

# Aging effects on early-stage face perception: An ERP study

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## Abstract

We compared early stages of face processing in young and older participants as indexed by ERPs elicited by faces and non-face stimuli presented in upright and inverted orientations. The P1 and N170 components were larger in older than in young participants. However, the early distinction between stimulus categories as reflected by N170 face was similar across groups. Face inversion increased and delayed the N170 peak in the younger group while in older participants inversion delayed the N170 peak but had no effect on amplitude. The N170 amplitude was right-lateralized in the young, but not in the older group. Yet, the difference between the N170 elicited by faces and non-face stimuli was similarly right-lateralized in both groups. These data suggest that detection of faces and their streaming to face-characteristic structural encoding is not altered by age. In contrast, the absence of face-inversion effects on N170 amplitudes in the elderly suggest that face individuation, which is probably the default strategy in younger people, might not be attempted by default in older people, at least when they look at young faces.

**Descriptors:** Aging, Face perception, N170 effect, Face inversion

Ample evidence indicates that cognitive processes, such as recall and recognition, decline with aging (e.g., Craik & Jennings, 1992; Craik & McDowd, 1987; Spirduso, 1995). In addition to cognitive ability, low-level visual functions are also frequently impaired in normal elderly people; among those are visual acuity, spatial contrast sensitivity, and spatial vision (Spear, 1993). However, whether higher-level visual perception abilities are affected by aging is less evident. To this end, in the present study we investigated possible aging effects on early stages of face processing.

Faces are ecologically important stimuli that provide essential cues with regard to a person's identity, mood, emotion, or intent, perceptual information that forms the basis for interpersonal communication. Therefore, it is not surprising that considerable efforts have been invested to investigate how face processing might change with advanced age. Most of these studies, however, focused on memory of faces (e.g., Craik & McDowd, 1987; Craik & Jennings, 1992) with an underlying assumption that age-related impairments in face recognition are part of a broader

memory decline that is characteristic to advanced aging, rather than reflecting a perceptual deficit in face processing per se (Bartlett & Fulton, 1991; Chaby, Jemel, George, Renault, & Fiori, 2001; Searcy, Bartlett, & Memon, 1999). Supporting this assumption, a recent study showed that, although elderly people have a greater difficulty in recognizing faces than recognizing objects (e.g., Grady, 2002), they demonstrated normal processing of configural and holistic information that are essential for efficient face identification (Boutet & Faubert, 2006). These data go along with previous reports that showed normal global precedence in perceiving "Navon" letters by elderly people (Bruyer, Scailquin, & Samson, 2003), while the global interference on local processing was even more pronounced in older than in younger participants (Roux & Ceccaldi, 2001).

Normal holistic and configural processing, however, does not ensure that face processing is intact. In fact, several studies reported that, despite normal or corrected to normal visual acuity, elderly people require higher contrast to detect faces or match unfamiliar faces (Owsley, Sekuler, & Boldt, 1981). It is possible, therefore, that age may have a deleterious effect on face processing that is independent of memory. To address this question in the present study, we explored early stages in face perception using the N170, an electrophysiological index of early face processing (Bentin, Allison, Puce, Perez, & McCarthy, 1996).

The N170 is a robust negative deflection peaking normally between 160 and 180 ms at occipito-temporal sites with

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significantly larger amplitude for faces relative to other object categories (Bentin et al., 1996; George, Evans, Fiori, Davidoff, & Renault, 1996). While considered by some to be an index of face structural encoding (Rossion & Gauthier, 2002; Eimer, 2000), there is ample evidence against this view. The N170 is not sensitive to face familiarity (Bentin & Deouell, 2000; Eimer, 2000), and it is not affected by scrambling the configuration of inner components either within or outside the face contour (Zion-Golumbic & Bentin, 2007), manipulations that should affect structural encoding of faces. Further, it is enhanced and slightly delayed when face components (particularly eyes) are presented outside the face contour (Bentin, Golland, Flevaris, Robertson, & Moscovitch, 2006; Itier & Taylor, 2004) as well as by face inversion (Bentin et al., 1996; Rossion et al., 1999). Since both face inversion and the isolation of components from the face contour impede configural processing, the robust N170 observed in these stimulus conditions suggests that it is elicited even when the face-specific structural encoding is interrupted. Based on this pattern, Bentin and his collaborators suggested that the N170 indexes a mechanism tuned to detect faces or face-related information in the visual field and initiates the perceptual processes that facilitate the individuation of faces within-category, and their identification (Bentin et al., 1996; Bentin et al., 2006; Sagiv & Bentin, 2001; Zion-Golumbic & Bentin, 2007). According to this view, the latency delay observed in some conditions reflects an increased difficulty to associate a stimulus to the faces category, when relevant information is spatially distorted or missing.

Previous N170 studies of face processing in the elderly are few. Chaby and colleagues found that N170 latency was unaffected by aging, but its amplitude was higher for older than younger participants and did not display the usual right larger than left hemisphere asymmetry (Chaby, George, Renault, & Fiori, 2003; Chaby et al., 2001; cf., Schweinberger & Sommer, 1991). Pfützte, Sommer, and Schweinberger (2002) did not find any age-related effects on the N170 elicited by either famous or unfamiliar faces, regardless of whether the faces were repeated or not during the experiment. However, these authors also report finding a shift from a right-dominant distribution of the N170 in the young group, towards a more symmetric distribution in the aged population. Unfortunately, the interpretation of these studies addressing face processing is limited by the absence of a non-face control condition. Indeed, the particular sensitivity of the N170 potential to faces is reflected by the *difference* between its amplitude in response to faces relative to other objects. For example, in a recent study of a congenital prosopagnosic person, Bentin and colleagues (2007) found robust N170 potentials in response to faces, which, however, were not distinguished from those elicited by watches (see also Bentin et al., 1996, for a similar pattern). Hence, the investigation of possible changes in early face processing associated with age as manifested by the N170 should address the N170-effect, rather than the N170 amplitude per se.

In the present study, we explored possible age-related changes in processing faces focusing on detection (as reflected by N170-effect) and the application of configural processing strategies (reflected by N170 inversion effect). An oddball paradigm was used, in which faces and non-face objects (tables) were randomly interspersed with butterfly pictures as visual target stimuli, and the participants kept a mental count of the occurrence of the target. A face-specific effect in early visual processing of elderly people should be reflected in the difference between the N170 elicited by faces and objects. Moreover, if aging does not impair

face configural processing, the N170 inversion effect should be similar for older and younger adults.

## Methods

### Participants

Sixteen right-handed elderly subjects (8 females, mean age 72.1 years, range 61–85 years) recruited from an elderly home participated in this study and 16 right-handed young undergraduates from the Dalian Medical University (8 females, mean age 22.8 years, range 23–35 years). All the participants reported normal or corrected-to-normal vision and had no history of current or past neurological or psychiatric illness and took no medications known to affect the central nervous system. They signed an informed consent approved by the Ethical Committee of Dalian Medical University and were paid for their participation.

### Stimuli and Task

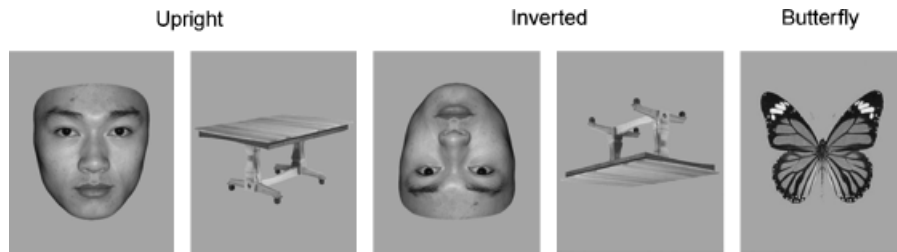
The stimuli were 72 unfamiliar young faces,<sup>1</sup> 72 tables, and 45 butterflies, all gray-scale 10.58 cm × 12.70 cm photographs. Half of the faces were male and half female, and were presented without hair, glasses, or other accessories (Figure 1). These stimuli were used to form 5 stimulus conditions: (a) upright faces, (b) (upside-down) inverted faces, (c) upright tables, (d) (upside-down) inverted tables, and (e) targets (butterflies). All images were equated for luminance and root mean square (RMS) contrast (not including the gray background in calculation), using Adobe Photoshop (www.adobe.com). The stimuli were presented at fixation and seen from a distance of 1.2 m occupied a visual angle of 5.05° × 6.06°.

Participants were tested in a dimly lit room. They sat in a comfortable chair and were instructed to keep a mental count of butterflies that occurred occasionally on the screen, while ignoring all other stimuli. This procedure has been frequently used in N170 research in order to assign similar task relevance to faces and non-face stimuli (e.g., Carmel & Bentin, 2002). The 333 stimuli were presented one at a time in three blocks, each consisting of 24 upright faces, 24 inverted faces, 24 upright tables, 24 inverted tables, and 14, 15, or 16 butterflies (targets). The order of trials within each block was randomized. Stimulus exposure time was 300 ms and separated by an inter-trial interval of 1200 ms. There was a 1-min break between blocks.

### Electrophysiological Recording and Measures

EEG was recorded continuously by a set of 30 Ag/AgCl electrodes placed according to the 10/20 system. The EEG recording sites were: FP1, FP2, F7, F3, Fz, F4, F8, FT7, FC3, FCz, FC4, FT8, T7, C3, Cz, C4, T8, TP7, CP3, CPz, CP4, TP8, P7, P3, Pz, P4, P8, O1, Oz, and O2. EOG was recorded via electrodes placed on the bilateral external canthi and the left infraorbital and supraorbital areas to monitor for eye movements and blinks. Both EEG and EOG were sampled at 1000 Hz, with a 0.1–100 Hz band pass using a Neuroscan Nuamps digital amplifiers system (Neuroscan Labs, El Paso, TX). The tip of the nose was used as reference during recording, and a common average reference was calculated off-line. Electrode impedances were kept below 5 kΩ.

<sup>1</sup>Unfamiliar young faces were used to isolate the face-detection processes from face individuation, which might be biased by an own-age advantage (see discussion).



**Figure 1.** Examples of target butterflies and non-target stimuli (faces and tables) in the upright and inverted orientations.

EOG artifacts were corrected using a correlation method proposed by Semlitsch and colleagues (Semlitsch, Anderer, Schuster, & Presslich, 1986) and supplied as part of the SCAN software. Following artifact correction, the raw EEG was re-referenced to a whole head averaged reference. Then, the EEG was segmented in epochs of 1000 ms beginning 200 ms prior to stimulus onset and averaged separately for each of the 5 conditions. Segments contaminated with artifacts exceeding amplitude of  $\pm 100 \mu\text{V}$  were excluded from averaging. After this procedure, averaged event-related potentials (ERPs) included at least 55 trials for faces and tables and 30 trials for butterflies. The averaged ERPs were low-pass filtered at 20 Hz (24dB/octave).

Based on previous studies (e.g., Bentin et al., 1996), and limited by the 30-sites montage, we have assessed the N170 components only at subset of sites including the lateral sites P7 and P8, TP7 and TP8, as well as more medially at O1 and O2 (see montage in Figure 2).<sup>2</sup> In addition, since group differences were observed for the preceding P1 component, we have also analyzed these differences at the same locations. The peak amplitudes and latencies were measured automatically between 70 ms and 120 ms and between 120 ms and 200 ms for the P1, and N170, respectively. These measures were analyzed using mixed-model ANOVA, with Group (young, older) as a between-subject factor, and Stimulus type (face, tables), Orientation (upright, inverted), Hemisphere (left, right) and site (P7/8, TP7/8, O1/2)<sup>3</sup> as within-subject factors. Since across stimulus types the amplitudes of the N170 were bigger in the old than in the young group, a normalization procedure was necessary to assess and compare the sizes of within-groups effects (cf., Sadeh, Zhdanov, Podlipisky, Hendler, & Yovel, 2008). To this end, a normalized N170-effect on the amplitudes at sites P7 and P8<sup>4</sup> was calculated as  $(\text{faces} - \text{tables}) / (\text{faces} + \text{tables})$ . Similarly, we calculated the stimulus-inversion effect as  $(\text{inverted} - \text{upright}) / (\text{inverted} + \text{upright})$ , for faces and tables separately. These ratios were analyzed using a mixed model (Group  $\times$  Orientation  $\times$  Hemisphere) ANOVA as well as (Group  $\times$  Stimulus type  $\times$  Hemisphere) ANOVA.

## Results

One elderly participant had to be excluded from the analysis due to excessive EOG artifacts. Hence the following results compare 16 young and 15 older participants.

<sup>2</sup>A similar analysis with the mean amplitude during an epoch between 135 to 185 ms, which encompasses the N170 peak, yielded a similar pattern of results. Therefore, conforming to the absolute majority of N170 literature we will report only the N170 peak analysis.

<sup>3</sup>The degrees of freedom for these factors have been adjusted using the Greenhouse-Geisser epsilon.

<sup>4</sup>At these sites the effects were maximal for both groups (see results).

Target monitoring was equally good in both groups (98.7% for older participants and 99.1% for young participants, respectively,  $F(1,29) < 1.0$ ). Non-target stimuli, i.e., faces and tables, elicited clear P1 and N170 components with significant occipital-temporal distribution in both young and older participants (Figure 2).

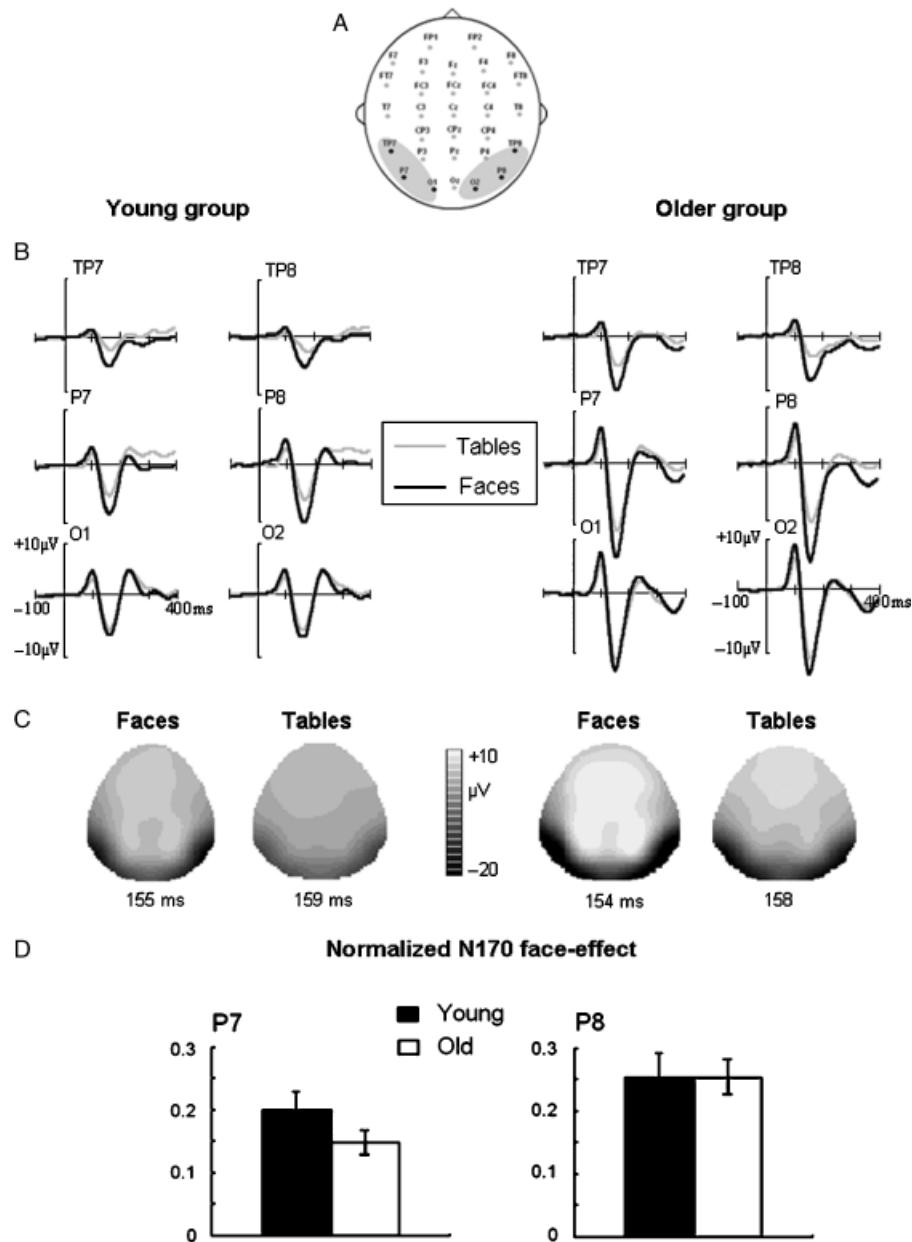
### P1 Component

As presented in Figure 2, the P1 component has been affected by experimental manipulations. These differences have been analyzed and the ANOVA tables for amplitude and latency are available in Appendix A and Appendix B, respectively. Across all sites and conditions, the P1 amplitude was larger in the older group (5.2  $\mu\text{V}$ ) than in the young group [3.4  $\mu\text{V}$ ;  $F(1,29) = 4.3$ ,  $p < .05$ ], but there was no main effect of Group on the P1 latency [100 ms and 99 ms for the older and young group, respectively;  $F(1,29) < 1.0$ ]. The analysis of the *amplitude* yielded several significant effects of factors with repeated measures, none of which, however, interacted with Group. The P1 elicited by faces (5.1  $\mu\text{V}$ ) was bigger than that elicited by tables (3.5  $\mu\text{V}$ ), inverted stimuli elicited a higher P1 (4.5  $\mu\text{V}$ ) than upright stimuli (4.1  $\mu\text{V}$ ) and, at the more posterior sites, the P1 was larger than at the more anterior sites (5.9  $\mu\text{V}$ , 4.9  $\mu\text{V}$ , and 2.0  $\mu\text{V}$  for O1/2, P7/8, and TP7/8, respectively). Both the Orientation and the Stimulus Type effects were modulated by significant interactions with Site. Although *t*-tests indicated that P1 for faces was larger than for tables at all sites, the difference was larger at both O1/2 (2.2  $\mu\text{V}$ ) and P7/8 (1.9  $\mu\text{V}$ ) than at TP7/8 (0.8  $\mu\text{V}$ ). The inversion effect was significant at O1/2 (0.62  $\mu\text{V}$ ) and P7/8 (0.38  $\mu\text{V}$ ), but not at TP7/8 ( $-0.01 \mu\text{V}$ ). No other factors influenced the P1 amplitude. Only two factors influenced the P1 *latency* significantly, and none of those interacted with age. Its latency was longer for inverted stimuli (100.7 ms) than for upright stimuli (98.5 ms), and the latency at O1/2 was shorter (97.8 ms) than at P7/8 (101.3 ms) while at TP7/8 the latency was not different than either of the other two sites (99.7 ms).

### N170 Component

The N170 amplitudes and latencies in the different experimental conditions are presented in Tables 1 and 2, respectively, and the full ANOVA tables are available in Appendices C and D, respectively. Figure 2-B displays these ERPs. Overall, the N170 component was significantly larger in the older group ( $-11.9 \mu\text{V}$ ) than in the young group [ $-7.3 \mu\text{V}$ ;  $F(1,29) = 12.4$ ,  $p < .001$ ], but the peak latency of the N170 did not differ between groups [160.5 ms and 162.3 ms for the older and young groups, respectively;  $F(1,29) < 1.0$ ].

In the N170 *amplitude* analysis, the following effects were significant and did *not* interact with the age Group: The N170 was larger for faces ( $-11.7 \mu\text{V}$ ) than for tables ( $-7.6 \mu\text{V}$ ). A Site



**Figure 2.** (A) The electrode sites layout and the approximate location of the analyzed sites. (B) Grand averaged ERPs elicited by upright faces and tables at the analyzed sites for young and older participants. (C) The 2D scalp topographic distributions of N170 peak amplitudes. (D) Normalized N170 face-effect in elderly and young groups.

× Stimulus Type interaction followed by separate ANOVAs for faces and tables revealed that, whereas for faces the N170 was larger at the P7/8 ( $-14.7 \mu\text{V}$ ) than at TP7/8 ( $-12.2 \mu\text{V}$ ) and smallest at O1/2 ( $-8.1 \mu\text{V}$ ), for tables the N170 was equally large at the lateral electrodes ( $-9.0 \mu\text{V}$  and  $-9.7 \mu\text{V}$  for P7/8 and TP7/8, respectively), both larger than at O1/2 ( $-3.9 \mu\text{V}$ ). Furthermore,  $t$ -tests showed that, although significant at all sites, the Stimulus Type effect was largest at the P7/8 sites and smallest at the O1/2 sites ( $-4.9 \mu\text{V}$ ,  $-3.8 \mu\text{V}$ , and  $-1.8 \mu\text{V}$ , for the P, TP, and O sites, respectively). Finally, a Stimulus Type × Hemisphere interaction followed by  $t$ -tests showed that the N170 elicited by faces was larger at right hemisphere sites ( $-12.2 \mu\text{V}$ ) than left hemisphere sites ( $-11.2 \mu\text{V}$ ), whereas for tables the N170 was equal bilaterally ( $-7.4 \mu\text{V}$  and  $-7.7 \mu\text{V}$  for the right and left

hemispheres, respectively). Furthermore, the Stimulus Type effect was larger at right hemisphere sites ( $-4.0 \mu\text{V}$ ) than at left hemisphere sites ( $-3.0 \mu\text{V}$ ). More relevant to the scope of the present study, however, were the effects which were modulated by age. A significant Orientation × Group interaction revealed that the Orientation effect was larger in the young than in the older group. This interaction was further qualified by a Orientation × Stimulus Type × Group interaction, which revealed that, whereas inversion did not increase the amplitude of the N170 amplitude elicited by tables for either older participants ( $-9.7 \mu\text{V}$  and  $-9.8 \mu\text{V}$  for inverted and upright tables, respectively) or young participants ( $-5.2 \mu\text{V}$  and  $-5.6 \mu\text{V}$ , for inverted and upright tables, respectively), face inversion increased the N170 elicited in young participants ( $-10.1 \mu\text{V}$  and  $-8.4 \mu\text{V}$  for

**Table 1.** N170 Amplitudes in Micro-Volts (SE) Elicited by Faces and Tables in Young and Older Participants

	Faces											
	Upright						Inverted					
	TP7	P7	O1	TP8	P8	O2	TP7	P7	O1	TP8	P8	O2
Young	-5.6 (0.7)	-9.5 (1.6)	-7.9 (1.5)	-6.2 (0.8)	-12.2 (1.4)	-9.0 (1.3)	-6.7 (0.7)	-11.1 (1.6)	-9.4 (1.6)	-7.6 (0.8)	-15.0 (1.3)	-11.0 (1.4)
Older	-10.5 (0.8)	-17.4 (1.6)	-14.4 (1.5)	-8.7 (0.8)	-17.3 (1.4)	-15.8 (1.4)	-10.4 (0.7)	-17.3 (1.6)	-14.4 (1.7)	-9.2 (0.7)	-18.1 (1.4)	-16.1 (1.5)

	Tables											
	Upright						Inverted					
	TP7	P7	O1	TP8	P8	O2	TP7	P7	O1	TP8	P8	O2
Young	-3.0 (0.5)	-6.3 (1.2)	-6.8 (1.4)	-3.2 (0.5)	-7.3 (1.0)	-7.1 (1.3)	-2.5 (0.5)	-5.9 (1.1)	-5.9 (1.2)	-3.2 (0.4)	-6.9 (1.0)	-6.5 (1.2)
Older	-5.7 (0.5)	-12.7 (1.5)	-12.9 (1.5)	-3.8 (0.5)	-10.5 (1.0)	-13.2 (1.3)	-5.7 (0.5)	-12.4 (1.1)	-12.6 (1.2)	-3.7 (0.5)	-10.3 (1.0)	-13.1 (1.2)

inverted and upright faces, respectively), but not in older participants ( $-14.2 \mu\text{V}$  and  $-14.0 \mu\text{V}$  for inverted and upright faces, respectively). A Hemisphere  $\times$  Group interaction followed by separate ANOVAs in each age group showed that, whereas in the young group the amplitude of the N170 amplitude was higher at right hemisphere sites ( $-7.9 \mu\text{V}$ ) than at left hemisphere sites ( $-6.7 \mu\text{V}$ ) and this right-hemisphere dominance was driven particularly by faces (RH =  $-10.1 \mu\text{V}$  and LH =  $-8.8 \mu\text{V}$  for faces versus RH =  $-5.7 \mu\text{V}$  and LH =  $-5.1 \mu\text{V}$  for tables), in the older group the Hemisphere effect was not significant, indeed, the N170 was numerically larger at left hemisphere sites ( $-11.7 \mu\text{V}$  and  $-12.2 \mu\text{V}$  for the right and left hemisphere, respectively), and did not interact with Stimulus Type. Finally a significant Site  $\times$  Group showed that, whereas in the young group the amplitude at the P7/8 sites ( $-9.3 \mu\text{V}$ ) were larger than at TP7/8 sites ( $-7.9 \mu\text{V}$ ), which were higher than at the O1/2 sites ( $-4.7 \mu\text{V}$ ), in the older group, there was no difference between the lateral electrodes (P7/8 =  $-4.5 \mu\text{V}$ ; TP7/8 =  $-14.1 \mu\text{V}$ ), both higher than those elicited at O1/2 sites ( $-7.3 \mu\text{V}$ ).

The analysis of the peak latency revealed that, overall, the N170 latency was similar in the young (163 ms) and elderly (160 ms) group. Moreover, although all the 4 main effects with repeated measures were small but significantly affected the N170 latency, none of these effects were directly modulated by age. The latency of the N170 was longer for inverted faces (164 ms) than for upright faces (160 ms), and longer for tables (163 ms) than for faces (160 ms). For distributional effects, we found that the N170 peak latency was longer at O1/2 (167 ms) than at P7/8 (161 ms), and shortest at TP7/8 (156 ms), and longer at right hemisphere sites (163 ms) than at left hemisphere sites (160 ms). A Stimulus Type  $\times$  Site interaction followed by  $t$ -tests at each site showed that the N170 peak latency was significantly delayed for tables relative to faces only at the TP7/8 sites. Finally, a significant Orientation  $\times$  Stimulus Type interaction showed that stimulus inversion delayed the N170 elicited by faces (5.3 ms) more than that elicited by tables (2.4 ms). This interaction was qualified, however, by a second order interaction with Group. Separate ANOVAs for each age group and planned  $t$ -tests revealed that, whereas for the young group the delay imposed on the N170 peak by stimulus inversion was similar for faces (3.7 ms) and tables (3.3 ms), for the elderly group inversion significantly delayed the N170 elicited by faces (7.1 ms) but had no significant effect on the N170 elicited by tables (1.5 ms).

As described in the Method section, the N170 face effect (the difference between faces and tables) and the N170 inversion effect (the difference between upright and inverted stimuli) were normalized relative to the absolute size of the potentials in each participant. Since the most conspicuous Stimulus Type as well as Orientation effects on the N170 amplitude were found at the posterior lateral sites, P7 and P8, this analysis was confined only to these sites.

*N170 Face Effect.* The normalized N170 face effect was calculated (see Methods) for upright faces and analyzed by a mixed-model ANOVA with Group (young, older) as a between-subject factor and Hemisphere (P7, P8) as a within-subject factor. As evident in Figure 2, the N170 effect was larger over the right hemisphere (0.26) than over the left [0.18;  $F(1,29) = 7.08$ ,  $p < .025$ ]. There was no difference between the young and the older group [0.23 and 0.20, respectively  $F(1,29) < 1.0$ ] and no Group  $\times$  Hemisphere interaction [ $F(1,29) < 1.0$ ].

**Table 2.** N170 Latency in Milliseconds (SE) Elicited by Faces and Tables in Young and Older Participants

	Faces											
	Upright				Inverted							
	TP7	P7	O1	TP8	P8	O2	TP7	P7	O1	TP8	P8	O2
Young	157 (3.1)	158 (2.9)	156 (3.2)	163 (4.0)	160 (3.2)	157 (3.2)	162 (2.8)	162 (2.5)	158 (2.7)	168 (3.3)	163 (3.1)	159 (3.1)
Older	159 (3.0)	157 (2.6)	152 (3.3)	160 (4.1)	157 (3.3)	152 (3.3)	169 (2.9)	164 (2.6)	157 (2.8)	168 (3.4)	164 (3.2)	158 (3.2)

	Tables											
	Upright				Inverted							
	TP7	P7	O1	TP8	P8	O2	TP7	P7	O1	TP8	P8	O2
Young	166 (4.0)	161 (4.0)	157 (3.1)	174 (4.5)	164 (3.5)	159 (3.3)	173 (3.4)	163 (3.4)	157 (3.3)	180 (3.8)	167 (3.6)	161 (3.8)
Older	162 (4.1)	160 (3.7)	155 (3.2)	170 (4.6)	161 (3.6)	156 (3.4)	163 (3.5)	161 (3.5)	155 (3.4)	176 (4.0)	162 (3.7)	156 (3.9)

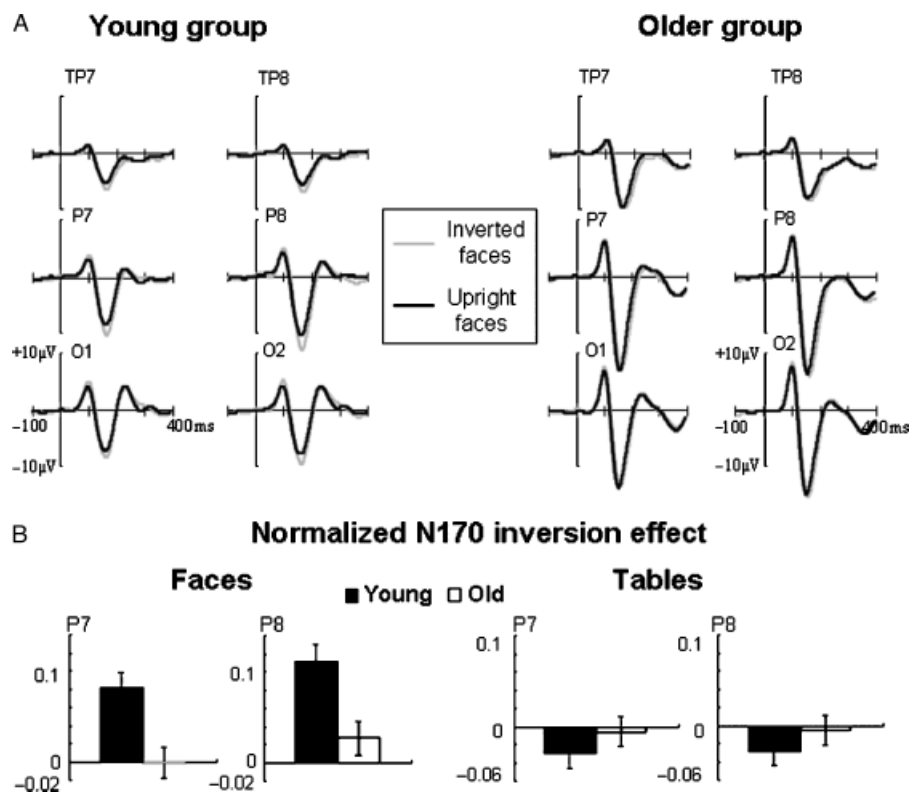
*N170 Inversion Effect.* The inversion effect on the normalized N170 amplitude was analyzed using a mixed model, Group  $\times$  Stimulus type  $\times$  Hemisphere ANOVA. As presented in Figure 3, the inversion effect was larger for young participants (0.03) than for older participants [0.00;  $F(1,29) = 4.54$ ,  $p < .05$ ], and larger for faces (0.06) than for tables [ $-0.02$ ;  $F(1,29) = 19.35$ ,  $p < .001$ ]. The normalized inversion effect for tables was not significantly different from zero [ $t(30) = -1.69$ ,  $p = .10$ ]. A significant Stimulus type  $\times$  Group interaction [ $F(1,29) = 10.78$ ,  $p < .005$ ] showed that the main effect of Stimulus type was different for young and older participants. Post hoc analysis of this interaction showed that, whereas for young participants the face inversion effect (0.10) was larger than the inversion effect on tables [ $-0.3$ ;  $t(15) = 4.40$ ,  $p < .001$ ], the inversion effect in the older group was similar for both stimulus types [0.01 and  $-0.00$  for faces and tables, respectively;  $t(14) = 1.26$ ,  $p = .23$ ]. Indeed, in the older group, like tables, the normalized face-inversion effect on N170 amplitudes was not different from zero. There was no main effect of Hemisphere [ $F(1,29) = 1.90$ ,  $p = .18$ ] and no additional significant interactions.

## Discussion

The aim of the present study was to investigate whether perceptual processes involved in early stages of face processing are influenced by normal aging. Would such effects be found, we sought to determine their nature and time course. To achieve this goal, the aging effects on face detection and configural analysis were assessed by recording the early ERP components (P1 and N170) elicited by faces and objects (tables) presented in upright and upside down orientations.

The major findings could be summarized as follows: Across all conditions, both the P1 and the N170 components were larger in the older than in the young group, while the peak latencies were not conspicuously different between groups. Across age groups the scalp distribution of P1 and N170 demonstrated that these two components are dissociated: P1 was largest at the occipital sites (O1 and O2), whereas the N170 was largest at the posterior lateral sites (P7 and P8). Moreover, whereas the N170 elicited by faces in the young group was lateralized to the right hemisphere, the P1 was equally large bilaterally for both stimuli. Nevertheless, the P1 amplitude was sensitive to stimulus manipulations as well as the N170: It was higher in response to faces than tables and higher for inverted than upright stimuli. Importantly, however, unlike the N170, none of these effects of P1 were influenced by age, and the inversion effect was equal for faces and tables. The distinction between faces and non-face stimuli as demonstrated by the normalized N170 face-effect was also similar across age groups. However, whereas face inversion delayed the N170 peak in the older group as well as in the young group, the inversion effect on amplitude was found only in the younger group. Finally, in contrast to the clear right hemisphere lateralization of the N170 amplitude in the young group, no lateralization was found in the older group. Yet, the N170-face effect was similarly right lateralized in both groups.

Although anticipating no P1 modulations, the present study focused primarily on the N170. Facing the pattern of results, we discuss the results post hoc. P1 is an early index of endogenous processing of visual stimuli, with sources in the striate and extrastriate cortex (e.g., Di Russo, Martinez, Sereno, Pitzalis, & Hillyard, 2002) and modulated primarily by low-level physical



**Figure 3.** (A) Grand averaged ERPs elicited by upright and inverted faces in elderly and young groups. (B) The normalized stimulus inversion-effects for faces and tables.

characteristics of the stimuli (Mangun, 1995). Indeed, most ERP studies of face processing did not find categorical sensitivity to faces at this latency (e.g. Bentin et al., 1996; Boutsen, Humphreys, Praamstra, & Warbrick, 2006; Rossion, Joyce, Cottrell, & Tarr, 2003; Rousselet, Husk, Bennett, & Sekuler, 2005, 2007). Yet, the present study is not the first to report higher P1 to faces than objects (e.g., Herrmann, Ehrlis, Ellgring, & Fallgatter, 2005; Itier & Taylor, 2002, 2004; Linkenkaer-Hansen, et al., 1998). The reason for this inconsistency is not clear. On the one hand, it might reflect insufficiently controlled low-level factors among stimulus categories in different studies. For example, although in the present study all images used in this study were equated for luminance and contrast, the area subtended by tables was much smaller than the area occupied by faces. On the other hand, the inversion effects on P1 found here as well as in several previous studies (e.g., Linkenkaer-Hansen, et al., 1998; Itier & Taylor, 2002, 2004; but see Rossion et al., 1999) can hardly be accounted for by low-level factors in vision. Note, however, that these effects (largest at the occipital sites, O1 and O2) were similar for faces and tables. Hence, on the basis of these results we cannot refute the view suggesting that P1 is not face-specific (cf., Rossion et al., 1999; Taylor, Edmonds, McCarthy, & Allison, 2001; for a recent in-depth discussion, see Rossion & Jaques 2008). Clearly determining whether P1 is or is not categorical specific awaits additional research. Importantly, however, the modulation of P1 by the experimental manipulations in this study was not influenced by aging.

The larger N170 amplitudes found in the older relative to the young groups is reminiscent of a similar relation between middle-aged and young participants reported by Chaby and colleagues (2003). However, in addition to testing a considerably older

group (~70 years in the present study versus ~50 years in Chaby and colleagues, 2003) our study extends that previous report in several important ways. First, including a non-face condition and calculating the difference between the N170 elicited by faces and that elicited by tables (the N170 face-effect), we were able to show that the enhancement in the amplitude of early components is not specific to face processing but rather of a more general nature. To reiterate, this view is also supported by the similar trend of differences found comparing the P1 amplitude elicited by all stimuli in old and young participants. Second, whereas the participants in Chaby and colleagues (2003) performed a detailed discrimination task (oriented locally to the face's eyes), and the faces were familiar to them, in our study unfamiliar faces were processed only at a basic (global) level, while monitoring the screen for the occasional appearance of a butterfly. Thus, the present results show that the higher N170 amplitudes in older relative to young participants are not contingent upon a difficult discrimination process, or associated with a face individuation. Rather, as some researchers proposed, the increased amplitude of early ERP components (including P1 and N170) can be explained by enhanced sensitivity to visual stimuli or some decrement in neural adaptation with aging (Chaby et al., 2003; Chaby et al., 2001; Pfütze et al., 2002). Similarly, age-related increases in sensory-evoked responses have been reported in the auditory modality as well (e.g., Alain & Woods, 1999; Chao & Knight, 1997). Hence, the similar N170 face-effect across ages along with the non-specific modulation of the early ERPs by age, the similar right-hemisphere lateralization of the normalized N170 face effect across the older and young participants, and the similar N170 peak latency across groups found both in our study as well as by Chaby and colleagues imply that

the early perceptual stage at which faces are detected in the visual field and submitted to further face-characteristic analysis is spared in the elderly (see Bentin et al., 2006, and Zion-Golumbic & Bentin, 2007, for discussions of the functional significance of the N170).

In contrast to the N170 face-effect, the inversion-effect on the N170, which was observed in the present young group and is well documented in the literature (e.g., Bentin et al., 1996; Rossion et al., 1999; Rossion & Gauthier, 2002), was evident in the elderly group for the peak latency but not on its amplitude (normalized as well as absolute). It is widely accepted that face inversion disrupts configural processing in faces, i.e., the computation of the relational metrics among the inner face components and their spatial location relative to the face contour (Bartlett & Searcy, 1993; Rhodes, Brake, & Atkinson, 1993; Searcy & Bartlett, 1996). Moreover, the pattern of inversion effects in the young group as well as previous N170 (e.g., Rossion, et al., 2000) and behavioral studies (e.g., Leder & Carbon, 2006) indicate that this effect is peculiar to faces. Therefore, the reduced face-inversion effects in the elderly group suggests that, although early detection of faces, which is putatively based on global perception, is not affected by age, older participants are not adversely affected by manipulations that interfere with configural processing of faces. By implication, this suggests that they were less prone to apply this kind of processes even when the faces were presented in normal, upright orientation relying primarily on features and/or global information.

Several studies investigated global and local perception in the elderly. Using hierarchically organized letters (Navon, 1977), several authors reported normal global precedence and normal global-to-local interference in older participants (for a review, see Bruyer, Scailquin, & Samson, 2003). Global processing, however, should not be confused with configural processing. Whereas global processing entails an integrated percept without detailed analysis of its components, configural analysis is based on distinction among the details and a relational analysis of their spatial location. Indeed, faces are distinguished from other stimulus categories on the basis of their well-defined global shape including (first-order relations, Maurer, LeGrand, & Mondloch, 2002), but distinguished one from another on the basis of detailed characteristics as well as different configural metrics of their inner components (second-order relations, Maurer et al., 2002). The similar N170 distinction between faces and tables (the N170 face-effect) across young and older participants goes along with the normal global perception while the putative reduced sensitivity to configural aspects of the face suggests a possible detriment in extracting individual-face-specific information during the structural encoding of the face (cf., Bartlett & Fulton, 1991). A recent study, however, suggested that this might not be the case (Boutet & Faubert, 2006). That study showed that, although forced-choice unfamiliar face recognition was better in young than in old participants, inversion reduced performance equally in both groups. Again, by implication, this pattern suggests that, similarly to young participants, the older people in that study took advantage of the configural information available to them when the faces were upright. How could this apparent discrepancy between the two studies be reconciled? A possible answer comes considering the difference in the task demands. Whereas in Boutet and Faubert's (2006) experiment participants were asked to memorize and later recognize faces, in our study, the task was passive monitoring for butterflies; that is, no explicit encoding of the face was requested. From this per-

spective, a possible interpretation based on both our present study and Boutet and Faubert (2006) is that the age factor affecting configural processing of faces is consequential only in default, task-void situation. In other words, it is possible that young observers attempt by default to individuate (and recognize) any face that they are exposed to. In contrast, older observers do not invest perceptual efforts in recognizing faces unless they are requested to do so. However, when face recognition is attempted, configural information is equally used by both age groups.

An additional insight into the early processing of faces in the elderly is provided by the pattern of inter-hemispheric differences. On the one hand, the well established right-hemisphere lateralization of the N170 amplitude, which was replicated in the current sample of young participants, was absent in the older group. On the other hand, the N170 face-effect, that is, the specific expression of face distinction, was equally larger in the right relative to the left hemisphere in both age groups. The reduced inter-hemispheric asymmetry of the N170 elicited by both faces and tables goes along with the well documented gradual reduction of inter-hemispheric asymmetries with age (for a review, see Cabeza, 2002). However, like in the present study, this trend was not confined to face processing. For example, the P1/N1 amplitude seen in the perception of speech sounds was higher over left than right hemisphere sites in children and young adults, but symmetrical in older people (Bellis, Nicol, & Kraus, 2000). Decreased hemispheric asymmetry with age has also been found using PET in a face matching study (Grady, 2000) and attributed to increased activity in the left hemisphere. Importantly, this pattern was observed in multi-modal associative areas, such as the pre-frontal cortex, whereas face-specific activity in the posterior ventral cortex reflected normal right-hemisphere lateralization (Grady, 2002). Based on this pattern as well as on similar findings from fMRI (Dolcos, Rice, & Cabeza, 2002) as well as on the pattern of differences in the performance of older and young participants in a variety of cognitive task, Cabeza (2002) proposed that the reduced inter-hemispheric asymmetry in the elderly reflects alteration of prefrontal activity, possibly associated with degeneration of commissural fibers in the anterior parts of the corpus callosum (Persson et al., 2006). In concert, these data support our interpretation of the age-related differences found in this study as reflecting changes in a general mechanisms while the right-lateralization of early face processing is probably not affected by age.

Most of the above interpretations are based on the pattern of amplitude modulations. Indeed, it is noteworthy that, overall, we found no evidence for age-related latency modulation in the present study either for P1 or for N170. This pattern contrasts previous visual evoked potentials (VEPs) studies that found increased P100 peak-latency with age (e.g., Mitchell, Howe, & Spencer, 1987). Note, however, that increased P100 VEP latency in normal aging has been found only at low-contrast and reduced luminance (Shaw & Cant, 1980; Sokol, Moskowitz, & Towle, 1981; Spear, 1993), or associated with color perception (Page & Crognale, 2005). Since in the present study all the stimuli were black and white, high-contrast, and matched for luminance, it is possible that low-level factors affecting the pattern-reversal VEP were inconsequential here. Hence, the present findings indicate that aging does not always influence the visual processing speed, raising questions about views assuming that age slows down all central processing stages (Birren & Fisher, 1991; Salthouse, 1992).



Before concluding, we should reiterate two procedural decisions that constrain the interpretation of the present findings. First, all the faces used in this study were unfamiliar to the participants. Using unfamiliar faces we hoped to isolate initial stages of face categorization reducing putative effects of face individuation and identification, processes that might have been tainted by memory factors.<sup>5</sup> Yet, as discussed above, the difference between the inversion effects in the young and older groups might reflect a default attempt of the former participants to individuate the faces, while no such attempts were made by the older group. In other words, it is possible that the age-related differences implied by the inversion effects reflect a change in perceptual strategies such as a different default level of categorization rather than different face processing abilities (see support for this assumption in Pfütze et al., 2002). Second, only young faces were included in this study. Studies on eyewitness identification found an own-age effect by which participants were more efficient in identifying present “culprits” of their own age than of a different age (Wright & Stroud, 2002). However, the own-age memory bias was not always observed for the older participants (e.g., Bäckman, 1991; Bartlett & Fulton, 1991; Bartlett & Leslie, 1986). Moreover, in a recent study we found no own-age bias in either Chinese or Israeli

participants (Zhao & Bentin, 2008). Particularly relevant to our present study is a recent report in which young and old faces were presented to young and old participants in an ERP study (Wiese, Schweinberger, & Hansen, 2008). However, like in all previous studies of own-age effects, the participants in that study were requested to individuate and identify previously learned faces and, indeed, these authors focused on components that peaked later than the N170. Hence, although these authors found a delayed N170 in the elderly group (for both young and old faces), they could not determine whether this effect was accounted for by processes associated with face detection and basic-level face categorization or reflected an own-age effect on face individuation.

These limitations notwithstanding, our findings suggest that the detection of faces in the visual field and their initial streaming to face-specific structural encoding mechanisms are not affected by age. However, subsequent face-specific configural processing, which in the young population is performed in a default attempt to individuate the face (Tanaka, 2001), in the elderly might not be automatically applied. Whether this pattern reflects a different default level of processing faces in the elderly or an own-age bias awaits further investigation.

## REFERENCES

- Alain, C., & Woods, D. L. (1999). Age-related changes in processing auditory stimuli during visual attention: Evidence for deficits in inhibitory control and sensory memory. *Psychology and Aging, 14*, 507–519.
- Anaki, D., Zion-Glumbic, E., & Bentin, S. (2007). Electrophysiological neural mechanisms for detection, configural analysis and recognition of faces. *Neuroimage, 37*, 1407–1416.
- Bäckman, L. (1991). Recognition memory across the adult life span—The role of prior knowledge. *Memory & Cognition, 19*, 63–71.
- Bartlett, J. C., & Fulton, A. (1991). Familiarity and recognition of faces in old age. *Memory & Cognition, 19*, 229–238.
- Bartlett, J. C., & Leslie, J. E. (1986). Aging and memory for faces versus single views of faces. *Memory & Cognition, 14*, 371–391.
- Bartlett, J. C., & Searcy, J. (1993). Inversion and configuration of faces. *Cognitive Psychology, 25*, 281–316.
- Bellis, J. T., Nicol, T., & Kraus, N. (2000). Aging affects hemispheric asymmetry in the neural representation of speech sounds. *The Journal of Neuroscience, 20*, 791–797.
- Bentin, S., Allison, T., Puce, A., Perez, E., & McCarthy, G. (1996). Electrophysiological studies of face perception in humans. *Journal of Cognitive Neuroscience, 8*, 551–565.
- Bentin, S., DeGutis, J. M., D’Esposito, M., & Robertson, L. C. (2007). Too many trees to see the forest: Performance, ERP and fMRI manifestations of integrative congenital prosopagnosia. *Journal of Cognitive Neuroscience, 19*, 132–146.
- Bentin, S., & Deouell, L. Y. (2000). Structural encoding and identification in face processing: ERP evidence for separate mechanisms. *Cognitive Neuropsychology, 17*, 35–54.
- Bentin, S., Golland, Y., Flevaris, A., Robertson, L., & Moscovitch, M. (2006). Processing trees before the forest during initial stages of face perception: Electrophysiological evidence. *Journal of Cognitive Neuroscience, 18*, 1406–1421.
- Birren, J. E., & Fisher, L. M. (1991). Aging and slowing of behavior: Consequences for cognition and survival. *Nebraska Symposium on Motivation, 39*, 1–37.
- Boutet, I., & Faubert, J. (2006). Recognition of faces and complex objects in younger and older adults. *Memory & Cognition, 34*, 854–864.
- Boutsen, L., Humphreys, G. W., Praamstra, P., & Warbrick, T. (2006). Comparing neural correlates of configural processing in faces and objects: An ERP study of the Thatcher illusion. *NeuroImage, 32*, 352–367.
- Bruyer, R., Scailquin, J. C., & Samson, D. (2003). Aging and the locus of the global precedence effect: A short review and new empirical data. *Experimental Aging Research, 29*, 237–268.
- Cabeza, R. (2002). Hemispheric asymmetry reduction in older adults: The HAROLD model. *Psychology and Aging, 17*, 85–100.
- Carmel, D., & Bentin, S. (2002). Domain specificity versus expertise: Factors influencing distinct processing of faces. *Cognition, 83*, 1–29.
- Chaby, L., George, N., Renault, B., & Fiori, N. (2003). Age-related changes in brain responses to personally known faces: An event-related potential (ERP) study in humans. *Neuroscience Letters, 349*, 125–129.
- Chaby, L., Jemel, B., George, N., Renault, B., & Fiori, N. (2001). An ERP study of famous face incongruity detection in middle age. *Brain Cognition, 45*, 357–377.
- Chao, L. L., & Knight, R. T. (1997). Prefrontal deficits in attention and inhibitory control with aging. *Cerebral Cortex, 7*, 63–69.
- Craik, F. I. M., & Jennings, J. M. (1992). Human memory. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition*. Hillsdale, NJ: Erlbaum.
- Craik, F. I. M., & McDowd, J. M. (1987). Age differences in recall and recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13*, 671–684.
- Di Russo, F., Martinez, A., Sereno, M. I., Pitzalis, S., & Hillyard, S. A. (2002). Cortical sources of the early components of the visual evoked potential. *Human Brain Mapping, 15*, 95–111.
- Dolcos, F., Rice, H. J., & Cabeza, R. (2002). Hemispheric asymmetry and aging: Right hemisphere decline or asymmetry reduction. *Neuroscience & Biobehavioral Reviews, 26*, 819–825.
- Eimer, M. (2000). The face-specific N170 component reflects late stages in the structural encoding of faces. *NeuroReport, 11*, 2319–2324.
- George, N., Evans, J., Fiori, N., Davidoff, J., & Renault, B. (1996). Brain events related to normal and moderately scrambled faces. *Cognitive Brain Research, 4*, 65–76.
- Grady, C. L. (2000). Functional brain imaging and age-related changes in cognition. *Biological Psychology, 54*, 259–281.
- Grady, C. L. (2002). Age-related differences in face processing: A meta-analysis of three functional neuroimaging experiments. *Canadian Journal of Experimental Psychology, 56*, 208–220.
- Herrmann, M. J., Ehlis, A.-C., Ellgring, H., & Fallgatter, A. J. (2005). Early stages (P100) of face perception in humans as measured with event-related potentials (ERPs). *Journal of Neural Transmission, 112*, 1073–1081.

<sup>5</sup>This is also the reason for focusing primarily on the N170 signature of face processing, which is probably insensitive to face familiarity (Anaki, Zion-Golumbic, & Bentin, 2007; Bentin & Deouell, 2000).

- Itier, R. J., & Taylor, M. J. (2002). Inversion and contrast polarity reversal affect both encoding and recognition processes of unfamiliar faces: A repetition study using ERPs. *NeuroImage*, *15*, 353–372.
- Itier, R. J., & Taylor, M. J. (2004). Source analysis of the N170 to faces and objects. *NeuroReport*, *15*, 1261–1265.
- Leder, H., & Carbon, C. C. (2006). Face-specific configural processing of relational information. *British Journal of Psychology*, *97*, 19–29.
- Linkenkaer-Hansen, K., Palva, J. M., Sams, M., Hietanen, J. K., Aronen, H. J., & Ilmoniemi, R. J. (1998). Face-selective processing in human extrastriate cortex around 120 msec after stimulus onset revealed by magneto- and electroencephalography. *Neuroscience Letters*, *253*, 147–150.
- Mangun, G. R. (1995). Neural mechanisms of visual selective attention. *Psychophysiology*, *32*, 4–18.
- Maurer, D., LeGrand, R., & Mondloch, C. J. (2002). The many faces of configural processing. *Trends in Cognitive Sciences*, *6*, 255–260.
- Mitchell, K. W., Howe, J. W., & Spencer, S. R. (1987). Visual evoked potentials in the older population: age and gender effects. *Clinical Physics Physiological Measurement*, *8*, 317–324.
- Navon, D. (1977). Forest before trees: The precedence of global features in visual perception. *Cognitive Psychology*, *9*, 353–383.
- Owsley, C., Sekuler, R., & Boldt, C. (1981). Aging and low-contrast vision: face perception. *Investigative Ophthalmology & Visual Science*, *21*, 362–365.
- Page, J. W., & Crognale, M. A. (2005). Differential aging of chromatic and achromatic visual pathways: Behavior and electrophysiology. *Vision Research*, *45*, 1481–1489.
- Persson, J., Nyberg, L., Lind, J., Larsson, A., Nilsson, L. G., Ingvar, M., et al. (2006). Structure-function correlates of cognitive decline in aging. *Cerebral Cortex*, *16*, 907–915.
- Pfütze, E. M., Sommer, W., & Schweinberger, S. R. (2002). Age-related slowing in face and name recognition: Evidence from event-related brain potentials. *Psychology and Aging*, *17*, 140–160.
- Rhodes, G., Brake, S., & Atkinson, A. P. (1993). What's lost in inverted faces? *Cognition*, *47*, 25–57.
- Rossion, B., Delvenne, J. F., Debatisse, D., Goffaux, V., Bruyer, R., Crommelinck, M., et al. (1999). Spacial-temporal localization of the face inversion effect: An event-related potentials study. *Biological Psychology*, *50*, 173–189.
- Rossion, B., & Gauthier, I. (2002). How does the brain process upright and inverted faces? *Behavioral and Cognitive Neuroscience Reviews*, *1*, 62–74.
- Rossion, B., Gauthier, I., Tarr, M. J., Despland, P., Bruyer, R., Linotte, S., et al. (2000). The N170 occipito-temporal component is delayed and enhanced to inverted faces but not to inverted objects: An electrophysiological account of face-specific processes in the human brain. *NeuroReport*, *11*, 69–74.
- Rossion, B., & Jaques, C. (2008). Does physical interstimulus variance account for early electrophysiological face sensitive responses in the human brain? Ten lessons on the N170. *NeuroImage*, *39*, 1959–1979.
- Rossion, B., Joyce, C. A., Cottrell, G. W., & Tarr, M. J. (2003). Early lateralization and orientation tuning for face, word, and object processing in the visual cortex. *NeuroImage*, *20*, 1609–1624.
- Rousselet, G. A., Husk, J. S., Bennett, P. J., & Sekuler, A. B. (2005). Spatial scaling factors explain eccentricity effects on face ERPs. *Journal of Vision*, *5*, 755–763.
- Rousselet, G. A., Husk, J. S., Bennett, P. J., & Sekuler, A. B. (2007). Single-trial EEG dynamics of object and face visual processing. *NeuroImage*, *36*, 843–862.
- Roux, F., & Ceccaldi, M. (2001). Does aging affect the allocation of visual attention in global and local information processing? *Brain and Cognition*, *46*, 383–396.
- Sadeh, B., Zhdanov, A., Podlipsky, I., Hendler, T., & Yovel, G. (2008). The validity of the face-selective ERP N170 component during simultaneous recording with functional MRI. *NeuroImage*, *42*, 778–786.
- Sagiv, N., & Bentin, S. (2001). Structural encoding of human and schematic faces: Holistic and part-based processes. *Journal of Cognitive Neuroscience*, *13*, 937–951.
- Salthouse, T. A. (1992). Why do adult age differences increase with task complexity? *Developmental Psychology*, *28*, 905–918.
- Schweinberger, S., & Sommer, W. (1991). Contributions of stimulus encoding and memory search to right hemisphere superiority in face recognition: Behavioural and electrophysiological evidence. *Neuropsychologia*, *29*, 389–413.
- Searcy, J. H., & Bartlett, J. C. (1996). Inversion and processing of component and spatial-relational information in faces. *Journal of Experimental Psychology: Human Perception and Performance*, *22*, 904–915.
- Searcy, J. H., Bartlett, J. C., & Memon, A. (1999). Age differences in accuracy and choosing in eyewitness identification and face recognition. *Memory & Cognition*, *27*, 538–552.
- Semlitsch, H. V., Anderer, P., Schuster, P., & Presslich, O. (1986). A solution for reliable and valid reduction of ocular artifacts applied to the P300 ERP. *Psychophysiology*, *23*, 695–703.
- Shaw, N. A., & Cant, B. R. (1980). Age-dependent changes in the latency of the pattern visual evoked potential. *Electroencephology Clinical Neurophysiology*, *48*, 237–241.
- Sokol, S., Moskowitz, A., & Towle, V. L. (1981). Age-related changes in the latency of the visual evoked potential: Influence of check size. *Electroencephology Clinical Neurophysiology*, *51*, 559–562.
- Spear, P. D. (1993). Neural bases of visual deficits during aging. *Vision Research*, *33*, 2589–2609.
- Spiriduso, W. W. (1995). *Physical dimensions of aging*. Champaign, IL: Human Kinetics.
- Tanaka, J. W. (2001). The entry point of face recognition: Evidence for face expertise. *Journal of Experimental Psychology: General*, *130*, 534–543.
- Taylor, M. J., Edmonds, G. E., McCarthy, G., & Allison, T. (2001). Eyes first! Eye processing develops before face processing in children. *NeuroReport*, *12*, 1671–1676.
- Wiese, H., Schweinberger, S. R., & Hansen, K. (2008). The age of beholder: ERP evidence of an own-age bias in face memory. *Neuropsychologia*, *46*, 2973–2985.
- Wright, D. B., & Stroud, J. N. (2002). Age differences in lineup identification accuracy: People are better with their own age. *Law and Human Behavior*, *26*, 641–654.
- Zhao, L., & Bentin, S. (2008). Own- and other-race categorization of faces by race, gender and age. *Psychonomic Bulletin and Review*, *15*, 1093–1099.
- Zion-Golumbic, E., & Bentin, S. (2007). Dissociated neural mechanisms for face detection and configural encoding: Evidence from N170 and Gamma-band oscillation effects. *Cerebral Cortex*, *17*, 1741–1749.

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## APPENDIX A

**Table A1.** ANOVA Table for the P1 Peak Amplitude (1)

Source of Variance	Sum of Squares	df	Mean Square	F	Significance	Partial $\eta^2$
Orientation	19.7	1	19.7	15.8	.000	.35
Orientation $\times$ Group	1.2	1	1.2	.9	.341	.03
Error (Orientation)	36.1	29	1.2			
Stimulus Type	512.9	1	512.9	135.8	.000	.82
Stimulus Type $\times$ Group	14.5	1	14.5	3.8	.060	.12
Error (Stimulus Type)	109.5	29	3.8			
Site	2008.8	1.1	1740.9	30.8	.000	.52
Site $\times$ Group	109.3	1.1	94.7	1.7	.206	.05
Error (Site)	1889.8	33.4	56.5			
Hemisphere	4.7	1	4.7	.3	.598	.01
Hemisphere $\times$ Group	16.0	1	16.0	1.0	.336	.03
Error (Hemisphere)	484.3	29	16.7			
Orientation $\times$ Stimulus Type	.4	1	.4	.3	.606	.01
Orientation $\times$ Stimulus Type $\times$ Group	1.2	1	1.2	.7	.407	.02
Error (Orientation $\times$ Stimulus Type)	47.9	29	1.6			
Orientation $\times$ Site	12.8	1.4	6.4	10.9	.000	.27
Orientation $\times$ Site $\times$ Group	1.1	1.4	.7	.9	.377	.03
Error (Orientation $\times$ Site)	34.0	42.2	.8			
Stimulus Type $\times$ Site	60.6	1.6	36.8	47.6	.000	.62
Stimulus Type $\times$ Site $\times$ Group	.0	1.6	0.1	.0	.970	.00
Error (Stimulus Type $\times$ Site)	36.9	47.7	.8			
Orientation $\times$ Stimulus Type $\times$ Site	2.9	1.8	1.6	2.8	.069	.09
Orientation $\times$ Stimulus Type $\times$ Site $\times$ Group	1.9	1.8	1.0	1.8	.175	.06
Error (Orientation $\times$ Stimulus Type $\times$ Site)	29.9	52.2	.572			
Orientation $\times$ Hemisphere	.0	1	.0	.0	.968	.00
Orientation $\times$ Hemisphere $\times$ Group	.0	1	.0	.1	.804	.00
Error (Orientation $\times$ Hemisphere)	17.4	29	.6			

**Table A2.** ANOVA Table for the P1 Peak Amplitude (2)

Source of Variance	Sum of Squares	df	Mean Square	F	Significance	Partial $\eta^2$
Stimulus Type $\times$ Hemisphere	1.0	1	1.0	.5	.5	.02
Stimulus type $\times$ Hemisphere $\times$ Group	3.6	1	3.6	1.6	.212	.05
Error (Stimulus Type $\times$ Hemisphere)	63.8	29	2.2			
Orientation $\times$ Stimulus Type $\times$ Hemisphere	.5	1	.5	.7	.407	.02
Orientation $\times$ Stimulus Type $\times$ Hemisphere $\times$ Group	1.0	1	1.0	1.4	.237	.05
Error (Orientation $\times$ Stimulus Type $\times$ Hemisphere)	20.0	29	.7			
Site $\times$ Hemisphere	13.5	1.4	9.5	1.2	.291	.04
Site $\times$ Hemisphere $\times$ Group	14.6	1.4	10.3	1.3	.270	.04
Error (Site $\times$ Hemisphere)	319.4	41.0	5.5			
Orientation $\times$ Site $\times$ Hemisphere	.1	2.0	.07	.4	.688	.01
Orientation $\times$ Site $\times$ Hemisphere $\times$ Group	.5	2.0	.3	1.4	.252	.05
Error (Orientation $\times$ Site $\times$ Hemisphere)	11.3	57.0	.2			
Stimulus Type $\times$ Site $\times$ Hemisphere	.6	1.6	.4	.9	.396	.03
Stimulus Type $\times$ Site $\times$ Hemisphere $\times$ Group	.3	1.6	.2	.4	.611	.01
Error (Stimulus Type $\times$ Site $\times$ Hemisphere)	20.1	47.2	.4			
Orientation $\times$ Stimulus Type $\times$ Site $\times$ Hemisphere	.2	1.4	.1	.4	.589	.01
Orientation $\times$ Stimulus Type $\times$ Site $\times$ Hemisphere $\times$ Group	.2	1.4	.1	.5	.540	.02
Error (Orientation $\times$ Stimulus Type $\times$ Site $\times$ Hemisphere)	11.9	41.3	.3			

## APPENDIX B

**Table B1.** ANOVA Table for the P1 Peak Latency (1)

Source of Variance	Sum of Squares	df	Mean Square	F	Significance	Partial $\eta^2$
Orientation	917.1	1	917.1	10.9	.003	.27
Orientation $\times$ Group	39.4	1	39.4	.5	.500	.02
Error (Orientation)	2446.6	29	84.4			
Stimulus Type	93.2	1	93.2	1.4	.250	.04
Stimulus Type $\times$ Group	94.6	1	94.6	1.4	.245	.05
Error (Stimulus Type)	1957.2	29	67.5			
Site	1582.7	1.3	1174.4	4.3	.017	.13
Site $\times$ Group	152.4	1.3	113.1	.4	.581	.01
Error (Site)	10561.8	39.1	270.2			
Hemisphere	.3	1	.3	.0	.975	.00
Hemisphere $\times$ Group	19.5	1	19.5	.1	.783	.00
Error (Hemisphere)	7285.6	29	251.2			
Orientation $\times$ Stimulus Type	.2	1	.2	.0	.960	.00
Orientation $\times$ Stimulus Type $\times$ Group	34.5	1	34.5	.5	.478	.02
Error (Orientation $\times$ Stimulus Type)	1936.8	29	66.8			
Orientation $\times$ Site	3.3	1.5	1.7	.1	.857	.00
Orientation $\times$ Site $\times$ Group	33.1	1.5	22.6	.9	.389	.00
Error (Orientation $\times$ Site)	1079.2	42.6	25.4			
Stimulus Type $\times$ Site	195.3	1.6	125.1	2.8	.086	.09
Stimulus Type $\times$ Site $\times$ Group	67.7	1.6	43.3	1.0	.372	.03
Error (Stimulus Type $\times$ Site)	2050.2	45.3	45.3			
Orientation $\times$ Stimulus Type $\times$ Site	49.5	1.4	36.0	.7	.465	.02
Orientation $\times$ Stimulus Type $\times$ Site $\times$ Group	5.9	1.4	4.3	.1	.855	.00
Error (Orientation $\times$ Stimulus Type $\times$ Site)	2149.6	39.9	53.9			
Orientation $\times$ Hemisphere	146.2	1	146.2	4.0	.054	.12
Orientation $\times$ Hemisphere $\times$ Group	47.1	1	47.1	1.3	.264	.04
Error (Orientation $\times$ Hemisphere)	1052.2	29	36.3			

**Table B2.** ANOVA Table for the P1 Peak Latency (2)

Source of Variance	Sum of Squares	df	Mean Square	F	Significance	Partial $\eta^2$
Stimulus Type $\times$ Hemisphere	.1	1	.1	.0	.960	.00
Stimulus type $\times$ Hemisphere $\times$ Group	1.6	1	1.6	.0	.852	.00
Error (Stimulus Type $\times$ Hemisphere)	1284.2	29	44.3			
Orientation $\times$ Stimulus Type $\times$ Hemisphere	36.6	1	36.6	1.0	.324	.03
Orientation $\times$ Stimulus Type $\times$ Hemisphere $\times$ Group	1.3	1	1.3	.0	.853	.0
Error (Orientation $\times$ Stimulus Type $\times$ Hemisphere)	1052.0	29	36.3			
Site $\times$ Hemisphere	67.7	1.4	47.2	.4	.592	.01
Site $\times$ Hemisphere $\times$ Group	34.8	1.4	24.3	.2	.731	.01
Error (Site $\times$ Hemisphere)	4659.9	41.6	112.0			
Orientation $\times$ Site $\times$ Hemisphere	64.2	1.2	51.8	2.0	.161	.06
Orientation $\times$ Site $\times$ Hemisphere $\times$ Group	1.6	1.2	1.3	.1	.870	.0
Error (Orientation $\times$ Site $\times$ Hemisphere)	920.1	35.9	25.6			
Stimulus Type $\times$ Site $\times$ Hemisphere	115.3	1.5	57.6	1.6	.224	.05
Stimulus Type $\times$ Site $\times$ Hemisphere $\times$ Group	12.4	1.5	8.2	.2	.785	.01
Error (Stimulus Type $\times$ Site $\times$ Hemisphere)	2147.1	43.7	49.1			
Orientation $\times$ Stimulus Type $\times$ Site $\times$ Hemisphere	11.9	1.8	6.6	.3	.750	.01
Orientation $\times$ Stimulus Type $\times$ Site $\times$ Hemisphere $\times$ Group	32.1	1.8	17.9	.7	.489	.02
Error (Orientation $\times$ Stimulus Type $\times$ Site $\times$ Hemisphere)	1339.8	52.1	25.7			

## APPENDIX C

**Table C1.** ANOVA Table for the N170 Peak Amplitude (1)

Source of Variance	Sum of Squares	df	Mean Square	F	Significance	Partial $\eta^2$
Orientation	20.5	1	20.5	11.2	.002	.28
Orientation $\times$ Group	16.9	1	16.9	9.2	.005	.24
Error (Orientation)	53.3	29	1.8			
Stimulus Type	3187.7	1	3187.7	138.1	.000	.83
Stimulus Type $\times$ Group	11.9	1	11.9	.5	.4	.02
Error (Stimulus Type)	669.2	29	23.1			
Site	5018.5	1.42	2509.2	64.8	.000	.69
Site $\times$ Group	435.7	1.42	217.9	5.6	.013	.16
Error (Site)	2244.7	41.1	38.7			
Hemisphere	20.3	1	20.3	.895	.352	.03
Hemisphere $\times$ Group	141.3	1	141.3	6.2	.019	.18
Error (Hemisphere)	658.4	29	22.7			
Orientation $\times$ Stimulus Type	75.4	1	75.4	31.4	.000	.52
Orientation $\times$ Stimulus Type $\times$ Group	36.3	1	36.3	15.1	.001	.34
Error (Orientation $\times$ Stimulus Type)	69.7	29	2.4			
Orientation $\times$ Site	1.8	1.5	.9	1.4	.248	.05
Orientation $\times$ Site $\times$ Group	2.1	1.5	1.1	1.7	.187	.06
Error (Orientation $\times$ Site)	35.9	42.3	.8			
Stimulus Type $\times$ Site	319.2	1.7	190.9	33.4	.000	.56
Stimulus Type $\times$ Site $\times$ Group	30.2	1.7	18.0	3.2	.060	.10
Error (Stimulus Type $\times$ Site)	276.9	48.5	5.7			
Orientation $\times$ Stimulus Type $\times$ Site	5.0	1.4	3.6	2.8	.09	.09
Orientation $\times$ Stimulus Type $\times$ Site $\times$ Group	1.25	1.4	.9	.7	.45	.02
Error (Orientation $\times$ Stimulus Type $\times$ Site)	51.5	40.0	1.3			
Orientation $\times$ Hemisphere	7.7	1	7.7	9.4	.005	.24
Orientation $\times$ Hemisphere $\times$ Group	.1	1	.1	.2	.677	.006
Error (Orientation $\times$ Hemisphere)	23.8	29	.8			

**Table C2.** ANOVA Table for the N170 Peak Amplitude (2)

Source of Variance	Sum of Squares	df	Mean Square	F	Significance	Partial $\eta^2$
Stimulus Type $\times$ Hemisphere	72.2	1	72.2	7.7	.010	.21
Stimulus type $\times$ Hemisphere $\times$ Group	.5	1	.5	.06	.815	.002
Error (Stimulus Type $\times$ Hemisphere)	272.8	29	9.4			
Orientation $\times$ Stimulus Type $\times$ Hemisphere	2.3	1	2.3	2.2	.147	.07
Orientation $\times$ Stimulus Type $\times$ Hemisphere $\times$ Group	.02	1	.02	.02	.890	.001
Error (Orientation $\times$ Stimulus Type $\times$ Hemisphere)	30.8	29	1.1			
Site $\times$ Hemisphere	75.4	1.5	49.0	3.1	.070	.10
Site $\times$ Hemisphere $\times$ Group	80.2	1.5	52.2	3.2	.060	.10
Error (Site $\times$ Hemisphere)	715.5	44.6	16.0			
Orientation $\times$ Site $\times$ Hemisphere	.50	1.9	.265	1.0	.364	.03
Orientation $\times$ Site $\times$ Hemisphere $\times$ Group	.01	1.9	.01	.03	.966	.001
Error (Orientation $\times$ Site $\times$ Hemisphere)	14.2	54.7	.26			
Stimulus Type $\times$ Site $\times$ Hemisphere	34.6	1.5	23.6	7.6	.004	.21
Stimulus Type $\times$ Site $\times$ Hemisphere $\times$ Group	.03	1.5	.02	.00	.985	.00
Error (Stimulus Type $\times$ Site $\times$ Hemisphere)	132.4	42.5	3.1			
Orientation $\times$ Stimulus Type $\times$ Site $\times$ Hemisphere	1.3	1.8	.8	3.1	.061	.1
Orientation $\times$ Stimulus Type $\times$ Site $\times$ Hemisphere $\times$ Group	.5	1.8	.3	1.1	.342	.04
Error (Orientation $\times$ Stimulus Type $\times$ Site $\times$ Hemisphere)	12.7	50.9	.249			

## APPENDIX D

**Table D1.** ANOVA Table for the N170 Peak Latency (1)

Source of Variance	Sum of Squares	df	Mean Square	F	Significance	Partial $\eta^2$
Orientation	2815.8	1	2815.8	66.6	.000	.70
Orientation $\times$ Group	34.2	1	34.2	.8	.376	.03
Error (Orientation)	1226.7	29	42.3			
Stimulus Type	1996.1	1	1996.1	9.4	.005	.24
Stimulus Type $\times$ Group	502.3	1	502.3	2.4	.135	.07
Error (Stimulus Type)	6163.2	29	212.5			
Site	13696.8	1.3	10545.9	33.5	.000	.54
Site $\times$ Group	64.2	1.3	49.4	.2	.759	.00
Error (Site)	11850.5	37.7	314.6			
Hemisphere	1623.6	1	1623.6	7.5	.010	.21
Hemisphere $\times$ Group	112.5	1	112.5	.5	.475	.02
Error (Hemisphere)	6243.3	29	215.3			
Orientation $\times$ Stimulus Type	412.8	1	412.8	7.1	.013	.20
Orientation $\times$ Stimulus Type $\times$ Group	307.9	1	307.9	5.3	.029	.15
Error (Orientation $\times$ Stimulus Type)	1690.8	29	58.3			
Orientation $\times$ Site	470.9	1.3	357.2	12.2	.000	.30
Orientation $\times$ Site $\times$ Group	3.5	1.3	2.6	.1	.914	.00
Error (Orientation $\times$ Site)	1121.7	38.2	29.3			
Stimulus Type $\times$ Site	1735.8	1.6	1060.6	10.35	.000	.27
Stimulus Type $\times$ Site $\times$ Group	352.6	1.6	214.8	2.2	.129	.07
Error (Stimulus Type $\times$ Site)	4603.5	47.5	97.0			
Orientation $\times$ Stimulus Type $\times$ Site	28.7	1.5	18.4	1.1	.339	.04
Orientation $\times$ Stimulus Type $\times$ Site $\times$ Group	14.2	1.5	9.1	.5	.550	.02
Error (Orientation $\times$ Stimulus Type $\times$ Site)	782.4	45.1	17.3			
Orientation $\times$ Hemisphere	.6	1	.6	.0	.853	.00
Orientation $\times$ Hemisphere $\times$ Group	5.8	1	5.8	.3	.565	.01
Error (Orientation $\times$ Hemisphere)	494.9	29	17.1			

**Table D2.** ANOVA Table for the N170 Peak Latency (2)

Source of Variance	Sum of Squares	df	Mean Square	F	Significance	Partial $\eta^2$
Stimulus Type $\times$ Hemisphere	344.1	1	344.1	4.2	.048	.13
Stimulus type $\times$ Hemisphere $\times$ Group	68.2	1	68.2	.8	.367	.03
Error (Stimulus Type $\times$ Hemisphere)	2349.8	29	81.0			
Orientation $\times$ Stimulus Type $\times$ Hemisphere	21.8	1	21.8	1.4	.252	.04
Orientation $\times$ Stimulus Type $\times$ Hemisphere $\times$ Group	8.4	1	8.4	.5	.475	.02
Error (Orientation $\times$ Stimulus Type $\times$ Hemisphere)	464.3	29	16.0			
Site $\times$ Hemisphere	826.1	1.3	621.0	6.6	.003	.19
Site $\times$ Hemisphere $\times$ Group	16.9	1.3	12.7	.1	.785	.01
Error (Site $\times$ Hemisphere)	3604.5	38.6	93.4			
Orientation $\times$ Site $\times$ Hemisphere	3.6	1.6	2.3	.2	.805	.00
Orientation $\times$ Site $\times$ Hemisphere $\times$ Group	11.2	1.6	7.0	.5	.571	.02
Error (Orientation $\times$ Site $\times$ Hemisphere)	659.2	46.2	14.3			
Stimulus Type $\times$ Site $\times$ Hemisphere	217.6	1.6	136.1	2.6	.096	.08
Stimulus Type $\times$ Site $\times$ Hemisphere $\times$ Group	275.3	1.6	172.2	3.3	.057	.10
Error (Stimulus Type $\times$ Site $\times$ Hemisphere)	2429.5	46.4	52.4			
Orientation $\times$ Stimulus Type $\times$ Site $\times$ Hemisphere	22.1	1.4	16.2	.8	.414	.03
Orientation $\times$ Stimulus Type $\times$ Site $\times$ Hemisphere $\times$ Group	57.0	1.4	42.0	2.1	.154	.07
Error (Orientation $\times$ Stimulus Type $\times$ Site $\times$ Hemisphere)	803.8	39.4	20.4			