ERP Correlates of Covert Facial Processing in Static and Dynamic Conditions

by

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ABSTRACT

The P300, evoked in response to familiar and unfamiliar faces, was recorded from a prosopagnosic subject and a group of healthy controls. Faces were studied in either static or rotating conditions to establish familiarity. Using an oddball paradigm, participants completed a forced-choice recognition task for a novel angle of the studied faces embedded within a set of unfamiliar faces. Control subjects displayed no difference in P300 amplitude or latency in response to familiar and unfamiliar faces, nor did they display differences between presentation conditions. A prosopagnosic subject did not demonstrate the expected covert recognition for familiar faces based on P300 amplitude. Possible explanations for the lack of differential electrophysiological responses proposed include difficulty in establishing familiarity and difficulty in assessing familiarity.

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Spieth, & Deecke, 1990). One of the most frequently applied models was proposed by Bruce and Young (1986) and is comprised of four distinct stages (DeHaan, Young, and Newcombe, 1991; Young and Bruce, 1991; Lander, Christie, & Bruce, 1999).

In the first stage, a physical analysis of the visual pattern (i.e., serial detection of salient features such as the eyes, nose, angle of jaw) results in a structural description of the face. Second, this structural description, or template, is compared against a set of previously stored representations, called face recognition units (FRUs). In the third stage, should the template surpass a threshold for the given FRU, semantic knowledge of that person is retrieved in the form of person identity nodes (PINs). The PINs contain relevant information about the person belonging to that face such as personality, context in which they are known, likes, dislikes, and so-on. In the fourth and final stage, the person's name is retrieved. It is within this framework that much of the research on human face recognition has been conducted. In addition its ability to describe normal facial processing, one of the key advantages of this model is its ability to explain abnormal facial processing including the case of prosopagnosia.

Prosopagnosia

Originally described by Bodamer in 1947, the syndrome of prosopagnosia has been identified in the clinical literature in one form or another since the turn of the century (Hécaen, 1978; Damasio, Damasio, & Van Hoesen, 1982; DeHaan, Young, & Newcombe, 1987a, 1987b; Levine & Calvanio, 1989; DeHaan, Bauer, & Greve, 1992; Nachson, 1997). Prosopagnosia is a rare neurological syndrome characterized by an inability to recognize the faces of familiar individuals. Although prosopagnosics understand that they are viewing a face and can discriminate between two different faces, they are unable to identify familiar individuals and appear to have difficulty becoming familiar with new faces. Typically these patients compensate by becoming adept at gathering essential information through environmental cues such as observing characteristic body movements, the unique pattern of a person's voice, or the presence of a particular perfume which provide clues about identity. While prosopagnosia is a form of visual agnosia, visuo-spatial capacities (i.e., spatial orientation and localization) remain intact and facilitate positive identification of an individual (Levine & Calvanio, 1989).

Onset of the syndrome is frequently abrupt and typically the result of cerebrovascular accidents (CVAs). Specifically, prosopagnosia is normally associated with an embolism of the posterior cerebral artery branches from the basilar artery, which supply blood to the infero-medial portions (i.e., lingual and fusiform gyri) of the occipito-temporal cortex (Renzi, Perani, Carlesimo, Silveri, & Fazio, 1993; Tovée, Cohen- Tovée, 1993; Afifi & Bergman, 1998). While not as frequent, focal head injury or cerebral tumors in this posterior region have also been shown to lead to the clinical presentation of prosopagnosia (Tovée, Cohen- Tovée, 1993; Damasio, 1985).

Electroencephalography

Facial processing has been studied in both clinical and control populations, using a variety of behavioral, perceptual, and psychometric paradigms. Increasingly, researchers have also used electroencephalographic techniques to further our understanding of both normal and disordered facial processing. The electroencephalography (EEG) is a method for measuring the brain's electrical activity. As neurons send and receive signals along the axon, they produce either a positive or negative charge. An electrode attached to the scalp can gather a summation of the charges produced by a collection of these neurons. Compared to a baseline measure, the direction and overall degree of activity at this site can be quantified. The placement of a group of electrodes allows for a measurement of the electrical activity across the entire surface of the scalp. Figure 1 depicts the International 10-20 System, which is the accepted system for the placement of electrodes (Pivik, Broughton, Coppola, Davidson, Fox, & Nuwer, 1993). This system derives its name from the fact that the various locations are either 10% or 20% of the distance between two standard measurement points (Andreassi, 1995).

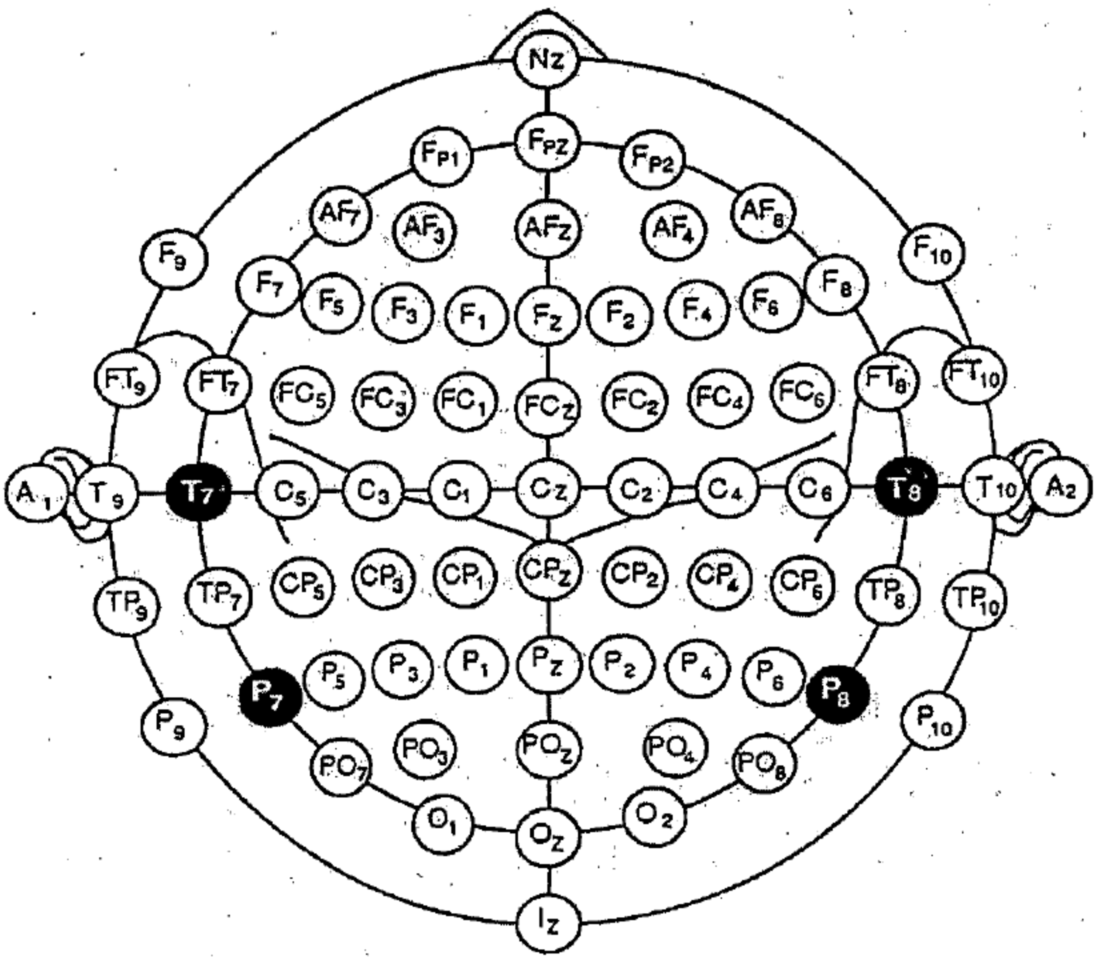

Figure 1. International 10-20 System for Electrode Placement

Brainwave activity resulting from this technique is characterized by amplitude and frequency. Amplitude provides a rating of intensity by measuring the waveform's voltage at any given point in micro volts (μV) compared to a baseline of zero volts. Frequency provides a rating of the waveform's speed measured in hertz (Hz), which reflects the cycles per second.

Hans Berger, in 1929, was the first to record EEG in humans (Duffy, Iyer, & Surwillo, 1989). He noted that when at rest with eyes closed, most persons produce a rhythmic high-amplitude, slow-moving (20 – 60 μV, 8 – 13 Hz) waveform subsequently called the *alpha wave* (Andreassi, 1995). Since this time, a number of other consistent waveform patterns related to human behavior have been identified (see Figure 2).

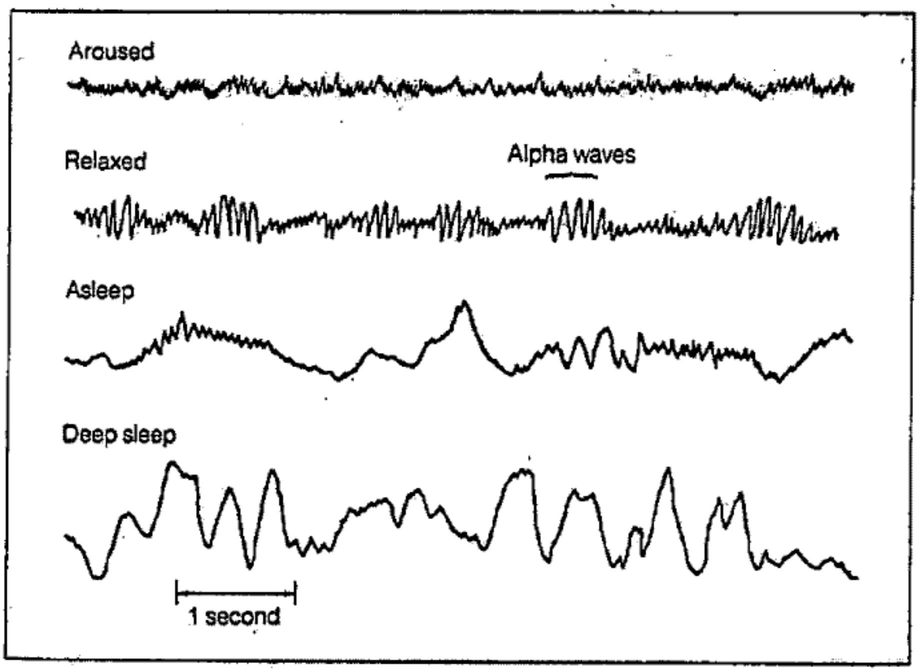

Figure 2. Electroencephalographic Records During Excitement, Relaxation, and Varying Degrees of Sleep

When a simple task (e.g., a 2-step multiplication problem) is introduced to someone producing alpha waves at rest, EEG frequency increases (14 – 30 Hz) and amplitude decreases (14 – 30 μV). This less regular pattern of activity, called the *beta wave,* is commonly exhibited when a person engages in a physical or mental task (Stern, Ray, & Davis, 1980). EEG can also provide diagnostic information regarding normal and abnormal brain functioning. *Delta* waves (20 – 200 μV, .5 – 3.5 Hz) that appear in healthy individuals during the deep sleep stage, are indicative of a brain abnormality such as a tumor when observed in a waking person (Duffy, et al., 1989). In epilepsy, EEG recordings localize the focal point and classify the type of seizure disorder (Guberman, 1994).

Event-Related Potentials

The benefits of this technology are not limited to the information gathered from a continuous recording of brainwave activity. A subset of the EEG record called an evoked potential or event-related potential (ERP) allows for a measure of the brain's response to specific external stimuli or internal psychological events. ERPs are brief segments of EEG time-linked to the presentation of a stimulus. These waveforms are small and difficult to identify when they are embedded within the larger EEG record; therefore, they must be extracted. This is done through the process of averaging. Continuous EEG recordings are divided into epochs, which contain the onset of the stimulus and a predetermined period after the stimulus (e.g. 1200 msec). The period captured in the epoch is up to the researcher's discretion and may even include segments of the data immediately prior to the presentation of a stimulus.

Offline, these epochs are grouped together according to the type of stimulus (e.g., target, non-target; target 1, target 2, etc.) and averaged. Through this process, positive and negative charges produced by the brain's electrical fields, which are unrelated to the presentation of the stimulus, begin to cancel each other out. After enough trials have been averaged, a distinctive pattern of neural activity eventually emerges from the background. This pattern provides a summary of the brain's electrophysiological response to that stimulus.

ERPs can be elicited from visual images and patterns, auditory tones, somatosensory stimuli, or internal psychological reactions to external objects. Waveform peaks (i.e., positive and negative shifts) or "components" reflect the timing of the flow of information through different stages and levels of information processing (Viggiano, 1996). These individual components are often differentiated and named by the direction of polarity and the average peak latency (e.g., N200 is a negative moving peak generally found 200 msec after stimulus onset). The characteristics of the resulting waveforms are determined by a number of factors. The sensory modality stimulated, physical characteristics of the stimulus, physical characteristics of the subject, and the area from which the ERP is recorded (Stern, et al., 1980) can all play a role in its composition. Furthermore, these various components within the human evoked potential can be characterized as either exogenous or endogenous. Presence or absence of an exogenous component is determined primarily by the characteristics of an external stimulus (e.g., the loudness of a tone). In contrast, an endogenous component is dependent upon the subject's psychological reaction to the stimulus (Picton, 1992). For example, the contingent negative variation (CNV) is a negative shift that occurs prior to the presentation of an expected stimulus (Gevins & Cuttillo, 1986). Cognitive factors such as motivation, attention, and distraction can impact heavily on the formation of the CNV and other endogenous waveforms.

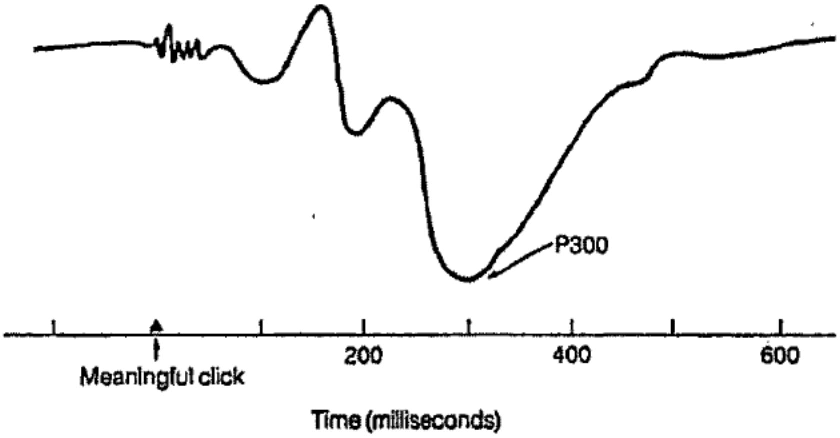

Figure 3. Example of a Standard P300 Response

P300 Waveform

The P300 is a much-studied endogenous component of the human evoked potential that is believed to reflect general information processes such as attention allocation and immediate memory (Polich & Kok, 1995). This positive moving wave component occurs 300 msec after the onset of an informative, task-relevant stimulus in healthy adult subjects (Picton, 1992). Because the waveform is maximally observed over the midline centro-parietal regions of the brain, it is normally recorded from the Pz, Cz, and Fz sites (see Figure 1). It can be elicited in all stimulus-modalities (i.e., auditory, visual, and somatosensory) and is often reported at Pz, especially when evoked by visual stimuli (Altenmuller & Gerloff, 1999). The P300 is typically obtained using an "oddball" paradigm in which a subject is asked to identify an infrequent stimulus (target) that is randomly mixed with a collection of frequent stimuli (non-targets). Courchesne, Hillyard & Courchesne (1977) determined that the composition of non-targets is not as crucial as the probability of the target stimulus. Simply put, the less frequently a target stimulus occurs, the greater the P300 response. Past research indicates that the ratio of 20% targets, 80% non-targets is ideal (Polich, 1990).

While its definitive role is still debated, it is believed that the P300 waveform provides an index of working memory (Gevins & Cuttillo, 1986; Polich & Kok, 1995; Polich, 1990; Katayama & Polich, 1998; Eimer, 2000). Specifically, the P300 amplitude is thought to reflect the allocation of attentional resources (Katayama & Polich, 1998). Increased P300 amplitudes have been demonstrated to correspond with superior memory performances in healthy adults (Polich & Kok, 1995). Latency on the other hand, is thought to provide a measure of stimulus evaluation time (Unsal & Segalowitz, 1995; Polich, 1999). Shorter latencies in normal subjects are associated with a faster processing speed and greater processing capacity (Polich, 1999).

P300 methodology has been useful in expanding our knowledge of cognitive functioning (e.g., memory, attention, perception) in healthy adults. The application of ERPs to information processing models of cognitive psychology has been useful because they provide indicators of cognitive processes and dysfunction not readily accessible to behavioral testing, such as perception occurring below the level of conscious awareness. When used in conjunction with neuropsychological tests that assess the allocation and maintenance of attentional resources, a prolonged P300 latency has proven a valuable diagnostic tool of cognitive damage in dementia, Huntington's disease, progressive supranuclear palsy, and head injuries (Altenmuller & Gerloff, 1999).

Brain potentials have also been used to investigate a variety of questions in the area of facial processing. ERPs, including the P300 component, have been used to investigate spontaneous emotional reactions to faces (Pizzagalli, Koenig, Regard, & Lehmann, 1998), the analysis of facial identity and expression (Potter & Parker, 1997; Münte, Brack, Grootheer, Wieringa, Matzke, & Johannes, 1998), lateralization of face processing (Viggiano, 1996), the effects of repetition priming and associative priming on recognition (Schweinberger, Pfütze, & Sommer, 1995; Schweinberger, 1996), and covert recognition in prosopagnosia (Renault, Signoret, DeBruille, Brenton, & Bolgert, 1989).

Covert Recognition, Prosopagnosia, and the P300 Component

Behavioral and autonomic evidence indicates that some prosopagnosics are able to process known faces at a "covert" level despite their inability to consciously acknowledge any familiarity. Through a series of behavioral tasks sensitive to face familiarity that did not require an overt response (e.g. identity matching, semantic categorization, and associative learning) Young and DeHaan found a pattern of processing comparable to normal participants (DeHaan, et al., 1987a, 1987b; Young & DeHaan, 1988; DeHaan, et al., 1992). Greve and Bauer (1990) exposed a series of subthreshold (15 msec) faces to a prosopagnosic patient who later selected the target stimuli at chance level. Following this, a "preference" test phase was administered in which the subject was instructed to select the face he "liked best" from an additional set of facial pairs. The patient performed well above chance and comparable to a healthy control group, suggesting that he had processed the visual stimuli at an "implicit" level. In addition, several studies have found that as with healthy controls, prosopagnosics display larger electrodermal skin conductance responses to familiar faces than they do for unfamiliar faces (Bauer 1984; Tranel & Damasio, 1985; Bauer & Verfaellie, 1988).

Using a variation of the oddball paradigm, Renault, et al. (1989) provided evidence of covert recognition in the absence of overt recognition by recording a prosopagnosic subject's ERP responses to familiar and unfamiliar faces. Static photographs of the subject, members of his family, and well-known faces were combined with static photographs of unfamiliar faces. There were two conditions for this experiment and for each condition, the ratio of familiar to unfamiliar faces varied. In condition 1, the ratio was 33% familiar faces to 66% unfamiliar faces whereas in condition 2, the ratio was 50% familiar to 50% unfamiliar. When tested, P300 amplitude was higher for the familiar category in condition 1 but did not vary between familiar and unfamiliar categories in condition 2. Because the subject's P300 amplitude was sensitive to changes in stimulus probability, the authors conclude that a categorization has occurred. These results suggest that the prosopagnosic subject perceived familiar faces differently and validates the use of the P300 component of the human evoked potential as an indicator of covert facial recognition.

While Renault et al.'s (1989) finding that a prosopagnosic subject could categorize highly familiar faces is remarkable, the factors that permit effective categorization by a prosopagnosic remain unclear. One factor that may have influenced this ability to categorize may be the quality of the FRU. The frequency, duration, and emotional salience of exposures to these significant faces in the subject's everyday life may have allowed the formation of a robust FRU which in turn facilitated successful matching of a new template with the FRU. The current study will begin to address the question of how prosopagnosics are able to covertly recognize familiar faces by attempting to manipulate the quality of an FRU. Dynamic movement is an aspect of facial processing which is believed to influence FRU quality.

Movement and Face Recognition

Faces encountered in daily life are usually in motion (e.g., a person may turn their head or change their facial expression). The impact this motion has on familiar face recognition is not well understood. It is believed however, that motion may affect the formation of the structural unit or template. Seeing a face from multiple viewpoints may provide the viewer with additional information about the structure and shape of that face which is useful in the formation of these templates. As described above in Bruce and Young's model of facial processing, recognition, or the sense of familiarity is based on a positive match between this template and an FRU. It is likely therefore, that the additional information provided by dynamic movement contributes to the positive match and subsequent identification of a familiar face.

With few exceptions, the majority of research has employed static images of faces to test facial recognition (Christie & Bruce, 1998). Recent investigations, which have incorporated dynamic movement of faces into their design, have met with mixed results. Pike, Kemp, Towell, & Phillips (1997) argued that a moving face provides information "qualitatively different from that available in static views" (p 412). To investigate this claim, the authors presented either static photographs, video sequences of unfamiliar individuals (in the form of head shots rotating 360^0), or out-of-order video sequences (the same head shots in random order) to groups of participants. When recognition was later tested using static photographs, a significant advantage was discovered for the group that had initially viewed rotating faces in the proper sequence. Pike et al. concluded that motion facilitated the construction of a 3-D structure, improving the overall quality of the FRU and the increasing the likelihood that the previously unfamiliar target individual would be recognized later.

In contrast, Christie and Bruce (1998) were unable to find evidence that movement is helpful in the building or retrieval of representations for previously unfamiliar faces. In the study phase of their experiment, subjects were exposed to either moving or static images of faces. In the moving condition, motion was either nonrigid or rigid. Nonrigid movement consisted of a change of expression (i.e., smile to frown). Rigid movement consisted of head nodding or head shaking. Upon testing, no advantage was found in recognition for either movement condition. Christie and Bruce account for their discrepant results by suggesting that changes in lighting between the study and test phases of Pike et al.'s rigid movement design likely introduced a non-optimal condition for recognition.

While Christie and Bruce do agree that movement facilitates recognition, the authors suggest that the type of information provided by movement is only relevant under non-optimal viewing conditions. For example, when a static image of a face is insufficient in building a structural representation to match against the FRU, 3-D shape information provided by movement may compensate. This theory has been supported by a number of studies. Using a point-light technique in which reflective dots placed on the face highlight key structural features, Bruce and Valentine (1988) found that movement facilitated identification of an image as a face when only the dots were visible. Knight and Johnston (1997) presented the negative exposure of videotaped faces of celebrities (as well as negative still frames of the videotaped segments) to groups of healthy subjects. These negative images retained the 2-D shape of the face yet made the task of recognition more difficult. Under these conditions, movement improved recognition. In addition, Lander, et al. (1999) found that movement aided in recognition when images of faces were negative, upside-down, or *thresholded* (i.e., multiple gray level images converted to 1-bit per pixel black and white format).

The results of these studies, while valuable to our investigation of the factors involved in facial recognition, reveal a limitation of current designs. As Lander, et al. (1999) point out, when viewing faces under good conditions, "the visual recognition of familiar faces is at or near ceiling levels leaving little room to investigate any beneficial effects that movement may have" (p. 975). Although the use of degraded images provides a means of investigating the contribution of movement in the recognition of faces, the manipulation of these images limits the generalizability to everyday life. The degree to which dynamic movement of a face helps to build a more robust structural representation outside of non-optimal conditions remains unclear.

Current Study

The current study addressed two distinct and important questions concerning the process of face recognition. First, this study investigated covert recognition of familiar faces in a prosopagnosic subject through the use of electrophysiological recording of internal cognitive responses. Specifically a measure P300 amplitude and latency was collected to provide evidence for the categorization of familiar and unfamiliar faces, thereby providing evidence of covert recognition. Second, collected brainwave activity was examined to investigate the role movement plays in face recognition. P300 waveforms were compared in response to familiar faces learned through the presentation of both rotating and static views.

In the current study, P300 responses to familiar and unfamiliar faces were recorded in healthy adults and a prosopagnosic subject. Several trials of novel faces were presented in order to establish familiarity. In the study phase, they were presented in one of two formats; sequentially rotated through a series of angles giving the impression of movement, and a static presentation. All participants viewed faces under both conditions. In the test phase of the study, the participants viewed a static photograph of a face presented at an angle not viewed in either the rotated or static conditions. The faces presented to the participants came from one of two groups; individuals exposed during the study phase and individuals the subject has never seen before. The presentation of these new angles followed an oddball paradigm with the previously viewed (familiar) individuals constituting the infrequent group and the never-seen-before (unfamiliar) individuals constituting the frequent group. During this presentation, participants completed a forced-choice recognition task while EEG data was collected.

Hypotheses

To address the issue of covert recognition in a prosopagnosic subject, P300 responses to familiar faces were be compared with P300 responses to unfamiliar faces. A larger P300 amplitude indicates categorization of a stimulus even when this categorization occurs outside of overt recognition. It was predicted that P300 amplitude in response to familiar faces would be significantly larger than the P300 amplitude in response to unfamiliar faces.

To examine the role movement plays in the building of a structural representation of faces, P300 responses to faces learned through rotated presentations were compared with P300 responses to faces learned through static presentations. It was hypothesized that P300 waveforms in healthy subjects would provide a reliable indicator of differential encoding of facial information between faces presented in dynamic movement as compared with faces presented statically. Furthermore, it was expected that the prosopagnosic subject would not differ from the healthy controls in his responses to rotated and statically presented faces.

Method

Overview

The purpose of this study was to examine differences in the P300 response to familiar vs. unfamiliar faces for a prosopagnosic patient and a group of healthy control participants. Electroencephalographic data was gathered to compare group performance (10 controls vs. 1 prosopagnosic) and the effects of the exposure condition (exposure to full range of angles vs. exposure to a single angle) on establishing familiarity.

Participants

LR is a 48 year old, right-handed male, who after sustaining a head injury in the early 1970's was left with the inability to recognize faces. He was in a motor vehicle accident in which his vehicle rolled several times. At some point LR was impaled by the stick shift, which entered his left cheekbone and emerged though the right parietal area, fracturing his skull and damaging his sixth cranial nerve. Since this accident he has undergone numerous operations in an attempt to repair nerve and tissue damage.

On neuropsychological tests, LR performed well on measures of vocabulary, general information, and abstraction. His overall IQ, as measured by the Wechsler Adult Intelligence Scale – Revised (WAIS-R), was in the High Average range. He also performed in the average range on tests of memory although his lowest scores were in his memory for visual designs. LR has participated in a wide variety of cognitive studies at the University of Victoria to examine his unique condition. For this study, he was reimbursed $15 per hour of his time.

Participants for the control group included undergraduate students from the University of Victoria, British Columbia, and members of the surrounding community. These 11 individuals (mean age = 37.5 years, SD = 7.9 years) had no history of a head injury or seizure disorder. Either they were selected from a list of students that had indicated an interest in participating in research projects sponsored by the University of Victoria Psychology department or the principal investigator individually recruited them. All participants were reimbursed $15 for their time.

General Procedures

Each participant scheduled a two-hour visit in which they met with the principal investigator. They were informed that they were being asked to participate in a study that examines how human faces are processed. The expectations and potential risks were outlined and informed consent was obtained. The participants were then instructed to sit in a chair while electrodes were applied to their scalp to record brain wave activity. It was explained that they were to make decisions about a series of faces presented on a computer monitor situated directly in front of them. Up to two breaks of one to two minutes were provided as needed. Upon completion of two main test blocks, the electrodes were removed and the participants were debriefed. The true nature of the study was revealed and all questions the participants had were answered. Immediately following this session, participants were paid in cash.

Facial Stimuli

Photographs of 96 University of Victoria undergraduate students from the neck up were used as facial stimuli. Each student was photographed from 6 separate angles (0^0, 10^0, 30^0, 50^0, 70^0, and 90^0) while wearing a swimming cap. The photographs were edited using Adobe PhotoShop to remove any distinguishing, extraneous features. Twenty-four students were randomly selected from the larger group of 96 and designated as "target individuals" that composed the target group. The target group was further divided into two separate exposure groups. Twelve target faces were randomly assigned to the Static (ST) condition, while the other 12 were assigned to the Rotation **(RO)** condition. The remaining 72 faces not selected for the target group would not be seen during the exposure phase. They were assigned to a third group referred to as the Non-target (NT) condition.

Apparatus

The Adobe PhotoShop files of the faces were presented via PSYCHLAB program using a Macintosh computer. The center of the monitor was adjusted to eye level for each participant as they sat in a chair. A computer keyboard recorded the participants' conscious decisions regarding the faces. Specifically, the "1" key represented "male" and the "2" key represented "female" in the exposure phase, while the "Z" key represented "studied group" and the "M" key represented "not from studied group" for the test phase.

Recording Conditions and EEG Data Procedures

During the test phase, EEG activity was recorded with tin electrodes mounted in an ECI (Electro-cap International, Eaton, Ohio) electrode cap and collected using the Bio-Logic Brain Atlas program (Bio-Logic Systems). Placement followed the international 10/20 system (Pivik, et al., 1993). Simultaneous scalp electrical activity was recorded from 14 electrode sites including Pz and Cz. Additional electrodes were placed at the outer canthus and supraorbitally to the right eye with a bipolar recording made of the electrooculogram (EOG). All electrodes were referred to the mastoid processes with a forehead ground and impedance at 10 KΩ or less. The biosignals were amplified with a bandpass from 0.1 to 30 Hz, digitized at 250 points per second and stored on magnetic disk.

Waveforms were averaged offline using an EEG editing program developed by Brain Mapping Institute, Inc. (1989). Raw EEG data was edited into segments tied to externally driven pulse markers. Segments were rejected automatically if the EEG or EOG exceeded a preset criterion (80 μV). The resulting segments were averaged together into three separate files (based on ST, RO, and NT marker classification) for each participant. A grand mean and standard deviation was computed for each file. P300 waveforms were identified and peak amplitudes and latencies were recorded.

Design and Procedure

This study was comprised of two phases. During the exposure phase, faces of target individuals were presented several times to establish a sense of "familiarity". During the test phase, participants rated familiarity for target and non-target faces (presented at a novel 30^0 angle) as EEG data was collected.

Exposure phase. All members of the target group were exposed for 3 seconds. The number of angles presented for these target individuals was dependent on the exposure condition to which they had previously been assigned. Specifically, a single 0^0 photograph of the target individual was held on the screen for 300 milliseconds in the ST condition. A pivoting image of the target faces was presented in the RO condition. The image on the screen began with the target face presented at 0^0. This image was removed and the next angle in the series (for that same target individual) was presented. All angles in the series (0^0, 10^0, 50^0, 70^0, 90^0, 70^0, 50^0, 10^0, 0^0) except that target individual's 30^0 photograph were presented in rapid succession to give the appearance of movement. The participants saw the image of a target head rotating from center, to the side, and then back to center. To match the exposure period in the ST condition, exposure of the full series was completed in 300 milliseconds. Each angle was presented on the screen for 30 milliseconds in one direction and 30 milliseconds coming back the other direction for a total exposure time of 60 milliseconds per angle.

The twelve target faces for each condition were presented 3 times each in random order. (Target faces from the NT group were not viewed during this phase.) Participants were not told the true nature of the exposure phase in order to ensure a measure of covert recognition was obtained. Instead, participants were informed that this first part of the study involved gender classification. The following instructions were provided:

> "I am now going to start the computer. You will see different faces presented on the screen in front of you. Sometimes you will see a face start in the center, rotate to the left, and then come back to center. Other times you will see a face start in the center and remain there until it goes off the screen. Each time, I would like you to make a decision about the person's gender. Specifically, I

> would like you to tell me if the face you saw on the screen was a male or a female. Please press the key "1" if it was a male or "2" if it was a female. Do you have any questions?"

Testing phase. In the testing phase, participants were asked to make decisions of familiarity based on a 30^0 presentation of the faces. The 30^0 photographs from the 72 target individuals in the NT group were selected. These were added with the never-before-seen 30^0 photographs of the 24 target individuals from the exposure phase, resulting in a combined group of 96 30^0 photographs. The order was randomized and each of the 96 faces was presented twice for a complete set of 192 trials. The following instructions were given to the participants:

> "Good job. Now, from here on out, we are going to refer to that collection of faces you just viewed as the "studied" group. In this next section you will see a larger collection of faces presented one at a time on the screen. When a face appears, I would like you to decide whether the face was, or was not from the "studied" group. As before, I'd like you to indicate your answer by pressing one key on the keyboard. This time, press the "Z" key if the face was from the "studied" group and press the "M" key if it was not. You will see some of these faces more than once but each time I want you to base your decision on whether the face was, or was not, a member of the "studied" group you just viewed.
>
> As I mentioned before, this next collection of faces is larger than the one you just finished viewing. I will provide you with breaks as we work through this section so it is important that you focus on the faces in front of you as they are presented. Try to keep as relaxed as you can in the chair, okay? Do you have any questions?"

Following these instructions, EEG data collection was initiated and the blocks were started.

Debriefing

Following data collection, the Electro-cap was removed and a debriefing session was conducted to explain the nature of the study, the significance of the P300 wave in the human event related potential, and it's importance in this study. All questions posed by the participants were answered. The participants were paid $15 for their time and the session was ended.

Results

ERP data. P300 responses (amplitude and latency) to the presentation of familiar and unfamiliar faces were collected. P300 amplitude was maximal at Cz for all conditions (ST, RO and NT). Three control group participants' data were not included in the final analyses. In the first, excessive amounts of non-organic channel noise was present, making interpretation of underlying brain-wave activity unreliable. In the other two cases, the P300 response could not be detected. It is likely that the data for these two participants lacked a sufficient number of artifact-free trials to resolve the waveform.

Twenty-four trials were possible for both ST and RO conditions and 144 trials were possible for the NT condition. Trials not rejected due to ocular artifact for the control group (range: ST 19-26 trials, RO 15-26 trials, NT 117-144) and LR (ST 20 trials, RO 16 trials, NT 119 trials) were averaged across target conditions. The control participants' mean P300 amplitudes were combined to calculate a grand mean for each condition. They are presented in Table 1 along with LR's P300 amplitudes for the corresponding condition.

Table 1

Mean P300 Amplitudes (μV) in Response to Face Category at Cz

		Static	Rotated	Non-target
Controls (n = 8)				
	M	11.88	10.97	10.85
	SD	3.42	5.97	3.82
LR		6.76	5.97	7.05

Regarding the hypothesis that LR would not differ from the control group in his response to "familiar" and "unfamiliar" faces, 90% confidence intervals were constructed to illustrate the relationship between LR's mean amplitude and the control group's grand mean amplitudes across stimulus conditions. As can be seen in Figures 4 and 5, LR's mean P300 responses to Rotated, Static, and Non-target face conditions lay within the 90% confidence interval around the controls' grand mean P300 responses at both CZ and PZ sites. This suggests that LR's responses to the stimuli were not significantly different than controls' responses, although his overall amplitudes were in the low range across all conditions when compared to the controls.

An underlying assumption in this study was that healthy controls would exhibit greater P300 amplitudes in response to "familiar" faces when compared to "unfamiliar" faces. In the terminology of this study, it was expected that controls would display greater amplitudes in response to the ST and RO conditions in comparison to the NT condition. An initial test of this hypothesis was conducted using a multivariate ANOVA with two within subjects factors, face type condition (i.e., ST, RO, NT) and recording location (i.e., CZ, PZ). None of these tests were significant. This suggests that overall responses to the faces did not differ by condition, site, or the interaction between the two. Because there was no overall difference in mean P300 amplitudes, post-hoc statistical tests comparing ST and RO conditions to the NT condition can only be considered exploratory.

To evaluate differences between each of the familiar face conditions to the unfamiliar face condition post-hoc, two paired-samples t-tests were conducted. Controls' mean P300 amplitudes in the ST condition did not significantly differ from mean P300 amplitudes in the NT condition (t(7) = 1.50, p <. 178). Neither did P300 amplitudes in the RO and NT conditions differ significantly (t(7) = .23, p <. 826). A post-hoc analysis comparing P300 amplitudes to the first 30 NT faces and the final 30 NT faces presented to controls was not significant suggesting that the novelty of the NT faces did not diminish through repeated presentations (CZ controls: t(7) = -.78, p > .05; PZ controls: t(7) = -1.81, p > .05).

A paired-samples t-test was also conducted to test the second hypothesis that members of the control group will display a greater response in amplitude to rotated faces than statically presented faces. While there was a statistical difference between the two conditions (t(7) = 2.43, p <. 045), contrary to expectations, the results indicated a greater P300 amplitude response to the statically presented faces.

Behavioral response data. Although no hypotheses were formulated regarding behavioral responses, these data are presented to provide a complete description of the participants' responses to familiar and unfamiliar faces. The control subjects performed consistently at or above chance, though by no means at ceiling levels. Given that a lack of overt awareness for familiar faces is fundamental to the definition of prosopagnosia, one would not expect LR to be able to recognize familiar faces. As is apparent in Table 2, LR correctly identified some of the familiar faces (33% for both Static and Rotated faces) but many more of the unfamiliar faces (92% for Non-target faces) in comparison to the control group. As will be seen in the following section, these accuracies levels probably reflect response bias, rather than accurate perceptual judgements.

Table 2

Mean Number and Mean Percent Correct Responses Across Face Categories

		Static		Rotated		Non-target	
		# Correct	% Correct	# Correct	% Correct	# Correct	% Correct
Controls (n=8)							
	M	15.6	65	15.5	65	111.9	78
	SD	3.85	16.0	3.51	14.6	15.36	10.7
LR		8	33	8	33	132	92

To determine the effect of motivational states, response biases, and sensory capacities on the participants' responses, signal detection theory was applied to these data. Hits (i.e., correct identification of ST or RO faces as previously viewed) and false alarms (i.e., incorrect identification of NT faces as previously viewed) were used to calculate d', criterion values, and beta for both the control group and LR. The sensitivity index (d') reflects the participants' ability to discriminate a target face from a non-target face, while beta (β) provides a measure of the participants' response bias to preferentially respond to the face on the screen as a non-target (i.e., not from the studied group). The results of these calculations are presented in Table 3 for each member of the control group and LR.

Table 3

Summary of Signal Detection Statistics for Control Group and LR

ID	d'	Criterion value	β
$Control_1$	1.346	0.468	0.759
C_2	1.894	1.282	1.884
C_4	1.412	1.080	1.696
C_5	0.339	0.440	1.096
C_8	1.087	1.036	1.709
C_9	1.508	0.954	1.353
C_{10}	1.029	0.878	1.453
C_{11}	1.018	0.279	0.791
M	1.204	0.802	1.343
SD	0.457	0.360	0.426
LR	0.965	1.405	2.436

A 90% confidence interval was constructed to visually compare LR's signal detection results to those of the control group. Figure 6 reveals that although LR's sensory capacity for discriminating between target and non-target faces was similar to those of the control group, he displayed a more conservative response pattern than the controls, being more likely to indicate that a face was not from the studied group (Mean Control $\beta = 1.343$; LR $\beta = 2.436$).

Table 4 displays a summary of mean correct and incorrect reaction times for LR and the control group. To further explore differential patterns of responses across conditions, a comparison of mean RT for correct responses was conducted. A repeated measures ANOVA with one within-subjects factor comparing mean RTs across the three face conditions for the control subjects was not significant (F (1, 7) = .76, p < .41). Figure 7 displays the 90% confidence intervals of the controls' and LR's mean RTs across face categories. While LR's RT to faces from the familiar categories appears to be similar to those of the control group, his mean RT to unfamiliar faces appears to be slower than those of the control group.

Table 4

Mean Reaction Times (msec) for Correct and Incorrect Responses Across Face Categories

		Static		Rotated		Non-target	
		Correct	Incorrect	Correct	Incorrect	Correct	Incorrect
Controls (n=8)							
	M	3371	3206	3649	3164	3932	4541
	SD	2483	1766	2870	1691	1389	2760
LR		5281	4686	6077	4723	7940	7287

Discussion

The purpose of this study was to determine whether a prosopagnosic patient would demonstrate electrophysiological responses to familiar and unfamiliar faces in a manner similar to healthy control subjects. Faces were displayed in two different conditions to establish a sense of "familiarity". Faces of target individuals were presented either statically or rotated through a series of angles. A new angle of these target individuals was then combined with a larger set of never before seen faces (non-targets) while EEG data were collected. Past research has shown that prosopagnosics display greater P300 amplitudes in response to familiar faces when compared to unfamiliar faces. In this study, the evoked P300 response was used as a measure of the degree of covert familiarity for faces.

It was predicted LR's P300 response would not differ from the control group in his response to familiar faces. The P300 is believed to measure non-conscious processing for familiar visual images. Therefore, it was reasoned that the overt recognition of a face as "familiar" or "unfamiliar" should not affect the formation of the P300 waveform. Indeed, these results indicate that LR's P300 amplitudes did not differ significantly from those of the control group across the two face categories. Overall, LR's P300 responses to the presented faces were not dissimilar to those of the control group. It is important to note that although he tended to show lower than average amplitudes across the three conditions, it is not known whether LR's reduced amplitudes are limited to faces or if his evoked potentials are generally lower overall (e.g., alternate visual images, auditory stimuli, somatosensory stimuli). In future studies, a pre-test measure of evoked potential amplitude in response to non-facial stimuli would help to clarify this question.

It was also predicted that for the control group, P300 amplitudes would be greater in response to previously viewed, familiar faces than they would be for the faces that they had never seen. These data detected no differences between these two conditions.

Finally, it was predicted that the normal control group would exhibit relatively larger P300 amplitudes for the rotated faces than for static faces. It was hypothesized that the rotated condition, in providing additional information about the target face, would aid in the construction of a more complete mental image of the face, and thereby increase the likelihood of establishing a sense of familiarity. This hypothesis was not supported. In fact, in an entirely exploratory post-hoc analysis, the P300 amplitudes were actually greater in the static condition as compared to the rotated condition. In retrospect, it would have been prudent to ensure that the hypothesized effects in controls were detectable using the current methodology. A large pilot sample of normal control subjects would have provided more information regarding the natural variability in observed behavioral and P300 responses to the set of faces used in this design.

The fact that the control group exhibited no significant differences in P300 amplitude for the "familiar" and "unfamiliar" categories provides a major limitation and calls into question any firm conclusions drawn from these data. The relative degree of familiarity for the faces is unknown. There are numerous possibilities why a sense of familiarity could not be identified. These fall under two possible categories; errors in establishing familiarity and errors in assessing familiarity.

Establishing familiarity. In the current study, familiarity was established during the exposure phase while the participants completed a forced-choice discrimination task. Target faces were exposed three times and the participants made determinations of gender. It is possible that the number of exposures was not sufficient to establish a sense of familiarity and should be increased. It is also possible that the rotation of the target during the exposure phase introduced a complexity to the processing of a visual image, which interfered with the establishment of familiarity. This seems unlikely however, given that faces are often seen rotating through various angles in everyday life and therefore, most people are likely practiced at the perception of a moving face.

The faces used in this study were all of undergraduate students of roughly the same age, ethnicity and socio-demographic background. The photos were edited to remove any and all distinguishing features (e.g. birth marks or blemishes). It is possible that this uniformity increased the difficulty in differentiating one face from another. When novel non-target faces were introduced, it is possible that they did not differ enough to be deemed "unfamiliar". Indeed, several of the control participants commented that the task in the test phase was difficult because the faces "all looked alike." Although this may not completely account for the lack of a clear difference in P300 amplitudes to target and non-target faces, this uniformity is likely a contributing factor to these results. While the electrophysiological results suggest uniformity, the sensitivity index derived from the behavioral data indicates that the control group was sensitive to the differences between the studied faces and the novel faces. This was true for LR as well. His d' of .965 (i.e., a value sufficiently close to 1) indicates that he was able to perceive differences between the studied faces and the novel faces, although his strong bias to not report familiarity (i.e., produce "no" responses) made interpretation of his performance difficult. These behavioral indicators suggest that the faces were not so uniform that they couldn't be distinguished at a sensory level. The question remains whether this level of sensory discrimination, which retains a great deal of overlap between familiar and unfamiliar faces, provides a sufficient degree of familiarity.

Assessing familiarity. The probability of a target stimulus has been shown to directly affect P300 amplitude (Renault, et al., 1989; Polich, 1990; Picton, 1992; Cohen & Polich, 1997). Specifically, larger P300 amplitudes are elicited when the proportion of familiar to unfamiliar faces is relatively small (i.e., a ratio of 1:20 elicits a larger response than 1:2). While the ideal ratio would set the target ("familiar") stimuli at 20% (1:5) and the non-target ("unfamiliar") stimuli at 80% (4:5), the 1:3 ratio used in the current study should have been sufficient to generate a detectable difference in P300 amplitude between the two conditions (Polich, 1999). Furthermore, Polich (1990) determined that variations in the P300 amplitude were not affected by target probabilities when the inter-stimulus interval was relatively long (i.e., a few seconds). Because the inter-stimulus interval was 4 seconds, it is unlikely that the 1:3 ratio in the current study adversely affected the P300 response to familiar stimuli.

In order to assess familiarity, a sufficient number of trials needed to be collected for each of the target conditions. Polich (1999) suggests a minimum of 20 trials to reliably resolve the P300 waveform from the background noise. In the current study, the target conditions were each tested a total of 24 times. Following the data editing procedure in which trials corrupted by EOG artifact were removed, this number decreased. It is possible that not all of the participants had a sufficient number of trials to resolve the P300 waveform (trials included for each participant: ST 19-24 trials, RO 15-24 trials). Although the number of trials tested for each condition should have been sufficient, an increase in the number of trials included in the offline averaging procedure could have only improved the resolution of the P300. Given the number of difficulties outlined above, it is unclear to what degree these data reflect varying degrees of familiarity.

Although differences were not found between the target and non-target faces, post-hoc exploratory analyses suggested that members of the control group did respond differently to the static and rotated images. As stated above, it was originally hypothesized that the rotated faces would elicit a larger P300 response. It was thought that presenting a face from several angles would provide a more complete representation of the target individual than could be gathered after viewing a single 0^0 image. These participants, however, had a larger response in their P300 waveform to the static condition. This electrophysiological evidence suggests that control participants perceived the statically presented faces as more familiar. Several factors might explain why a) the rotated faces were not perceived as more familiar than the static faces, and b) the rotated faces were actually perceived as less familiar.

Faces are encountered continuously in everyday life and quickly translating the information they provide is vital to social interaction. If perceiving faces is a well-practiced activity, then seeing a face from additional, alternate angles may not necessarily increase the efficiency with which that information is processed. That is, seeing a photograph at zero degrees may be sufficient to construct a 3-D representation of that individual in the brain – so seeing multiple angles does not enhance the original 3-D representation. Alternatively, viewing multiple angles of a face might provide new information about a face/individual, but not the quality of information required to affect the establishment of familiarity. Either of these scenarios would explain a situation in which rotated faces were not more familiar than statically presented faces. However, neither of these explanations account for a situation in which rotated faces would be less familiar than static faces.

While these results preclude the classification of any face as "unfamiliar", rotated faces did appear to elicit somewhat lower P300 amplitudes in comparison to the statically presented faces. It is possible that providing additional angles during the exposure phase made the process of establishing familiarity less efficient. While the participants had more information about the target individual, they were also had more information to process within the same amount of time. During the three-second exposure, a participant was required to compile a larger amount of visual information into a representation of that target individual. Whereas, with a statically presented image, the participant can devote more resources to encoding the same image rather than integrating multiple images. By virtue of the fact that there was more information to encode and there was potential for distraction in the apparent movement of the image, establishing familiarity within the rotated condition might have been a more difficult task.

It is clear from the methodological problems in this study that few conclusions can be drawn regarding how prosopagnosics and normal subjects process faces. Numerous factors could have contributed to difficulties in the establishment and assessment of familiarity for the faces presented. While it is worth noting that LR did respond in a similar fashion to the normal controls, including a larger P300 response to statically presented faces in comparison to rotated faces, there is no evidence of covert recognition for familiar faces. Unfortunately this is due to the fact that the classification of "familiar" and "unfamiliar" is not possible with the current electrophysiological results. One can cautiously conclude however, that rotating a face during its exposure does not result in a greater sense of familiarity as measured by the P300 wave of the human evoked potential. The question remains unanswered however, whether or not increasing the information about a face can heighten a sense of familiarity. Furthermore these data and the design do not enlighten us as to the amount nor the characteristics of the visual information required to effect a change in familiarity for faces.

Future directions. Future studies will benefit from using a larger sample of more diverse faces, an increased number of exposure trials to better establish familiarity, and an increased number of test trials to enhance resolution of the P300 response. These methodological improvements are paramount to examining the way information about faces is being processed. The question of whether persons derive more information about a face by seeing a variety of angles should be more thoroughly explored. This would also improve our understanding of the factors that affect the establishment of familiarity for faces. These steps are necessary before conclusions can be drawn about any possible differences in the way prosopagnosics and healthy individuals recognize a human face.

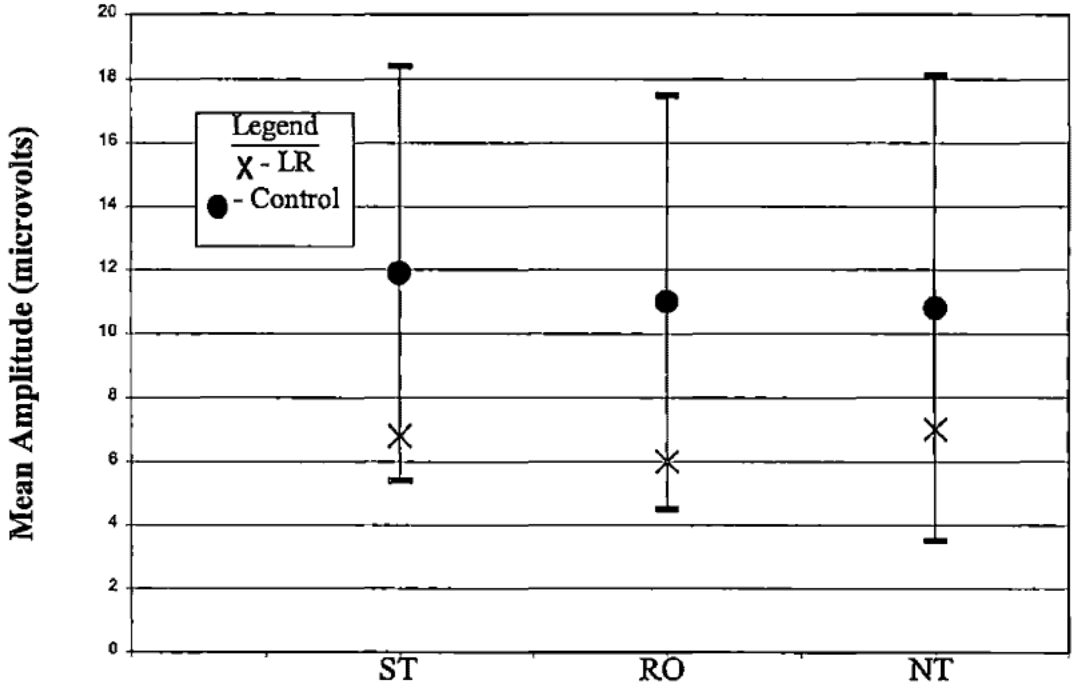

Figure 4. 90% Confidence Intervals for P300 at CZ

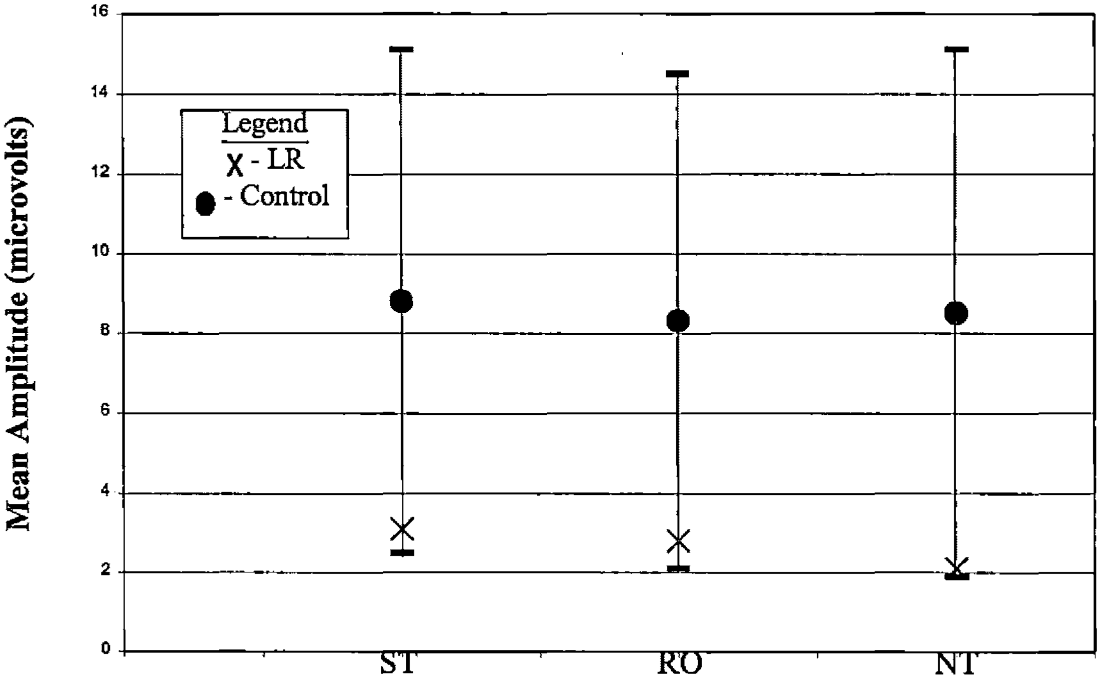

Figure 5. 90% Confidence Intervals for P300 at PZ

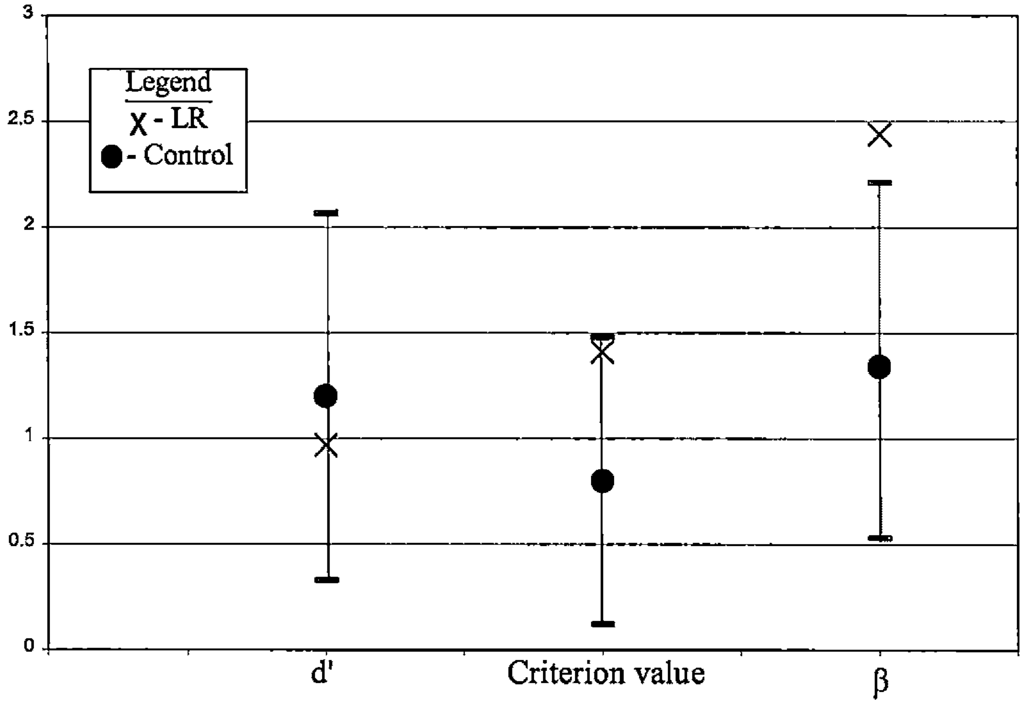

Figure 6. 90% Confidence Intervals for Signal Detection and Response Characteristics

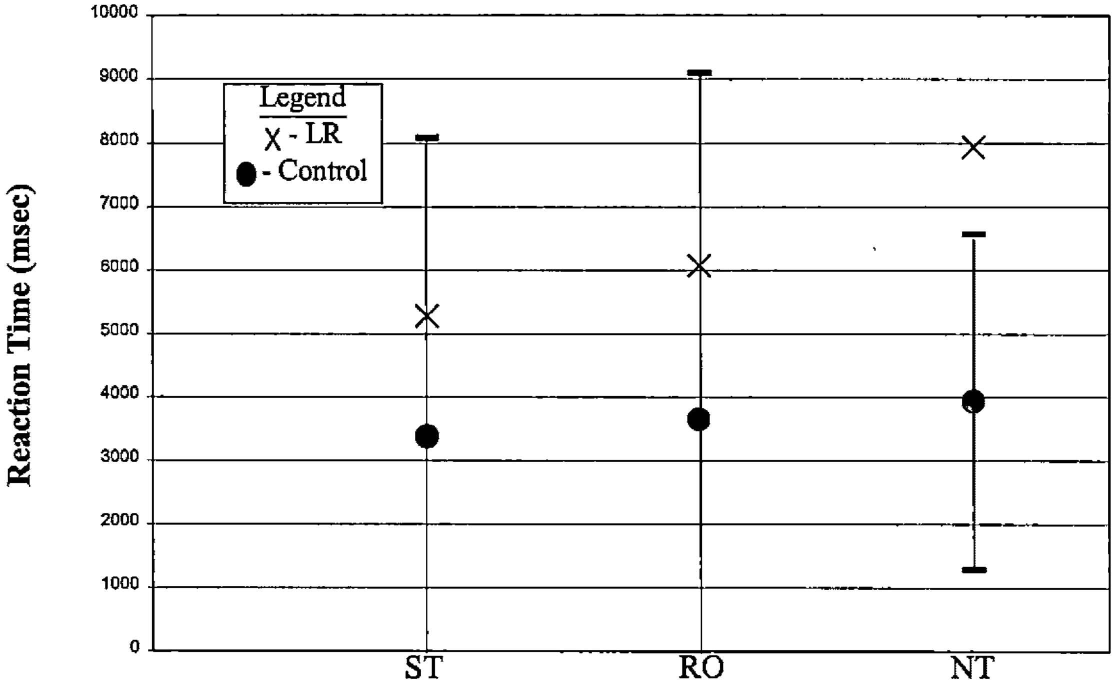

Figure 7. 90% Confidence Intervals for Accurate Response Reaction Times

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