials and interference from incongruent trials compared with the isolated-part baseline. An adult face load had less impact on holistic processing of child faces compared with a child face load. On the other hand, both child and adult face loads were accompanied by small congruency effects for the adult composites. However, interference from task-irrelevant parts in incongruent trials, the typical source of holistic processing (Richler et al., 2009, 2008b), was eliminated only with an adult face load but not with a child face load. This result is consistent with the possibility that an adult face load had a greater influence than a child face load on adult composites. The congruency effects for the adult composites here arose mostly from facilitation in congruent trials compared with the isolated-part baseline, which is in contrast with prior work where facilitation was less reliable than interference in the composite paradigm (Richler et al., 2009, 2008b). How to predict the often absent and much more variable contribution of facilitation to congruency effects is however not yet well understood (MacLeod, 1991; MacLeod & MacDonald, 2000). In any case, any difference between the two loads on the two types of composite suggests that the relationship between the target and load faces matter. Our results refute the hypothesis that the effect of visual working memory load on holistic processing is simply determined by whether the load items belong to the face category, the fact that they are processed holistically (consistent with our findings in Experiment 3) or only by the coarse similarity of all faces because of a shared first-order configuration of parts. Instead, interference on holistic processing in working memory appears to depend on similarity at a more fine-grained scale (either visual or semantic similarity, which are likely interdependent), presumably because of the challenge of maintaining distinct representations of similar objects in working memory.

General Discussion

The goal of the present study was to investigate the nature of competition on holistic face processing in working memory. To summarize the findings, all working memory loads impaired overall performance in the face composite task compared with a no load condition (Experiments 1 to 3). Critically, a load of three faces reduced holistic processing in the face composite task (Experiment 1). However, an equally demanding load of three watches did not (Experiment 2). Notably, the watch load did reduce overall performance but still did not affect holistic processing. The lack of interference from an object working memory load could be because of the differences in processing strategies for faces and objects: faces are processed holistically but objects are processed in a part-based manner (Biederman, 1987; Farah et al., 1998; Tanaka & Farah, 1993). But Experiment 3 refuted this hypothesis and showed that even objects of expertise that are encoded in a similar holistic manner to faces (Gauthier et al., 2003; Gauthier & Tarr, 2002; McGugin & Gauthier, in press; Wong, Palmeri, & Gauthier, 2009) do not cause interference. Experiment 4 also confirmed that a load of faces processed holistically is not sufficient to completely reduce holistic processing of any other faces. It further suggested that holistic processing of faces is influenced by the degree of overlap among working memory representations, because holistic processing of child faces was more reduced by a load of child faces than by an adult face load, and the only two conditions where incongruent trials were no different from isolated trials were those where the load and target stimuli were faces of the same age group.

These findings are consistent with research showing that working memory capacity is influenced by similarity (Awh et al., 2007; Robinson et al., 2008; Scolari et al., 2008; Wong et al., 2008). Because high-resolution representations are required to discriminate such items (Alvarez & Cavanagh, 2004), the ability to process task-irrelevant information is likely to be reduced.

In addition, we found that the interference effect was larger with a face load placed before the presentation of a test face than a study face in Experiment 1, suggesting that opportunities to influence holistic processing are greater when participants have to both process a test face and make a perceptual decision about its identity, compared with when they only have to encode and maintain a study face (Richler et al., 2008a, 2008b; Wenger & Ingvalson, 2002, 2003). Interference in working memory might occur either while an item is encoded or while a representation in memory is compared with the test face. Our results suggest that there may be a cumulative effect of encoding and comparison when a working memory load is held during the test phase of the composite task.

Given the limitations of working memory to no more than four objects (e.g., Cowan, 2000; Luck & Vogel, 1997; Xu & Chun, 2006) and typically much less for objects from the same category (e.g., Alvarez & Cavanagh, 2004; Awh et al., 2007; Eng et al., 2005; Olsson & Poom, 2005; Wong et al., 2008), finding any holistic processing in our dual-task paradigm is somewhat impressive. For instance, consider the load during test trials, where participants must store the top part of a face composite in working memory, then manage to store between two and three of the objects in the load triplet, and then must compare the correct top part with the top part of the face presented at test. Finding a congruency effect under these conditions suggests not only that the irrelevant bottom part of the study face was encoded, but that it was maintained through the trial and retrieved during the comparison process. We conjecture that the irrelevant part, which the participants are explicitly instructed not to encode and which they should not be motivated to maintain in working memory, comes along for the ride because of the strong bias we have to encode faces holistically. However, while in working memory, this task-irrelevant information may be especially susceptible to interference. While the ability to actively maintain task-relevant information was affected by a load of any complex objects, the passive maintenance of task-irrelevant information was more selectively disrupted by a load of highly similar objects.

Our finding of interference on holistic processing with similar faces is consistent with the specialized load theory (Kim et al., 2005; Park et al., 2007). On the other hand, we also observed a cross-domain increase of holistic processing of faces with a load of transformed cars, consistent with the cognitive load theory (Lavie, 2005). Thus, the reduction and the increase of holistic processing likely arise from different mechanisms, which have both independently received empirical support. According to the cognitive load theory (de Fockert et al., 2001; Lavie et al., 2004), a working memory load that engages frontal resources can increase the influence of task-irrelevant information compared with no load, because the load reduces the resources available for prioritizing task-relevant over irrelevant information (de Fockert et al., 2001; Lavie et al., 2004). The specialized load theory stands in opposition to the idea of a general effect for all types of working memory load, suggesting that the increase or decrease in distractor processing is determined by the overlap in category or process of load with target or distractor information (Kim et al., 2005; Park et al., 2007). Our findings of selective interference on holistic processing provide further support for the specialized load theory account. In addition, our results clarify that the nature of the specialized load effect is influenced by the similarity of representations (Dutta, Schweickert, Choi, & Proctor, 1995; see also Hirst & Kalmar, 1987; Navon & Miller, 1987), at least at a level distinguishing faces of different ages, but not by the overlap in the perceptual processing strategies used to encode stimuli in working memory (Gauthier et al., 2003; Rossion et al., 2007).

In summary, the present study demonstrates that the nature of the interference on holistic processing in working memory is different from that which arises at the perceptual level. While perceptual interference can arise from the competition for holistic processing resources between two domains of expert object processing (Gauthier et al., 2003; McKeeff et al., 2007; Rossion et al., 2007, 2004; Williams et al., 2007), interference in visual working memory is produced by the limited capacity for visually or psychologically similar representations. In addition, our findings suggest that there may be a qualitative difference in interference on the information that is actively maintained in working memory, relative to information that is incidentally encoded and maintained. We find that the first appears to be susceptible to interference from any information recruiting working memory resources (a "general load" effect; Lavie, 2005; Lavie et al., 2004), whereas the second appears to be more selectively affected by the encoding of similar information (a "specialized load" effect, Park et al., 2007).

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