Linking Cognitive Neuroscience and Molecular Genetics: New Perspectives from Williams Syndrome
Ursula Bellugi and Marie St. George (Eds.)

III. Electrophysiological Studies of Face Processing in Williams Syndrome

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Abstract

■ Williams Syndrome (WMS) is a genetically based disorder characterized by pronounced variability in performance across different domains of cognitive functioning. This study examined brain activity linked to face-processing abilities, which are typically spared in individuals with WMS. Subjects watched photographic pairs of upright or inverted faces and indicated if the second face matched or did not match the first face. Results from a previous study with normal adults showed dramatic differences in the timing and distribution of ERP effects linked to recognition of upright and inverted faces. In normal adults, upright faces elicited ERP differences to matched vs. mismatched faces at approximately 320 msec (N320) after the onset of the second stimulus. This ''N320'' effect was largest over anterior regions of the right hemisphere. In contrast, the mismatch/match effect for inverted faces consisted of a large positive component between 400 and 1000 msec (P500) that was largest over parietal regions and was symmetrical. In contrast to normal adults, WMS subjects showed an N320-mismatch effect for both upright and inverted faces. Additionally, the WMS subjects did not display the N320 right-hemisphere asymmetry observed in the normal adults. WMS subjects also displayed an abnormally small negativity at 100 msec (N100) and an abnormally large negativity at 200 msec (N200) to both upright and inverted faces. This ERP pattern was observed in all subjects with WMS but was not observed in the normal controls. These results may be linked to increased attention to faces in subjects with WMS and might be specific to the disorder. These results were consistent with our ERP studies of language processing in WMS, which suggested abnormal cerebral specialization for spared cognitive functions in individuals with WMS. ■

INTRODUCTION

The relative influence of genetic, maturational, and experiential factors on the development of cerebral specialization is a central issue in cognitive neuroscience. The unusual neurocognitive and genetic profiles in Williams Syndrome (WMS) provide an opportunity to examine how these factors interact to shape cerebral specializations for language and nonlanguage cognitive functions. Williams syndrome is a genetically based disorder characterized by remarkable sparing in some domains, such as language and face recognition, in contrast with marked deficits in other domains, such as spatial abilities (see Bellugi, Lichtenberger, Jones, Lai, & St. George, this volume). This disorder is also associated with concomitant abnormalities in brain structure, such as curtailment of the posterior-parietal and occipital regions (see Galaburda & Bellugi, this volume; Reiss et al., this volume). One approach to studying structure-function relations would be to link abnormalities in brain structure with specific cognitive deficits. For example, deficits in spatial abilities may be linked with abnormal structure (Galaburda & Bellugi, this volume) and abnormal function (Atkinson, Braddick, Nokes, Anker, & Braddick, 1997) in the dorsal-visual stream. However, this approach does not provide information about the organization of spared cognitive functions such as language and face processing.

In early neuroanatomical studies, MRI analyses of individuals with WMS suggested normal volumetric measures of frontal and cerebellar structures, which might underlie spared language abilities (Jernigan & Bellugi, 1994). The volume of gray matter in the inferior-posterior medial cortex was positively correlated with face-recognition abilities in individuals with WMS (Jones, Rossen, Hickok, Jernigan, & Bellugi, 1995). Of particular interest was whether a configuration of relatively normal brain structure in regions typically associated with the spared cognitive abilities would be indicative of normal brain function in WMS, as suggested by Bellugi, Mills, Jernigan, Hickok, and Galaburda (1999b). Alternatively, the brain systems that underlie the spared cognitive functions might be abnormally organized due to interactions with known structural abnormalities in other parts of the WMS brain (Galaburda & Bellugi, this volume; Reiss et al., this volume). From a developmental perspective, it was also important to examine whether the functional organization of brain systems linked to face processing in WMS might be similar to that found in normal brains at an earlier point in development. This result would indicate normal but delayed brain development. In contrast, it is also possible that WMS brains process this information in a different, perhaps unique, way.

In this study, we employed the event-related potential (ERP) technique to examine the organization of brain activity for face recognition, a spared cognitive function in WMS. We tested the hypothesis that the brain systems underlying face processing may be abnormally organized in WMS.

The Neural Basis of Abnormal Language Processing in WMS

In WMS, evidence from ERP studies of auditory language processing suggested abnormal patterns of cerebral specialization for language processing (Bellugi et al., 1999b; Bellugi, Lichtenberger, Mills, Galaburda, & Korenberg, 1999a; Mills, 1998; Neville, Mills, & Bellugi, 1994). Like face processing, auditory language comprehension and production have been shown to be remarkably spared in WMS adolescents and adults, in spite of the late onset of auditory language acquisition. Recent electrophysiological evidence (cited above) suggested that there were marked differences in the organization of language-relevant brain systems that might be unique to individuals with WMS. In normal adults and school-aged children, ERPs to closed class (i.e., grammatical function) words display a left-anterior asymmetry from at least 9 years of age. The presence of this asymmetry has been linked to performance on tests of comprehension of syntax (Neville, Coffey, Holcomb, & Tallal, 1993). Although WMS adolescents and adults have relatively spared grammatical abilities, most WMS subjects did not show the left-anterior asymmetry to closed class words. Additionally, WMS subjects showed an abnormally organized ERP response to processing semantic information in auditory sentences. Several ERP studies of normal adults and children have shown that a semantically anomalous word at the end of a sentence produces a robust negativity, called an N400, that has been linked to integration of word meaning (see Kutas & Hillyard, 1980). In adults, the visual N400 tends to be largest over posterior regions of the right hemisphere. However, in WMS subjects the N400 to semantic violations tended to be larger than normal and had a different distribution. In WMS, the N400 was larger over anterior than posterior regions and was larger from the left than the right hemisphere. In summary, the ERP studies of sentence processing described here suggest that the organization of neural systems that mediate different aspects of language, a spared cognitive function in WMS, is abnormally organized.

Face Processing and Other Spatial Abilities in WMS

Adolescents and adults with WMS have been shown to be quite adept at discriminating and learning to recognize unfamiliar faces. Behavioral studies suggest that most individuals with WMS are at, or close to, normal levels of performance on standardized tests of face processing, such as the Benton Test of Facial Recognition (Benton, Hamsher, Varney, & Spreen, 1983a), the Mooney Closure Test (Mooney, 1957), and the Warrington Recognition Memory Test (Warrington, 1984) (see Bellugi et al., 1999a; Bellugi et al., 1999b). This is in marked contrast to their impaired performance on tests of other spatial abilities. For example, most individuals with WMS are unable to match the angular orientation of two lines with lines in an array on the Benton Judgment of Line Orientation (Benton, Hamsher, Varney, & Spreen, 1983b), and perform very poorly on other form copying tasks such as the Test of Visual-Motor Integration (VMI; Beery, 1997), the block construction tasks in the Wechsler Intelligence Scale for Children—Revised (WISC; Wechsler, 1974) and in the Wechsler Adult Intelligence Scale—Revised (WAIS; Wechsler, 1981) (see Bellugi et al., this volume). Additionally, when asked to copy a line drawing of a house, WMS subjects tend to reproduce the local features, e.g., door, windows, chimney, but do not preserve the overall global configuration of the drawing (Bellugi et al., this volume). The tendency for WMS subjects to reproduce only the local elements in an array is also displayed in a hierarchical forms task (Bihrle, Bellugi, Delis, & Marks, 1989). For example, when asked to copy a large "Y" comprised of smaller "H"s, WMS subjects only produce the small "H"s, i.e., the local elements. This is of particular interest in relation to face-processing abilities that are generally thought to call on global or configural processing strategies in normal adults (Farah, Wilson, Drain, & Tanaka, 1998; Farah, Tanaka, & Drain, 1995;

Tanaka & Farah, 1991; Diamond & Carey, 1986; Carey, Diamond, & Woods, 1980).

The hypothesis that upright faces are processed in a global or configural manner is supported by studies showing a disproportionate inversion effect for faces over other objects (Valentine, 1988; Diamond & Carey, 1986; Yin, 1969). The decrement in performance for recognition of inverted vs. upright faces is considerably larger than for other objects such as houses or cars. A series of recent studies by Farah et al. (1998) suggests that upright faces are recognized ''holistically,'' whereas inverted faces and other types of objects are recognized by decomposition of their parts. One might predict that if WMS subjects show a bias for local processing, they would use similar strategies for processing upright and inverted faces. That is, they might not show an inversion effect. A preliminary study with WMS adults and adolescents supported this hypothesis (Rossen, Jones, Wang, & Klima, 1995). A recent study on children with WMS (ages 6 to 14 years) directly investigated the link between local/global strategies and performance on recognition of upright and inverted faces. In that study, most WMS children showed a preference for local processing on the hierarchical forms task. In contrast to the earlier study with adults, most WMS children showed a larger inversion effect than did normal age-matched controls (Jones, Hickok, & Lai, 1998). However, in that study, WMS children were presented with an example stimulus in the upright orientation and asked to find the matching face from an array of inverted stimuli. The mental rotation component, rather than the inversion of the stimuli, could have accounted for the increased decrement in performance. Moreover, in that study, behavioral scores on the matching task for upright and inverted faces were not correlated with scores on local/global processing. The results suggest that global processing of faces and hierarchical forms do not index the same processes.

Face-Specific Brain Mechanisms

The idea that there are brain systems specific to face recognition is supported by several lines of research. One line of evidence comes from brain-injured patients with prosopagnosia. These patients typically display an inability to recognize familiar faces without a concomitant decrement in other forms of object recognition. The lesions that produce the disorder are usually bilateral and extend along temporal and occipital cortical regions (Damasio, Tranel, & Damasio, 1990; Damasio, Damasio, & Van Hoesen, 1982). Some studies of patients with right-hemisphere lesions have described similar effects (Yin, 1970). A double dissociation exists in that other types of patients show preserved face-processing abilities with deficits in object recognition (Hécaen, Goldblum, Masure, & Ramier, 1974). Recently, Moscovitch, Winocur, and Behrmann (1997) described such a patient, CK, with normal face recognition but with object agnosia. CK performed as well as controls on tasks involving faces as long as they were upright and maintained the configurational properties of a face regardless of whether they were photographs, cartoons, or faces comprised of objects.

In normal adults, studies using brain-imaging techniques further support the hypothesis that there are specialized brain mechanisms within the occipito-temporal regions for face perception and recognition. A series of PET studies indicated increased regional blood flow within the fusiform gyrus in response to human faces (Sergent, Ohta, & MacDonald, 1992; Haxby et al., 1991; Haxby et al., 1994). Recent studies using fMRI have also shown activation of the fusiform gyrus in response to both passive viewing, and active matching tasks involving upright faces, but not to other types of visual stimuli including: non-face objects, scrambled faces, and inverted schematic (Mooney) faces, (Kanwisher, Tong, & Nakayama, 1998; Kanwisher, McDermott, & Chun, 1997; Clark, Maisog, & Haxby, 1997; McCarthy, Puce, Gore, & Allison, 1997; Clark et al., 1996; Puce, Allison, Gore, & McCarthy, 1995). Additionally, activation within this region was increased with selective attention to faces (Wojciulik, Kanwisher, & Driver, 1998).

Electrophysiological recordings made directly from occipito-temporal cortex in epileptic patients also showed activation to faces but not to other types of visual stimuli (Allison, McCarthy, Nobre, Puce, & Belger, 1994b; Allison, Puce, Spenser, & McCarthy, 1999; McCarthy, Puce, Belger, & Allison, 1999; Puce, Allison & McCarthy, 1999). A surface-negative potential at 200 msec, called the N200, was observed in response to faces but not scrambled faces, or pictures of cars, scrambled cars, or butterflies. Face-specific activity was observed in three regions: the ventral face area (lateral fusiform and adjacent inferior temporal gyri), the lateral face area (middle temporal gyri), and the anterior face area (anterior fusiform, cortex of the ventral-temporal pole and entorhinal cortex; Allison et al., 1999). The N200 was generated in the ventral and lateral face areas and was active during face perception but was not elicited by affective stimuli, diminished by habituation, affected by familiarity of the face, nor affected by semantic priming or face naming (Puce et al., 1999). Moreover, stimulation within face-specific regions produced an inability to name previously correctly identified faces (Allison et al., 1994a).

Face-specific ERPs have also been recorded from scalp electrodes (deHahn, Olivers, & Johnson, 1998; Bentin, Allison, Puce, Perez, & McCarthy, 1996; Botzel, Grusser, Haussler, & Naumann, 1989). A negative potential that peaked at 170 msec, called the N170, was elicited by faces and face components, especially eyes, but not by other types of visual stimuli (Bentin et al., 1996). Considering differences in the functional sensitivity of the N170 to eyes alone, and the depth and orientation of the fusiform where the N200 is generated, it is unlikely that

the N170 and the subdural N200 reflect the same brain systems. Moreover, the N170 was maximal over right-posterior temporal regions and was, therefore, thought to be generated lateral to the fusiform region that generated the N200 (Bentin et al., 1996).

Preliminary research with WMS individuals also provided evidence consistent with the involvement of areas including the fusiform in face processing. In a study of WMS individuals (ages 10–20 years) using structural MRI, Jones et al. (1995) found that increased volume of gray matter in the inferior-posterior medial cortex, i.e., an area including the fusiform, was correlated with performance on the Benton Test of Facial Recognition. This finding raised the possibility that face perception and recognition may be normally organized in this population. However, the presence of structural abnormalities in posterior brain regions (Galaburda & Bellugi, this volume) raises the equally plausible hypothesis that the brain systems that underlie face processing in this population may be abnormally organized, or displaced anteriorly. This pattern might be reflected in a more anterior distribution of ERP effects, that is, increased activation, over the anatomically spared anterior regions.

Right Hemisphere Involvement in Face Processing

Several lines of evidence have suggested a greater involvement of the right than the left hemisphere in face processing, including: studies of patients with right-hemisphere lesions (de Renzi, 1986; Yin, 1970), epileptic patients who have undergone surgical callosectomy, (Levy, Trevarthen, & Sperry, 1972), behavioral studies of normal subjects that have shown visual field preferences in face processing (e.g., Magnussen, Sunde, & Dyrnes, 1994; Schweinberger, Sommer, & Stiller, 1994; Schweinberger & Sommer, 1991; Sergent, 1986; Rhodes, 1985; Leehy, Carey, Diamond, and Cahn, 1978), brain imaging studies using PET and fMRI techniques that showed bilateral activation that was greater on the right side (Kanwisher et al., 1997; Kanwisher et al., 1998; McCarthy et al., 1997; Haxby et al., 1993; Sergent et al., 1992), and ERP studies that showed right-greater-than-left asymmetries in face-relevant components in adults (Alvarez, Mills, & Neville, 1999; deHahn et al., 1998; Bentin et al., 1996). A recent hemifield study using subdural recordings from epileptic patients suggested that the right hemisphere was better at processing information about upright faces, whereas the left hemisphere was better at processing information about inverted faces (McCarthy et al., 1999).

The present study was based on a recent ERP investigation of recognition for upright and inverted faces in normal adults (Alvarez et al., 1999). In that experiment, ERPs were recorded as subjects watched photographic pairs of upright or inverted faces presented sequentially on a computer monitor. The subject's task was to indicate whether the second face in the pair (''target'') was the same or a different person as in the first photograph (''prime''). Results from normal adults showed marked differences in the timing and distribution of ERP effects linked to recognition of upright and inverted faces, and are consistent with other evidence suggesting that, in adults, nonidentical brain systems mediate processing of upright and inverted faces. Recognition of mismatched upright faces elicited a negativity at 320 msec and was most prominent over anterior regions of the right hemisphere (see also Barrett, Rugg, & Perrett, 1988). In contrast, ERPs to mismatched inverted faces were characterized by a positivity that occurred later (at 500 msec) and displayed a bilateral posterior distribution. These different patterns of brain activity are consistent with behavioral studies of adults suggesting that differences in processing upright and inverted faces may be associated with differences in processing configurational vs. featural information. Alvarez and Neville (1995) also used this paradigm to study the development of these brain systems in normal children at 9, 13, and 16 years of age. The results suggest that children, unlike adults, display a similar pattern of ERPs to upright and inverted faces. Moreover, the mature pattern of right-greater-than-left asymmetry to upright faces is not evident until the late teens. These data are consistent with behavioral research suggesting that children use a similar analysis strategy for both upright and inverted faces (Carey & Diamond, 1977).

RESULTS

Behavioral Data

Normal adults were faster and more accurate than the WMS adults [main effect of group: reaction time, $F(1,1) = 10.28$, $p < .001$; accuracy, $F(1,1) = 21.69$, $p < .001$] (Figure 1). However, most of the WMS adults scored within the range of the normal adults. Examination of the accuracy data from individual subjects showed that for the upright faces 15 of the 18 WMS adults performed within the range of the normal adults (range for normal adults = 74–100%). For the inverted faces, 12 out of 18 WMS adults showed accuracy scores within the range of the normal adults (range for normal adults = 59–100%).

Both normal and WMS adults were faster and more accurate at recognizing upright than inverted faces [main effect of orientation: reaction time,[1] $F(1,35) = 11.67$, $p < .001$; accuracy, $F(1,39) = 114.89$, $p < .001$], and were faster and more accurate at correctly identifying matched than mismatched targets [main effect of condition: reaction time, $F(1,1) = 11.48$, $p < .001$; accuracy, $F(1,1) = 4.44$, $p < .05$].

Of particular importance was that the WMS and normal adults showed similar inversion effects. Relative to upright faces, inverted faces produced a 10% drop in

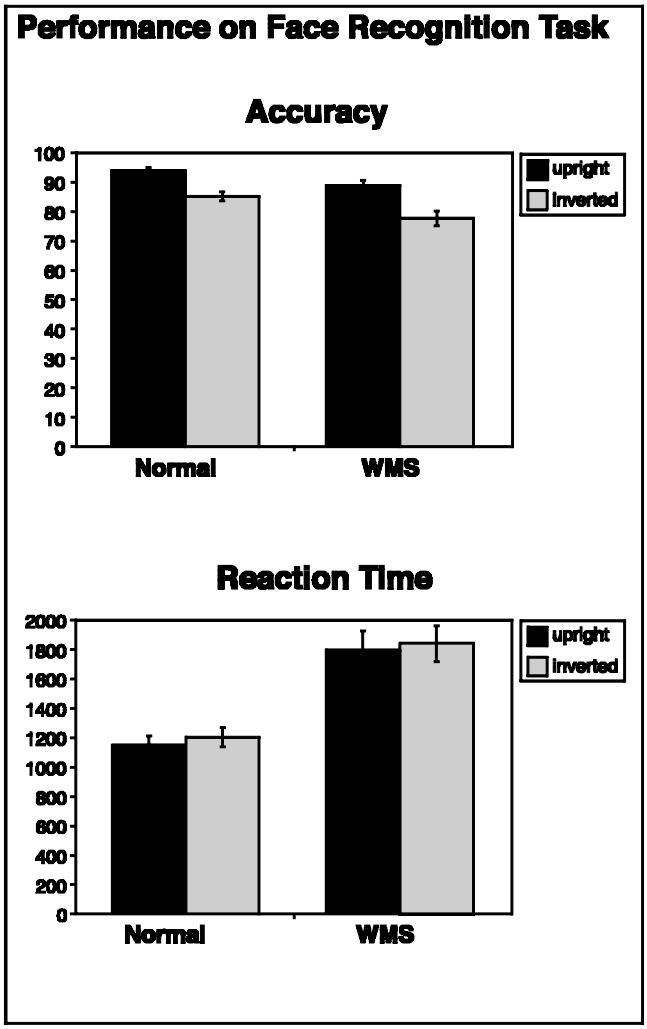

Figure 1. Performance on the face-recognition task upright and inverted faces by Normal and WMS adults. Error bars indicate the standard error of the mean. Top: Percent correct identification averaged across matched and mismatched targets. Bottom: Reaction time in msec for correct responses to matched and mismatched target faces.

accuracy and a 50 msec increase in reaction time for both the WMS and normal adults.

ERP Results

Results from a larger sample of normal controls on this paradigm are presented in Alvarez et al. (1999). The ERP patterns for the normal controls participating in this study are presented along with the data from the WMS subjects in the sections below. Any differences in the findings between the normal subjects in this sample and the previous study by Alvarez are noted in the corresponding analyses. For practical purposes, this paper will emphasize group differences in responses to upright and inverted faces and matched vs. mismatched targets. The organization of the Results section is as follows: Each component is discussed separately in temporal order. The main effects for group differences are presented first. These effects are followed by main effects, and interactions with group, for orientation (upright vs. inverted), condition (match vs. mismatch), and distribution. Because ERPs between the two groups differed in amplitude, the data were normalized to assess true differences in distribution according to the formula recommended by McCarthy and Wood (1985).

Occipital sites are discussed separately due to differences in the latencies and morphology of the components over this area.

Primes: (i.e., the First Face in the Pair)

The morphology of the ERP components to the first face in the pair (prime) was similar to the targets, which are discussed in detail below (Figure 2).[2]

N100. The first negative component peaked around 100 msec (N100). The latency of the N100 was later and the amplitude tended to be smaller in WMS subjects than normal controls [latency: group, $F(1,35) = 6.76$; amplitude: group, approached significance, $p < .10$]. Additionally, the amplitude of the N100 was larger from the left than the right hemisphere, but this effect was significant only for the normal controls [normalized amplitudes: hemisphere, $F(1,35) = 3.71$, $p = .06$; group × hemisphere, $p = .11$; for normal controls, hemisphere, $F(1,22) = 10.40$, $p < .001$; for WMS, n.s.]. The N100 was larger to inverted than upright faces, but again, only for the normal controls [amplitude: group × orientation, $F(1,35) = 8.79$, $p < .01$; amplitude for normal controls: orientation, $F(1,22) = 8.07$, $p < .01$; for WMS, n.s.].

P170. The first positive component peaked around 170 msec (P170) for both normal and WMS subjects. The P170 was larger for normal than WMS adults [amplitude: group, $F(1,35) = 13.98$, $p < .001$]. Like the N100, the P170 was larger to inverted than upright faces, but only for the normal controls [amplitude: orientation, $F(1,35) = 4.66$, $p < .05$; group × orientation, $F(1,35) = 7.34$, $p < .01$; amplitude for normal controls, $F(1,22) = 14.71$, $p < .001$; WMS, n.s.].

N200. There were no group differences or effects of orientation for the latency of the N200. The N200 response to both the prime and target stimuli (discussed below) was larger in WMS subjects than controls [amplitude: group, $F(1,35) = 29.39$, $p > .001$] (see Figures 2 and 3). The N200 was larger for upright than inverted faces for both groups [amplitude: orientation, $F(35) = 6.51$, $p < .05$].

N300–500. The mean amplitude between 300 and 500 msec poststimulus onset was also examined for differ-

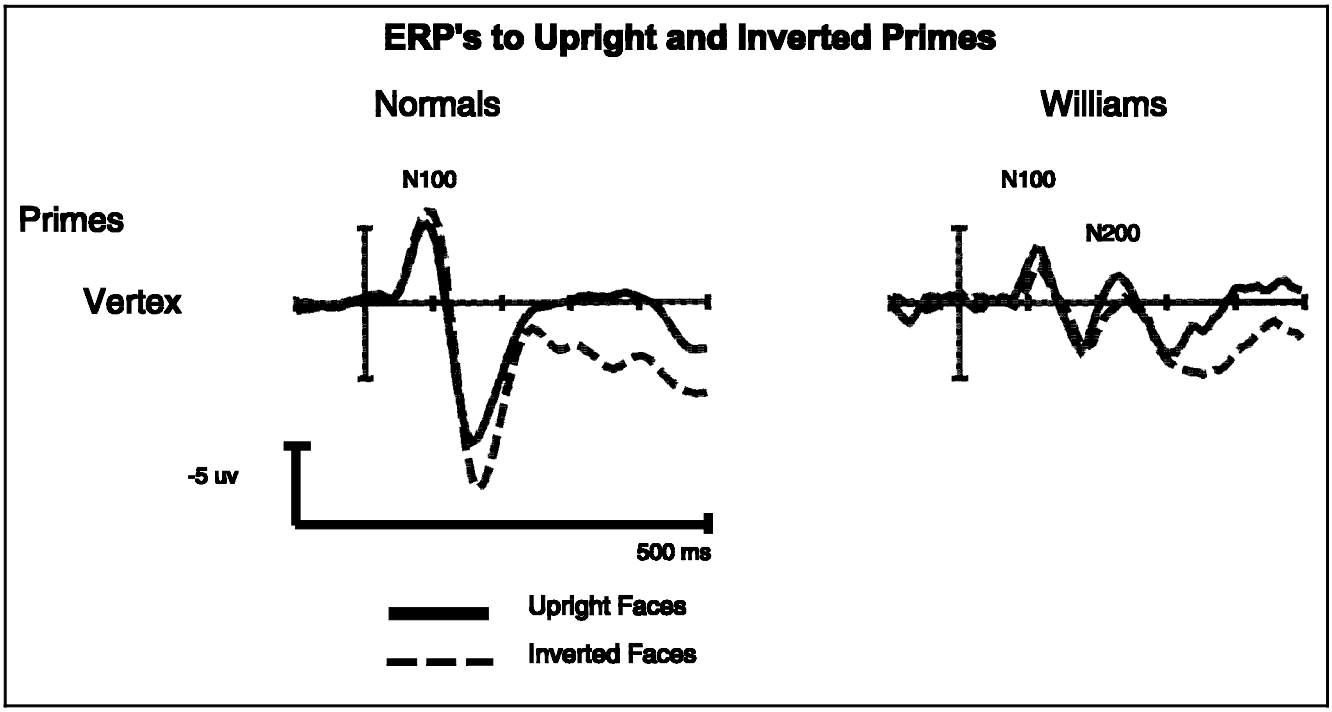

Figure 2. ERPs to upright primes (solid) and inverted primes (dashed) are compared for normal subjects (left side) and WMS subjects (right side). Negative voltage is plotted up. Vertex refers to the electrode site (over the middle of the head) from which the ERPs shown in the figure were recorded.

ences in ERPs to upright and inverted faces. For both normal and WMS adults, the mean amplitude between 300 and 500 was more negative for upright than inverted faces [$F(1,35) = 32.21$, $p < .001$]. Additionally, the N300–500 was larger over the left than the right hemisphere [mean amplitude: hemisphere, $F(1,35) = 5.04$, $p < .05$], and was larger over anterior than posterior regions [mean amplitude: electrode site, $F(3,105) = 49.54$, $p < .001$].

Targets: (i.e., Second Face in the Pair)

ERPs to the second face in the pair (target) were characterized by a series of negative and positive deflections in the following temporal order: A negativity at 200 msec, N200, and approximately 100 msec, N100; a positivity at 150 msec, P150; a negativity at 200 msec, N200, and 320 msec, N320; and a late positivity P500.

ERPs Anterior to the Occiput

N100. The amplitude of the N100 was smaller, i.e., approximately half, for the WMS subjects than for the normal controls (mean; WMS = 5.7 μv, controls = 3.1 μv) [main effect of group: $F(3,117) = 6.92$, $p < .001$], (Figures 4 and 5). There was no main effect of group for peak latency.

For both groups, the N100 was larger and peaked later over anterior than posterior regions [main effect of electrode site: amplitude, $F(3,117) = 61.11$, $p < .001$, latency: $F(3,117) = 22.11$, $p < .001$]. And the N100 was larger and peaked later over the left than the right hemisphere [main effect of hemisphere: normalized amplitude, $F(1,39) = 5.52$, $p < .05$; latency, $F(1,39) =$

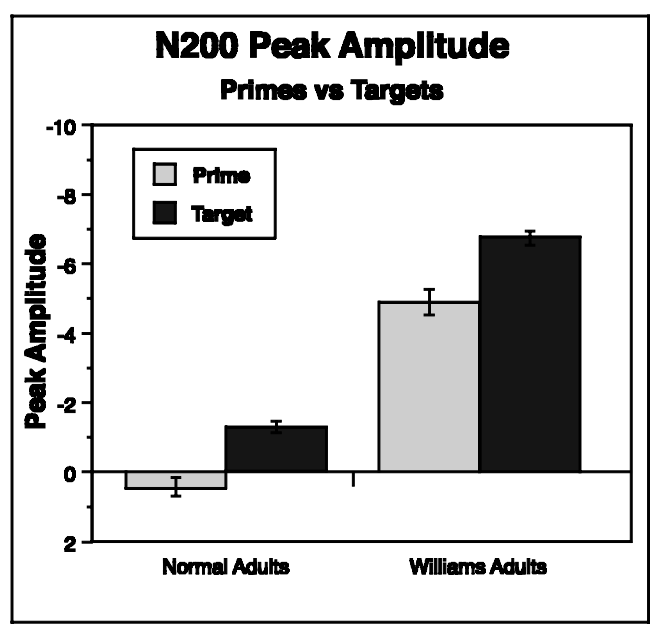

Figure 3. N200 amplitudes in μv for the first (prime) and second (target) faces presented within the pairs of stimuli. The N200 amplitudes are averaged across all cites anterior to the occiput. The results for normal adults are shown on the left and for WMS adults on the right. Results show N200 amplitudes for both primes and targets are dramatically larger for WMS than normal adults.

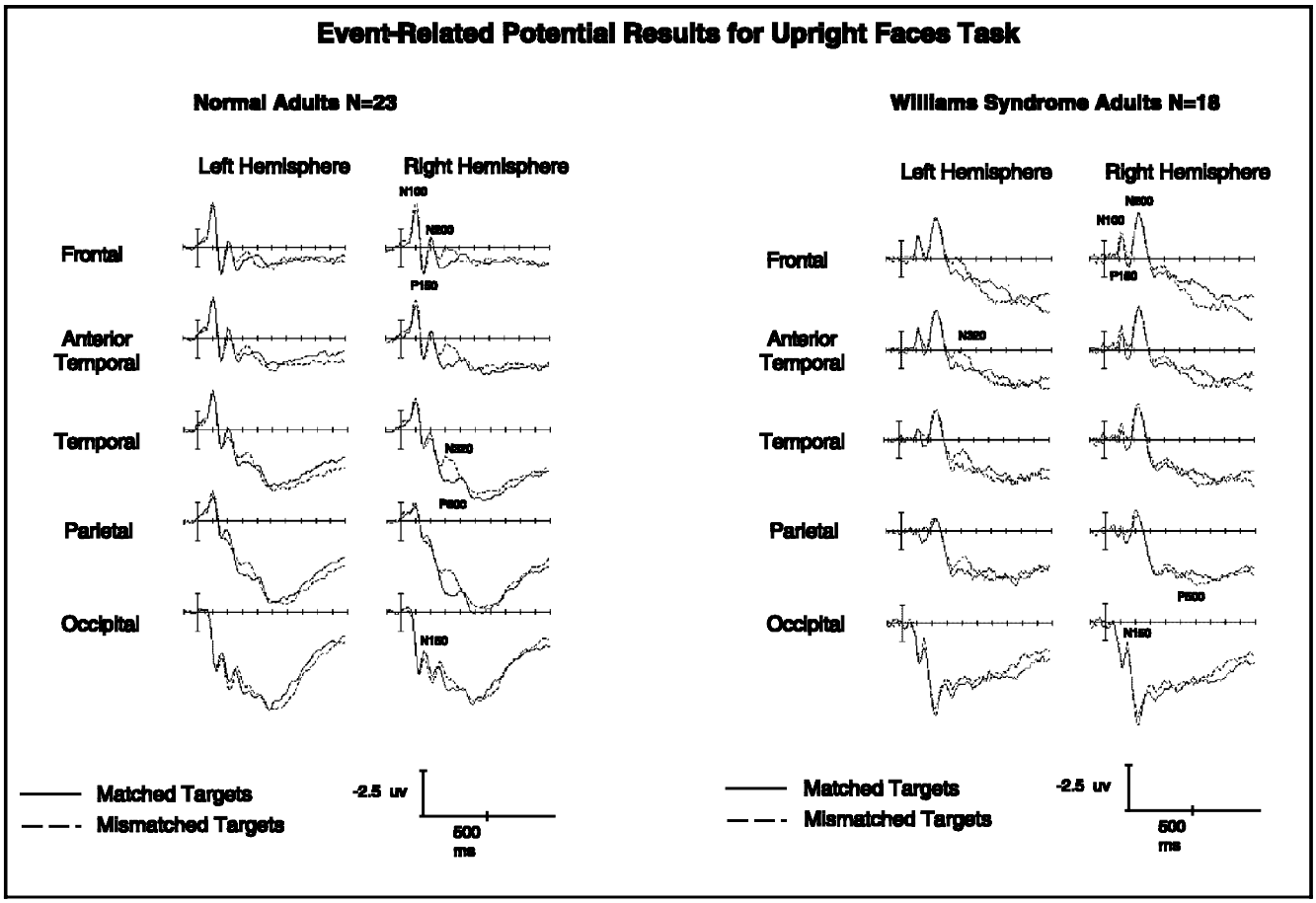

Figure 4. ERPs to upright faces for normal (left side) and WMS (right side) adults. The solid line represents ERPs to targets that matched the preceding face. The dashed line represents ERPs to targets that differed (mismatch) from the preceding face.

4.60, $p < .05$], especially over temporal and parietal regions, [normalized amplitude: hemisphere × electrode, $F(3,117) = 5.45$, $p < .01$)]. However, the lateral effects for both latency and amplitude were significant for the normal controls but not the WMS subjects [latency: group × hemisphere, $F(1,39) = 4.40$, $p < .05$ (normal controls, $p < .01$; WMS, n.s.); group × hemisphere × electrode, $F(3,117) = 2.74$, $p < .05$ (normal controls, $p < .01$; WMS, n.s.); normalized amplitudes: group × hemisphere, approached significance, $F(1,39) = 2.89$, $p = .10$; group × orientation × hemi- sphere × electrode, $F(3,117) = 4.71$, $p < .01$]. Examination of the interactions with amplitude showed that the WMS subjects displayed a more symmetrical distribution of the N100.

For both groups, the N100 was smaller and peaked earlier to upright than inverted faces [main effect of orientation: amplitude, $F(1,39) = 5.08$, $p < .05$; latency, $F(1,39) = 12.07$, $p < .001$].

Previously, Alvarez et al. (1999) found that matched and mismatched targets elicited similar N100 responses. In the present study, there was a larger negativity to mismatched than matched targets [match/mismatch, $F(1,39) = 4.80$, $p < .05$]. Examination of an interaction with group, [normalized amplitude: group × match/mismatch × orientation × hemisphere, $F(1,39) = 6.37$, $p < .05$] showed that the match/mismatch effect approached significance for the WMS subjects, $p = .06$, but not the normal adults. Further examination of this interaction showed that for the WMS subjects the match/mismatch effect approached significance over the left hemisphere for upright faces, and over the right hemisphere for inverted faces.

P150. Like the N100, the P150 was smaller, but also peaked earlier, in the WMS subjects than the normal controls [main effect of group: amplitude, $F(1,39) = 3.81$, $p < .05$; latency, $F(1,39) = 7.50$, $p < .01$].

Consistent with earlier findings (Alvarez et al., 1999), the P150 was earlier for upright than inverted faces for both groups [latency: $F(1,39) = 9.67$, $p < .001$]. In the Alvarez et al. (1999) study of normal adults, there were no other main effects or interactions for the P150. However, like the results from the N100, the WMS subjects, but not the normal controls, showed a significant difference in amplitude between the matched and mismatched targets [amplitude: group-×match/mismatch: $F(1,39) = 12.70$, $p < .001$; main effect of match/mismatch for WMS subjects, $F(1,17) = 12.06$, $p < .001$; normal controls, n.s.].

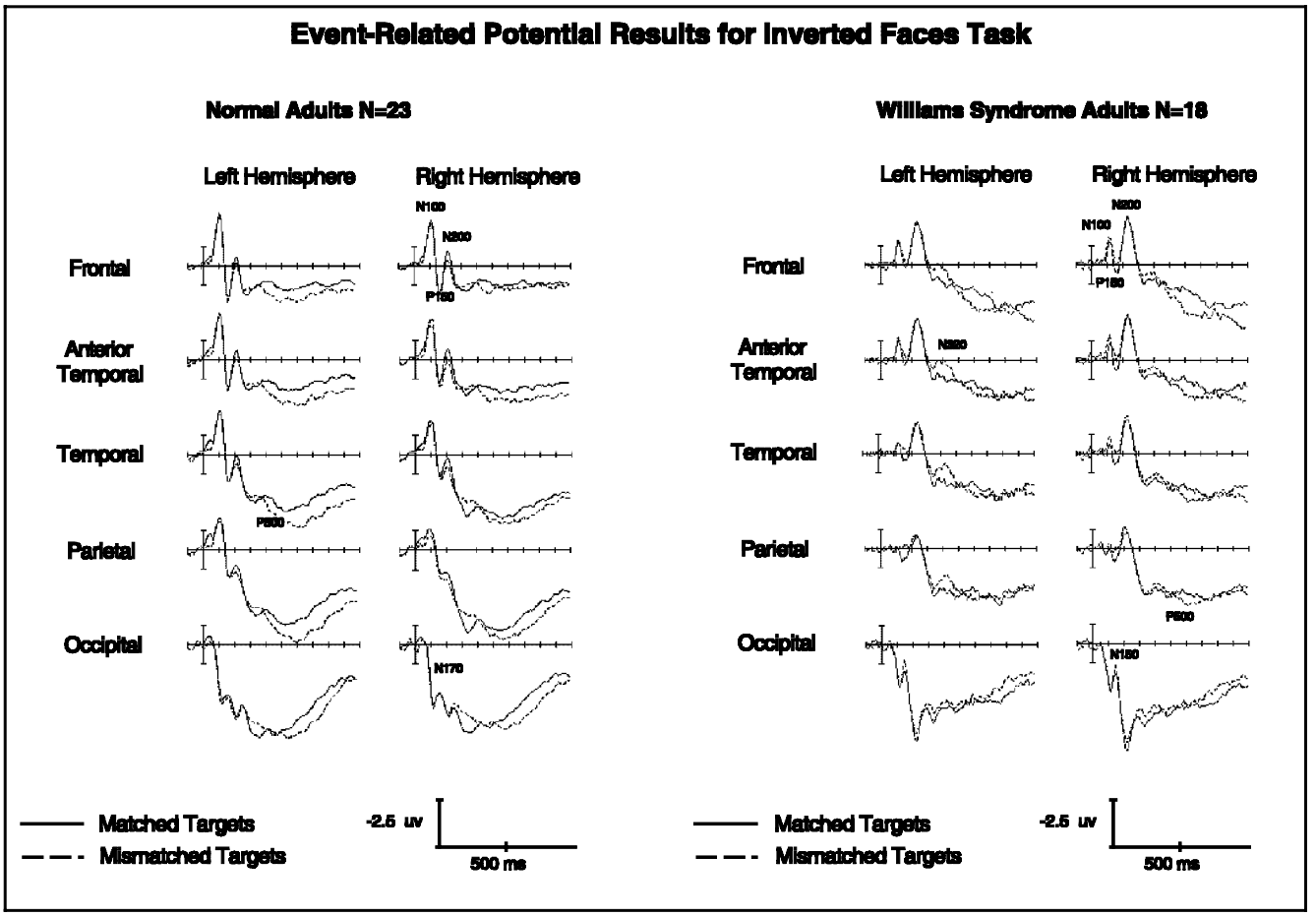

Figure 5. ERPs to inverted faces for normal (left side) and WMS adults (right side). The solid line represents ERPs to targets that matched the preceding face. The dashed line represents ERPs to targets that differed (mismatch) from the preceding face.

N200. The most striking difference in ERPs between the two groups was that the amplitude of the N200 was approximately six times larger in the WMS subjects (mean = -6.2, μv *SD* = 3.4) than in the normal controls (mean = -1.1, μv *SD* = 3.9) [amplitude: main effect of group: $F(1,39) = 35.90$, $p < .001$] (Figures 2, 3 and 4). The latency of the N200 was also 12 msec later in the WMS than in the normal adults [main effect of group: $F(1,39) = 6.54$, $p < .01$].

Like the previous results (Alvarez et al., 1999), the N200 was largest at frontal cites and peaked earliest over parietal cites [main effect of electrode: amplitude, $F(3,117) = 29.41$, $p < .001$; latency, $F(3,117) = 21.17$, $p < .001$.

The N200 was larger and earlier to upright than inverted faces [main effect of orientation: amplitude, $F(1,13) = 7.96$, $p < .01$, latency: $F(1,39) = 6.54$, $p < .01$]. But the amplitude effect was significant only for the WMS group [group × orientation, $F(1,39) = 4.95$, $p < .03$; orientation for WMS, $F(1,17) = 11.08$, $p < .01$; normal controls, n.s.].

Like the N100 and P150, the match/mismatch effect for N200 amplitude differed for WMS subjects and controls [group × match/mismatch, $F(1,39) = 10.04$, $p < .001$]. Although neither group showed a significant mismatch/match amplitude effect on the N200, the slope of the match/mismatch difference went in opposite directions. That is, for the WMS subjects, like the results from the N100, the N200 tended to be larger to mismatched than matched targets. The opposite trend was observed in the controls. Again, these data were consistent with the findings for the N100 and P150 showing earlier match/mismatch effects in the WMS subjects.

N320. The N320 was larger and peaked 30 msec later in the WMS than the control subjects [main effect of group: amplitude, $F(1,39) = 4.68$, $p < .04$; latency, $F(1,39) = 9.19$, $p < .001$]. However, the group differences were significant only over temporal and parietal regions [group × electrode: normalized amplitude, $F(3,117) = 3.46$, $p = .06$; latency, $F(3,117) = 5.09$, $p < .01$].

The N320 was largest over frontal regions [electrode site: amplitude, $F(3,117) = 52.45$, $p < .001$]. In the Alvarez et al. (1999) paper, the normal adults showed a right-hemisphere asymmetry over the anterior regions. In this study, the group × hemisphere × electrode interaction only approached significance, [normalized amplitude,

$F(3,11) = 2.43$, p = .11]. Because of the a priori hypothesis that WMS subjects may show abnormal asymmetries, we examined hemisphere effects separately for each group. Like the previous paper, the normal adults showed a right-hemisphere asymmetry over anterior regions [amplitude for normal adults: hemisphere × electrode site:, $F(3,66) = 5.52$, $p < .05$]. For the WMS subjects, the N320 tended to be larger from the left than the right but this effect did not reach statistical significance.

Like the N200, the N320 for both groups was larger and peaked earlier for upright than inverted faces [main effect of orientation: amplitude, $F(1,39) = 24.08$, $p < .001$; latency, $F(1,39) = 4.09$, $p < .05$].

Target faces that were different from the first face (mismatched targets) elicited a significantly larger and earlier N320 than did targets that matched the first face, (Figure 3) [match/mismatch: amplitude, $F(1,39) = 34.22$, $p < .001$; latency, $F(1,39) = 14.55$, $p < .01$]. The match/mismatch difference was larger for the WMS than the normal adults [amplitude: group × match/mismatch: $F(1,39) = 9.49$, $p < .001$]. Moreover, the lateral distribution of the match/mismatch difference was opposite in the two groups, [normalized amplitude, group × match/mismatch × hemisphere: $F(1,39) = 4.13$, $p < .05$]. That is, the match/mismatch difference tended to be larger from the right than the left for normal controls, but larger from the left than the right in WMS subjects. Both of these trends only approached significance.

Upright and inverted faces elicited different match/mismatch patterns [amplitude: orientation × condition, $F(1,39) = 13.56$, $p < .001$]. However, this pattern differed for the normals and WMS subjects [normalized amplitude: group × orientation × match/mismatch × electrode, $F(3,117) = 3.95$, $p < .05$]. As in Alvarez et al. (1999), normal adults displayed a larger N320 to the mismatched than the matched targets for upright, but not inverted, faces [amplitude for normal adults: orientation × match/mismatch, $F(1,22) = 5.22$, $p < .03$; upright faces: match/mismatch, $F(1,22) = 11.86$, $p < .001$; inverted faces, n.s.]. In contrast, the WMS subjects displayed an N320 match/mismatch effect for both upright and inverted faces [amplitude for WMS: upright faces: match/mismatch, $F(1,17) = 41.89$, $p < .001$; inverted faces: match/mismatch, $F(1,17) = 8.68$, $p < .01$]. However, even in the WMS group, the effect was attenuated for the inverted faces [amplitude for WMS: orientation × match/mismatch, $F(1,17) = 8.8.14$, $p < .01$].

P500. A positive slow-wave component that peaked around 500 msec, the P500, was larger for controls than WMS subjects over temporal and parietal regions [normalized mean area: group × electrode, $F(3,117) = 20.03$, $p < .001$. Examination of this interaction showed that although the P500 was larger over posterior than anterior regions for both groups [normalized mean area: electrode site, $F(3,117) = 72.03$, $p < .001$], the posterior distribution appeared to be more pronounced in the normal controls [mean area for normal controls: electrode site: $F(3,66) = 65.63$, $p < .001$; mean area for WMS, electrode site $F(3,51) = 8.68$, $p < .01$; see Figures 4 and 5].

As in the previous study (Alvarez et al., 1999), the normal adults displayed a larger P500 to mismatched than matched targets, for the inverted but not the upright faces (Figure 5) [mean area for normal adults: orientation × match/mismatch, $F(1,22) = 9.68$, $p < .01$; inverted, match/mismatch, $F(1,22) = 14.41$, $p < .001$; upright, match/mismatch, n.s.]. In contrast, the WMS subjects did not show a significant P500 match/mismatch effect for either the upright or inverted faces [mean area: group × match/mismatch, $F(1,39) = 5.45$, $p < .05$; mean area for WMS: match/mismatch, n.s.].

ERPs over Occipital Regions

P100. The first positive component peaked at 116 msec. There were no group differences in the latency of the P100. Like the anterior N100, the occipital P100 appeared to be smaller in the WMS subjects than controls, but the difference did not reach significant levels.

N150. The first negative component peaked at approximately 150 msec for both groups. In contrast to the anterior P150, the N150 was larger in the WMS than normal adults [group, amplitude, $F(1,39) = 7.24$, $p < .01$]. However, like the anterior P150, the WMS subjects but not the normal controls showed a match/mismatch effect, suggesting earlier recognition processes in the WMS subjects [group × match/mismatch, amplitude, $F(1,39) = 15.42$, $p < .001$; WMS, match/mismatch, amplitude, $F(1,17) = 6.86$, $p < .02$].

N200. The second negative component peaked earlier for the normal controls (257 msec) than for the WMS subjects (280 msec) [latency: group, $F(1,39) = 10.56$, $p < .001$]. In contrast to the anterior N200, there were no group differences in the amplitude of the N200 over the occiput. The mismatched faces elicited a larger N200 than did the matched faces [amplitude: match/mismatch, [$F(1,39) = 7.03$].

N320. Like the occipital N200, the N320 tended to be earlier for the normal controls (382 msec) than for the WMS subjects (393 msec) [latency: group, $F(1,39) = 3.75$, $p = .06$, n.s.). The mean amplitude of the N320 was larger for mismatched than matched targets [mean area: match/mismatch, $F(1,39) = 3.88$, $p = .06$]. However, unlike the anterior N320, this effect did not interact with orientation. The match/mismatch effect tended to be larger from the right than the left hemisphere for the normal controls and tended to be larger from the left

than the right for the WMS subjects [normalized mean area: group × hemisphere, $F(1,39) = 6.30$, $p < .05$]. However, the effect of hemisphere was not significant for either group alone.

P500. Like the anterior cites, the P500 was larger to mismatched than matched targets, only for inverted faces, and only for the normal controls [mean area: group × match/mismatch, $F(1,39) = 4.32$, $p < .05$; orientation × match/mismatch, $F(1,39) = 5.37$, $p < .05$; inverted faces: group × match/mismatch, $F(1,39) = 5.61$, $p < .05$]. The P500 match/mismatch effect was larger over the left than the right hemisphere for normal controls, but not for WMS subjects [mean area: group × hemisphere, $F(1,39) = 5.37$, $p < .05$].

Correlations with Benton Scores and ERP and Task Performance Scores in WMS

Only the WMS subjects had scores for the Benton Test of Facial Recognition (Benton et al., 1983a, b; see Table 1). Therefore, the following correlations and other statistical treatments apply only to the WMS subjects.

Benton scores and accuracy on ERP task. The WMS subjects with higher Benton Test of Facial Recognition scores tended to be more accurate on the match/mismatch task [Spearman, $r = 43$, $p = .07$; Pearson, $r = .45$, $p < .05$].

Benton scores and N200 amplitude. Because the N200 was dramatically larger in WMS than normal adults, we were particularly interested in its functional significance. WMS subjects with larger amplitude N200 components tended to score higher on the Benton Test of Facial Recognition [Spearman, $r = .51$, $p < .05$; Pearson, $r = .38$, $p = .10$; see Figure 6, top]. Because the Pearson correlation only approached significance, we further examined the relationship between the Benton scores and the N200 amplitude. Subjects were divided into two groups based on their scores on the short form of the Benton Test of Facial Recognition. Those who scored above 23 were designated as the high group: i.e., high Benton group, mean = 24.3, range 23 to 26; and low Benton group, mean = 19.3, range 17 to 22. The high Benton group had larger N200 amplitudes than did the low Benton group [for WMS group: $F(1,16) = 6.61$, $p < .05$].

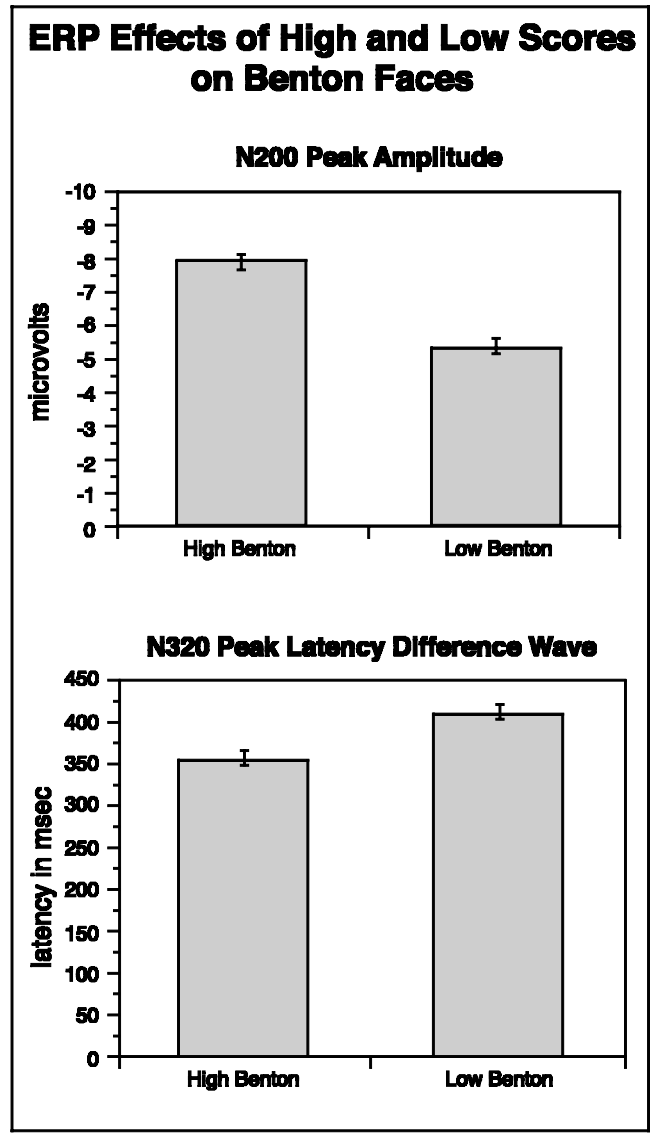

Figure 6. Differences in ERPs for WMS subjects who scored high vs. low on the Benton Facial-Recognition Task. The group differences were based on a median split of the data. The top half of the figure shows a larger amplitude N200 response by WMS subjects who scored in the High Benton group. The bottom half of the figure shows that subjects who scored in the High Benton group tended to have an earlier N320-peak latency for the mismatch minus mismatch difference wave.

Table 1. Characteristics of Subjects with Williams Syndrome in Comparison to Normal Performance Based on Standardized Scores

	Age	*FSIQ*	*Benton*	*PPVT*
Williams Subjects				
mean	25	61	22	62
range	18–38	51–76	17–26	33–79
standard deviation	5.9	16.9	2.9	12.22
Normal Performance				
standardized mean		100	22	100
standard deviation		15	3	15

FSIQ=Full-scale IQ from Weschler adult-intelligence scale.
BENTON=Benton Test of Facial Recognition.
PPVT=Peabody Picture-Vocabulary Test.

Benton scores and N320 match/mismatch latency for upright faces. We predicted that WMS subjects who scored higher on the Benton might also show earlier ERP effects of face recognition. In the original study, the match/mismatch effect for face recognition occurred on the N320 for upright faces. However, neither the amplitude nor the latency of the N320 match/mismatch effect was correlated with scores on the Benton. In contrast, for the WMS subjects the latency of the N320 match/mismatch effect was positively correlated with reaction time on the ERP task [Spearman, $r = .54$, $p < .05$; Pearson, $r = .46$, $p < .05$; ANOVA for WMS, group: $F(1,16) = 7.07$, $p < .05$; see Figure 6, bottom].

Benton and P500 match/mismatch effect for inverted faces. Earlier studies using this paradigm showed that the P500 match/mismatch effect for inverted faces develops with increasing age and proficiency. In the present study, the WMS subjects did not show this effect. Therefore, we examined whether the WMS subjects who scored high on the Benton and/or high on accuracy on the match/mismatch task would show the P500 effect for inverted faces. There were no correlations or other significant differences based on the high Benton vs. low Benton groups described above.

DISCUSSION

ERP Indices of Face Perception

In individuals with WMS, the morphology of the first 200 msec of the ERP waveform in response to faces for both primes and target stimuli was strikingly different from normal. For primes, the N100 and P170 components were smaller for WMS than normal adults. In contrast, the WMS adults displayed an N200 to primes that was absent or attenuated in the ERPs to primes from normal adults. For target stimuli, the amplitude of the N100 in WMS subjects was approximately half the amplitude of the N100 in normal adults. In contrast, the amplitude of the N200 to targets was more than twice the size of the N200 in normal adults. These differences were not subtle, that is, they were larger than two standard deviations of the mean for the normal subjects. This ERP pattern, a small N100 and large N200, was observed in all of the adult subjects with WMS reported here, as well as in all children with WMS we have tested (unpublished data). We have not observed these ERP patterns in normal adults, children, or infants at any age, nor in any of the other populations (i.e., Down syndrome, language impaired children, children with early left- or right-hemisphere brain injury) we have studied. Importantly, these ERP patterns were not observed in two subjects who had a clinical diagnosis of WMS but who did not have the genetic deletion based on the florescence in situ hybridization (FISH) test (not included in this sample). However, to the extent that ERPs index information about brain function, we would expect to find variables that modulate the amplitude and latency of these components in other populations who share specific neurological and neurocognitive characteristics in common with WMS. It is also possible that these effects are linked to subtle structural abnormalities, e.g., abnormal folding or orientation of sulci in the areas generating these components, which may be present in all individuals with WMS (see Galaburda & Bellugi, this volume, for a discussion of abnormal configuration of gyri in WMS). Another consideration is that the amplitude of the N200 was correlated with performance on the Benton Test of Facial Recognition. This is of particular interest because larger volumetric measures of the inferior-posterior medial cortex revealed in MRI analyses were also correlated with performance on the Benton Test of Facial Recognition in WMS subjects (Jones et al., 1995).

We are currently conducting a study of black and white photographs of upright and inverted cars to determine whether the abnormal N100/N200 complex in WMS is specific to face processing. Preliminary results from 10 normal adults and 10 adults with WMS are shown in the right side of Figure 7. Based on visual inspection of the data from individual subjects, there were two main findings. First, the ERP patterns observed for faces, i.e., small N100/larger N200 pattern for WMS, and larger N100/smaller N200 pattern for normal controls were also present to cars (Mills, St. George, & Zangl, unpublished data). This finding could be consistent with the hypothesis that the abnormal N100/N200 pattern indexes activity related to general object perception and might be linked to structural abnormalities in the temporo-occipital regions including the fusiform gyrus. However, the ERP differences between WMS and control subjects were more pronounced for faces than for cars. Second, for both normal controls and WMS subjects, ERPs to cars differed from ERPs to faces. At first glance, it appeared that the ERPs were just larger to faces than to cars. However, the amplitude differences were more complex. For WMS subjects, the N100 was approximately the same size for faces and cars, but the amplitude of the N200 was markedly reduced for cars. This pattern of results is consistent with the hypothesis that the amplitude of the N200 may be linked to increased attention to faces in WMS. For normal controls, the N100 was larger to faces than to cars, whereas the N200 was similar in amplitude to faces and cars. Additionally, both the anterior-posterior and lateral distributions of the N100 and N200 differed for cars and faces for WMS and normal subjects. This finding is important because it provides further evidence that faces and objects are mediated by non-

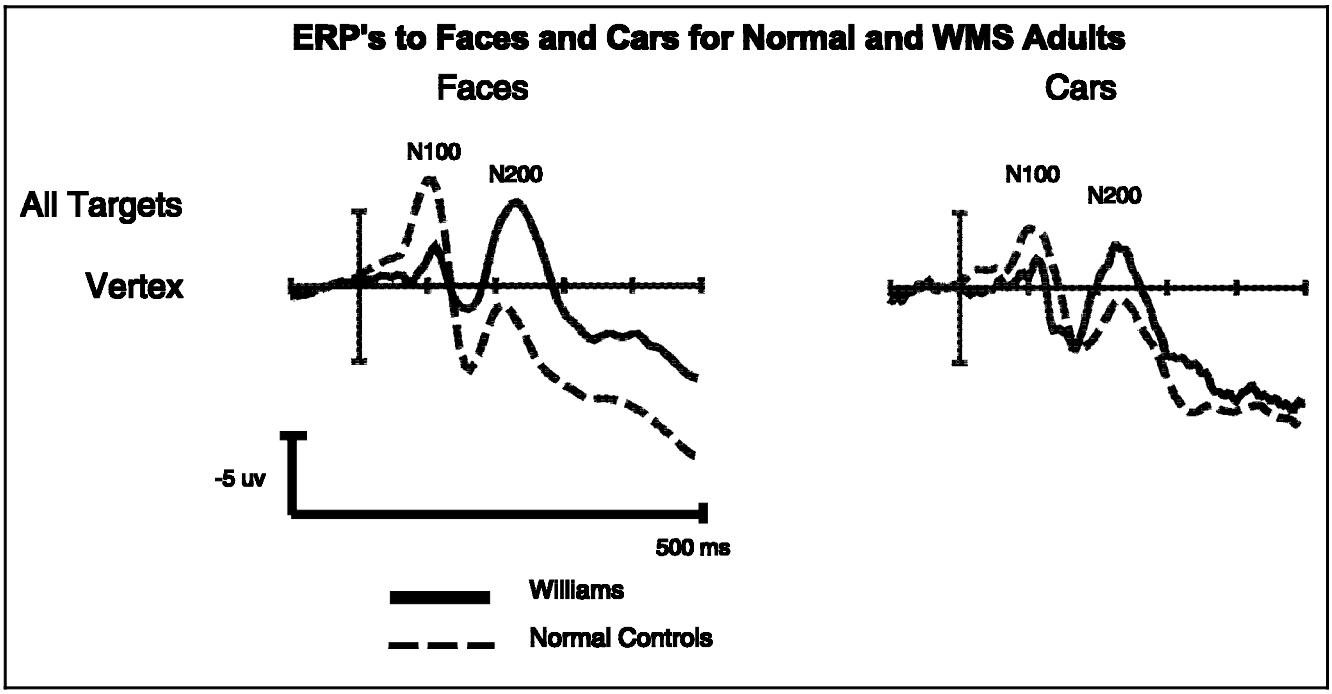

Figure 7. ERPs for WMS (solid lines) subject are directly compared with normal subjects (dashed lines) for faces on the left side of the figure and for cars on the right side of the figure. ERPs to cars were recorded from an additional 10 normal adults and 10 adults with WMS (ages 18 to 14). The data for faces were from the 23 normal and 18 WMS subjects described in this study.

identical neural systems. Although the abnormal N100/N200 complex in WMS may not be specific to faces, it appeared to be different for faces as compared to non-face stimuli.

In studies of normal visual processing, the N100 and N200 components have been linked to perceptual and attentional rather than recognition processes per se (Mangun & Hillyard, 1991). In normal adults, studies of non-face visual stimuli have shown that the amplitude of the N100 increases with attention, and is sensitive to the physical parameters of the visual stimuli, i.e., it increases with increased stimulus intensity, and is probably generated in extrastriate visual cortex (e.g., Mangun, Hillyard, & Luck, 1993). The N200 has been linked with discrimination, categorization, and feature identification (Polich, Ellerson, & Cohen, 1996; Harter, Ainne, & Schroeder, 1984; Hillyard & Kutas, 1983).

In the present study, match/mismatch effects, that is, larger amplitude ERPs to the mismatched targets, were observed on the N100, P150, and N200 in subjects with WMS but not in the normal adult controls. Research with normal adults has shown that the amplitudes of both the N100 and N200 components are modulated by attentional effects (see Hillyard, Mangun, Woldorff, & Luck, 1995 for a review). Moreover, attention to faces has been shown to lead to increased activity in the fusiform, i.e., the area linked to face perception (Wojciulik et al., 1998). Anecdotal evidence from individuals with WMS shows increased interest and fixation on human faces, especially the eyes (Bellugi et al., this volume). Therefore, we propose that the earlier match/mismatch effect in WMS may be due to increased attention to faces in WMS.

It is unlikely that the N200 observed in the present study is the same N200 response observed in subdural recordings (Allison et al., 1994a; Allison et al., 1994b). The N200 observed here had an anterior distribution. As noted by Bentin et al. (1996), the orientation of the neurons producing a surface negative potential over the fusiform region would not produce a negative ERP over more superior scalp. It is also equally unlikely that the N200 observed here is the same component as the N170 described by Bentin, which was specific to faces and face components (Bentin et al., 1996). The N200 in the present study and the N170 also displayed different distributions. The N170 was maximal over occipito-temporal regions, T5/T6 (not recorded here), vs. the anterior distribution of the N200. However, it is possible that the occipital N150 observed here may index the same systems as the occipito-temporal N170. In the present study, the occipital N150 was larger in WMS than normal adults. This is consistent with the hypothesis that WMS individuals have increased neural activity to faces. Further research is needed to test this hypothesis.

ERP Patterns Linked to Recognition

On the ERP face-recognition task, normal adults were faster and more accurate than the subjects with WMS. However, both groups displayed similar behavioral inversion effects. That is, both groups were 10% less

accurate and 50 msec slower to recognize inverted than upright faces. Unlike the normal adults, the WMS subjects did not show marked differences in the morphology, latency and distribution of the match/mismatch effect to upright and inverted faces. For upright faces, both the normal adults and adults with WMS showed a larger N320 component to the mismatched targets. This effect displayed an anterior distribution and was larger from the right than the left hemisphere in the normal adults. In the WMS subjects, the N320 effect also displayed an anterior distribution but tended to be larger from the left than the right. For inverted faces, the normal adults did not show an N320 effect. Rather, the mismatched inverted faces elicited a positive component, which peaked later around 500 msec, displayed a posterior distribution and was symmetrical. In contrast, the WMS subjects displayed an N320 effect that was smaller for inverted than upright faces, but displayed the same anterior-posterior and lateral distributions for upright and inverted faces. That is, the orientation of the stimuli modulated the amplitude of the effect, but did not provide evidence of distinct neural systems. These findings are consistent with earlier behavioral studies suggesting that in individuals with WMS, similar brain systems mediate recognition of upright and inverted faces (Rossen et al., 1995).

Examination of developmental data from an experiment using the same paradigm in normal 9-, 13-, 16-, 18-, and 22+-year-olds revealed that for the WMS subjects, behavioral performance on the face-recognition task was similar in accuracy and reaction times to the average performance of 13-year-old normal children (Alvarez & Neville, 1995). Similar to the WMS subjects, the ERP effects for normal 13-year-olds displayed an N320 effect that was the same amplitude for upright and inverted faces and was larger over the left than the right hemisphere. In contrast, the amplitudes of the N100 and N200 were dramatically different in WMS adults and normal 13-year-olds. Like normal adults, the normal 13-year-olds showed larger N100 than N200 components to faces. These results suggested that in contrast to the brain systems that mediate face *perception*, which are abnormal in WMS, the brain systems that mediate face *recognition* might be normally organized but developmentally delayed.

CONCLUSIONS

Based on the findings presented here, we offer the following conclusions: ERP patterns that index face *recognition*, that is, the N320 match/mismatch effect, suggest that adults with WMS, like normal children, do not employ markedly different brain systems for recognizing upright and inverted faces, as do normal adults. Additionally, we propose that the early match/mismatch effects on the N100, P150, and N200 components, which were not observed in the normal controls, might be linked to increased attention to faces in WMS and, in part, may arise from and mediate the remarkably spared function in this population. In contrast, abnormalities in the early ERP patterns that index face *perception* may be specific to WMS. Because the small N100/large N200 complex to faces was observed in all WMS subjects, including children with WMS whose data were not reported here, and has not been observed in any of the other clinical populations we have tested, nor in normal development at any age between 3 and 35 years, we believe the abnormal N100/N200 complex might be an electrophysiological marker for abnormal face perception in WMS. We will further evaluate whether these effects are specific to faces in our ongoing electrophysiological and behavioral studies of object recognition. Although sparing of the ventral-visual stream is likely to be associated with spared face-recognition abilities in this population (Galaburda & Bellugi, this volume; Atkinson et al., 1997), the reliability of this abnormal N100/N200 complex suggests that it may be linked to subtle structural abnormalities, for example, abnormal orientation of specific sulci, which are common among all individuals with WMS. In our continuing studies, we plan to examine whether the variability in the amplitudes and scalp distributions of these components can be linked to variability in neurological and genetic profiles of individuals with WMS.

METHODS

Subjects

Subjects included 18 adults (18–38 yr, mean = 25 yr; 9 females) with WMS and 23 normal adults (18–38 yr, mean = 24 yr; 13 females). All but three of the WMS subjects were right handed as determined by handedness and medical questionnaires. All subjects with WMS were diagnosed clinically by a medical geneticist prior to induction into the study through genetic probes and medical/genetic records. Subjects were part of the Program Project ''Williams Syndrome: Bridging Cognition and Gene,'' and concurrently took part in neurocognitive, neuromorphological, electrophysiological, and molecular genetic probes (see Preface and Bellugi et al., this volume). Subjects were excluded from the study if they had a history of concurrent medical conditions not typically associated with WMS, particularly those with confounding medical or neurological consequences. All clinical diagnoses were confirmed by trained researchers using the Williams Syndrome Diagnostic Scoresheet, a screening measure developed by the medical advisory board of the Williams Syndrome Association.

Additional information for the WMS subjects is provided in Table 1. Normal adults were all native monolingual speakers of English and were right handed as determined by the Edinburgh Handedness Assess-

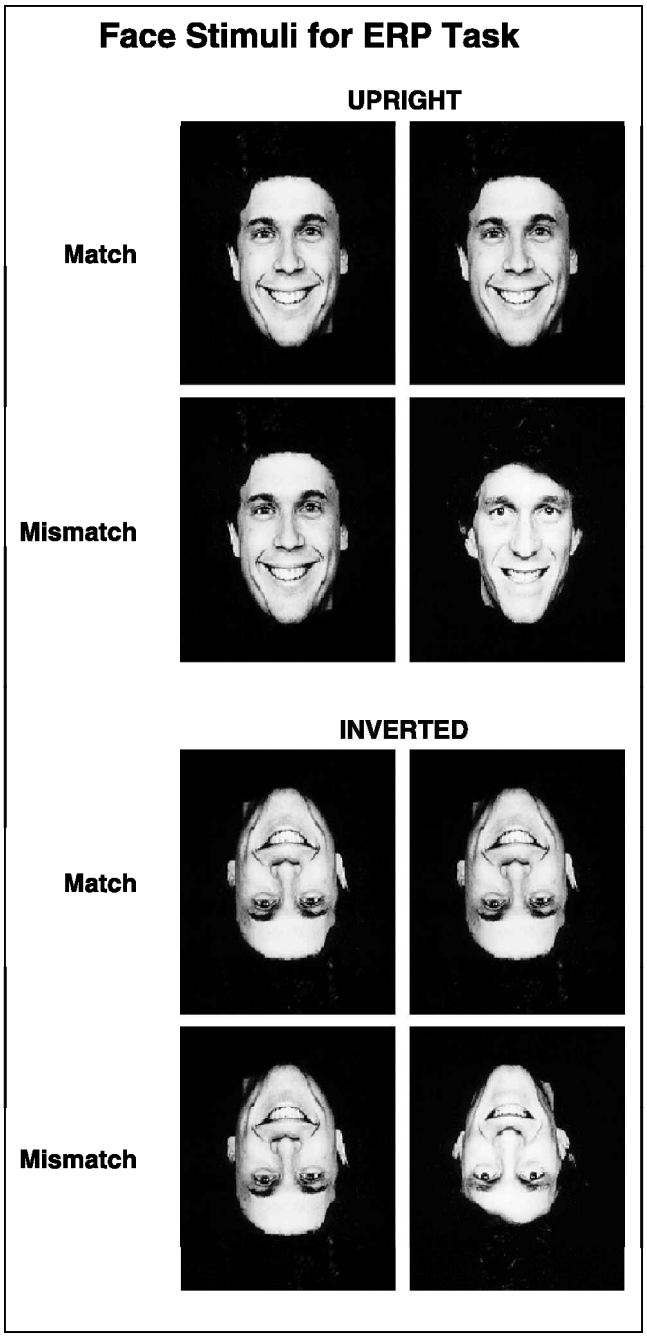

Figure 8. Sample stimuli for primes (left column) and targets (right column) for all four conditions (top: upright matched and upright mismatched; bottom: inverted matched and inverted mismatched).

ment. All subjects had normal or corrected-to-normal vision.

Stimuli

The stimuli were the same as described in Alvarez et al. (1999). The stimuli consisted of 38 pairs of digitized black and white photographs of adult faces (half female) displayed on a video monitor. Each model displayed a neutral facial expression. To control for differences in hairstyle, all of the models were wearing the same gender-appropriate wig. There were two variations of physiognomy (same or different person), and orientation (right-side-up or upside-down, see Figure 8). On one-half of the trials, both faces in a pair were the same person; on the other half, the photographs were of different people (same gender). In the condition where the faces were of the same person, two different photographs were used. Half of the images in each condition were presented right-side up and half were upside-down. When different faces within a pair were presented, complexion and outer contour shape of the faces were similar.

Procedure

The experiment was conducted in a sound attenuated chamber. The video monitor was placed 57 in. from the bridge of the subject's nose. At the beginning of each trial, the subjects fixated on a small cross in the center of the screen. The subjects initiated each trial by pressing a button. Trials consisted of the sequential presentation of two faces. Each face was shown for 1500 msec with an inter-stimulus interval (ISI) of 1000 msec between faces (see Figure 8). The subject was instructed to press a button labeled either "yes" or "no" as quickly as possible to indicate whether the second face matched (yes—was the same person) or did not match (no—different person) the first face. Fifteen practice trials were given before the experiment began.

ERP Recording

The electroencephalogram (EEG) was recorded using tin electrodes (Electro-cap International) from 14 sites over left and right frontal, (Fp1/Fp2, F7/F8), anterior temporal (one-half the distance between F7/F8 and T3/T4), temporal (33% of the distance from T3/T4 to C3/C4), left and right parietal (50% of the distance between T3/T4 and P3/P4), midline (Cz, Pz), and occipital regions (O1/O2). Additionally, the electrooculogram from over (Fp1) and under the left eye was recorded to monitor blinks and vertical eye movements and from the right outer canthus to monitor horizontal eye movements. Impedances were maintained below 5 kΩ. All electrodes were referenced to linked mastoids. The EEG was filtered with a bandpass of .01 to 100 Hz.

Data Analysis

Behavioral Data

Accuracy scores and reaction times were calculated for each condition: Upright faces (matched and mismatched), and inverted faces (matched and mis-

matched). Responses were classified as correct for those trials on which the subject pressed the appropriate button within 200–3000 msec after the onset of the target stimulus (i.e., pressed the "Yes" button when the prime and target were the same person, or the "No" button when the prime and target were different faces). Reaction times were calculated as the latency from the onset of the target stimulus to the button press for a correct response.

Event-Related Potential Data

Artifact rejection. Artifact rejection was conducted off-line using a custom computer program. Criteria for rejection of trials containing eye blinks, horizontal eye movement, muscle movement, or amplifier blocking were set for each subject individually based on visual inspection of the data on a trial-by-trial basis. ERPs for correct responses were then averaged separately for primes and targets. For prime stimuli, the ERPs were averaged separately according to orientation (upright or inverted). For target stimuli, the ERPs were averaged separately according to the type of stimulus pair presented (i.e., upright matched, upright mismatched, inverted matched, inverted mismatched). ERP component amplitudes were quantified with reference to a 100 msec prestimulus baseline. Peak latencies and amplitudes (for the maximum negative or positive voltage in a specified time window) were measured for all components showing a clear peak. Mean area measurements (the mean voltage in a specified time window) were taken for components without clear peaks, i.e., the occipital N320, and the anterior and occipital P500 to the target stimuli.

Component definitions and measurements. All measurements were relative to a 100 msec prestimulus baseline. For the prime stimuli, the first negative component peaked around 100 msec, called the N100, and was defined as the most negative peak occurring between 50 and 150 msec after stimulus onset. The first positive component peaked at approximately 170 msec, called the P170, and was defined as the most positive peak between 100 and 250 msec. The next negative peak observed, referred to as the N200, was measured within a window of 150–275 msec poststimulus onset. The N300–500 was defined as the mean amplitude between 300 and 500 msec.

For target stimuli, at electrodes anterior to the occiput, the first component was negative-going and peaked around 100 msec, called the N100. The N100 was defined as the most negative peak occurring between 50 and 150 msec poststimulus onset. The next component, called the P150, was positive and peaked at approximately 150 msec. The P150 was defined as the most positive peak between 100 and 200 msec poststimulus onset. A second negative component observed at approximately 200 msec, called the N200, was measured within a window of 150–275 msec poststimulus onset. A third negative component, called the N320, peaked at approximately 320 msec, and was measured within a window of 250–400 msec poststimulus onset. Finally, a late, positive-going waveform, called the P500, was measured between 400 and 800 msec poststimulus onset.

Over the left and right occipital sites, the first peak was a positive component that peaked at approximately 100 msec, called the P100. The P100 was defined as the most positive peak occurring between 50 and 150 msec (P100). Following the P100, a negative component, called the N100, was measured within a window of 100–225 msec poststimulus onset. The second negative peak, called the N200, was measured between 200 and 325 msec after stimulus onset. The third negative peak over the occipital regions was observed between 325 and 450 msec poststimulus onset, called the N320. Finally, the P500 was also observed over the occiput and was measured within the same window at more anterior electrodes, 400–800 msec poststimulus onset.

Normalization procedures. To examine the group differences in the distribution of ERP effects, the data were normalized according to the procedures outlined by McCarthy and Wood (1985). Analyses including main effects and interactions with hemisphere and electrode site are reported for the normalized amplitudes.

Data analysis. Statistical analyses were conducted for each of the components separately. The design employed a mixed-model ANOVA using the BMDP 4V program with Geisser and Greenhouse corrections for repeated measures (Geisser & Greenhouse, 1959). For the prime stimuli, the ANOVA included two levels of group (normal and WMS), two levels of orientation (upright and inverted), two levels of hemisphere (left and right), and four levels of electrode (frontal, anterior temporal, temporal and parietal). For the target stimuli, the ANOVAs were performed with the levels described above plus two levels of condition (matched and mismatched). Because the morphology (i.e., presence or absence of specific peaks) of the waveforms differed over occipital and more anterior sites, separate ANOVAs were conducted for occipital sites and for sites anterior to the occiput. The ANOVAs for the occipital measures included two levels of group (normal and WMS), two levels of orientation (upright and inverted), two levels of condition (match, mismatch), and two levels of hemisphere (left and right). When it was necessary to explore significant effects or interactions, appropriate simple effects tests were used for a priori hypotheses; post hoc comparisons were conducted using Tukey's HSD tests (Tukey, 1977).

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Notes

1. Due to computer problems, reaction time data were lost for four of the normal adults.
2. Due to a technical problem, ERPs to the primes are available for 14 of the 18 adults with WMS.

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