# Face Processing in Williams Syndrome: ICA Provides New Insights into ERP Data

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## Abstract

We applied independent component analysis (ICA) to event-related potential (ERP) data that were collected during a face recognition task with two subject groups: normal adults and adults with Williams Syndrome (WMS), a genetic disorder. A previous analysis of the data utilized traditional ERP analysis techniques to identify a single late positive component, called P500. That analysis identified a P500 match-mismatch effect, which was interpreted as evidence that unlike normal adults, WMS adults do not use markedly different brain systems to recognize upright and inverted faces. Using ICA, we determine that the P500 in this task is not unitary, but rather is composed of at least two (in WMS adults) or three (in normal adults) spatially fixed, functionally distinct independent components. We attribute the P500 match-mismatch effect in normal adults to a combination of two of these components, only one of which depends on face orientation. Surprisingly, WMS adults have a similar orientation-dependent independent component, providing evidence that like normal adults, WMS adults do in fact use different brain systems to recognize upright and inverted faces.

## 1 Introduction

Event-related potentials (ERPs) are electrical potentials on the scalp that are time-locked to particular events. The variations in electric potential measured at the scalp are primarily caused by currents flowing across the cell membranes of pyramidal cells in the cortex [<Kutas and Dale, 1997>]. The effects of many of these cortical sources add up to produce the electric potential waveform measured at each scalp electrode.

Much of ERP research involves the identification and characterization of components of the observed waveforms. In traditional ERP analysis, components of the response are often identified by the amplitude and latency of averaged response waveforms at individual electrodes. These components are measured by the peak amplitude or mean amplitude (area) of the original average waveforms or of differences between the waveforms of two experimental conditions. If a response is composed of two or more spatially fixed components that overlap in time, it may be difficult to resolve the response into its component parts using traditional methods of ERP analysis. Independent Component Analysis (ICA), a new approach to linear decomposition [<Bell and Sejnowski, 1995>], can overcome this limitation [<Makeig et al., 1996, 1999>].

In an ERP study of face processing [<Mills, 1998; Mills et al., 2000>], normal adults were compared to adults with Williams Syndrome (WMS), a genetic disorder involving a deletion on chromosome 7. Face processing in WMS adults is of particular interest because despite their impaired performance in many cognitive domains including other forms of spatial cognition, WMS adults perform in the normal range on face processing tasks [<Bellugi et al., 1999>]. This raises the question of whether the brain systems that mediate face recognition in WMS adults are normally organized, or are organized differently than those in normal adults. The Mills et al. study, which used traditional methods of ERP analysis, focused on the early response wave. The study found only one late component, called P500, comprising the activity between 400 and 800 ms.

We used ICA to analyze the Mills et al. data, focusing on the late wave ($t$ > 400 ms after stimulus onset). We found that the P500 in this task is not unitary, but consists of at least two (in WMS adults) or three (in normal adults) functionally distinct independent components. The Mills et al. study found electrophysiological evidence that normal adults process upright and inverted faces differently, but found no such evidence for WMS adults. We were able to attribute the difference between upright and inverted face processing found in the late wave of normal adults to a single independent component, which we call P7um. In addition, we found a functionally similar P7um component in the late wave of the WMS adults. This provides, for the first time, electrophysiological evidence that upright face processing is different from inverted face processing in WMS adults, and that this difference is analogous to the late-wave difference between upright and inverted face processing in normal adults.

## 2 Results of the original Mills et al. study

In an ERP study [<Mills ,1998;Mills et al,2000>], subjects were shown sequentially-presented photographic pairs of upright or inverted faces and were asked to indicate whether the second face (the target) did or did not match the first face (the prime). Matched pairs were non-identical photographs of the same face; mismatched pairs were photographs of the faces of two different people (same gender). Half of the stimuli were female faces. 16-channel ERPs were recorded while the task was performed by 23 normal adults and by 18 adults* with Williams Syndrome (WMS). For more details on the experimental design, see [<Mills et al 2000>].

Using traditional ERP analysis techniques, Mills et al. found characteristic differences between the ERPs of the WMS group and those of the normal control group. The analysis identified a single late positive component, called P500,

* Due to a technical problem, ERPs to the primes stimuli were only available for 14 of the 18 adults with WMS. For our ICA analysis, we only included the 14 WMS subjects whose primes data were complete.

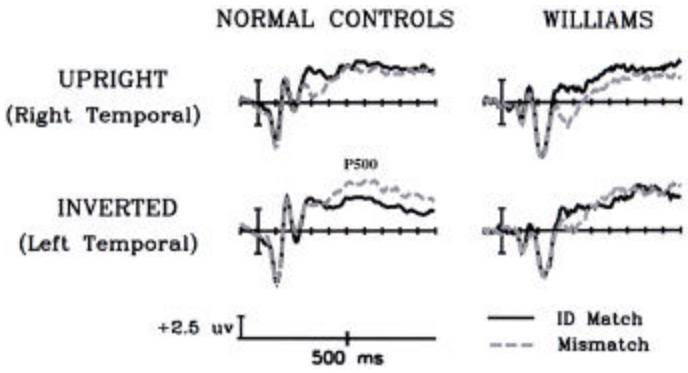


Figure 1: P500 found in the Mills et al. study, shown for matched (solid line) and mismatched (dashed line) targets. Mean area is larger for mismatched than matched targets, only for normal subjects in response to inverted face stimuli (lower left graph). The P500 match-mismatch difference was not significant in the other target conditions shown. Each graph shows just one channel (right temporal or left temporal) of the ERP, but significance tests used data from all channels (see [<Mills etal, 2000>]).

encompassing the brainwave activity in both subject groups from 400 ms through 800 ms after stimulus onset. In normal adults but not in WMS adults, the P500 was significantly larger in response to mismatched targets than to matched targets, for the inverted targets only (see Figure 1).

This P500 match-mismatch effect was part of the evidence that led Mills et al. to conclude that normal adults employ markedly different brain systems in the recognition of upright faces than in the recognition of inverted faces. The lack of a P500 match-mismatch effect in WMS adults was viewed as evidence that WMS adults do not employ markedly different brain systems for recognizing upright and inverted faces.

## 3 ICA analysis of the ERP data

Independent component analysis (ICA) [<Bell and Sejnowski, 1995>] decomposes ERP data into the sums of component activations that are compatible with information processing in a small number of brain networks whose spatial projections to the scalp are fixed across time and task conditions [<Makeig et al., 1996, 1999>]. We performed two separate ICA analyses: one on the normal control group ERPs and one on the WMS group ERPs. The waveforms used in each analysis were grand average waveforms (averages across all subjects) for 16 stimulus conditions: every combination of {upright, inverted}, {matched, mismatched}, {primes, targets}, and {male, female}. Because the original ERP recording used 16 electrodes, the analysis yielded 16 independent components. Of these, we selected those components that were active in the late wave ($t$ > 400 ms) and that varied systematically across experimental conditions. We found that the P500 in this task is not unitary, but is composed of at least two (in WMS adults) or three (in normal adults) spatially fixed, functionally distinct independent components.

### 3.1 Normal control group ICA components

The ERP data for the normal control group show a marked difference between the responses to primes (first face in the pair) and the responses to targets (second face in the pair). In Figure 2(a,b), the thick black lines are the envelope of all 16

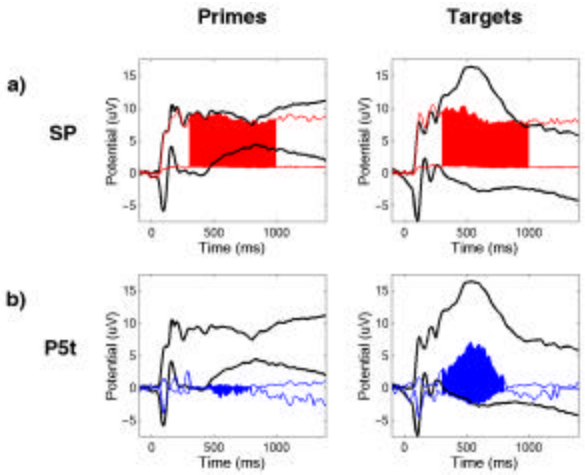


Figure 2. Normal control group envelope plots of the data and the SP and P5t independent components. Left column: responses to prime stimuli. Right column: responses to target stimuli. The thick black lines are the envelope of all 16 channels of grand average data. (a) The envelope of the contribution of the SP component to the data channels is filled in red. (b) The envelope of the P5t component is filled in dark blue.

channels of the normal adults' ERP responses to primes and targets. Between about 400 ms and 800 ms, the response to targets is larger than the response to primes.

### 3.1.1 The SP component

One of the independent components of the normal adults ERPs was consistently positive and roughly constant in amplitude across all eight stimulus conditions and for the entire time range of the late wave. We call this component SP, for sustained positivity. We measured mean SP activation for each condition and each subject, and performed a three-way ANOVA with factors for upright/inverted, match/mismatch, and primes/targets, with repeated measures for the subjects. The ANOVA did not find any significant main effects or interactions for the SP. Figure 2(a) shows the envelope of the SP contribution to all 16 channels. The SP envelope is filled in the time window over which we measured (300 ms < $t$ < 1000 ms).

### 3.1.2 The P5t component

A second independent component resulting from the normal adults analysis peaked at roughly 500 ms and was much larger in the targets conditions than in the primes conditions. We call this component P5t, where "t" stands for "targets". Figure 2(b) shows the envelope of the P5t in response to primes and targets. The envelope is filled in the time window over which the P5t mean activation was measured (300 ms < $t$ < 800 ms). A three-way ANOVA on the mean activation measures verified that the P5t is significantly larger in response to targets than to primes [$F(1,22) = 7.45$, $p = 0.012$]. There was a marginally significant interaction in the P5t activation because the P5t is larger in response to mismatched targets than to matched targets [match/mismatch × targets/primes: $F(1,22) = 3.604$, $p = 0.071$]. Together, the two components SP and P5t account for 97% of the variance of the 16-channel grand average late wave data (400 ms < $t$ <1400 ms) in the targets conditions.

### 3.1.3 The P7um component

A third independent component showed a much larger response in the upright matched targets condition than in any of the other stimulus conditions. We call it P7um, where "um" stands for "upright matched". Figure 3 shows the envelope of the P7um (along with the P5t) for the four targets conditions. The envelope of the P7um is filled in light green. The envelope is filled in the time window over which the P7um mean activation was measured (400 ms < $t$ < 900 ms). We used separate one-tailed paired $t$-tests to compare the mean P7um activation in the upright matched targets condition with each of the other seven conditions (all other possible combinations of {upright, inverted}, {match, mismatch}, and {primes, targets}). All seven $t$-tests support the conclusion that the P7um is significantly larger ($\alpha = 0.05$) in the upright matched targets condition.

## 3.2 WMS group ICA components

The WMS subjects grand average data do not exhibit the same marked late-wave difference as the control group between responses to targets and responses to primes. Not surprisingly, the ICA we performed on the WMS group data did not yield a component with the same functional profile (that was active and inactive in the same conditions) as the P5t in normal subjects.

ICA on the WMS adults data *did* find independent components with the same functional profiles as the normal adults SP and P7um components. We call these the Williams SP and P7um components. Note that ICA was applied separately to the controls data and the WMS data, and the electrode coefficients that define the Williams SP are not equal to the coefficients that define the controls SP (the Williams P7um and controls P7um are likewise different). We therefore *cannot* say that the Williams SP and P7um are the *same* component as the controls SP and P7um. However, we *can* say that they are functionally analogous, because they are correspondingly active and inactive in response to the same stimulus conditions.

### 3.2.1 The Williams SP component

The Williams SP component was consistently positive and roughly constant in amplitude across all eight stimulus conditions and for the entire time range of the late wave. A three-way ANOVA on the mean Williams SP activation (same factors and time window as controls SP) did not find any significant main effects or interactions.

### 3.2.2 The Williams P7um component

The Williams P7um component was larger in the upright matched targets condition than in any of the other stimulus conditions. We used separate one-tailed paired $t$-tests to compare the mean Williams P7um activation (same time window as controls P7um) in the upright matched targets condition with each of the seven other stimulus conditions. The difference was significant ($\alpha = 0.05$) for six of the seven conditions, and was marginally significant ($p = 0.055$) for one of the seven conditions (the inverted matched targets condition).

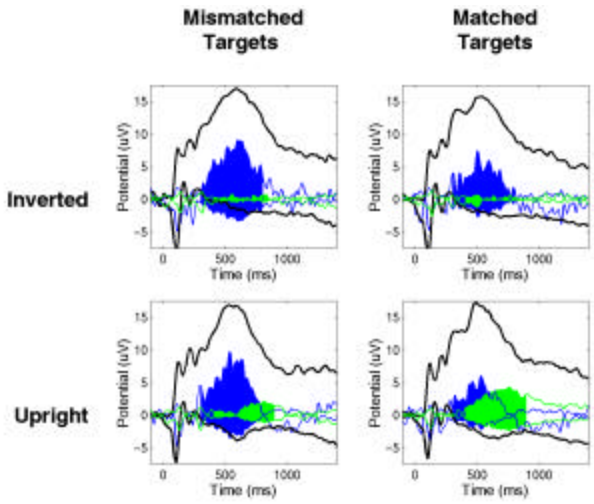


Figure 3: The P500 match-mismatch effect in normal adults explained by a combination of the P5t and the P7um. The P5t (envelope filled in dark blue) has a larger activation in response to mismatched target stimuli (left column) than to matched target stimuli (right column). In the upright targets conditions (bottom row), this match-mismatch difference is offset by the presence of the P7um (envelope filled in light green), which is most active in response to upright matched targets.

# 4 Methods

## 4.1 Evoked responses

In the targets conditions, ERP averages only included trials in which the subject responded correctly (with the correct button indicating match or mismatch) within 200–3000 ms after the onset of the stimulus.

## 4.2 Independent Component Analysis

The "infomax" ICA algorithm we used [<Bell and Sejnowski, 1995>] exploits temporal independence to perform blind separation. Infomax ICA uses gradient ascent to find a square unmixing matrix that maximizes the joint entropy of a nonlinearly transformed ensemble of zero-mean input vectors. For more information on the use of ICA for analysis of grand average ERP data and the assumptions it entails, see [<Makeig et al., 1999>].

We performed ICA analysis on the grand average ERP from 100 ms before stimulus onset to 1400 ms after stimulus onset. We end the time window for the analysis at 1400 ms because the stimulus was removed at 1500 ms, and eye artifacts were not removed from the data after that time. The choice of 1400 ms instead of 1500 ms was somewhat arbitrary; ICA analysis using 1500 ms instead yielded similar results.

# 5 Conclusions

We approached this analysis with the intent of determining what light ICA, a new method for ERP analysis, could shed on an existing data set that had already been

analyzed using traditional ERP analysis techniques. In a traditional ERP analysis of two groups' responses to face stimuli, Mills et al. identified a single late positive component, called P500, comprising all of the late wave data. By performing ICA on the data, we determined that the P500 in this task is not unitary, but rather is composed of two (in the WMS group) or three (in the controls group) spatially fixed, functionally distinct independent components.

In the original study, Mills et al. found a P500 match-mismatch effect that was present in normal adults but not in WMS adults. Now that we have decomposed the P500 into its component parts, we can decompose the match-mismatch effect into *its* component parts. The P500 match-mismatch effect refers to the observation that the mean area of the response to mismatched targets was larger than the response to matched targets, but only for inverted targets, and only for the normal adults.

The difference in size between the responses to mismatched and matched targets can be explained by the P5t. Figure 3 demonstrates the larger activation of the P5t (envelope filled in dark blue) in the two mismatched targets conditions than in the two matched targets conditions. However, the P5t alone is not enough to explain the P500 match-mismatch effect. The P500 match-mismatch effect was only observed for inverted targets, but the P5t difference between matched and mismatched targets is present for both inverted and upright target conditions.

The missing piece of the puzzle is the P7um. Figure 3 shows the envelope of the P7um (filled in light green) overlaid on the envelope of the P5t (filled in dark blue) for all four targets conditions. The activation of the P7um in the upright matched targets condition compensates for the smaller activation of the P5t, causing there to be no significant difference between the upright matched and upright mismatched targets conditions.

In the Mills et al. study, the P500 match-mismatch effect in normal adults was viewed as evidence that normal adults employ different brain systems in the recognition of upright faces than they use in the recognition of inverted faces. Having decomposed the P500 match-mismatch effect into a combination of the P5t and the P7um, we realize that only the P7um indexes the significant difference observed between upright and inverted face processing.

In the Mills et al. study, the lack of a P500 match-mismatch effect in WMS adults was viewed as evidence that unlike normal adults, WMS adults do not employ different brain systems in the recognition of upright and inverted faces. By employing ICA to decompose the late positive component for WMS adults, however, we found a P7um component whose activation is larger in response to upright matched targets than in all other stimulus conditions.

We can conclude that WMS adults *do* exhibit an electrophysiological difference in the way they recognize upright and inverted faces, which suggests that different brain systems may be involved in upright and inverted face recognition in WMS adults. Furthermore, as far as the late wave ERP is concerned, the difference between upright and inverted face processing that we observe in adults with Williams Syndrome is analogous to the difference between upright and inverted face processing that we observe in normal adults.

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