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Word and Face Processing Engage Overlapping Distributed Networks: Evidence From RSVP and EEG Investigations

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Words and faces have vastly different visual properties, but increasing evidence suggests that word and face processing engage overlapping distributed networks. For instance, fMRI studies have shown overlapping activity for face and word processing in the fusiform gyrus despite well-characterized lateralization of these objects to the left and right hemispheres, respectively. To investigate whether face and word perception influences perception of the other stimulus class and elucidate the mechanisms underlying such interactions, we presented images using rapid serial visual presentations. Across 3 experiments, participants discriminated 2 face, word, and glasses targets (T1 and T2) embedded in a stream of images. As expected, T2 discrimination was impaired when it followed T1 by 200 to 300 ms relative to longer intertarget lags, the so-called attentional blink. Interestingly, T2 discrimination accuracy was significantly reduced at short intertarget lags when a face was followed by a word (face–word) compared with glasses–word and word–word combinations, indicating that face processing interfered with word perception. The reverse effect was not observed; that is, word–face performance was no different than the other object combinations. EEG results indicated the left N170 to T1 was correlated with the word decrement for face–word trials, but not for other object combinations. Taken together, the results suggest face processing interferes with word processing, providing evidence for overlapping neural mechanisms of these 2 object types. Furthermore, asymmetrical face–word interference points to greater overlap of face and word representations in the left than the right hemisphere.

Keywords: face processing, word processing, attentional blink, EEG, visual perception

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Faces and words have distinct visual properties and associated neural responses, but as complex visual stimuli they involve many common processes. Biases in ventral occipitotemporal regions have been well established for face processing in the right hemisphere (Kanwisher, Mcdermott, & Chun, 1997) and word processing in the left hemisphere (Cohen et al., 2000), but the degree of domain specificity in these regions is contentious. On one hand, the apparent dissociation of face processing to the fusiform face area (FFA) in the right hemisphere and word processing to the visual word form area (VWFA) in the left hemisphere supports the idea of independent high-level visual processes for these types of stimuli. However, growing evidence challenges this view. For instance, despite hemispheric biases, activation to faces and words is generally bilateral. The terms "left FFA" and "right VWFA" represent the smaller, homologous face and word-specific regions in the nondominant hemispheres (Cohen et al., 2003; Kanwisher et al., 1997). Furthermore, there are spatially overlapping regions of FFA and VWFA in both hemispheres (Bouhali et al., 2014; Harris, Rice, Young, & Andrews, 2016), indicating that word and face perception might involve some of the same processes. In the temporal domain, the N170, a negative event-related potential (ERP) component observed at approximately 170 ms over posterior temporal electrodes, has been used to study face, word and object perceptual processes (Itier & Taylor, 2004; Maurer, Rossion, & McCandliss, 2008) and is associated with high-level visual processes in the fusiform gyrus (Ghuman et al., 2014). The N170 tends to be left lateralized in response to words and right-lateralized in response to faces (Bentin, Allison, Puce, Perez, & Mccarthy, 1996; Mercure, Dick, Halit, Kaufman, & Johnson, 2008). Importantly, despite differential lateralization, the N170 to faces and words is temporally overlapping, has similar dipolar sources, and is more similar in amplitude in the left than the right hemisphere (Rossion, Joyce, Cottrell, & Tarr, 2003). Taken together, it seems likely that object perception might be subserved by distributed but integrated systems (Behrmann & Plaut, 2015; Plaut & Behrmann, 2011). With increasing knowledge that many cognitive pro-

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cesses involve complex brain networks, it seems reasonable that face and word processing involve more distributed systems that originally believed.

One line of research that supports the graded distributed view of face and word processing comes from human lesion studies. Individuals with right hemisphere (RH) damage in ventral cortex resulting in a face recognition deficit, prosopagnosia, were shown to have some deficits in word processing and individuals with damage to left hemisphere (LH) ventral regions who exhibited pure alexia, a deficit in word perception, were found to have poorer facial recognition performance than healthy individuals (Behrmann & Plaut, 2014). Such evidence indicates that LH or RH lesions can cause both face and word deficits, lending support to the idea that processing of both stimuli types involves bilateral neural processes despite hemispheric biases. Another aspect of face and word lateralization that suggests more distributed processing is the fact that hemispheric biases vary widely across individuals. In general, right-handed people demonstrate LH lateralization for words and RH lateralization for faces. However, left-handed individuals are less predictable; VWFA tends to co-localize to the same hemisphere as Broca's area, which can be RH lateralized, LH lateralized, or bilateral in left handers (Van der Haegen, Cai, & Brysbaert, 2012). Furthermore, FFA is not necessarily RH lateralized in left handers (Bukowski, Dricot, Hanseeuw, & Rossion, 2013; Dundas, Plaut, & Behrmann, 2015; Willems, Peelen, & Hagoort, 2010). Among right-handed individuals, there is also variability in FFA (Kanwisher et al., 1997) and VWFA (Cohen et al., 2000). Furthermore, the magnitude of the LH word N170 predicts the RH face N170 response, as well as the right visual field advantage for faces (Dundas et al., 2015). Such evidence speaks to the idea that various anatomical and functional pressures of the brain, for example from language areas, along with experience, lead to differential neural organization for high-level visual perception.

Increasing evidence suggests that development of the distributed face and word perception networks involves competition in the fusiform gyrus. For instance, as literacy increases, there is stronger activation of LH ventral visual cortex for letter strings and a complementary decrease in face selectivity in the same region (Dehaene et al., 2010). In addition, decreased activation to non-preferred categories within face- and letter-selective areas in children is correlated with better identification of preferred objects, suggesting that expertise leads to reduction of object overlap in object-selective areas (Cantlon, Pinel, Dehaene, & Pelphrey, 2011). Expertise has also been found to influence the degree of overlap between objects and faces (Gauthier, Curran, Curby, & Collins, 2003a; Gauthier, Skudlarski, Gore, & Anderson, 2000; Mcgugin, McKeeff, Tong, & Gauthier, 2011). Futhermore, reading competence during development correlates with right lateralization in face perception, indicating a competitive relationship between face and word processing (Dundas, Plaut, & Behrmann, 2013). In essence, it seems likely that overlapping areas of ventral cortex are involved in high level visual processing for multiple object types, and specifically indicates that face and word perception involve integrated systems.

The theory that some overlapping high-level neural processes are required for specialized face and word processing leads to specific hypotheses regarding the interactions of these two stimuli types. If spatially overlapping regions of FFA and VWFA are responsible for some common processes in both face and word perception, we might expect perceptual interference to manifest under certain conditions. For instance, it should be more difficult to sequentially process a face and a word than other object types. One paradigm that is ideal for testing such a hypothesis is rapid serial visual presentation (RSVP), in which a stream of images is presented foveally at a very fast rate and participants have to detect or identify target images within the stream. RSVP has been used to study the *attentional blink* (AB), a phenomenon in which the second of two target images is undetected if it appears within 200 to 500 ms of the first target (Raymond, Shapiro, & Arnell, 1992). The attentional blink has been conceptualized as reflecting the temporal limits of attention (Dux & Marois, 2009). Specifically, the AB seems to arise from the demands associated with processing Target 1 (T1), disengaging to process Target 2 (T2), and limitations of parallel processing and response selection (Dux, Asplund, & Marois, 2009; Dux & Marois, 2009; Olivers & Nieuwenhuis, 2006). Importantly, initial processing of T2 seems to proceed as normal despite lower target detection or discrimination performance. Using EEG, Sergent, Baillet, and Dehaene, (2005) found T1 and T2 processing were intact until 270ms after T2 presentation, but then varied according to whether T2 was correctly identified or missed. Other studies have illustrated a lower P300 component to targets presented during the attentional blink period compared with targets outside the AB (Kranczioch, Debener, & Engel, 2003; Vogel, Luck, & Shapiro, 1998). Thus, the AB seems to primarily influence processes occurring later than those supporting visual detection or discrimination.

The aim of this study was to investigate how the overlapping neural mechanisms of face and word processing manifest in perceptual interference in healthy individuals. To do this, we used an RSVP paradigm to investigate sequential processing of two objects. This approach allowed us to obtain a measure of the typical AB phenomenon, and also to lever this effect to look at how perceptual interference can enhance the short-lag deficit. If faces and words involve more overlapping neural processes than other objects, we would expect sequential face and word processing to exhibit greater T2 discrimination deficits during RSVP than face–object and word–object pairings. Face and word deficits would therefore be associated with conflicts during visual processes occurring in the fusiform gyrus such as those supporting object discrimination, in addition to the later AB conflicts such as those relating to working memory. Across three experiments, we presented images of faces and words and another control object class (i.e., glasses) during rapid serial visual presentation. In two behavioral experiments, using different tasks, we found that faces as T1 disproportionately interfered with word T2 discrimination, supporting the view of overlapping face and word perceptual processes. In a third experiment, EEG indicated that relatively larger LH face N170 amplitudes were associated with greater deficits in word discrimination.

General Method

Participants

This study was approved by the Institutional Review Board of Carnegie Mellon University (CMU). Informed consent was obtained from all participants. Across three experiments, 88 partici-

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pants were recruited from CMU and either received course credit or payment ($10 behavior; $50 EEG) for their participation. Participants completed the Edinburgh Handedness Inventory and a questionnaire regarding their age, gender race and ethnicity. Participants were only recruited if they were White Caucasian and not Hispanic or Latino, to avoid any potential influences of the other-race face effect. All the participants reported they were right-handed, White, not Hispanic or Latino, and all had normal or corrected-to-normal vision.

Design and Stimuli

All experiments employed an RSVP paradigm with images presented centrally at 10 Hz. Participants had to discriminate two target objects within the visual stream. T1–T2 asynchrony varied in each experiment so that T2 was presented within the AB period (<500 ms after T1) and outside the AB period (>500 ms after T1). There were three possible target object types (faces, words, glasses). Faces were randomly selected from a set of 32 images, with equal numbers of female and male images. The words were *beat*, *boat*, *bolt*, and *belt*, presented in Arial font. The glasses were images of circular or rectangular eyeglass frames, with three exemplars of each. Distracters were overlaid images of faces, words, and glasses. One factor that influences the attentional blink is how well the target images are masked (Raymond, Shapiro, & Arnell, 1995), so our distracters were chosen so that they would equally mask the different target images. At the end of each trial, participants had to respond to the identity of the first target (T1), and then the identity of the second target (T2) using key presses. No feedback was given regarding accuracy. Extensive pilot testing was undertaken before Experiment 1 to ensure face, word and glasses discrimination tasks were equated for difficulty, as judged by T1 performance.

Behavioral Analysis

T2 accuracy was calculated as the proportion of trials in which T1 was correctly identified (T2|T1). During RSVP streams, participants often switch the order of T1 and T2. For all three experiments, switch trials were coded as correct. The trend of results did not change if these switch trials were coded as incorrect.

For each experiment, a repeated-measures analysis of variance (ANOVA) was conducted to assess the influence of T1 object, T2 object and T1–T2 stimulus onset asynchrony (lag) on T2|T1 report. A significant three-way interaction was followed up by two-way ANOVAs for each T2 object. Finally, pairwise analyses were performed to compare T2|T1 accuracy at short T1–T2 lags (200-300ms; i.e., the deepest point of the AB) with accuracy at long lags (700 ms to 900 ms) to assess the magnitude of the AB for each condition (Bowman & Wyble, 2007). An alpha level of 0.05 was used for all statistical tests, and Bonferroni-Holm correction used for follow up tests. Effect sizes were calculated for all statistical comparisons. Generalized eta-squared values (η_g^2) were calculated for ANOVA results, and Hedges' g_{av} was calculated for paired samples *t* tests (Bakeman, 2005; Lakens, 2013).

Experiment 1

Method

Forty-two participants (18 male, 24 female; age range 18–25 years) completed Experiment 1. Four participants were excluded for performing two standard deviations below the group mean for one of the stimulus classes at T1, equating to 29.32% for words, 49.77% for faces and 52.10% for glasses. These participants were unable to distinguish the targets much better than chance.

On each block, the participants were presented with two pre-specified targets (faces and words and glasses) among fused face/word/glasses distracters during RSVP (Figure 1a). The two targets appeared within 2, 3, 7, or 9 images of one another, corresponding with 200 ms, 300 ms, 700 ms, or 900 ms target asynchrony (lag). The Cogent Toolbox in Matlab was used to present the visual stimuli on an 18-in. CRT monitor with 100 Hz refresh rate. Images were presented for 20 ms (two frames) with 80 ms gap between successive images. Faces and glasses were grayscale bitmap images presented within a square of size 4 × 4 degrees of arc and words were presented as text in midgray (RGB 0.5, 0.5, 0.5) using Arial font with the letters 1.4 degrees high. Distractors were chosen from the same group of images as T1 and T2. Faces and words and glasses were randomly chosen for each distractor and overlaid as fused face/word/glasses images using the alpha trans-

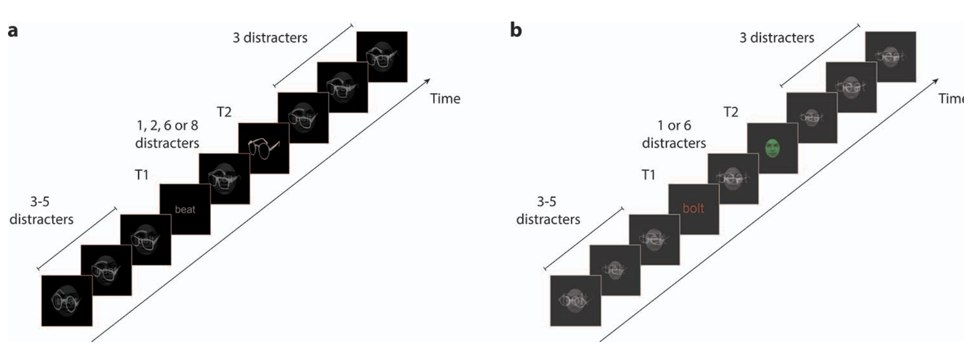

Figure 1. Schematic representation of the rapid serial visual presentation (RSVP) trial sequence. (a) Experiment 1: T1 word (beat, boat, belt, or bolt) and T2 glasses (round or rectangular frames). (b) Experiment 2: T1 word and T2 face, designated by different colors. Both targets had to be categorized as face, word or glasses. T1 = Target 1; T2 = Target 2. See the online article for the color version of this figure.

parency tool in Cogent. Faces, glasses and word distractors were presented with transparency values of 0.8, 0.5 and 0.3, respectively. These values were chosen based on pilot data in an effort to equate the difficulty of the face, word, and glasses tasks. T1 and T2 images were presented alone in original formats (transparency = 0).

All combinations of T1, T2, and lag were presented during the experiment. There were nine blocks, each containing a different combination of T1 and T2 objects. Participants had to perform different discrimination tasks on face targets (male or female), word targets (discriminate the words *belt*, *bolt*, *beat*, or *boat*), and glasses targets (circular or rectangular frames). Chance performance was 25% for words and 50% for faces and glasses. Again, this design was adopted to equate overall accuracy across the three stimulus classes. At the start of each block, participants were told to search for specific T1 and T2 objects and all possible exemplars were shown on the monitor. For example, in the T1 face/T2 word block, participants were told the first target would be a face, and shown all possible faces with correct labels female and male, and then told the second target would be a word, and shown the words *bolt*, *belt*, *beat*, and *boat*. There were 18 trials per combination of lag, T1 and T2 class, resulting in 648 trials for the whole experiment. To ensure small trial numbers per cell did not lead to extreme T2|T1 values and bias the results, additional analyses were conducted by collapsing across lags 200 ms and 300 ms (short lag) and 700 ms and 900 ms (long lag), which led to the same trend in results (see the online supplemental materials for details).

Results and Discussion

Experiment 1 was designed to determine whether interactions between face and word processing would manifest during a dual-task RSVP paradigm and how these might differ compared with other paired visual stimuli. T1 discrimination performance was above chance (M = 73.04%) and did not vary significantly across the different T1 objects on average (see online supplemental materials for details). Notably, participants were better at discriminating T1 when both targets were the same type of object relative to when the targets were different object types, perhaps a result of backward priming.

To assess the cost of detecting both targets as a function of object class, T2 performance was assessed conditionally on trials in which T1 was correctly identified (T2|T1). All conditions exhibited in a typical dual task "attentional blink" effect, such that short T1–T2 lags (200 ms to 300 ms) resulted in poorer T2|T1 performance relative to longer lags (700 ms to 900 ms; see Figure 2). A 3 × 3 × 4 repeated–measures ANOVA revealed a marginal main effect of T1 class, $F(2, 74) = 2.82$, $p = .066$, $\eta_g^2 = .008$, and a significant main effect of T2 class, $F(2, 74) = 5.09$, $p = .008$, $\eta_g^2 = .035$. There was a significant main effect of lag, $F(1, 37) = 96.87$, $p < .001$, $\eta_g^2 = .208$, such that T2|T1 accuracy was lower at lags 200 ms and 300 ms than at lags 700 ms and 900 ms, $ts(37) > 7.44$, $ps < .001$, $gs_{av} > .916$, indicative of the typical AB effect. Critically, however, there was a significant three way interaction between T1 class, T2 class and lag, $F(4, 148) = 3.49$, $p = .009$, $\eta_g^2 = .016$. To follow up this interaction, 3 × 4 ANOVAs with factors of T1 class (face, word, glasses) and lag (2, 3, 7, 9) were conducted for each T2 class. These analyses were chosen so as to investigate how the discrimination of the same T2 objects differed depending on different preceding objects.

For glasses T2, a 3 × 4 ANOVA revealed a significant main effect of T1 class and a significant main effect of lag ($Fs > 7.54$, $ps < .001$, $\eta_g^2s > .073$) but no significant interaction between T1 class and lag, $F(74) = .27$, $p = .765$, $\eta_g^2 = .003$. T2|T1 performance was significantly higher for glasses T1 than for face and word T1, $ts(37) > 3.37$, $ps < .004$, $gs_{av} > .544$. There were no significant differences between face and word T1, $t(37) = -.053$, $p = .958$, $g_{av} = .008$. Performance improved as lag increased between 300 ms, 700 ms, and 900 ms, $ts(37) < -3.96$, $ps < .001$,

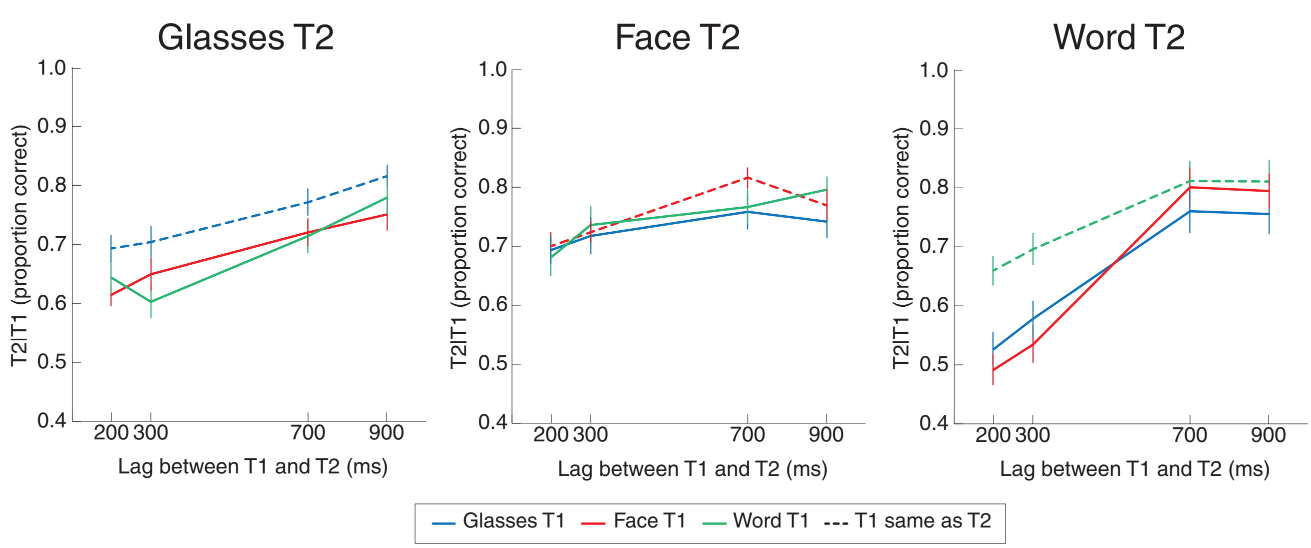

Figure 2. Mean accuracy of T2|T1 identification for the glasses, face and word T2 conditions of Experiment 1, plotted as a function of T1 condition and T1–T2 temporal lag. Error bars represent one standard error of the mean. T1 = Target 1; T2 = Target 2. See the online article for the color version of this figure.

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$gs_{av} > .368$, but there were no significant differences between lags of 200 ms and 300 ms, $t(37) = -.080$, $p = .937$, $g_{av} = .016$. These results reveal a typical attentional blink effect for glasses T2 regardless of T1 class, but they also suggest that participants found it easier to detect glasses T2 when the T1 was also glasses (see Figure 2a and Figure 3).

For face T2, a 3 × 4 ANOVA revealed no significant main effect of T1 class and no significant interaction between T1 class and lag ($Fs < .96$, $ps > .386$, $\eta^2_g < .012$). There was, however, a significant main effect of lag, $F(1, 37) = 25.42$, $p < .001$, $\eta^2_g = .105$. T2|T1 performance was significantly higher at lags 700 ms and 900 ms than 200 ms and 300 ms, $ts(37) > 2.58$, $ps < .042$, $gs_{av} > .312$, a classic short-lag (attentional blink) deficit. There were no significant differences between 200 ms and 300 ms lags or between 700 ms and 900 ms lags, $ts(37) < 1.85$, $ps > .143$, $gs_{av} < .254$. Essentially, preceding word, face and glasses T1s produced equivalent short-lag deficits for face T2 discrimination (Figure 2b and Figure 3).

The most interesting findings emerged for word T2. A 3 × 4 ANOVA revealed a significant main effect of T1 class, a significant main effect of lag, and a significant interaction between T1 class and lag ($Fs > 7.081$, $ps < .002$, $\eta^2_g > .060$). The interaction was further analyzed by calculating the difference in T2|T1 accuracy between long lags and short lags, that is, the maximum performance at 700 ms to 900 ms lag minus the minimum performance at 200 ms to 300 ms lags, to provide an estimate of the short-lag deficit per condition, and we compared this magnitude across the different T1 conditions (see Figure 3). For word T2, follow up tests with Bonferroni-Holm correction revealed marginal differences in dual task deficit between word T1 and glasses T1, $t(37) = -2.06$, $p = .076$, $g_{av} = .385$, and between glasses T1 and face T1, $t(37) = -2.15$, $p = .076$, $g_{av} = .497$, and a significant difference between word T1 and face T1, $t(37) = -4.41$, $p < .001$, $g_{av} = .919$. Although the difference between the face–word and glasses–word combinations did not reach significance with multiple comparisons correction, it was clear that the face–word deficit was numerically larger than that of the glasses–word combination. Furthermore, as Figures 2c and 3 show, a preceding face T1 elicited a much greater deficit for word T2 than a preceding word T1, indicating that face discrimination interfered with word discrimination.

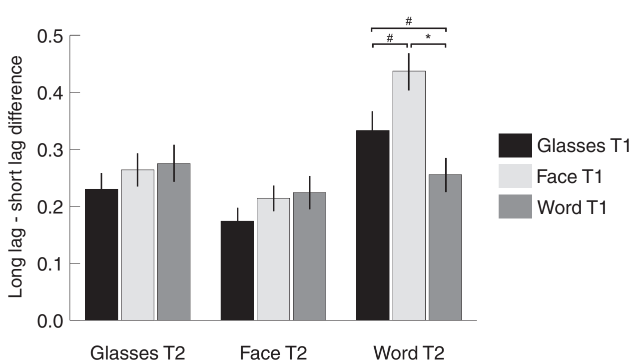

Figure 3. Magnitude of the long–short-lag deficit, or "attentional blink" effect for the face, word, and glasses T2 conditions of Experiment 1, plotted for each T1 condition. Deficit was calculated as difference between long and short T1–T2 lags for proportion T2|T1 correct. Error bars represent one standard error of the mean. * $p_{corrected} < .05$. # $p_{corrected} < .10$. T1 = Target 1; T2 = Target 2.

Overall, Experiment 1 yielded AB effects for all combinations of faces, words, and glasses, such that performance at short lags was lower than that at longer lags. Importantly, however, face T1 processing disproportionately interfered with word T2 processing during RSVP. A word image was significantly less likely to be detected when it was preceded by a face image than by another word image. The opposite effect was not found; that is, whereas the word–face combination exhibited a short-lag (AB) deficit, the magnitude of this deficit was no different to glasses and face T1 classes paired with face T2. Importantly, faces did not cause a larger deficit for glasses T2 compared with the other T1 classes, indicating that faces do not cause a general deficit in object discrimination. Essentially, the face–word combination resulted in interference at short stimulus onset asynchronies over and above typical AB effects. Face–word interference seems to reflect conflicts in perceptual processing rather than domain general conflicts (e.g., the attentional blink, task switching), which are unlikely to manifest greater interference in response to specific stimulus combinations. Previous evidence suggests that faces and words involve spatially overlapping processes, so it seems likely that face–word interference is due to overlapping processes relating to object discrimination in occipitotemporal brain regions. Overall, these results suggest that overlapping representations of faces and words result in asymmetric face–word interference during RSVP.

Experiment 2

It could be argued that the size of the stimuli and the specific discrimination tasks used in Experiment 1 was responsible for or contributed to the observed patterns of disproportionate face–word interference. For example, perhaps faces masked words more than any other combination of stimuli because the face stimuli covered a larger area than the sparse words, or the different discrimination tasks interfered specifically for face–word combinations. To rule out these alternative explanations, we conducted Experiment 2 to test the generality of these findings and to examine whether the increased face–word interference manifests during RSVP when participants perform a different task on the targets (categorization) and when the sizes of the stimuli are varied.

Method

Twenty participants (16 male, 4 female; age range = 18–23 years) completed Experiment 2. All participants performed above chance on the task, so no participants were excluded. As in Experiment 1, participants were presented with two targets (faces and words and glasses) among fused face–word–glasses images during rapid serial visual presentation (see Figure 1b). The two targets appeared within two or seven images of one another, corresponding with 200 ms and 700 ms target asynchrony. Only these lags were used because, in Experiment 1, they sufficed to reveal the long-lag decrement and the reduction of levels of the factor offered more power (more trials) to reveal the effects of interest. Because of increased power, fewer participants were tested in this experiment. The Psychophysics Toolbox in Matlab was used to present the visual stimuli on a 19-in. LCD monitor

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with 60 Hz refresh rate. Images were presented for 16.67 ms (one frame) with 86.67 ms gap between successive images. Faces and glasses were the same gray scale bitmap images as used in Experiment 1. Words were gray scale jpeg images constructed using Arial font. To equate the images, the rectangular bounding box of each object was constructed from the same pixel area, and contrast and luminance were matched across the images. During RSVP, distractor and target size varied randomly between 3.3–4.7 degrees of arc. Target images were presented in red (RGB: 150, 0, 0) and green (RGB: 0, 150, 0) using the Psychophysics toolbox modulate color tool. One target was red and one target was green, and the order was counterbalanced across participants. Faces, words, and glasses were overlaid as fused images using the transparency tool in the Psychophysics toolbox with transparency values of 0.4, 0.5, and 0.2, respectively.

Participants had to perform a simple three-way category discrimination task on each target to determine if the object presented was a face, word or glasses. Chance performance was 33.33%. Responses to T1 and T2 were given via three-alternative forced choice button presses using the same hand. Left and right hand responses were counterbalanced across participants. All combinations of T1 type, T2 type and lag were presented in random order. There were 35 repeats of each lag, T1 and T2 combination, resulting in 630 trials for the whole experiment. Trials were split into five blocks of 126 trials.

Results and Discussion

T1 categorization performance was well above chance (M = 94.51%) and did not significantly vary across the different object classes on average (see the online supplemental materials for details). As in Experiment 1, performance was higher when both targets were from the same object class compared with different object class combinations.

T2|T1 performance largely yielded the same pattern of results as Experiment 1 (see Figure 4). A 3 × 3 × 2 repeated-measures ANOVA revealed significant main effects of T1 class, T2 class and lag (Fs > 6.08, ps < .005, $\eta_g^2 > .036$). Critically, there was a significant three-way interaction between T1 class and T2 class and lag, $F(4, 76) = 11.82$, $p < .001$, $\eta_g^2 = .112$. Notably, when the T1 and T2 were the same object class (e.g., face–face), performance on short-lag trials was not significantly different to that of long-lag trials, ts(19) < 1.29, ps > .212, gs$_{av}$ < .206, indicating there was no AB for these combinations. When T1 and T2 were different classes, long-lag performance was better than short-lag performance, ts(19) > 2.02, ps < .058, gs$_{av}$ > .607, reflecting the AB. To further follow up on the three-way interaction, analyses were conducted separately for each T2 class.

For glasses T2 (see Figure 4a), a 3 × 2 ANOVA revealed a significant main effect of T1 class, a significant main effect of lag, and a significant interaction between T1 class and lag (Fs > 3.58, ps < .038, $\eta_g^2 > .065$). As Figure 5 shows, the long–short–lag deficit was significantly larger when T1 was a face than when T1 was glasses, $t(19) = 2.97$, $p = .024$, $g_{av} = 1.000$, and the deficit was larger for word T1 than glasses T1, but this did not reach statistical significance, $t(19) = 1.90$, $p = .144$, $g_{av} = .614$. There was no significant difference between the face T1 and word T1 classes, $t(19) = -.34$, $p = .736$, $g_{av} = .074$.

For face T2 (see Figure 4b), a 3 × 2 ANOVA revealed significant main effects of T1 class and lag (Fs > 5.66, ps < .028, $\eta_g^2 >$ .102) and a significant interaction between T1 class and lag, $F(2, 38) = 4.79$, $p = .014$, $\eta_g^2 = .067$. Paired t tests revealed long–short-lag difference (see Figure 5) was larger for glasses T1 than face T1, $t(19) = 3.12$, $p = .017$, $g_{av} = .914$, and marginally larger for word than face T1, $t(19) = 2.21$, $p = .080$, $g_{av} = .650$. There was no difference in AB magnitude between glasses and word T1, $t(19) = -.11$, $p = .912$, $g_{av} = .020$. Essentially, words and glasses evoked a larger short-lag deficit for face T2 than face T1.

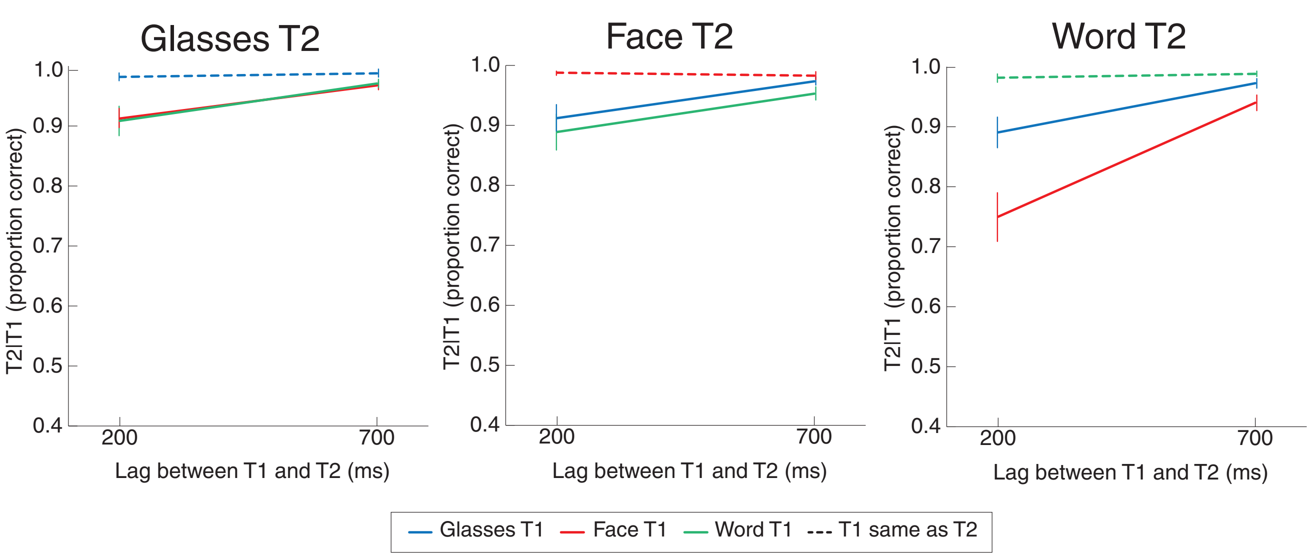

Figure 4. Mean accuracy of T2|T1 identification for the glasses, face and word T2 conditions of Experiment 2, plotted as a function of T1 condition and T1–T2 temporal lag. Error bars represent one standard error of the mean. T1 = Target 1; T2 = Target 2. See the online article for the color version of this figure.

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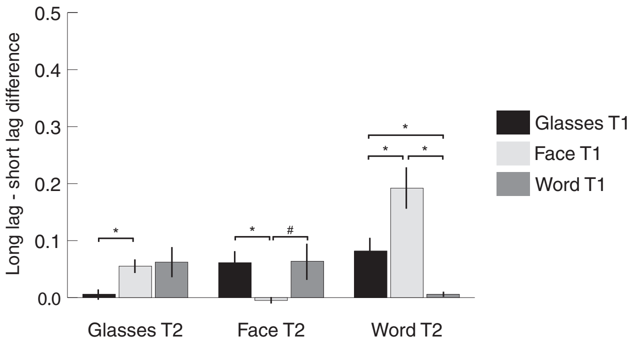

Figure 5. Magnitude of the long–short-lag decrement effect for the face, word and glasses T2 conditions of Experiment 2, plotted for each T1 condition. Error bars represent one standard error of the mean. $^{*}\ p_{\text{corrected}} < .05$. $^{\#}\ p_{\text{corrected}} < .10$. T1 = Target 1; T2 = Target 2.

Finally, for word T2, a 3 × 2 ANOVA revealed a significant main effect of T1 class, a significant main effect of lag, and a significant interaction between T1 class and lag (Fs > 18.14, ps < .001, $\eta_g^2 > .214$). As can be seen in Figure 5, the short-lag deficit was significantly larger when T1 was a face than when T1 was a word or glasses, ts(19) > 3.71, ps < .003, $g\text{s}_{\text{av}} > .774$, and the deficit was larger for glasses T1 than for word T1 (t = 2.98, p = .008, g_{av} = .965). The results of Experiment 2 show once again that face T1 processing interfered with word T2 processing to a greater extent than other target combinations.

Overall, the results of Experiment 2 replicate those of Experiment 1, revealing that face processing interferes disproportionately with word processing. Furthermore, these results showed the face–word decrement manifested during RSVP using a completely different task with altered stimuli sizes and unpredictable T1 and T2 classes, confirming the previous finding and once again supporting a perceptual interference account of face–word deficits.

Experiment 3

Face–word interactions observed in Experiments 1 and 2 are consistent with interference due to overlapping neural mechanisms of face and word processing (with some asymmetry in their relationship). On this hypothesis, interference would be expected to occur during perceptual processes involving occipitotemporal regions such as those involved in object detection, categorization and/or discrimination. Interestingly, previous evidence suggests that high level perceptual processes (such as object discrimination, approximately 150 ms to 200 ms after T2 onset) are intact during the AB, and interference effects are only noticeable later, approximately 270 ms post T2-onset (Kranczioch et al., 2003; Sergent et al., 2005). To determine the time course of the observed face–word interference and test that face–word interference occurs at a different (earlier) time period than the typical attentional blink effect, the same RSVP paradigm as Experiment 1 was used in conjunction with electroencephalography (EEG) in Experiment 3.

Method

Participants were 26 adults recruited from CMU (17 male, 9 female; age range = 18–29 years). Each participant completed the same RSVP task as in Experiment 1 while electroencephalography (EEG) was recorded from the scalp. Three participants were excluded for performing two standard deviations below the mean or below chance on the RSVP task for at least one T1 object class.

RSVP task. The RSVP task of Experiment 3 was very similar to that in Experiment 1. The targets appeared within either two or seven images of one another, corresponding with 200 ms and 700 ms T1–T2 lag. T1 objects were faces, words, and glasses, as in the previous experiments, but only faces and words were presented as T2 objects because we were specifically interested in the decrement in T2 accuracy for these two classes as a function of T1 object type. This was also done to increase the sampling of trials for the key conditions for the event-related potential averaging. The Psychophysics Toolbox in Matlab was used to present the visual stimuli on a 24-in. LCD monitor with 60 Hz refresh rate. Images were presented for 16.67 ms (1 frame) with a 83.33 ms gap between successive images. The experiment contained six blocks, one for each combination of T1 and T2 condition. There were 50 repeats of each lag, T1 and T2 combination, resulting in 600 trials for the whole experiment.

EEG recording. Continuous EEG data were recorded using a BioSemi Active Two system (BioSemi, Amsterdam, Netherlands), digitized at a 512-Hz sample rate with 24-bit A/D conversion. The 128 electrodes were arranged according to the international standard 10–5 system for electrode placement (Oostenveld & Praamstra, 2001) using a nylon head cap. During recording, all scalp electrodes were referenced to the standard BioSemi reference electrodes. Eye movements were monitored using bipolar horizontal EOG electrodes placed at the outer canthi of each eye and bipolar vertical EOG electrodes placed above and below the left eye.

EEG analysis. EEG data analysis was performed offline using EEGlab (Delorme & Makeig, 2004). The data were preprocessed using the PREP pipeline (Bigdely-Shamlo, Mullen, Kothe, Su, & Robbins, 2015): Data were temporarily high pass filtered at 1 Hz, line noise was filtered, bad channels were removed, average reference was applied and bad channels were interpolated. To remove artifacts, independent component analysis was performed on the data. Independent component analysis (ICA) was conducted on epochs –200 ms to 1,000 ms from T2 onset. ICA weights were applied to the preprocessed continuous data and artifact-related ICA components were removed to result in one continuous, artifact-free EEG dataset per participant. For analysis, data were subjected to low-pass (0.1 Hz) and high-pass (20 Hz) zero-phase filters. Epochs were constructed relative to T2 onset and baseline corrected for 200ms prior to T1 onset, to avoid any T1-related activity contaminating the baselines of T2 ERPs. Epochs were rejected if posterior channels exceeded ±100 uV from 0 ms to 500 ms from T2 onset. Remaining epochs were averaged to form ERPs per condition.

For EEG analysis, we focused on four ERP components relating to T1 and T2 processing. The time periods of all components are named in relation to T2 onset for consistency (0 ms = T2 onset), although the earliest component is likely to reflect T1 processing for the short-lag trials, and activity from previous distractors in long-lag trials. We analyzed the large negative peaks for the N170 component in response to T1 processing (0 ms to 50 ms post T2 = 200 ms to 250 ms post T1 for short-lag trials) and the N170 in response to T2 processing (200 ms to 250 ms post T2). We also

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analyzed another T2-related negative component, which occurred at the typical time for the N170 component (150 ms to 170 ms post T2). Finally, a later P3-like peak was also analyzed (350 ms to 450 ms), a component implicated in attentional blink-related mechanisms. The electrodes chosen for analysis were clusters over left occipitotemporal (P7, P9, PPO9h, PO7) and right occipitotemporal (P8, P10, PPO10h, PO8) regions, previously shown to be associated with lateralized N170 face and word responses (Figures 8b and 10b). Average evoked potentials were calculated for each cluster and time window, for trials in which T1 and T2 were both correct. The same statistical results were observed when analyses were conducted with all T1 correct trials, regardless of T2 accuracy. For each T2 class and electrode cluster, two-way ANOVAs were conducted to assess how the evoked EEG response varied across T1 object condition and T1-T2 lag. To account for the multiple tests, an alpha level of $0.05/4 = .0125$ was used.

In a final set of analyses, we investigated the relationship between behavioral performance and neural activity for each T1 object at the critical time points per participant. The correlation between the behavioral short-lag deficit (i.e., T2|T1 accuracy for long lag minus T2|T1 for short lag) and the difference in T2 ERPs between long and short lags was calculated for each time point and condition ($\alpha = .0125$). Only significant results are reported.

Results and Discussion

Behavioral results. Average T1 performance was similar to that of Experiment 1, but performance for face T1 discrimination ($M = 68.15\%$) was lower than that of glasses discrimination ($M = 75.67\%$), which was in turn lower than word discrimination ($M = 85.46\%$; see online supplemental materials for details). The differences in T1 performance across stimulus class were unexpected because performance was relatively consistent across class in Experiment 1. Despite attempts to equate stimuli salience between E1 and E3, differences display parameters between Cogent on a CRT monitor (E1) and Psych Toolbox on an LCD monitor (E3) might have resulted in slight differences across stimulus classes. However, the differences in T1 performance across the object classes did not preclude the more relevant analysis of T2 performance. T2|T1 was compared for different T1 conditions on the same T2 class, so any differences in T2 accuracy should stem from different processing limitations associated with dual task identification of both targets, rather than inherent difficulty in T2 target identification.

T2|T1 performance largely yielded the same pattern of results as Experiments 1 and 2 (see Figure 6). A 3 × 2 × 2 repeated measures ANOVA revealed significant main effects of T1 class, lag and T2 class ($Fs > 17.81$, $ps < .001$, $\eta_g^2 > .092$). Critically, there was once again a significant three-way interaction between T1 class, T2 class and lag, $F(2, 44) = 4.01$, $p = .025$, $\eta_g^2 = .020$. For face T2, a 2 × 3 ANOVA revealed no significant main effect of T1 class, $F(2, 44) = 1.38$, $p = .262$, $\eta_g^2 = .021$, but there was a marginal main effect of lag, $F(1, 22) = 4.17$, $p = .053$, $\eta_g^2 = .058$, and marginal interaction between T1 class and lag, $F(2, 44) = 2.84$, $p = .069$, $\eta_g^2 = .042$. To investigate the marginal interaction, the difference in face T2|T1 accuracy between short and long lags was compared across T1 classes (see Figure 7). Although it was clear that the word–face combination did not exhibit an AB effect, whereas the other face T2 combinations showed a short-lag deficit, follow-up tests revealed that the long–short-lag difference did not vary significantly across T1 class, $ts(22) < 2.21$, $ps > .11$, $gs_{av} < .554$. It is possible that the lower face discrimination performance in this Experiment led to lower AB effects for faces in general, particularly for the word–face combination.

Importantly, for word T2, a 3 × 2 ANOVA revealed a significant main effect of T1 class, a significant main effect of lag, and

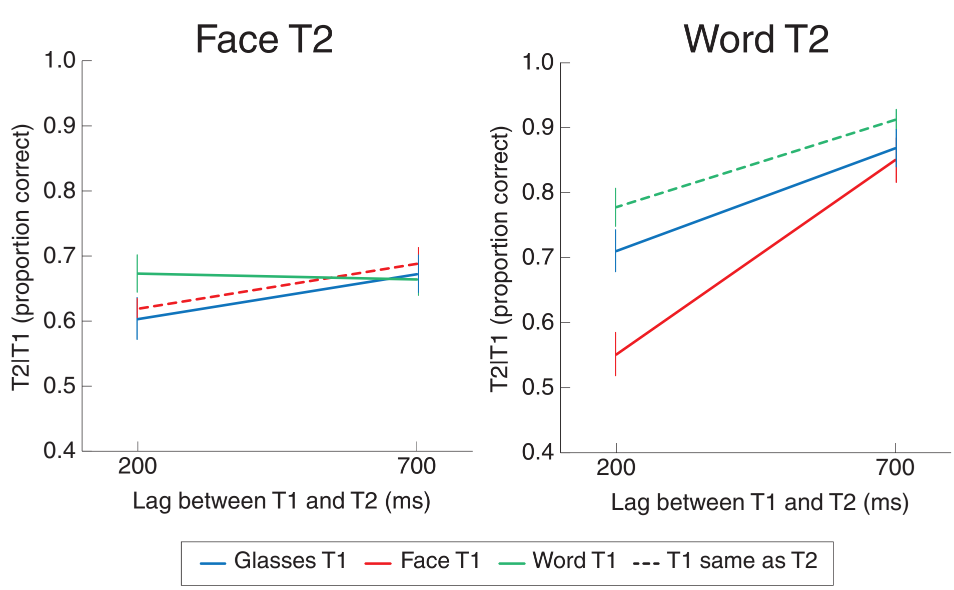

Figure 6. Mean accuracy of T2|T1 identification for the face and word T2 conditions of Experiment 3, plotted as a function of T1 condition and T1–T2 temporal lag. Error bars represent one standard error of the mean. T1 = Target 1; T2 = Target 2. See the online article for the color version of this figure.

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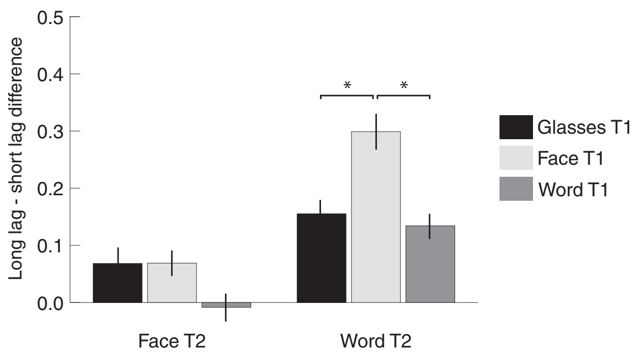

Figure 7. Magnitude of the long–short-lag deficit, or "attentional blink" effect for the face and word T2 conditions of Experiment 3, plotted for each T1 condition. Error bars represent one standard error of the mean. $^{*}\ p_{\text{corrected}} < .05$. T1 = Target 1; T2 = Target 2.

a significant interaction between T1 class and lag ($Fs > 13.45$, $ps < .001$, $\eta_g^2 > .138$). Follow up tests revealed the short-lag deficit was much larger when T1 was a face than when T1 was a word or glasses, $ts(22) > 3.92$, $ps < .002$, $gs_{av} > .843$. There was no significant difference in word T2 AB magnitude between glasses and word T1 ($t = .84$, $p = .408$, $g_{av} = .148$). As Figure 7 shows, a preceding face T1 elicited a much greater dual task deficit for word T2 than a preceding word or glasses T1, replicating the results of Experiments 1 and 2, and further indicating that face processing interfered with word processing.

EEG results. We focused our analyses on face T2 and word T2 at the selected time points as a function of T1.

Face T2. EEG waveforms are depicted in Figure 8a for the LH and RH electrode clusters. Results from the omnibus ANOVAs are presented in Table 1.

Peak 0 ms to 50 ms. As can be seen in Figure 8c, over the LH there was a larger negative peak for the short than long-lag condition, indicative of the N170 in response to T1 in short-lag trials. In the right electrode cluster, at short lags, glasses T1 evoked larger negative responses than faces and words, $ts(22) > 3.90$, $ps < .001$, $gs_{av} > .783$. Although unexpected, this large RH deflection for glasses T1 reflects some form of lateralized processing for the glasses stimuli, most likely due to the leftward orientation of the glasses frames.

Correlation plots for face T2 neural activity and behavior are presented in Figure 9. Although there were differences in the

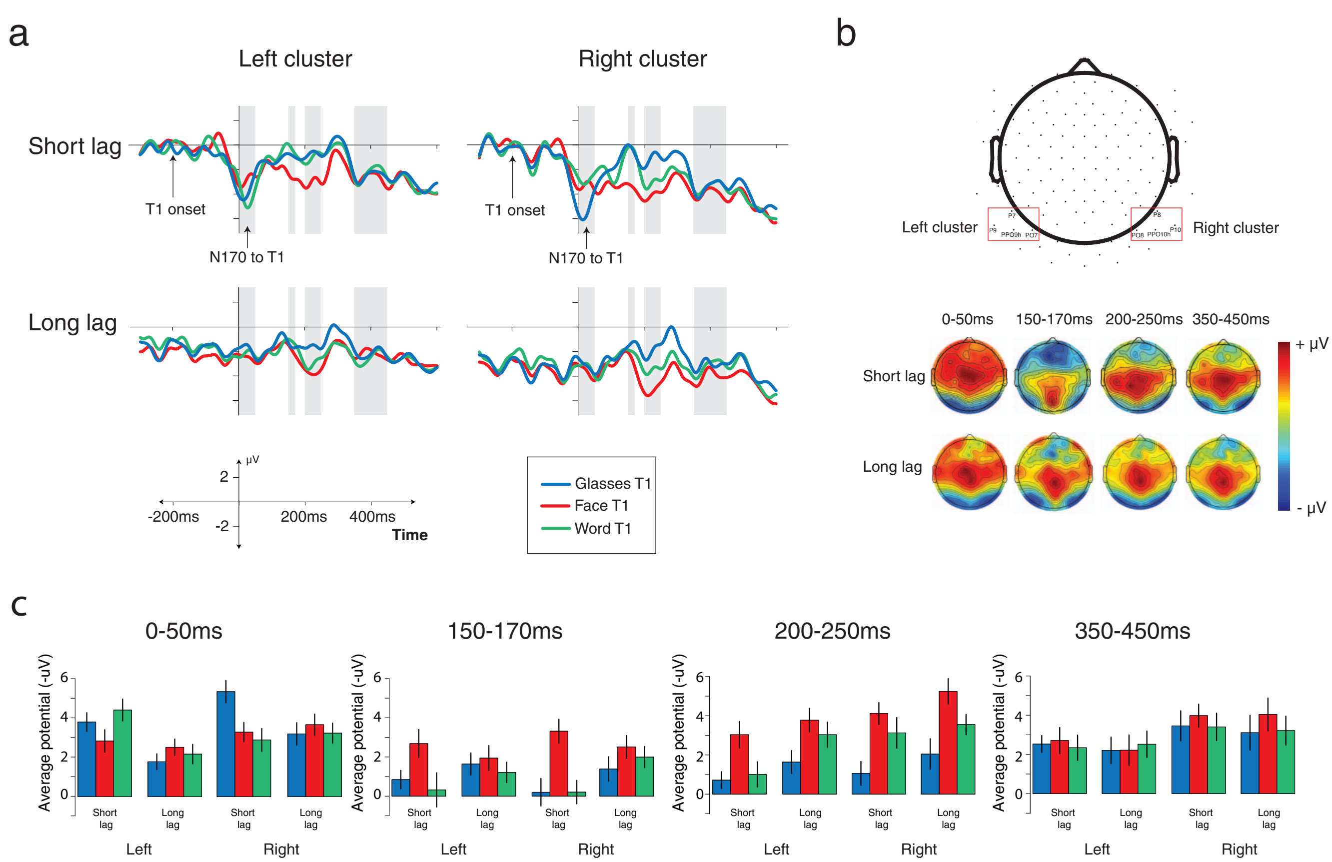

Figure 8. Electroencephalography (EEG) results for Face T2 over left and right occipitotemporal electrodes. (a) Event-related potentials in response to Face T2 for each experimental condition. Gray bars indicate the time windows analyzed. (b) Scalp maps showing average EEG response on the scalp for the time windows analyzed. (c) Bar plots quantifying the ERP amplitude at each critical time window for each condition. T1 = Target 1; T2 = Target 2. See the online article for the color version of this figure.

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Table 1
Results of Statistical Tests for Face T2 Event Related Potentials

Factors	*df*	Left *F*	Left *p*	Right *F*	Right *p*
0 ms to 50 ms					
T1 object	2, 44	1.61	.211	9.00	.001*
Lag	1, 22	9.86	.005*	.86	.36
T1 × Lag	2, 44	3.59	.036	7.06	.002*
150 ms to 170 ms					
T1 object	2, 44	4.65	.015	11.49	<.001*
Lag	1, 22	.53	.475	3.87	.062
T1 × Lag	2, 44	2.01	.146	4.79	.013
200 ms to 250 ms					
T1 object	2, 44	18.45	<.001*	31.23	<.001*
Lag	1, 22	7.41	.013	3.65	.069
T1 × Lag	2, 44	1.63	.207	.46	.632
350 ms to 450 ms					
T1 object	2, 44	.02	.980	1.56	.221
Lag	1, 22	.29	.595	.14	.717
T1 × Lag	2, 44	.50	.612	.16	.855

Note. For each time point and hemisphere, a 3 × 2 repeated-measures analysis of variance was conducted with factors of T1 class (face, word, glasses) and lag (short T1–T2 lag and long T1–T2 lag). T1 = Target 1; T2 = Target 2.
* $p < .0125$ (significant effects).

absolute amplitudes for different T1 objects at this time period, relative neural activity for long and short lags did not correlate with T2 discrimination performance. There was no significant correlation for any T1 class over LH electrodes ($-.05 < rs < .07$, $ps > .744$) or RH electrodes ($-.20 < rs < .03$, $ps > .354$).

Negative Peak 150 ms to 170 ms. Over the LH, the face–face combination evoked a larger negative deflection during short-lag trials than the other T1 classes, but this did not reach significance. Similarly, over the RH, the face–face combination evoked a larger negative response than glasses and words, $ts(22) < -4.07$, $ps < .001$, $gs_{av} > .761$, which was particularly evident for short-lag trials. This larger face–face negativity is in keeping with a previous article describing ERP modulation of faces during the attentional blink as early as 150 ms post T2 onset (Darque, Del Zotto, Khateb, & Pegna, 2012). Importantly, however, we found no significant correlation between long–short-lag ERP differences and behavioral performance for any T1 class over LH ($-.23 < rs < .19$, $ps > .290$) or RH electrodes ($-.22 < rs < .03$, $ps > .304$).

Peak 200 ms to 250 ms. This peak reflected the N170 to the face T2, with larger peaks over the RH than the LH. In the left cluster, face T1 gave rise to a larger negative response to face T2 than words and glasses, $ts(22) < 3.27$, $ps < .004$, $gs_{av} > .518$, but the difference between glasses and word T1 did not reach significance after multiple comparisons correction, $ts(22) = 2.63$, $p = .015$, $g_{av} = .357$. In the right cluster, face T1 again evoked a larger negative response than glasses and words, and words evoked a larger negative response than glasses, $ts(22) > 3.90$, $ps < .001$, $gs_{av} > .491$. Amplitude analyses at this peak thus indicate differential responses to faces depending on the preceding T1 object class. Long-lag–short-lag behavioral performance did not correlate with ERP differences for any T1 condition over the LH ($-.18 < rs < -.12$, $ps > .410$) or over the RH ($-.39 < rs < -.01$, $ps > .065$).

Peak 350 ms to 450 ms. There were no significant effects of lag or T1 on face T2 ERPs over left or right electrodes. Furthermore, behavioral performance did not correlate with ERP differences over the LH for the word or glasses T1 conditions ($-.13 < rs < -.001$, $ps > .540$), but there was a marginal correlation for face T1 ($r = .48$, $p = .020$; given $\alpha = .0125$). There were no significant correlations over the RH ($-.32 < rs < .09$, $ps > .133$).

Overall, face T2 ERPs showed some modulation depending on the T1 object class, with differential effects for the face–face combination in particular. Nevertheless, relative ERP amplitude did not correlate with behavioral performance across participants for any of the time points analyzed.

Word T2. EEG waveforms are depicted in Figure 10a for the left and right electrode clusters. Results from the omnibus ANOVAs are presented in Table 2.

Peak 0 ms to 50 ms. As can be seen in Figure 10, short-lag ERPs at this time window were indicative of the N170 in response to T1. Over the LH, word T1 resulted in significantly larger negative deflection than glasses and faces, $ts(22) > 2.83$, $ps < .010$, $gs_{av} > .432$, but the difference between face and glasses T1 was only marginal after stringent correction, $t(22) = 2.68$, $p = .014$, $g_{av} = .652$. Over right electrodes, for short-lag trials, glasses T1 resulted in larger negativity than words and faces, $ts(22) > 4.82$, $ps < .001$, $gs_{av} > .620$, but there was no significant difference between face and word T1, $t(22) = 2.48$, $p = .021$, $g_{av} = .476$. This trend was the same as for the Face T2 ERPs.

Correlation plots for word T2 neural activity and behavior are presented in Figure 11. There was no significant relationship between long-lag–short-lag T2|T1 neural activity with relative behavioral performance for word or glasses T1 over the left hemisphere ($rs < .15$, $ps > .502$). There was, however, a significant correlation for face T1 ($r = .59$), $t(21) = 3.36$, $p = .003$, such that a relatively larger negative deflection in short-lag trials was associated with a larger attentional blink effect. Essentially, a relatively larger left N170 to face T1 was associated with a larger deficit in discriminating word T2. Over right hemisphere electrodes, there were no significant correlations for any T1 class ($-.28 < rs < .09$, $ps > .189$). Furthermore, the face–word correlation in the left hemisphere was significantly larger than the right hemisphere correlation ($z = 2.36$, $p = .02$).

The significant left neural-behavior correlation suggests that for processing of face T1, relatively larger negative deflections for short than long lags over the left hemisphere (typically the nondominant hemisphere for face processing and dominant hemisphere for word processing) predicted deficits in word T2 discrimination. Notably, when all T1 correct trials were analyzed regardless of T2 accuracy (such that more trials were included in the ERPs for each participant,) the strong face–word LH neural-behavior correlation remained ($r = .58$), $t(21) = 3.28$, $p = .004$. Furthermore, subsequent analyses revealed that on trials in which face T1 was correct but word T2 was incorrect, a larger LH negative peak was observed compared to trials on which both targets were correctly discriminated, $t(22) = 2.45$, $p = .023$, $g_{av} = .512$ (see the online supplemental materials for details). This result provides further evidence that a larger LH face N170 led to interference with subsequent word discrimination. Overall, these results support a perceptual interference account of face–word interference as described behaviorally in Experiments 1 through 3.

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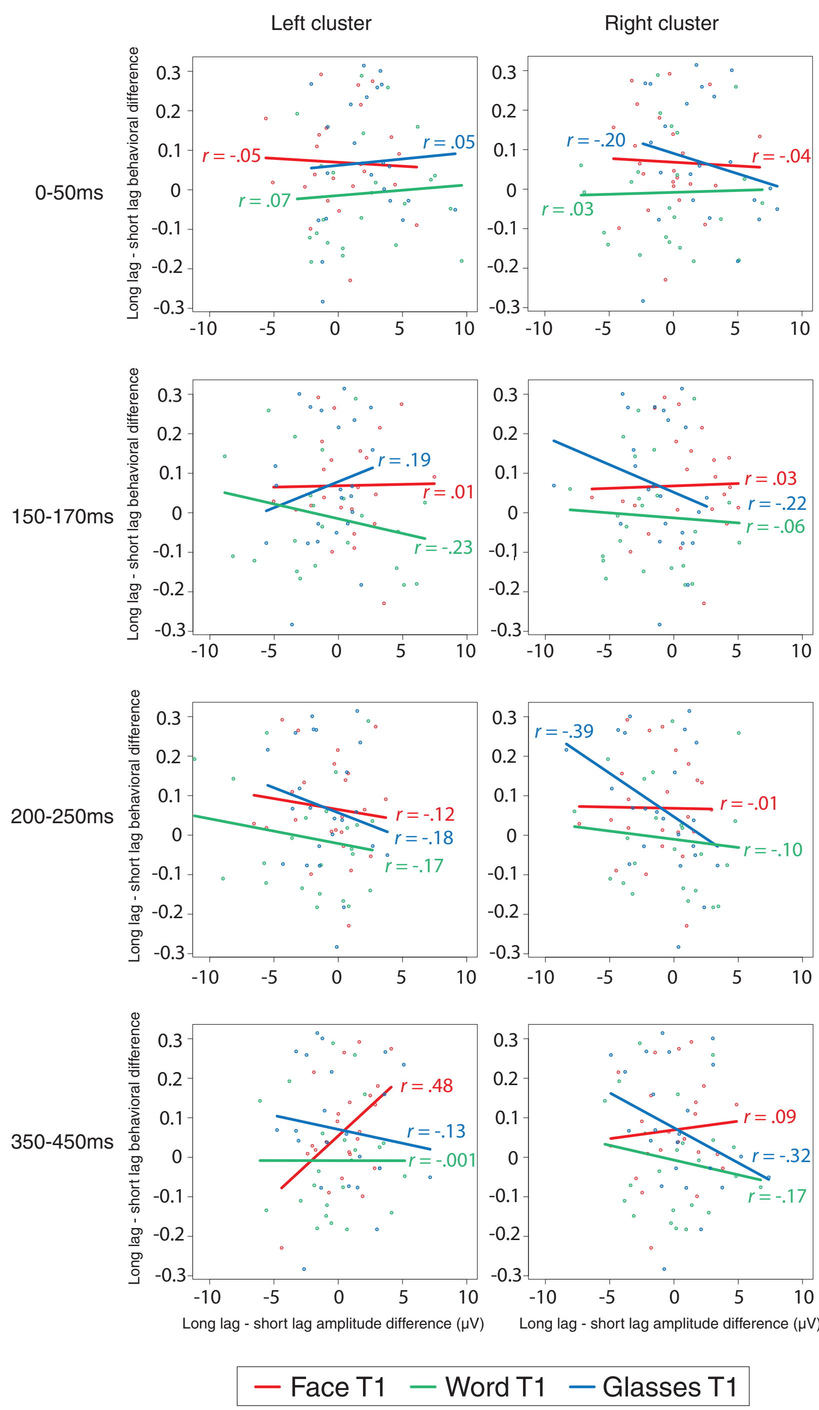

Figure 9. Face T2 scatter plots showing correlations between long–short-lag ERP amplitude difference and long–short-lag behavioral deficit for each T1 condition. Separate plots are shown for the left and right electrode clusters and four different time periods. None of the correlations reached significance given $\alpha = .0125$. T1 = Target 1; T2 = Target 2. See the online article for the color version of this figure.

Negative Peak 150–170 ms. Face T1 evoked larger negativity at this peak than the other T1 classes during short-lag trials. Over the LH, face T1 evoked a larger negative response than glasses, $ts(22) = -3.20$, $p = .004$, $g_{av} = .642$, there was no significant difference between glasses and word T1, $t(22) = .97$, $p = .341$, $g_{av} = .160$, and the difference between faces and words was marginal, $t(22) = -2.49$, $p = .021$, $p_{corrected} = .083$, $g_{av} = .452$. Over the RH, face T1 evoked a larger negativity than glasses, $t(21) = -4.63$, $p = .001$, $g_{av} = .654$, and there were marginal differences between face and word T1, and between word T1 and

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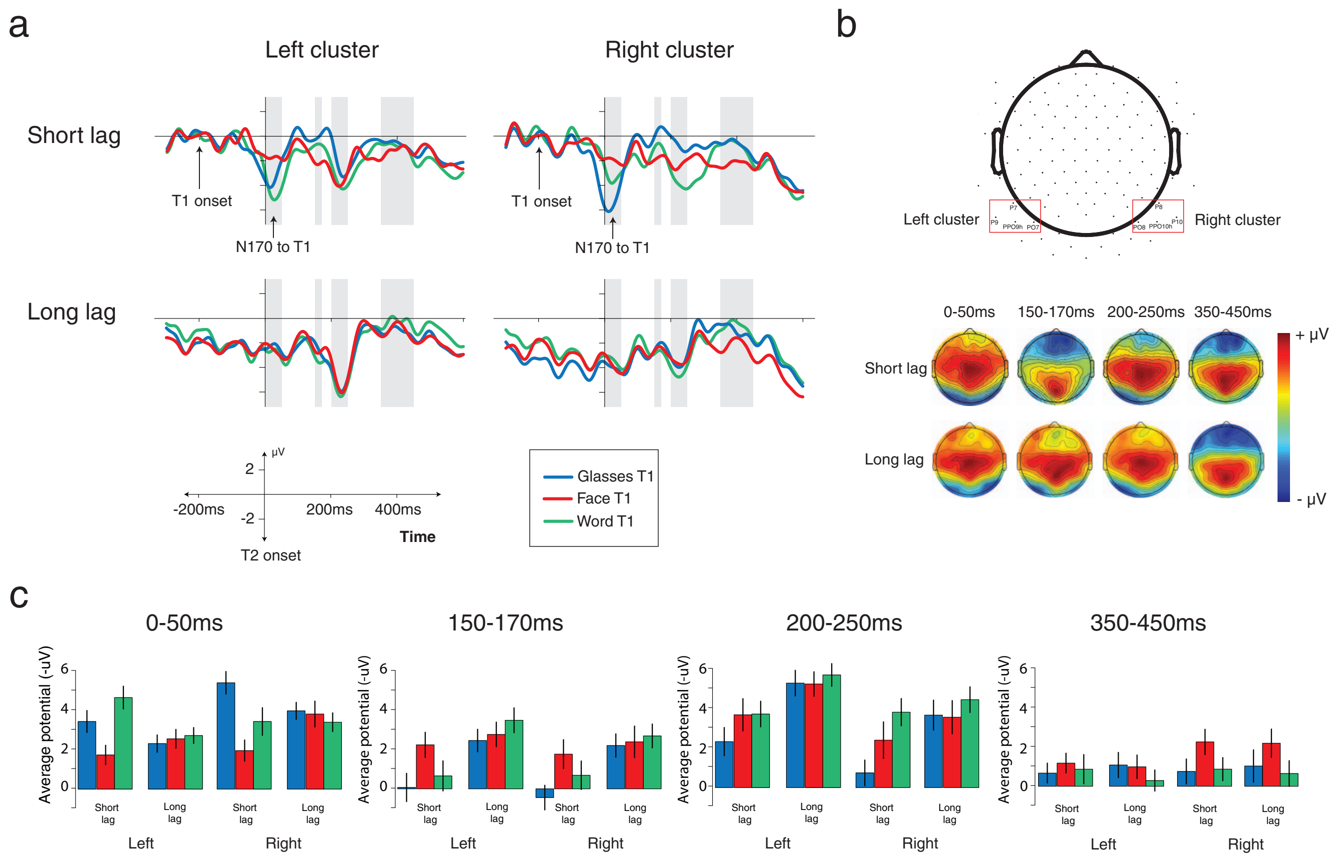

Figure 10. Electroencephalography (EEG) results for word T2 over left and right occipitotemporal electrodes. (a) Event-related potentials in response to word T2 for each experimental condition. Gray bars indicate the time windows analyzed. (b) Scalp maps showing the electrode clusters analyzed, and average EEG response on the scalp for the time windows analyzed. (c) Bar plots quantifying the ERP amplitude at each critical time window for each condition. T1 = Target 1; T2 = Target 2. See the online article for the color version of this figure.

glasses T1, $ts(22) > 2.42$, $p < .024$, $gs_{av} < .339$. These effects echoed the ERP results for face T2.

Importantly, while there was no significant correlation for glasses or word T1 neural activity with behavior over the left hemisphere, $ps > .246$, there was a marginal positive correlation for face T1 ($r = .37$, $p = .082$). Over right hemisphere electrodes, there was again a marginal correlation between neural activity and behavior for face T1 ($r = .46$, $p = .028$), but also a marginal effect for glasses T1 ($p = .082$) and a smaller positive correlation for word T1 that did not reach significance ($p = .354$). Overall, differences in EEG amplitude between long and short lags at this time point were associated with word T2 behavioral performance, particularly for the face–word combination.

Peak 200 ms to 250 ms. This peak reflected the N170 to word T2, with larger amplitude over the left than the right electrode cluster. Over both hemispheres, the 200-ms to 250-ms peak was larger for the long-lag condition than the short-lag condition, indicating the AB causes a reduction in this peak. Over the RH, word T1 evoked a greater negative response than glasses, $t(22) = 4.77$, $p < .001$, $g_{av} = .634$, and face T1 evoked potential was between glasses and word T1, $ts(22) < 2.42$, $ps > .024$, $gs_{av} < .340$. As can be seen in Figure 10c, this T1 effect is driven by differences in the short-lag condition.

For the relationship between neural activity and behavioral performance, there was no significant correlation for glasses or word T1 over the left hemisphere ($-.13 < rs < -.11$, $ps > .540$), but there was a marginal positive correlation for face T1 ($r = .41$, $p = .051$). Similarly, over right hemisphere electrodes, there was a marginal correlation between relative neural activity and behavior for face T1 paired with word T2 ($r = .39$, $p = .066$), but no significant correlation for glasses or word T1 ($-.07 < rs < .157$, $ps > .475$). Overall, analyses suggested a trend such that relatively larger negative deflections for the word T2 N170 on short lags was correlated with the behavioral deficit on face–word trials. Interestingly, these results along with the 0-ms to 50-ms peak results indicate that larger face–word AB effects were associated with larger left N170 peak to face T1 and larger left and right N170 to the subsequent word T1 on short-lag trials relative to long-lag trials.

Peak 350 ms to 450 ms. At this later peak, there were no significant effects in the left cluster for word T2 ERPs. In the RH, face T1 evoked a lower response than glasses, $t(22) = 3.14$, $p = .005$, $g_{av} = .421$, and marginally lower than words, $t(22) = 2.76$, $p = .011$, $g_{av} = .521$, but there were no significant differences between glasses and words, $t(22) = .25$, $p = .805$, $g_{av} = .044$.

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Table 2
Results of Statistical Tests for Word T2 Event Related Potentials

Factors	*df*	Left *F*	Left *p*	Right *F*	Right *p*
0 ms to 50 ms					
T1 object	2, 44	8.48	.001*	14.03	<.001*
Lag	1, 22	2.31	.143	.08	.783
T1 × Lag	2, 44	6.97	.002*	5.99	.005*
150 ms to 170 ms					
T1 object	2, 44	3.89	.028	4.08	.024
Lag	1, 22	11.94	.002*	9.00	.007*
T1 × Lag	2, 44	6.68	.003*	3.97	.026
200 ms to 250 ms					
T1 object	2, 44	1.81	.176	9.32	<.001*
Lag	1, 22	29.62	<.001*	10.11	.004*
T1 × Lag	2, 44	1.58	.219	4.11	.023
350 ms to 450 ms					
T1 object	2, 44	.61	.549	5.34	.008*
Lag	1, 22	.11	.746	.00	.993
T1 × Lag	2, 44	1.01	.373	.28	.761

Note. For each time point and hemisphere, a 3 × 2 repeated-measures analysis of variance was conducted with factors of T1 object (face, word, glasses) and lag (short T1–T2 lag and long T1–T2 lag). T1 = Target 1; T2 = Target 2.
* $p < .0125$ (significant effects).

There was no significant EEG-behavior correlations for glasses or word T1 over the left hemisphere ($-.10 < r\text{s} < -.001$, $p\text{s} > .651$), but there was a significant positive correlation for face T1 ($r = .46$, $p = .029$). Over right hemisphere electrodes, there was a marginal correlation between long-lag–short-lag neural activity and behavior for face–word ($r = .41$, $p = .051$) and a significant correlation for glasses–word ($r = .56$, $p = .006$) and a small positive correlation for word–word that did not reach significance ($r = .24$, $p\text{s} = .263$). Overall, there was a trend suggesting LH EEG responses for the 350-ms to 450-ms peak correlated with behavior for both face T2 and word T2 when preceded by face T1. Furthermore, word T2 behavioral performance was positively correlated with evoked EEG responses over right hemisphere electrodes for all T1 conditions, particularly for face and glasses T1. These results suggest this time period might be indicative of the AB effect exhibited by all object class combinations, which is supported by previous EEG studies of the attentional blink (Kranczioch et al., 2003; Sergent et al., 2005; Vogel et al., 1998).

Overall, Experiment 3 replicated the behavioral effects of Experiments 1 and 2 to provide further evidence that face T1 processing disproportionately interferes with word T2 processing during rapid serial visual presentation. EEG results indicated that face T1 influenced neural responses to word T2 at all time points analyzed. In particular, faces resulted in smaller amplitude responses for short-lag trials 0 ms to 50 ms after word T2 onset (200 ms to 250 ms after T1 onset) than the other T1 objects. At this time period, the ERP amplitude difference between long and short lags over LH electrodes was also significantly correlated with the long–short-lag behavioral deficit, indicating that relatively larger face responses in the left hemisphere led to greater interference for word discrimination. Positive neural-behavior correlations were observed at every time point for the face–word combination, but not consistently for other T1–T2 combinations, indicating that neural responses to faces resulted in a different pattern of responses at all stages of word processing in the short-lag condition. Face–word interactions observed in Experiment 3 therefore support the hypothesis that face–word interference occurs due to overlapping mechanisms of face and word processing in ventral areas of the brain.

Meta-Analysis of Behavioral Word Interference From Experiments 1 and 3

To investigate the common behavioral results across experiments, we conducted a mini meta-analysis on the word T2 data from Experiments 1 and 3, which contained the most similar experimental designs. The analysis was conducted in R using the Metafor package, taking into account effect sizes and sample sizes of the two experiments. The analysis revealed that overall, the deficit for the face–word combination was significantly greater than either the glasses–word (see Figure 12a) or word–word combinations (see Figure 12b; $p\text{s} < .001$). Furthermore, the word–word combination was not significantly different from the glasses–word combination (see Figure 12c; $p = .106$). Across these two experiments (as well as in Experiment 2), it is clear that the face–word combination induced significantly greater perceptual deficits than both the glasses–word and word–word combinations, indicating that faces specifically interfere with word processing.

General Discussion

The aim of this study was to determine whether and how overlapping mechanisms between faces and words manifest in perceptual interference during rapid serial visual presentation in healthy individuals. This question is particularly pertinent given the recent findings that the underlying mechanisms supporting the representation of faces and words are not as independent as previously assumed.

Across three experiments, we showed that discrimination of two face, word or glasses targets generally resulted in a deficit in T2 discrimination when T1–T2 target asynchrony was 200 ms to 300 ms (short lag) relative to 700 ms to 900 ms (long lag); a typical attentional blink effect. Crucially, however, face discrimination reduced subsequent word discrimination to a greater extent than the deficits observed with other target combinations. In Experiment 1, the face–word combination resulted in significantly greater interference than word–word combination, but only marginally greater interference than the glasses–word combination. Behavioral results from Experiments 2 and 3 revealed the face–word combinations resulted in significantly greater interference than the glasses–word and word–word combinations. To assess the consistency of these effects, a meta-analysis was conducted for the word T2 discrimination results of Experiments 1 and 3, which had very similar experimental designs. Overall, this analysis revealed a clear interference effect of the face–word combination over and above that of the glasses–word and the word–word combinations. Clearly, faces interfered with word perception for object-specific discrimination (Experiments 1 and 3) and category discrimination tasks (Experiment 2). Furthermore, electroencephalography results (Experiment 3) revealed hemispheric-dependent responses such that relatively greater face T1 activity in the left hemisphere was associated with greater interference for word T2 discrimination.

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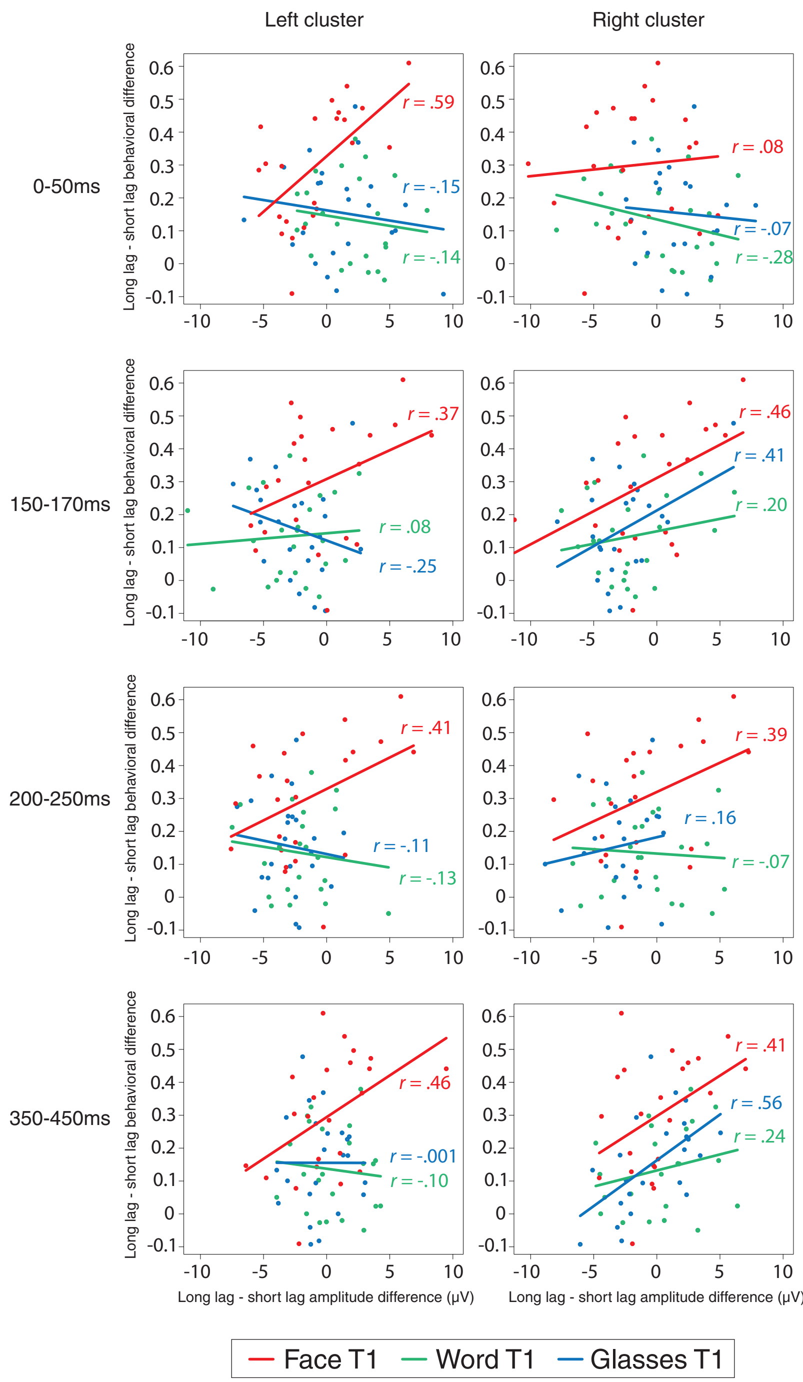

Figure 11. Word T2 scatter plots showing correlations between long-short lag event-related potential (ERP) amplitude difference and long-short lag behavioral deficit for each T1 condition. Separate plots are shown for the left and right electrode clusters and four different time periods. See the online article for the color version of this figure.

The AB for Faces and Words

When considering the results from all T1–T2 object combinations, it is clear that the short-lag deficit is a combination of a typical "attentional blink" effect and a cost associated with a task switch, presumably due to interference at an earlier stage of visual processing. Previous research has indicated that task switching and AB limitations can be additive (Chun & Potter, 2001). In the current study, target discrimination performance was much higher when T1 and T2 were from the same class of objects and did not require a task switch (e.g., word–word) than when the targets were two different objects (e.g., glasses–word). Crucially, however, face–word combinations resulted in a greater AB deficit than other object combinations, indicating that

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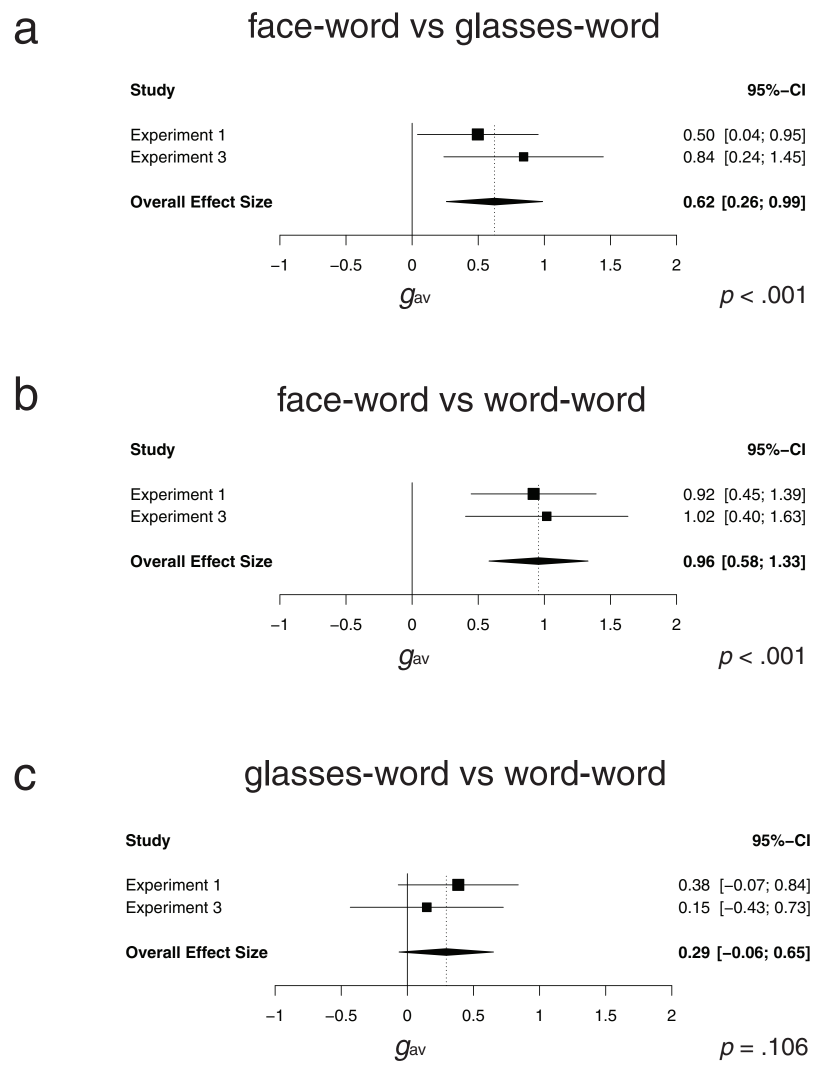

Figure 12. Forest plots quantifying the effect sizes and overall significance and across Experiments 1 and 3 for (a) face-word vs glasses-word, (b) face-word vs word-word, and (c) glasses-word vs word-word T1-T2 target combinations.

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the costs involved in processing a face and a subsequent word are larger than the switch cost for other object combinations. Note also that the converse was not true and a word T1 did not differentially compromise a face T2, indicating that the face–word deficit was not due to a switch cost involving two independent processes. Face T1 did not cause a larger AB for glasses T2 than word T1, negating the possibility that faces cause a general impairment in subsequent object processing. Essentially, faces interfered with word processing, indicating that the demands for these two processes involve common psychological and neural mechanisms.

EEG results in Experiment 3 revealed marked differences in the neural responses to the targets depending on the T1 and T2 objects and the lag between them. Face T1 trials induced smaller negative peaks 0 ms to 50 ms and larger negative peaks 150 ms to 170 ms after T2 onset compared with glasses and word T1, for both face and word T2, indicating face processing differentially influences subsequent neural responses. Importantly, however, relatively larger LH negativity in the short-lag trials 0 ms to 50 ms following T2 onset (N170 in response to T1) was significantly correlated with the behavioral short-lag deficit for face–word trials but not for other object combinations. This peak was too early to indicate a neural response to T2, but rather a neural response to the preceding T1 object and distractors. For short-lag trials, this peak was 200 ms to 250 ms post T1 onset, and exhibited features of the canonical N170 component to T1. Specifically, this component was a large negative deflection, and word T1 objects evoked a larger negative peak over the left cluster during this time period. Interestingly, this peak was much smaller in response to face T1 and did not show a larger negative deflection over the right hemisphere, possibly reflecting greater neural adaptation for faces than other objects in

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this paradigm. Our results show that the first neural correlate of face–word interference occurred during the LH N170 component to face T1, indicating that LH occipito-temporal face processing causes the subsequent deficit in word perception. Indeed, it is logical that neural correlates of the perceptual deficits should also manifest in the ERP traces for word T2 at later time points. In terms of ERP amplitude, face T1 caused a greater negativity in the RH in the time period 350 ms to 450 ms relative to word and glasses T1. This effect was found for both short- and long-lag trials, meaning it was not residual face T1 processing (in long-lag trials, this time period corresponded with 1050 ms to 1150 ms post face T1 onset, which is likely too late to reflect face processing). This result was not specific to short lags and thus is not directly related to our behavioral face–word interference effect, but it is clear evidence that faces influence subsequent word processing. There were also positive correlations between long-lag–short-lag ERP amplitude difference and behavioral interference for the face–word combination at all analyzed time points in the left hemisphere, not just at 0 ms to 50 ms, and also present over the RH beginning at a later time point, from 150 ms to 170 ms post T2. Interestingly, the positive face–word neural-behavior correlation was observed at 200 ms to 250 ms and 350 ms to 450 ms even though there was no significant difference in the evoked LH amplitudes for different T1 classes at these time points. That is, these components are likely to reflect neural responses to word T2, rather than face T1. Taken together, it seems most likely that left face N170 responses altered subsequent word processing, leading to poorer word discrimination.

Neural Bases of the Asymmetric Face–Word AB

The interference between faces and words observed in these experiments is consistent with shared processing resources for face and word perception. Specifically, this result adds to the growing body of evidence that face and word processing is subserved by distributed, overlapping representations in occipitotemporal areas of the brain. Previous research has shown that faces and words have unique responses in fusiform areas compared with objects, and these areas (FFA and VWFA) seem to perform functions specifically for processing these objects of expertise. There is overlap between FFA and VWFA in both hemispheres, however, which speaks to some shared mechanisms for face and word perception. This study shows for the first time that in healthy individuals, faces disrupt word processing, and the degree of LH face N170 activity is correlated with interference in word processing. The N170 has been widely studied and is known to be associated with activity in the fusiform gyrus (Ghuman et al., 2014). The involvement of the face N170 component in face–word interference thus points to meaningful overlapping neural processes for faces and words in the left fusiform gyrus supporting object discrimination. Importantly, the left hemisphere is the nondominant hemisphere for face processing, but the dominant hemisphere for word processing. This result has implications for the function of the nondominant hemisphere for face and word perception, suggesting at the very least that face and word perception both involve left hemispheric processing.

Face–word interference observed across the three experiments was asymmetric; that is, faces hampered word processing, but words did not interfere with face processing more than face–face or glasses–face combinations. This is a particularly intriguing result. It could be that the degree of overlap between face and word processing is different in the left and right hemispheres. One theory of visual lateralization is that word representations are left lateralized due to proximity with language areas, and acquisition of reading results in competition with face processes, causing face representations to become more right lateralized (Behrmann & Plaut, 2015). The current results that LH face processing interferes with word perception may be a signature of such LH face–word competition that remains in adulthood. Using fMRI, Harris et al. (2016) found there were more voxels selective for both faces and words in the left than the right hemisphere, indicating greater face–word overlap in the left than the right hemisphere. Face–word interference in the current study was associated with initial left hemispheric responses, indicating that the degree to which the nondominant hemisphere was involved in processing face T1 was predictive of word T2 interference. In the word–face condition, perhaps right hemispheric word processing was not sufficient to interfere with subsequent face processing, or did not necessitate the same processes as right hemispheric face processes. The asymmetry finding actually supports the account of overlapping face and word representations more than any alternative explanation (e.g., low-level visual interference, working memory conflicts), which to our knowledge cannot explain face–word interference, behavioral asymmetry and a LH locus of interference.

Another point that might influence the asymmetry of face–word interference, however, is that faces seem to exhibit different patterns of results during RSVP. Several studies have found that face T2s are often spared from the attentional blink deficit, perhaps because they are relatively more salient than other stimuli types (Awh et al., 2004; Landau & Bentin, 2008; Müsch, Engel, & Schneider, 2012). Furthermore, T2 faces during the AB period have been shown to exhibit lower ERP amplitudes 150 ms to 260 ms post onset (Darque et al., 2012), an earlier time point than other stimuli classes, indicating a different locus of AB target interference for faces. We observed typical behavioral AB effects for face T2 in this study, albeit sometimes smaller than the other stimuli, indicating that faces were not immune to the attentional blink using this paradigm. It is possible, however, that face T2 salience might have resulted in lower word–face interference than the reverse order of stimuli. In the future, the timing of face–word interference could be characterized by looking at the N170 components evoked when targets are presented at variable intervals.

We found that overlapping neural mechanisms for faces and words result in face–word interference during RSVP. However, a question remains: Why is it that when the two targets were from the same object category (e.g., word–word), and therefore necessitated the same processes, the AB was attenuated, or even eliminated (as in Experiment 2)? As mentioned earlier, it could be that it was easier to perform the two-target task when no task switch was required. Additionally, perhaps two words, faces or glasses objects are easily processed in parallel, such that objects could prime another object from the same category during RSVP. Indeed, we found that performance was generally higher for T1 and T2 when the images were from the same category, speaking to a general priming effect for both targets. Reading fundamentally involves quick discrimination of successive words, so it seems likely that two words can be processed in parallel, or at least in very rapid succession. Face and word discrimination, in contrast,

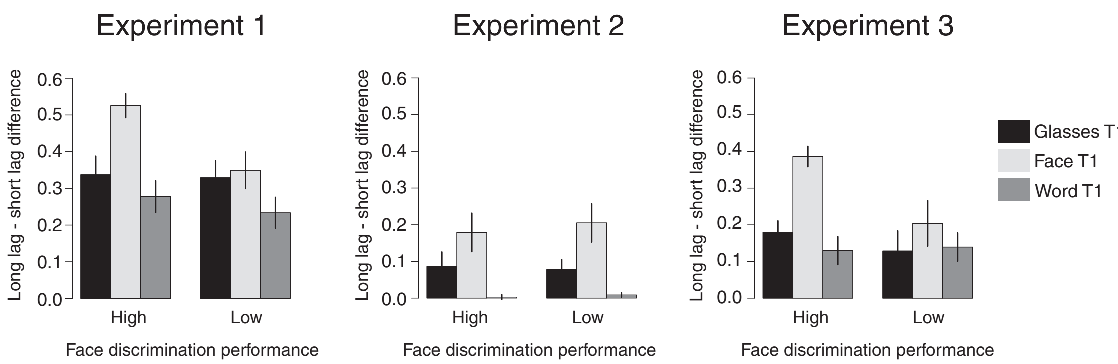

Figure 13. Long-lag–short-lag behavioral decrement for word T2 as a function of face discrimination performance and T1 condition in Experiments 1 through 3. T1 = Target 1; T2 = Target 2.

are not often performed successively, so there is little need for parallel processes. Previous research found evidence of parallel processing for letters within a word after learning, particularly when words were presented to the right visual field, indicating that the left hemisphere processes letters within familiar words in parallel (Ellis et al., 2009). Whether such parallelized perceptual processes might extend to multiple words is unknown, but the possibility is interesting. On a broader level, there is evidence for perceptual priming of different objects within a category; multiple studies showed increased behavioral performance for repeated objects, even when different exemplars of the objects were shown (Koutstaal et al., 2001; Simons, Koutstaal, Prince, Wagner, & Schacter, 2003). Furthermore, different exemplars of an object exhibited repetition suppression within the left fusiform gyrus, very close to the approximate location of VWFA, whereas the right fusiform only exhibited exemplar-specific suppression (Koutstaal et al., 2001). Taken together, it seems that left fusiform gyrus might support enhanced perception of successive similar objects, for example those within the same category. We propose that the face–word interference observed in Experiments 1 through 3 are a consequence of the functional overlap in face and word processing, without the advantage of within-category priming or parallel processing.

Expertise Effects and the face–word AB

The results of this study also yield insight into the development and features of lateralized visual perception. A current theory is that visual perception becomes lateralized due to experience as well as pressures from other brain areas such as those involved in language (Behrmann & Plaut, 2015). A hypothesis offered by this account is that as word representations become optimized in the left hemisphere with reading acquisition, so the face representations become increasingly (albeit not solely) lateralized to the right hemisphere.

Consistent with this hypothesis, previous studies have found that expertise influences the degree of overlap between objects and faces (Gauthier et al., 2000, 2003a; Mcgugin et al., 2011), but whether this might also be true for the well-learned categories of faces and words has not been explored. To examine this issue, we identified participants who were high and low face discriminators (a proxy for face expertise), based on a median split of face T1 accuracy, and examined their word T2|T1 performance (see Figure 13). In Experiments 1 and 3, participants with high face discrimination ability exhibited greater face–word AB deficits. This effect was not observed in Experiment 2, possibly because of a ceiling effect; mean performance of the "low" face categorizers in this experiment was 91.6%. In the attentional blink literature, investigations into the relationship between T1 accuracy and the attentional blink has yielded variable results, but whenever a significant effect has been found, higher T1 accuracy yielded lower AB deficits (Arnell, Howe, Joanisse, & Klein, 2006; Seiffert & Di Lollo, 1997; Visser, 2007). The observed relationship between face discrimination performance and face–word interference is thus in the opposite direction to that expected because of working memory or other high level limitations. This result adds support to the idea that perceptual interference is responsible for our observed face–word deficits. It is plausible that greater expertise for faces results in larger face–word competition in fusiform brain areas, in a similar manner to that found for car expertise and car–face interference (Gauthier, Curran, Curby, & Collins, 2003b).

Overall, the results of the three RSVP studies show that faces interfered with word processing to a greater extent than other object combinations. Furthermore, the behavioral face–word interference was associated with the N170 response to faces over left occipitotemporal electrodes, consistent with a role of overlapping regions in the LH for both face and word processing. On a broader level, this adds to the growing body of evidence that face and word areas of the brain develop in part because of mutual competition between faces and words (Behrmann & Plaut, 2015), and has implications for the bilateral nature of face and word representations.

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