University of Alberta

P300 AND TARGET IDENTIFICATION COMPLEXITY USING NUMERICAL AND LINE SEGMENT STIMULI

by

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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE

DIVISION OF NEUROSCIENCE

Edmonton, Alberta

Fall 1998

0-612-34361-8

University of Alberta

Library Release Form

Name of Author: Wolf Angela Fazikas

Title of Thesis: P300 and Target Identification Complexity Using Numerical and Line Segment Stimuli

Degree: Master of Science

Year this Degree Granted: 1998

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Oct. 2, 1998

University of Alberta

Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled P300 AND TARGET IDENTIFICATION COMPLEXITY USING NUMERICAL AND LINE SEGMENT STIMULI by WOLF A. FAZIKAS in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE.

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September 30, 1998

ABSTRACT

Twenty-four volunteers and University students (mean age 22.1) participated in two within-subjects oddball experiments that varied the complexity of target categorisation. A simple condition required one operand for target categorization; a complex condition required two. One experiment used 3-digit numbers; a second experiment used dotted lines. Using EEGs, the P300 (P3) waveform is widely assumed to reflect the completion of target evaluation; its latency was predicted to increase with task complexity. P3 amplitude, sensitive to resource allocation to a task, was predicted to vary as well. Target P3 latency decreased with increasing task complexity using numbers, but not using lines. Target P3 amplitude in both experiments decreased with increasing complexity ($p < .05$). These results do not support that P3 indexes the completion of target evaluation. ERP and RT data support that target identification complexity may be reflected in a greater post-P3, ERP positivity.

Table of Contents

List of Tables

List of Figures

List of Symbols, Nomenclature, and Abbreviations

A = peak amplitude of P3 measured in a given post-stimulus latency window

c = comparison performed

EEG = electroencephalogram

EP = evoked potential

ER = error rate

ERP = event-related potential

l = scalp electrode location

L = latency of the peak amplitude of the P3 measured in a given post-stimulus latency window

ms = millisecond

P3 = P300 waveform

R = positive area of the P3 waveform measured

RT = reaction time

Z = normalized P3 amplitude using McCarthy-Wood formula

-- = not statistically significant ($p < .05$)

* = approached statistical significance ($p < .05$)

INTRODUCTION

ERPs and the P3

Electroencephalographic (EEG) activity is a record over time of cerebral electrical activity. Evoked potentials (EPs) are averaged epochs of EEG with a fixed temporal relationship to specific stimuli. EPs recorded from the scalp are used to monitor the changes in the nervous system that are stimulated by a discrete external event (Goodin, 1986). The separate components of the EPs can be described by their polarity, amplitude and latency. The early EP waveforms occurring within the first 100 ms of stimulus presentation are obligatory responses, dependent upon the physical characteristics of external stimuli. They occur regardless of the task demands and are independent of attention allocated to a stimulus. Occurring later in time than these "exogenous" waveforms, are "endogenous" or event-related potentials (ERPs). These reflect changes dependent on selective attention to salient stimuli and can be independent of the physical characteristics of stimuli. The P300 (P3), a positive-going waveform occurring approximately 300 ms post-stimulus is one of the larger amplitude components of the ERP. It is traditionally elicited in an "oddball" paradigm where subjects must differentiate an infrequent stimulus (target) from a background of other stimuli (nontargets) (Goodin, 1986). Large P3s are elicited when the target stimuli are low in frequency, task-relevant, and require a differential response (Donchin, 1981). More than one subcomponent of the P3 has been identified. However, a centroparietal P3b is the main contributor to the P3 component and is associated with active discrimination of task-relevant target stimuli (Růžička & El Massioui, 1993). Furthermore, many studies do not differentiate between P3b and P3. Accordingly, this component will be referred to as P3 for the remainder of this thesis. The dependence on task requirements and the possibility for its elicitation in the absence of an expected stimulus suggests that the P3 is related to cognitive processing stages of a task rather than the initial perceptual processing of the stimuli presented (Goodin, 1986).

Determinants of P3 Amplitude

In 1965, Sutton, Braren, Zubin, and John performed a study where the test stimulus was cued to occur in a) the visual modality, b) the auditory modality or c) in either the visual or auditory modality. Subjects verbalized their prediction of the sensory modality after each cue and before each test stimulus. The results demonstrated a larger amplitude P3 for lower probability stimuli - the amplitude varied as a function of whether the subject was certain of the modality of stimulus presentation. Sutton et al. theorized that the amplitude of P3 is dependent on the amount of information delivered by a stimulus or the extent to which it is able to resolve uncertainty.

Horst, Johnson, and Donchin (1980) applied a paired associates learning task whereby feedback helped subjects learn the associations between stimuli. P3 amplitude was not related to actual probability nor to the correctness of a prediction, but to the subject's confidence (rated) in their prediction; the lower the confidence or subjective probability assigned to an outcome, the larger the P3. The inverse relationship between P3 amplitude and the subjective probability of stimulus presentation implies dependence upon and attention to previous stimuli (Donchin & Coles, 1988). Further confirmation that subjective probability influences P3 amplitude comes from a study that demonstrated that subjects judged probability of target presentation on the basis of the immediately preceding series of stimuli except when they were given information regarding the occurrence of upcoming stimuli. Under these conditions, the subjects appeared to ignore the preceding stimuli in selecting their responses (Duncan-Johnson & Donchin, 1982).

Donchin, Kramer and Wickens (1986) found that the more attention the primary task demanded in a dual task study, the lower the amplitude of P3 to stimuli from the concurrent oddball task. This suggests that P3 amplitude has a finite, measurable limit and P3 was in effect, distributed between tasks. Accordingly, they theorized that P3 amplitude was a measure of mental workload. Additional support for this theory comes from studies where an increase in perceptual difficulty corresponded with an increase in amplitude of the P3 elicited to a stimulus (Squires, Squires, and Hillyard, 1975; Johnson & Donchin, 1978).

Ruchkin & Sutton (1978) however, suggested that equivocation (uncertainty) can decrease the amplitude of the P3. A study by Kramer, Wickens, and Donchin (1983) supports this contention by demonstrating that P3 amplitude decreased with increased difficulty in a motor-visual tracking task.

Therefore, evidence suggests that P3 amplitude can be sensitive to information delivery, subjective probability, mental workload, and equivocation.

Determinants of P3 Latency

Several studies have demonstrated that an increase in the difficulty of target discrimination can increase P3 latency (Woodward, Brown, Marsh, and Dawson, 1991; Squires, Donchin, Squires, and Grossberg, 1977). Naylor, Halliday, Callaway, Yano, and Walton (1987) varied the stimulus discrimination of a target "X": one condition used a background of three dots, another condition used a background of three asterisks. They found a longer latency, smaller amplitude P3 for the more difficult discrimination task. In addition, a related study by Walton, Callaway, Halliday, and Naylor (1987) found that the latency of P3 was longer for stimuli that were of a lower contrast, lower intensity and thus more difficult to discriminate (background complexity was varied as in the Naylor et al. study).

McCarthy & Donchin (1981) manipulated stimulus discriminability by visually presenting the target words "right" or "left" in high or low visual noise backgrounds (letters versus asterisks). They also varied stimulus-response compatibility by cueing responses to be similar or opposite to the hand indicated by the target word. Although stimulus discriminability and stimulus-response compatibility had additive effects on reaction time (RT), stimulus-response compatibility had relatively little effect on P3 latency. However, visual stimulus discriminability was inversely related to P3 latency. In a similar set of studies, Magliero, Bashore, Coles, and Donchin (1984) found that counted, low probability targets elicited a larger P3 in the low background noise than in the higher noise condition, but had a longer latency in the higher noise condition. The noise conditions in the subsequent experiment varied the subset size of the alphabet from which the noise letters could be selected (eg. all letter A's; letters A-D; letters A-G;

letters A-Z). Again, although RT increased with noise manipulations and was affected by stimulus-response incompatibility, P3 latency increased primarily with manipulations of stimulus discriminability.

Kramer et al. (1983) define workload in the context of the interaction between the difficulty of the tasks in a dual task paradigm and the degree of overlap of processing resources required for the two tasks. In a dual task study, Fowler (1994) tested the sensitivity of target P3s in both visual and auditory oddball tasks to an operationally defined modulation of workload. Workload was increased by a stressor - hypoxia (which increases the latency of both auditory and visual P3s) and by task difficulty - manipulating turbulence in a flight simulation task. P3 latency consistently increased as a function of increases in both types of workload in both modalities. Fowler interpreted these results as supporting evidence that P3 indexes the slowing of perceptual / cognitive processing with increased workload rather than as a diminished resource pool available for this processing. Comparable results were found by Mäntysalo (1987): P3 latency was longer to both target and nontarget visual stimuli during and after auditory noise was present as compared to silent conditions. Together, these studies provide empirical evidence that P3 latency increases with perceptual difficulty in an oddball paradigm. Kutas, McCarthy, and Donchin (1977) suggested that as P3 was related to the duration of stimulus evaluation, its latency may be used as a relative measure of stimulus evaluation time. Similarly, Duncan-Johnson & Donchin (1982) proposed that because P3 amplitude is dependent upon target stimulus probability, the subject must first categorize a stimulus to assess its probability; consequently, stimulus evaluation and categorization must be completed before P3 is elicited.

Therefore, determinants of P3 latency include perceptual discriminability and workload. The latency of P3 appears to depend upon the time necessary for stimulus evaluation and categorization. However, the term "stimulus evaluation" does not make clear which specific process or processes are indexed by P3.

P3 and Task Complexity

Studies in the P3 latency literature often involve variations of the amount of a) perceptual difficulty via background noise, stimulus degradation, or probability (for a review, see Verleger, 1997) or b) motor response complexity or stimulus-response compatability. Few studies have varied the amount of cognitive processing necessary for target identification, and even fewer use paradigms where there are unconfounded manipulations of amount of processing. For example, a study by Heffley & Donchin (published abstract, 1978) found no P3 latency differences elicited by digits requiring a single arithmetic operation (addition) or two arithmetic operations (addition and squaring). As the correct answer was to be identified from a list of multiple choice answers, this was not a standard "target detection" task, limiting the validity of comparison to other P3 studies using oddball methods. Kutas et al. (1977) compared the P3s elicited by targets from three modified oddball conditions. The first condition used a male and a female name where the rare female name was the target, the second used many male / female names where the rare female names were the targets, and the third used targets that were synonyms for a given word within a background of unrelated words. These researchers concluded that P3 latency increased with difficulty or depth of semantic processing necessary for stimulus classification. However, conditions in this study differed not only in the depth of semantic processing of stimuli but also in the physical features of stimuli used, confounding interpretation on the basis of semantic differences. In addition, Ruchkin, Johnson, Mahaffey and Sutton (1988) conducted a study where subjects were required to perform one of three tasks involving numerical stimuli. The results indicated an increase in P3 amplitude to the categorization of divisional trials over those requiring subtracting or remembering. It was suggested that subjects classified stimuli into hard (requiring division) and easy (requiring one of the two easier tasks) categories. As the hard trials were of a lower probability, probability was assumed to have influenced the larger amplitudes. However, it is difficult to determine whether it was categorization and preparation for the most difficult task to be performed or the low probability of these trials that influenced the elicitation of the large P3s.

A set of studies by Neumann, Ullsperger, and Gille (1986) also assessed the effects of task complexity on the P3 although again, not via true target detection tasks. This research group theorized that changes to P3 amplitude can be influenced separately by changes in two visual attributes of a stimulus: its overall form or shape, and relations between components of its internal structure. The results from the first experiment indicated that controlling form (word length) and grading the processing difficulty of syllables (internal structure elements) in nonsense words affected only P3 amplitude, not latency. However, the words used between conditions were not kept constant. Numerical stimuli were kept constant between the conditions of the second experiment, controlling for both a stimulus' form and internal structure, and the processing difficulty was graded via the number of mathematical operations to be performed. The latter study demonstrated no P3 amplitude or latency differences with task complexity. They concluded that when both visual factors influencing P3 were held constant, processing difficulty would not be reflected by the P3 because it is independent of processing difficulty beyond that required for evaluation of a stimulus' physical characteristics. Similar results were found in a study by Ruchkin, Johnson, Canoune, and Ritter (1991) that used arithmetic and mental rotation tasks at two levels of difficulty. However, this study was not a true oddball paradigm, as targets and nontargets were equiprobable. For both types of tasks in this latter study, the ERP results at site Pz reflected a P3-like positivity occurring between 600 and 700 ms post-stimulus that was larger in amplitude for the less complex task, with no identifiable latency differences.

One study by McCallum (unpublished study, cited in a review, 1980) did use a true oddball paradigm presenting a random sequence of a square, circle or cross under five different task conditions. The task complexity of target identification was increased between conditions by requiring no responses to stimuli, responses to all stimuli, responses to just one target stimulus, responses to a given sequence of two stimuli, and responses to any one of three specific sequences of two stimuli. A large P3 occurred in the four latter conditions whose amplitude increased with complexity except for a decrease to the last, most complex condition. P3 latency however, increased steadily with the complexity increases between all five conditions.

The results from the Neumann et al. (1986), Ruchkin et al. (1991) and Heffley & Donchin (1978) studies provide evidence suggesting that P3 latency may not index the completion of processing necessary for full stimulus evaluation. However, the lack of direct comparability with standard P3 elicitation studies (oddball studies) and some data to the contrary (eg. Kutas et al., 1977; McCallum, 1980) the effect of processing complexity on P3 latency remains unclear.

The Purpose of this Study

The purpose of this study was to examine the effects on P3 latency of the complexity of cognitive processing required for target identification. The difference this study presents from other P3 studies is that a) task complexity has been operationally defined as the number of operands necessary for target identification, b) the probability of target occurrence is invariant across levels of complexity, and c) the physical parameters and response requirements for targets were unchanged across levels of complexity. "Operand" is functionally defined here as a process or processing. As the experimental manipulations in the following two experiments did not include the subject pool or the physical parameters of the targets between conditions, this establishes both a stable and reproducible ERP pattern both within and between subjects (Donchin & Coles, 1988).

If P3 does reflect the completion of target evaluation, its latency should increase as a function of task complexity. In addition, a more complex task would presumably require more cognitive resources. If the amplitude of the P3 is sensitive to this resource allocation, then P3 amplitude may vary as a function of target identification complexity. For both experiments, when classification of a target stimulus was more complex, the peak of the P3 was expected to be greater and its latency longer.

METHODS

Subjects

Twenty-four volunteers including undergraduate students given course credit at the University of Alberta served as subjects. When the data of an individual could not be used because of excessive incorrect answers (less than 80% correct responding), another subject was recruited to retain the number needed to counterbalance condition presentation. All subjects reported being free of psychiatric or neurological disorders and reported their vision to be normal or corrected-to-normal. Subjects' ages ranged from 17 - 32 years (mean = 22.1). Fourteen were female. All but two subjects reported right-handedness. Subjects were naïve to electrophysiological studies and the goal of the experimental procedure. Subjects provided written informed consent to their involvement in this study.

Procedures

Event-related potential recording

Electroencephalographic (EEG) activity was recorded at: Fz, Cz, Pz, Oz, P3, P4, T3, and T4. All sites were referred to linked mastoids with a forehead ground. Sites were cleaned with alcohol pads and lightly abraded with a conductive electrode gel to maintain the electrode resistance below 5 kΩ at 300 Hz. Gold plated disc electrodes were affixed using a water-soluble paste. Electro-oculogram (EOG) electrodes were placed suborbitally and at the outer canthus of the right eye to monitor vertical (VEOG) and horizontal (HEOG) eye movement. Data were collected using a 16 channel Grass Instruments Model 12 Neurodata EEG Acquisition System. Data for each stimulus were acquired and analysed off-line using software provided by InstEP Systems Ltd.

Amplification was 20 000 for the EOG, and 50 000 for the EEG channels. Trials on which the EEG exceeded ±200 μV or the EOG exceeded ±500 μV were automatically rejected during data acquisition.

The EEG was digitized at 256 points per sweep with a 1700 ms recording epoch including a 200 ms pre-stimulus baseline. The inter-stimulus-interval varied randomly between 2000 and 2400 ms to reduce anticipatory responding.

Stimulus presentation

Subjects were seated comfortably in a sound-attenuated, dimly lit room. A 26.67 x 19.05 cm computer monitor presented stimuli as black figures centred on a light grey background 1 m in front of the subject. Stimulus display duration was 200 ms.

Experimental procedures

Each of the 24 permutations of the four conditions (two per experiment) were presented to one subject during a single testing session. The total time necessary per subject was approximately two hours. The same randomisation sequence within a condition was presented to each subject. Stimuli from each condition were presented in one uninterrupted block. Subjects were given brief rest periods during which task instructions were given and comprehension of instructions was ascertained. It was stressed that subjects should minimize blinking and body and eye movement.

Out of the 500 stimuli presented for each condition, 20% were "targets": rare stimuli requiring a response different from the response to the more frequent stimuli. The response requirement upon a target presentation was to press the right button on a computer mouse; the response requirement for a nontarget was to press the left mouse button. For both experiments, the target stimuli used in the complex condition were the same 100 used in the corresponding simple condition.

A practice block of 50 stimuli (10 targets) was presented prior to each experimental session of each condition and repeated up to three times until the subject could attain 80% correct responding. The stimuli used for the practice sessions were not present in any of the experimental conditions.

Table 1 provides a summary of stimulus information for both experiments.

Experiment 1 - Numerical Stimuli:

Complex condition. Subjects viewed series of individually presented 3-digit numbers. Two operands were required for target identification: if a given number was a) odd, and b) the sum of its individual digits was less than or equal to 10, then it was categorized as a target. Otherwise, for stimuli that were even numbers or odd numbers whose sum was greater than or equal to 11, then it was categorized as a nontarget. Subjects were asked to judge odd versus even before summing the (odd) numbers. They were also asked to complete summation before pressing a mouse button, to reduce guessing. Emphasis was placed on correct decisions.

The numbers comprising the 3-digit numerical stimuli were each approximately

1.0 x 0.5 cm in size. The stimuli ranged from 000 to 900 with more stimuli chosen from the lower end of the range as a sum of 10 or less is more likely to occur in the lower range. Of the 400 nontargets, 240 were even nontargets ($p = 0.48$) and 160 were odd nontargets with a sum ≥ 11 ($p = 0.32$). These nontarget percentages corresponded to percentages set for the nontarget stimulus type subcategories in the task using line stimuli (Experiment 2) discussed later. Only the odd nontargets with sums ≥ 11 were unique to this condition.

Simple condition. One operand was required for target identification: subjects were to identify whether the 3-digit number presented was odd (target) or even (nontarget).

The nontargets were the even nontargets used in the complex condition with an additional 160 even numerical stimuli to increase nontarget set size to 400.

Experiment 2 - Line Stimuli.

Complex condition. Subjects viewed individually presented line segments made from dots connected by short straight lines (see Appendices A - D). Line segments were bent or straight, and varied in length depending on the number of dots used. Two operands were required for target identification: if a line segment was a) bent, and b) it was six dots long then it was categorized as a target. If a stimulus was bent and contained five or seven dots or straight containing five, six or seven dots, then it was categorized as a nontarget.

The dots were committed to the intersections of an invisible grid set at 32 x 25 pixels. Each bent configuration was presented in eight different 45 degree rotations; the next configuration would be presented in eight different rotations and so on, until the required quota needed for that stimulus subcategory was fulfilled. Only four possible 45 degree rotations could be created for any one length of straight line segment.

The 400 nontargets were evenly distributed between the following five stimulus subcategories: bent lines with five or seven dots, and straight lines with five, six or seven dots. Only the bent nontargets were unique to this condition. As the straight stimuli comprised the entire set of nontargets in the simple condition and were 48% of the total in the complex condition, the same percentage was allotted to the even nontargets for the complex condition of Experiment 1.

Simple condition. One operand was required for target identification: subjects were to determine whether a line was bent (target) or straight (nontarget).

The straight nontargets consisted of the 240 members used in the complex condition with 160 straight stimuli added to increase nontarget set size to 400. The straight five, six and seven dot line subcategories had 133, 134 and 133 members, respectively.

Offline analysis

Signal Analysis

A commercial computer program was applied to the EEG data to minimize the effects of eye movement artifact.

Separate averages of eye-corrected data were completed for each subject for each target and nontarget stimulus type. Epochs were excluded from averages if they exceeded + / - 150 μV for the EEG channels or + / - 500 μV for the EOG channels. Only the conditions where subjects' responding was above 80% correct both for targets and nontargets were used for averaging. Failure to meet this criterion in one or more conditions (simple / complex) resulted in exclusion of data from both conditions for that subject. Only ERPs corresponding to correct responses were included in averages. Table 2 indicates the minimum and mean number of trials accepted for averaging per subject for each stimulus subcategory of both Experiments 1 and 2.

The data were digitally filtered using 1.00 and 7.00 Hz cutoffs at 3 dB and subsequently at 0.80 and 8.00 Hz at 12 dB to maximally remove EEG activity above 7 Hz.

Eye-corrected, filtered epochs of EEG data were averaged across all subjects for each stimulus subcategory of each condition. The data from 20 subjects met criteria for Experiment 1, and 18 subjects met criteria Experiment 2. The analysis techniques described in the following section pertain to those performed on data collected from both experiments.

Dependent Variables

The latency window was chosen by visual inspection of the grand averaged waveforms of each condition to include the most prominent positive waveform at Pz in the 300 to 700 ms post-stimulus interval. This interval was likely to include the P3 component. Baseline-to-peak positive amplitude, the corresponding latency, and total positive area within the window was measured from the individual raw data. When no clear, positive inflection occurred, the maximal positive value within the window and the latency at that value were obtained.

For Experiment 1, the post-stimulus onset latency window for amplitude and latency measurements was 399 to 597 ms. The window for area measurements was 400 to 599 ms.

For Experiment 2, amplitude and latency measurements were taken from a latency window set at 299 to 597 ms. The window for area measurements was 299 to 599 ms.

The amplitude data were normalized using the McCarthy-Wood formula to scale data and eliminate differences in the amplitude of scalp distributions between the conditions so that amplitude differences across conditions would not produce spurious differences in location effects (see Appendix E, McCarthy & Wood, 1985).

The behavioral data collected were also averaged within each subject for each stimulus subcategory of each condition and then averged between subjects. Average reaction times (RTs) are summarized in Table 3. Error rates (ERs) were calculated as a percentage of the total possible correct for each subcategory of each condition for each subject and then averaged between subjects. Average percent ERs for each stimulus subcategory are summarized in Table 4.

Statistical Analysis

The following five tables present only the analyses that yielded significant results. Tables 5 and 6 outline the analyses of the behavioral and electrophysiological data, respectively from Experiment 1. Tables 7 and 8 outline the analyses of the behavioral and electrophysiological data, respectively from Experiment 2. Table 9 outlines the analyses performed on comparisons of electrophysiological data from Experiments 1 and 2.

A separate, repeated-measures analyses of variance (ANOVA) was performed within each experiment using all the information available within any one form of measurement. The ANOVA factors were stimulus type and scalp electrode location (Fz, Cz, Pz, Oz, P3, P4, T3, T4). Additional specific comparisons were performed to evaluate the effects of complexity of target identification as well as stimulus type on the P3 component. ANOVAs, corrected *t*-tests, and Tukey-HSD post-hoc tests were performed separately on each of the measurements of the conditions from both experiments. Collapsed data, averages of the data from two or more stimulus subcategories together, were used to compare the effects of task type on the different sizes and types of stimuli. Where the initial ANOVA performed on amplitude data for each experiment indicated an interaction between condition or stimulus type and location, the same analysis was repeated using normalized electrophysiological data to isolate the effects of electrode location. The degrees of freedom associated with the *F* ratios of all ANOVAs were corrected by application of the Greenhouse-Geisser procedure. Statistical significance was set at $p \leq .05$ to correct for non-sphericity.

RESULTS

Experiment 1: Numerical Stimuli

Behavioral results

Figures 1 and 2 are graphical representations of the RTs and percent ERs, respectively of Experiment 1. Figures 3 and 4 are graphical representations of the RTs and percent ERs, respectively of Experiment 2.

Tables 5 - 9 designate a number to each statistical comparison performed for ease of discussion (denoted by an italicized number in brackets).

RT data

(*1*) There was a main effect of subcategory membership on RTs across conditions.

Simple condition. (*2*) The control condition targets (763.17 ms) had longer RTs than did the nontargets (605.82 ms).

Complex condition. (*3*) There was a main effect of subcategory membership on RTs within the condition. (*4*) Target stimuli had longer RTs (1083.13 ms) than the RTs to collapsed nontargets (874.97 ms). (5) Post-hoc analyses revealed that reactions to the targets and to the odd nontargets (1005.51 ms) took substantially longer than to the even nontargets (744.43 ms). However, mean target RTs did not differ from the RTs to the odd nontargets.

Simple versus complex condition. (*7*) The complex condition targets had longer RTs than their counterparts from the simple condition. (*8*) The RTs to the even nontargets from the complex condition were longer than to those of the control condition.

b) ER data

(*1*) There was a main effect of subcategory membership on ERs across conditions.

Simple condition. (*2*) Response ER was higher for simple condition targets (7.80%) than nontargets (0.50%).

Complex condition. (*3*) There was a main effect of subcategory membership on ERs within the condition. (*4*) The target ERs (7.80%) were greater than the ERs of the collapsed nontargets (3.82%). (*5*) Post-hoc analyses demonstrated that there were greater ERs both to the targets and to the odd nontargets (5.53%) than to the even nontargets (2.10%).

Simple versus complex condition. (*7*) Although the target RTs differed between the two conditions, the ERs for target detection did not. (*8*) The even nontarget ERs from the complex condition exceeded those from the simple condition.

Electrophysiological results

ERP data

Grand-average ERPs associated with each stimulus subcategory of the simple condition are shown in Figure 5. There was an ERP characterized by a large, positive P3-like component with a peak latency of approximately 470 to 500 ms, maximal in amplitude for targets at the central parietal electrode (Pz) site. All amplitude, latency and area values in this section refer to the Pz site.

(*1*) There was a main effect of subcategory membership across conditions on all three ERP dependent variables.

Simple condition. *(2)* Target P3 amplitudes (7.85 μV) exceeded the nontargets' (4.42 μV). Similar effects were found for P3 latencies (499.59 ms, 470.04 ms) and areas (1142.70, 602.98).

Complex condition. Grand-average ERPs associated with each stimulus subcategory of the complex condition are shown in Figure 6. The ERP was characterized by a large, positive P3-like component with a peak latency between 465 and 495 ms, maximal at the parietal electrode site; target P3 amplitude was distinctly different from P3s of only one of the two nontarget stimulus subcategories. The targets elicited similar P3 amplitude waveforms to the even nontargets. The odd nontargets elicited a lower amplitude P3 with a similar onset to that elicited by the other two subcategories, but with a slightly earlier recovery.

(*3*) There was a main effect of subcategory membership on P3 amplitude and area but not latency.

(*4*) Target P3 amplitude (4.07 μV) was greater than that of the collapsed nontargets (3.47 μV) in amplitude, as well as area (535.79, 434.24). A P3 latency difference was not demonstrated in this condition.

(*5a*) The targets elicited P3s of larger amplitudes than the odd nontargets (3.01 μV) as well as larger areas (535.79, 349.29).

(*5b*) There were no differences in any of the three dependent variables between the complex condition target P3s and those of the even nontargets.

(*6*) Even nontarget P3s (3.92 μV) were larger than the odd nontargets both in amplitude and area (519.20, 349.29). There was no difference in latency.

Simple versus complex condition. Grand-average ERPs elicited by target stimuli from the simple and complex conditions are shown in Figure 7. The targets from the simple condition elicited P3s with substantially larger amplitudes than did those from the complex condition.

(*7*) Contrary to prediction, P3s elicited to the target stimuli were larger in amplitude and area and of longer latency for the simple condition than for the complex condition.

(*8*) Comparison of even nontarget P3s between conditions revealed no differences for any of the three ERP dependent variables.

Experiment 2: Line Stimuli

Behavioral results

RT data

(*1*) There was a main effect of subcategory membership on RTs across conditions.

Simple condition. (*2*) There was a main effect of subcategory membership on RTs within the condition. (*3*) Target RTs (670.09 ms) were greater than the collapsed RTs for the nontargets (493.05 ms). (*4*) Post-hoc tests indicated there were longer RTs for the control targets over each of the individual control nontargets (five dot straight nontargets: 490.42 ms; six dot straight nontargets: 490.56 ms; seven dot straight nontargets: 498.16 ms).

Complex condition. (*5*) There was a main effect of subcategory membership on RTs in the complex condition. (*6*) Similar to Experiment 1, the target RTs (1189.97 ms) exceeded the collapsed nontargets' (903.00 ms). (*7a*) However, no RT differences were found between the targets and bent nontargets (1163.47 ms); (*7b*) target RTs were only longer than the RTs of the straight nontargets (642.52 ms). (*8*) Bent nontarget RTs exceeded straight nontargets RTs. (*9*) Post-hoc comparisons demonstrated RTs to the five dot bent nontargets (1111.34 ms), the seven dot bent nontargets (1215.60 ms) and the targets each to to be different from the RTs of all three straight nontarget groups (five dot straight: 653.65 ms; six dot straight: 648.84 ms; seven dot straight: 625.09 ms), but not from each other.

Simple versus complex condition. (*10*) The RTs of the complex condition targets exceeded those from the simple condition. (*11*) The RTs of the straight nontargets from the complex condition were also longer than their counterparts in the simple condition.

ER data

(*1*) There was a main effect of subcategory membership on ERs across conditions.

Simple condition. (*2*) ERs differed across subcategories within the condition. (*3*)

There was a similar effect to that discussed in the RT analyses, with a greater ER to the targets (3.44%) than to the collapsed nontargets (0.44%). (*4*) Post-hoc tests demonstrated that the target ERs exceeded those of each of the nontarget subcategories (five dot straight nontargets: 0.63%; six dot straight nontargets: 0.25%; seven dot straight nontargets: 0.46%).

Complex condition. (*5*) There was a main effect of subcategory membership on the ERs within the condition. (*6*) Target ERs (11.11%) exceeded those of the collapsed nontargets (7.00%). The ERs to the targets (*7a*) were not different from those to the bent nontargets (16.39%) but (*7b*) exceeded ERs for straight nontargets (0.74%). (*8*) Bent nontarget ERs were substantially higher than ERs of the straight nontargets. (*9*) Post-hoc tests indicated that: a) the target ERs were higher than each of the straight nontargets' (five dot straight nontargets: 1.18%; six dot straight: 0.56%; seven dot straight: 0.49%); b) the five dot bent nontarget ERs (11.18%) were larger than each of the straight nontargets'; and c) the seven dot bent nontarget ERs (21.60%) were larger than each of the other nontarget subcategory ERs.

Simple versus complex condition. (*10*) The target ERs of the complex condition exceeded those of the simple condition. (*11*) There was no difference between the ERs of the straight nontarget groups from each condition.

Electrophysiological results

ERP data

Figure 8 presents the ERPs associated with each subcategory of the simple condition. There was an ERP characterized by a large, positive P3-like component with a peak latency between 370 and 430 ms, maximal in amplitude for targets, at the central parietal electrode (Pz) site. All amplitude, latency and area values in this section refer to the Pz site.

(*1*) There was a main effect of subcategory membership for each of the three ERP dependent measures across conditions.

Simple condition. (*2*) There was a main effect of subcategory membership on each of the three ERP measurement values within the condition.

(*3*) Nontarget P3 amplitude (6.97 μV) was smaller than target P3 amplitude (12.76 μV), with the same relative relationships for latency (380.32 ms, 429.38 ms) and area (1072.19, 2144.32).

(*4*) Comparisons between the control nontarget P3s revealed no significant differences on any ERP dependent variables.

Complex condition. Grand-average ERPs for each stimulus subcategory of the complex condition are shown in Figure 9. The ERPs were characterized by a large, positive P3-like component with a peak latency between 430 and 465 ms, maximal at the parietal electrode site. P3 amplitude was larger for the straight stimulus subcategories than for all the bent subcategories including the targets. Bent and straight stimuli elicited similar P3 waveforms in latency onset and duration of P3 peak return to baseline.

(*5*) There was a main effect of subcategory membership on P3 amplitude and area but not latency.

(*6*) Target P3 amplitudes (4.31 μV) were smaller than for the collapsed nontargets (6.18 μV) with a similar relationship for area (722.50 vs 1012.14). A latency difference was not demonstrated.

(*7a*) Visual impressions of the ERPs were corroborated by statistical analyses that showed no differences between the P3s of the targets and the collapsed bent nontargets in any of the ERP dependent variables.

(*7b*) Target P3s were of smaller amplitude than the straight nontargets (7.24 μV), as well as smaller areas, but latency did not differ.

(*8*) Bent nontarget P3 amplitudes (4.58 μV) and areas (707.28) were smaller than those of the straight nontargets, whereas there was no such effect of latency.

(*9a*) The bent nontarget P3s were not different from each other in any of the three ERP dependent variables.

(*9b*) The straight nontarget P3s differed in amplitude and area, but not latency.

Simple versus complex condition. Grand-average ERPs associated with the target stimuli from the simple and complex conditions are shown in Figure 10. The targets from the simple condition elicited larger amplitude P3-like waveforms at Pz.

(*10*) Contrary to predictions made regarding this experiment, the target P3s of the complex condition were smaller in amplitude and area than those of the simple condition, and were not different in latency.

(*11*) P3s of the straight nontargets from the simple condition had smaller values than their counterparts in the complex condition for each of the ERP dependent variables.

Experiment 1 versus Experiment 2

Electrophysiological results

Normalized ERP amplitude data.

(*1*) The complex condition targets from each of the two experiments were compared: a main effect of location with effects maximal at site Pz was indicated. (*2*) A comparison of the simple condition targets from the two experiments demonstrated a location effect and a Condition x Location interaction.

DISCUSSION

Inferences may be made about the timing of cognitive processes on the basis of latency changes in ERPs. P3 has been shown to reflect cognitive processes. If P3 reflects the completion of stimulus evaluation, increases in P3 latency would be expected when subjects are required to complete increasing numbers of cognitive tasks in order to identify target stimuli.

Reported here are two visual oddball studies designed to further delineate whether the P3 assesses completion of stimulus evaluation. The same targets were presented to normal subjects in two situations differing in the number of operationally defined cognitive processes required for target identification.

Similarities Between the Results of the Two Experiments

P3 Latency and Task Complexity

P3 latency was not longer for targets of the complex conditions even though their identification involved additional processing relative to the simple conditions. The absence of a later P3 latency to targets with an increase in task complexity was not comparable to the consistent increase demonstrated in RTs (see Fig 11). Change in mean target P3 latency from the simple to the complex condition in Experiment 1 was relatively independent of complexity - it decreased by almost 15 ms, whereas the RT increase was almost 320 ms. A similar change in mean target P3 latency in Experiment 2, though slightly more than 17 ms, was not significant (see Fig 12); this was not comparable to the increase in RT of almost 520 ms. By using P3 and RT data together, the effect of target identification complexity can be narrowed down within the responding time epoch; these results indicate that the effect of task complexity was incurred for the most part between the two measures in time. The bulk of the increase in RT appeared to be due to processes occurring after the P3. If P3 indexes the completion of stimulus evaluation time, then the pattern of P3 latency increase should have parallelled that of the RT increase between conditions. Instead, P3 latency was relatively unaffected by complexity. Thus, the effect of complexity occurs subsequent to the part of stimulus evaluation that is indexed by P3. Or, perhaps the pattern of P3 latency between the two conditions represents the results expected if the two operands were performed or initiated in a parallel manner. However, the ERP figures do not support a completion of target identification occurring within the time P3 was elicited. In addition, the effect of task complexity on RTs implies that the two operands do not terminate simultaneously, as responding to the targets requiring two operands for identification takes longer than to those with the one operand. These results suggest that P3 latency does not index the completion of target identification and classification. Therefore, either the more complex processing does not take longer than the simple processing, or alternatively, the P3 waveform does not index the completion of target identification, but an earlier process inherent to both conditions - this could be a decision or preparation to do further processing or not. Johnson & Donchin (1985) suggested that instead of indexing actual processing time, the P3 may index the time required to recognize the need to change the rules of processing. This decision would most likely take the same amount of time for stimuli from each of the subcategories within each condition, and the P3 elicited for each would occur at the same latency. This suggests an index of time relating to a decision to process, not to the subsequent processing of information based on that decision.

A similar postulate made by Ruchkin et al. (1988), suggested that the P3 may be related to recognition of the type of task and preparing the necessary resources to perform the task. In their study, the initial processing of the left digit out of a set of four elicited a large P3 - this stimulus indicated which operand to perform on the other digits. Processing of this number had to be completed before the operand could be initiated. This theory does not explain the P3 amplitude results found in the complex condition of the first experiment of the present study but it helps to explain the lack of P3 latency effects. This theory may even explain the amplitude differences in the complex condition of Experiment 2: it could be inferred from the data that recognition of the need for further processing of a stimulus elicits a smaller P3 than do stimuli that need no further processing to be categorized. In addition, the study by Heffley & Donchin (1978) mentioned earlier demonstrated no amplitude or latency difference of P3s elicited to digits following either an easy or more difficult arithmetic operand request; the P3 did not reflect the complexity difference of the operands between the conditions. The subsequent suggestion was that the P3 was associated with a simple, initial evaluation of the stimuli to be processed. Similar to that postulated in the present study, if the extra processing in the more complex task were reflected in the ERPs, it was not within the P3 time epoch.

P3 Amplitude and Task Complexity

Contrary to expectation, target P3 amplitude decreased with complexity. This decrease implies that P3 is a load-sensitive wave. The decrease in target P3 amplitude may reflect greater equivocation with increasing task complexity to decisions regarding target categorisation. These results parallel those found in several previously mentioned studies manipulating the difficulty of stimulus classification (Ruchkin & Sutton, 1978; Kramer et al., 1983; Naylor et al., 1987; Magliero et al., 1984; Ruchkin et al., 1991). Ruchkin, Sutton, and Stega (1980) found different effects of task demands on P3 and slow wave (post-P3) in a signal detection task: P3 amplitude decreased with decreasing accuracy while slow wave amplitude increased. Ritter & Ruchkin (1992) suggest that slow-wave amplitude increases with task difficulty and with decreases in subject's decision confidence. Their interpretation was that when either the perceptual or conceptual difficulty increased, larger slow-wave activity associated with a stimulus reflected the need of additional processing or continuously planning for the next trial to maximize accuracy of performance. The findings of the present study were consistent with these suggestions. The target ERPs of each simple condition were more positive-going within the P3 latency window than the target P3s of the corresponding complex condition, but the activity following the target P3s of each of the complex conditions was characterized by a readily observable prolonged positive wave (see Figures 7 and 10,). As this post-P3 positivity to targets of the complex condition exceeded that of the simple condition, it seems that the additional post-P3 processing reflects the complexity differences in target identification; these would be components most probably associated with the processing that ultimately leads to a final target / nontarget differentiation. The target ERPs from the complex condition showed greater positivity in these late components starting at approximately 650 ms in Experiment 1 and 600 ms in Experiment 2. This positivity was maintained until approximately 1200 ms post-stimulus in Experiment 1, and 950 ms in Experiment 2. In Experiment 1, this positivity lasts beyond the motor response to the targets of both conditions, while in Experiment 2, this positivity ends before the motor response to the targets of both conditions. Not only is this late waveform more positive and maximal centro-parietally, but like the P3 waveform, its characteristics appear to be controlled by psychological factors. Therefore, when the tasks are sufficiently complex in a dual-operand target identification task, the later, post-P3 positivity may be associated with subjects continuing to process information related to the task. However, preparation for the next trial may also account for this, since greater preparation may be needed in the complex conditions. Where P3 amplitude may index workload or resource allocation in a relatively simple task, more taxing tasks may elicit smaller P3 amplitudes and the later positivity may index later additional processing. It is therefore possible that P3 amplitude is reduced due to the spread of resources to the task over time.

The behavioral data of Experiment 2 suggested greater equivocation to the categorisation of bent stimuli, the most difficult stimuli to categorize. The smaller amplitude P3s elicited to bent stimuli than to straight nontargets may well index an increase in equivocation to decisions made in classifying the bent stimuli. The effects found in the complex condition of Experiment 1 also support that P3 amplitude may have been smaller to odd nontargets than to even nontargets because of greater equivocation involved in categorizing odd nontargets.

Additional Effects of Task Complexity

In the complex oddball tasks where there were two operands for target identification, target P3s were not larger or later than the P3s of each of the nontarget stimulus subcategories. RT and ER data reflected similar values for the targets and the corresponding nontargets that received the second operand; these values were larger than those for the nontarget subcategories most dissimilar to the targets that only required the first operand for response classification (all odd stimuli from Experiment 1 had larger RTs and ERs than even stimuli; all bent stimuli from Experiment 2 had larger RTs and ERs than straight stimuli). Therefore, the change from a more common response to a more rare response in the complex conditions did not necessarily elicit a corresponding change in RT or ER as it did in the simple conditions. Perhaps the highly repetitive task in each of the simple conditions was not fully engaging, and more errors to target stimuli may have been made due to lack of attention. The determinant factor affecting RTs and ERs in the complex conditions was more likely the extent of cognitive processing necessary for the task.

Task complexity was associated with increased RTs for the targets and also for the stimulus types most dissimilar to the targets (even nontargets in Experiment 1, and straight nontargets in Experiment 2). In Experiment 1, the time lapse between the mean RTs to the even nontargets and the targets was 157.35 ms in the simple condition, and 338.70 ms in the complex condition; in Experiment 2, the corresponding time lapses were 177.04 ms and 547.45 ms. This indicates that although the nontargets most dissimilar to the targets took longer to respond to in the more complex conditions than in the simple conditions, the increase in RT for the targets relative to these nontargets was much larger in the complex conditions. There are two possible explanations for why task complexity may have increased the RTs to the nontarget stimuli that were easiest to categorize. The first explanation is that the presence of the second operand may demand extra resource allocation to the processing of all the stimuli in each complex condition. This may occur via a general increase in activation, attention, or focused effort on the task and may increase the RTs to all stimuli in the task. Another explanation is that perhaps this effect was due to the application of additional resources such as inhibitory processes - suppressing processes linked to the second operand, thus increasing the associated RTs.

Effects of Nontarget Stimulus Type

In the simple oddball tasks, the targets elicited a longer latency, larger amplitude P3 with longer RTs and higher ERs than nontargets. Results from the second experiment suggest that given a simple task with more than one type of nontarget stimulus subcategory, RT, ER and P3 measurements could index the correct categorization of a stimulus as a target / nontarget (or bent / straight line) but not differentiate between nontarget stimulus subcategories.

Differences Between the Results of the Two Experiments

Task Complexity and Behavioral Data

Although the decrease in target P3 amplitude with increasing task complexity may reflect greater equivocation in each complex condition, the lack of uniform effects on target ERs does not support this suggestion. Though the target RTs of Experiment 1 increased with task complexity, ERs were unaffected. Response accuracy to the targets decreased with increasing task complexity only in Experiment 2. The effect of complexity in Experiment 1 was reflected in greater ERs to the even nontargets with increasing task complexity. However, this was not the case for analogous stimuli in Experiment 2. It is possible that a difference in the ease of stimulus categorisation and response selection may exist between the tasks of the two experiments or in the use of numerical and line stimuli.

P3 Amplitude

The P3s elicited by the targets and even nontargets in the complex condition of

Experiment 1 were similar in amplitude and both surprisingly larger than the odd nontargets. The greater the probability of a stimulus' presentation, the smaller the amplitude of the P3 that is expected. The less resources allocated to processing a stimulus, the smaller the amplitude of the P3 it is expected to elicit. The even nontargets have the greatest probability of presentation of any one stimulus subcategory within this condition and they require the least processing, and yet they elicited large amplitude P3s similar to the target P3s. These results violate hypotheses of the effects on P3 amplitude of either probability or the amount of resources allocated to a task. These results provide support that the complexity of target identification may not be clearly demonstrated by P3 amplitude. Although P3 amplitude target effects are usually maximal at Pz, it is possible that a more central maximum may be overlooked. Referring to Figure 6, whereas the ERPs at site Pz show no real difference between the targets and the even nontargets, a clear distinction between the targets and each type of nontarget stimulus can be identified at site Cz. At this latter electrode, a stepwise increase in amplitude can be identified from the odd nontargets up to the even nontargets and then to the targets. However, the statistical results were assessed with the use of data from all eight scalp electrode locations; the specific effects at individual sites were beyond the scope of this experiment. Visual inspection of the effects at site Cz continue to support that even nontargets elicited P3s of larger amplitude than did odd nontargets.

<u>Parallel Processing</u>

The amplitude difference between the P3s elicited by the odd nontargets and those elicited by the targets and even nontargets in the complex condition of Experiment 1 provides further support that a parallel initiation of the two task operands may occur. If the two operands are initiated or occur simultaneously and this processing is associated with the P3, the actual addition operand confirming this assessment may continue post-P3. For example, as subjects judged odd / even, they could concurrently make a quick judgement to identify numbers whose digits most likely sum together a total less than or more than 10 without the actual addition occurring. This may transpire in the same way that a motorist gauges the speed of an oncoming car to assess whether there is time to manoeuvre around it; although no real number has been assigned to the speed, a practised guess occurs quickly, followed by a more stringent analysis as the car approaches that confirms or disconfirms the initial decision. It is conceivable that the practise trials may help establish this effect in the oddball task (Pfefferbaum, Christensen, Ford, and Kopell, 1986) and would help to explain the lack of a P3 latency difference between the tasks requiring one or two operands. As with the effect of complexity on P3 latency, it does not seem likely that the processes involved with the two operands terminate simultaneously because the P3 amplitude of the targets and even nontargets are so similar; these two would be expected to demonstrate amplitude differences if this were the case.

Serial Processing

However, Ruchkin et al. (1980) suggest that the P3 may be associated with an "intermediate stage of event evaluation that is common to more than one mode of tasks while slow wave reflects an ensuing final evaluation process...". They further index the P3, in a more complex task, as possibly associated with perceptual classification rather than cognitive-related classification. Therefore the P3 may index categorisation based on simple physical evaluations, whereas additional higher-order processing of the stimulus information for further classification may be indexed by a more broad positive trend following the P3. The elicitation in each complex condition of P3s with similar latencies to stimuli with different cognitive processing demands also supports this theory. In the complex condition of Experiment 2, no P3 amplitude difference was demonstrated between the targets and the bent nontargets, yet the straight nontargets elicited P3s of greater amplitude than both. A parallel manner of processing with the two operands terminating together therefore seems dubious in Experiment 2. As stimuli from each of the nontarget subcategories were more rare ($p = 0.16$) than those of the corresponding targets, it would have been plausible to see stimuli from any one subcategory elicit larger P3s than the targets based on expected probability effects. Instead, the data indicate that stimuli were grouped together into two large categories: bent / straight lines. Each of these two categories represented much larger probabilities than did the individual subcategories: the straight nontarget category had a 48% probability whereas the bent nontarget category had a 32% probability. If probability was the strongest indicator of P3 amplitude, the targets should have then elicited larger P3s than either the bent or straight nontarget stimulus categories. The data however, do not support this theory. These results support that the P3 may be involved with processes related to perceptual categorization of the stimuli via basic physical properties into the two most visibly apparent categories: bent / straight lines. Donchin & Coles (1988) explain this as a feature detection step preceding higher level categorical processing. These results together with the finding that straight nontargets had longer RTs than did bent stimuli, suggest that the ERPs of Experiment 2 index a sequential dependence among the operands for target identification. The two operands seem to occur with the dot count or assessment and consequent decision of target / nontarget status being performed after a basic physical feature discrimination.

There are a few possibilities for the superiority of the complex condition of Experiment 2 over Experiment 1 in the clear elicitation of a P3 related to this feature detection step. Perhaps extracting basic, obvious physical features from the stimuli was not possible in Experiment 1 because of the use of numerical stimuli. Or, Squires et al. (1977) suggest that if the features on which the operands and classification of stimuli rely are highly separable, then separate P3s may be generated. If however, the cognitive rules separating the results of the two operands involve more integral and interdependent features of the stimuli used, as with numerical stimuli, then the two operands may be highly interrelated in processing and not generate separable P3s (cf. integrality / separable dimensions of stimuli - Squires et al.). The third possibility, as discussed earlier, is that perhaps the operands necessary for target identification in Experiment 1 were not performed in distinct stages such that the first operand was not as clearly linked to the elicitation of a P3 as in Experiment 2. Any of these suggestions may explain why Experiment 1 did not have the potential to generate large P3s to stimuli most physically dissimilar to the targets as did Experiment 2.

Change in Strategy

Donchin (1981) suggests that elicitation of the P3 may occur at an early stage of stimulus encoding. He theorized that memorable, distinctive items will be remembered best and thus elicit the strongest P3s. P3 amplitude in the complex condition of Experiment 2 seemed to be less affected by probability and a differential response, and seems to have been affected instead, by classification into more perceptually-linked and less cognitively-linked categories. Donchin (1984) and Klein, Coles, and Donchin (1984) suggest that it is possible for targets not to elicit a P3. Nontargets may then elicit a P3 due to the strategy chosen to perform the task whereby nontargets become a standard to which targets can be compared. Therefore, P3 amplitude may not determined by external, operationally defined target / nontarget criteria as set ad-hoc by the experimenter, but to a change in information processing strategy that the subject uses. It is possible that the classic target factors, such as low probability and a differential response may be overshadowed or influenced by the salience of other features. If a certain type of stimulus can be readily differentiated from the targets and other nontargets, it may become salient as it is the easiest stimulus to categorize and eliminate from further processing. This salience can change what the subject searches for in a stimulus sequence, making it target-like and eliciting target-like effects at that point of processing. In the complex condition of Experiment 2, this change in strategy may account for the larger amplitude P3s to the categorization of straight lines, which could be eliminated from further processing, as opposed to bent lines. Final target identification may well have been determined by belonging to a right mouse response category, but an additional, earlier target may have been determined exclusively by the first operand whereby a judgement was made solely on the physical structure of the stimulus (Duncan-Johnson and Donchin, 1982). This implies the identification of two "targets" to search for at different stages of processing. Thus, P3 may be a function of just the physical structure of the stimulus; an index of decisions made on its salient physical features. This may establish this part of the task as a basic, physical oddball detection - true target detection in a sense, like that in the simple condition. Evaluating it by its cognitive information may occur separately or later. The second target decision may not be associated with a single, positive waveform as clear as the P3, but by one or more broader waveforms. This effect is supported by the larger post-P3 positivity present in the target ERPs of the complex conditions.

When there are no large differences in physical features between the stimulus subcategories of a given complex condition, the first target may instead be a function of a basic categorization of the stimulus via the first operand required. In Experiment 1, the even nontargets were the stimuli most different from the targets. They may have become salient as they could be categorized quickly by performing the first operand. This salience of the even nontargets may account for the elicitation of larger P3s than to odd nontargets. The first target may therefore have been an even number, based on the first operand, whereas the second target would be an odd number whose sum equalled ten or less, based on the second operand..

Alternate Theories

Kutas et al. (1977) suggest that if targets differing in complexity do not differentially affect P3 latency, then the P3 may not be associated completely with stimulus evaluation. Instead, the P3 may not be specific to any given process but indicates the timing of many different processes. Donchin (1984) suggested the existence of multiple processors which are continually active and the occurrence of a stimulus interrupts or changes the pattern of their functioning. It is also possible that P3 does not index all processing occurring in its time frame (Walton et al. 1987); if this was the case, then the suggestion was that the subject may be double-checking their processing results after P3 has occurred. None of these theories mentioned here are efficient in explaining the clear amplitude differentiations between P3s elicited by bent and straight stimuli in the complex condition of Experiment 2. Any of these theories is entirely possible, however each is difficult to test experimentally, and the data from the present study do not seem able to prove or disprove their validity.

Effects of Nontarget Stimulus Type

Surprisingly, bent nontargets in the complex condition of Experiment 2 abstracted the same length of time for the same response, independently of length variations; the same effect was found for the straight nontargets.

One noteworthy finding was that not only did the ERs of each of the bent stimulus subcategories exceed the ERs of each of the straight nontarget subcategories, but ERs of the seven dot bent nontargets exceeded the ERs of each of the other nontarget subcategories. It is possible that some bent nontargets of a seven dot length were too complex and their processing may not have been possible in the allotted time. Alternatively, the difficulty of counting may increase with the number of times the lines between the dots change direction. If this question were of interest to the goals of this study, individual analysis on the error rates to individual seven dot bent stimuli would be able to determine whether specific stimuli were too difficult for all subjects or whether there was an overall threshold attained by using seven dot bent stimuli. Note however, that the complexity of processing was not reflected in RT differences between any of the bent stimulus subcategories. This finding suggests two possibilities: a) that difficulty of processing does not necessarily affect the time necessary to make a response, or b) that responses to the seven dot bent stimuli were sometimes made before an accurate count of their components had been completed. The greater ERs to seven dot bent stimuli over other bent stimuli support the latter possibility.

ERPs Across the Two Experiments: Normalized Amplitudes

The normalized amplitudes of the simple condition targets from the two experiments were found to vary by scalp location. These results imply that the topography of processing targets in simple oddball tasks differed with the use of numerical versus line stimuli or the different tasks used. The normalized amplitudes of P3s elicited by targets in the complex condition from both experiments were not significantly different. This implies that the nature and scalp distribution of the P3s elicited by numerical or line segment targets in the dual operand target identification tasks resembled each other. This supports that a similar neural generator contributes to the P3 waveform measurement in the complex condition using either type of visual stimuli.

Future considerations

The best method for evaluating the plausibility of a theory about the P3 is to find functional applications that can efficiently predict experimental consequences. Several recommendations for related future studies could be made. One would be to use target / nontarget response categories and to introduce a third response selection indicating uncertainty of categorisation to help reduce contamination of correct responses with guesses. In addition, interference of serial or parallel processing could be implemented to help determine if the order of processing does in fact proceed in a serial or parallel manner with different types of stimuli or tasks. This could be carried out via the use of distracters at the lower (eg. bent / straight level of processing eg. by varying the space between dots) or at the higher (eg. dot counting) level. Also, it is possible that many of the findings differing between the conditions in this study were due to overall attentional changes to different conditions. A study using a stimulus that codes the task to be performed before presenting each stimulus to be processed may help to elucidate the locus of these attentional effects. In addition, the findings from this study suggest variation in strategies dependent upon task instructions. A study introducing several different types of targets could help define what types of features make target-like effects and strategy changes most likely to occur. Walton et al. (1987) also suggest that if post-P3 ERPs reflect the additional processing in a complex oddball task then an experimental design should be introduced where RT occurs before or at the same time as P3.

One proposal for further research stemming from this study involves the use of an oddball task with an ad-hoc defined human face as a target. This realistic, computer generated or scanned human target face could be presented in a "crowd" of other faces, with variations of its facial / head accessories such as beards, glasses, or hats modifying its recognisability. The number of operands that would identify this face as the target would vary in different conditions. The utility of this study would be the application of more ecologically relevant stimuli and a study of the consequent change in the locus of ERP effects generated.

Summary

The main issue of this study concerned the effect task complexity would have on P3 latency in visual oddball tasks involving target detection within a sequence using either 3-digit numerical or dotted line segment stimuli. The present two experiments provide clear support that the simple, single-operand target identification task generated a predictable effect displayed by larger, later P3s to targets than to nontargets. However, the complex, dual-operand target identification task showed mixed results providing P3 effects with much less clarity. The key finding to report is that manipulations of target classification complexity failed to demonstrate a consistent effect on P3 latency. Nor did the inclusion of a more complex task for target identification increase the amplitude of the P3 as predicted using either type of visual stimuli: P3s in the more complex task tended to be of a smaller amplitude than in the simple task. The results are inconsistent with suggestions that increased amount of processing allocated to more complex target identification tasks should increase both the latency and the amplitude of the P3. These results were also inconsistent with suggestions that P3 latency is sensitive to target identification complexity and that it indexes the completion of target evaluation and categorization.

The relation between the magnitude of the P3 and the basic physical structure of the stimuli in the complex condition of Experiment 2 indicates that, when a second operand is necessary to complete the evaluation of target/ nontarget, subjects may perform a consistent evaluation of the first bent / straight line operand before evaluating the length of the bent stimuli. Thus, the initial extracting of physical features eliciting a P3 may be due to intergroup decision-making between the two physically distinct groups: bent / straight lines. This occurs before intra group decision-making within each of these two groups, further classifying by length. It is also possible that subjects first perform either a simple, initial evaluation of the stimuli on which the operand was to be performed, or decide or prepare to do further processing. P3 may also be an index of decisions made to change the rules of processing. The P3 amplitude indexing this first operand or decision may be affected by equivocation or physical stimulus complexity. Due to task instructions, either of these factors may stimulate a change in strategy whereby the salience of a stimulus' dissimilarity to the targets can make them "target-like" and elicit a large, target-like P3. Subsequent more complex processing can lead to a final target / nontarget categorisation. The change of strategy the subject may make is a strong indicator of the dependency of the P3 on cognitive variables. The results from Experiment 1 suggest that using numerical stimuli or the tasks introduced here on these stimuli may advance performance of the two operands into a more parallel manner of processing. Or, perhaps P3 elicitation is unaffected by task processing on numerical stimuli due to the association of P3 with the differentiation of a stimulus' physical features. Consequently, although P3 amplitude may have been affected by salient features, P3 latency was not.

By any of these suppositions, the P3 may not be an index of the completion of stimulus evaluation. However, the effects on target RTs as well as the ERP data, suggest that post-P3 positivity may reflect the underlying processes associated with the complexity of target identification. It is possible that the processing of the second operand in the complex condition of each experiment occurs post-P3 and may be indexed partly by the greater post-P3 positivity. Or, perhaps the two task operands occur or are initiated in a parallel or overlapping method and the remainder of the second operand processing occurs post-P3. This may provide an explanation for how two of the three stimulus subcategories within the complex condition of Experiment 1 showed similarities of their associated P3 amplitudes with one other and disparity with the third. In each complex task, full target identification may occur spread out over the measured time epoch and its form may not be readily discernable except possibly via an ERP data subtraction of simple condition targets from complex condition targets.

The averaged ERPs presented in this study support the possibility that post-P3 processing may reflect the complexity of target identification. However, it should be noted that due to the strong possibility of component overlap, the P3 and post-P3 positivity may not unambiguously reflect pure stages of cognition. Pritchard (1981) proposes that the epoch of the ERP that shows the load-related differences in the ERPs between the conditions could be due to either the modulation of one individual positive wave, or the integration of several overlapping positive waveforms, not each of which is dependent on task load / complexity. The results here may support a definition of the classic P3 as a multi-component waveform of a late variation but topographical maps would be needed to clarify this.

Conclusions

Trying to further elucidate the set of cognitive processes manifested by the P3 is difficult, as results from this study identify it to be a component whose timing is relatively insensitive to manipulations of target identification complexity. Ideally, the temporal occurrence of more than one cognitive operand may be delineated with the use of ERPs if they occur purely in a serial fashion. It is equally possible though, that dependent on what type of task, level of task complexity, or visual stimulus is used, two or more operands may be initiated or function in parallel, or the stimulus feature discrimination on which P3 elicitation relies may be hindered. These possibilities may preclude the ability of ERPs to clearly delineate separate cognitive processes in more complex target identification tasks.

Ruchkin et al. (1988) caution that topography may differ as a function of the task and suggest that the P3 may reflect the nature of the processing and involve different neural generators for different tasks. Their suggestion is that different manipulations of task type and complexity may therefore render use of the P3 unsuitable as a measurement of target detection in oddball tasks. Analyses from the present study however, showed that significant differences between the configuration of neural generators activated by targets of similar complex task conditions between the two experiments was not demonstrated by P3 waveform measurements. This effect supports the hypothesis that the brain events underlying the generation of the P3 are responsible for activity related to a dual-operand oddball task, regardless of the type of visual stimulus used.

The results from this study support the use of the P3 waveform elicited in simple visual oddball tasks as a tool in cognition, psychiatric and neurological studies. However, the cognitive operations which underlie the generation of the P3 can be unclear using more complex visual oddball tasks. This data supports that ERPs are useful in identifying physiological indexes of various stages of mental processing and the P3 can offer a relative measure of the timing of certain cognitive tasks, but a substantial amount of research belies a clear understanding of the processing involved. The concurrent recording of ERPs with behavioral measures like RTs is important to delineate the contribution of cognitive and response processing to the task. Therefore, instead of denouncing the ability of the P3 to index the relative timing of stimulus evaluation, a preferable suggestion is that P3 indexes the relative timing of an initial, obvious, stimulus evaluation or a decision or preparation for continued processing that may ultimately lead to target / nontarget identification.

Table 1

Summary of Stimulus Subcategories for Experiments 1 and 2: Brief Description and Probability

Experiment 1: numerical stimuli, $n = 20$		
Condition	Targets (100 total per condition)	Nontargets (400 total per condition)
Simple	NC2 odd (p 0.2)	NC1 even (p 0.8)
Complex	NE3 odd, $\sum \leq 10$ (p 0.2)	NE1 odd, $\sum \geq 11$ (p 0.32)
		NE2 even (p 0.48)
Experiment 2: line stimuli, $n = 18$		
Condition	Targets (100 total per condition)	Nontargets (400 total per condition)
Simple	SC2 bent, 6 dots (p 0.2)	SC1 straight, 6 dots (p 0.27)
		SC3 straight, 5 dots (p 0.27)
		SC4 straight, 7 dots (p 0.27)
Complex	SE2 bent, 6 dots (p 0.2)	SE1 bent, 5 dots (p 0.16)
		SE3 bent, 7 dots (p 0.16)
		SE4 straight, 5 dots (p 0.16)
		SE5 straight, 6 dots (p 0.16)
		SE6 straight, 7 dots (p 0.16)

Note. The capitalized letter-number designation for each stimulus subcategory is the assigned symbol as it appears on the tables and figures following.

Table 2

Number of ERP Trials Accepted for Averaging for Different Stimuli Per Subject in Experiments 1 and 2

Stimulus subcategory	Minimum	Mean	*SD*	Total possible
Experiment 1, *n* = 20				
NC1	258	357.80	35.91	400
NC2	30	77.25	16.18	100
NE1	118	142.40	9.56	160
NE2	183	220.15	15.07	240
NE3	26	82.05	15.93	100
Experiment 2, *n* = 18				
SC1	47	113.28	24.34	134
SC2	12	77.22	21.87	100
SC3	52	111.06	22.29	133
SC4	53	112.11	22.25	133
SE1	16	62.72	17.09	80
SE2	41	77.50	15.59	100
SE3	29	54.11	11.93	80
SE4	31	68.61	13.96	80
SE5	32	68.39	14.06	80
SE6	23	68.17	16.23	80

Note. Experiment 1 simple condition subcategories: NC1, 2; complex condition subcategories: NE1 - 3. Experiment 2 simple condition subcategories: SC1 - 4; complex condition subcategories: SE1 - 6. See Table 1 for a summary of stimulus subcategory abbreviations.

Table 3

Mean Reaction Time (RT) for Different Stimuli in Experiments 1 and 2

Stimulus subcategory	RT (ms)	*SD*
Experiment 1, *n* = 20		
NC1	605.82	60.92
NC2	763.17	77.61
NE1	1005.51	131.27
NE2	744.43	104.26
NE3	1083.13	143.67
Experiment 2, *n* = 18		
SC1	490.56	86.63
SC2	670.09	109.26
SC3	490.42	84.75
SC4	498.16	90.50
SE1	1111.34	144.94
SE2	1189.97	181.36
SE3	1215.60	185.73
SE4	653.65	95.02
SE5	648.84	102.99
SE6	625.09	94.02

Note. (ms) = milliseconds. Experiment 1 simple condition subcategories: NC1, 2; complex condition subcategories: NE1 - 3. Experiment 2 simple condition subcategories: SC1 - 4; complex condition subcategories: SE1 - 6. See Table 1 for a summary of stimulus subcategory abbreviations.

Table 4

Mean % Error Rate (ER) for Different Stimuli in Experiments 1 and 2

Stimulus subcategory	ER (%)
Experiment 1, $n = 20$	
NC1	0.75
NC2	7.75
NE1	5.53
NE2	2.10
NE3	7.95
Experiment 2, $n = 18$	
SC1	0.29
SC2	3.11
SC3	0.58
SC4	0.50
SE1	12.29
SE2	10.67
SE3	21.10
SE4	1.39
SE5	0.49
SE6	0.49

Note. Experiment 1 simple condition subcategories: NC1, 2; complex condition subcategories: NE1 - 3. Experiment 2 simple condition subcategories: SC1 - 4; complex condition subcategories: SE1 - 6. See Table 1 for a summary of stimulus subcategory abbreviations.

Table 5

Behavioral Data: Statistical Analyses for Experiment 1

Within Conditions									
Subcategory comparison factor	Subcategory comparison abbreviation	Statistical test performed	*df*	RT (ms)			ER (%)		
				F or *t*	*p*	ϵ	*F* or *t*	*p*	ϵ
Simple condition									
(2) Targets vs all nontargets	nc2 vs nc1	*t*-test	19	-9.46	<0.001		-7.50	<0.001	
Complex condition									
(3) All subcategories in the condition	ne1, ne2, ne3	repeated-measures ANOVA	2, 38	114.04	<0.001	0.93478	21.64	<0.001	0.90918
(4) Targets vs all nontargets	ne3 vs (ne1+ ne2)/2	*t*-test	19	11.53	<0.001		4.61	<0.001	
(5a, b) Targets vs nontarget subtypes; Nontarget subtype vs nontarget subtype	ne3 vs ne1; ne3 vs ne2; ne1 vs ne2	one-way ANOVA & HSD	2, 57	38.7552	<0.001		9.9240	<0.001	

Across conditions									
(1) Both conditions, all subcategories	nc1, nc2, ne1, nc2, ne3	repeated-measures ANOVA	4, 76	116.51	<0.001		24.65	<0.001	0.69145
(7) Simple vs complex targets	nc2 vs ne3	*t*-test	19	-12.82	<0.001		--		
(8) Nontarget subtype similar to both conditions	nc1 vs ne2	*t*-test	19	-6.47	<0.001		-3.40	0.003	

Note. The comparison factor was within-subject; $n = 20$. This table designates a number in brackets to each comparison performed. All analyses were performed separately on RT and ER data. ms = millisecond; RT = reaction time; ER = error rate. Dashes indicate statistical non-significance. Experiment 1 simple condition subcategories: NC1, 2; complex condition subcategories: NE1 - 3. See Table 1 for a summary of stimulus subcategory abbreviations.

Table 6

Electrophysiological Data: Statistical Analyses for Experiment 1

Within Conditions							
Subcategory comparison factor	Subcategory comparison abbreviation	Statistical test performed	Dependent variable	*df*	*F*	*p*	ϵ
Simple condition							
(2) Targets vs all nontargets	nc2 vs nc1	ANOVA	A: c	1, 19	52.13	<0.001	
			l	7, 133	53.99	<0.001	0.41689
			c x l	7, 133	16.34	<0.001	0.43636
			L: c		14.00	0.001	
			l		6.05	<0.001	0.53392
			c x l		4.83	<0.001	0.53738
			R: c		52.19	<0.001	
			l		57.34	<0.001	0.43748
			c x l		19.67	<0.001	0.39299
			Z: l		51.63	<0.001	0.41295
			c x l		5.26	<0.001	0.47365

Complex condition							
(3) All subcategories in the condition	ne1, ne2, ne3	ANOVA	A: c	2, 38	6.19	0.005	0.98102
			l	7, 133	21.27	<0.001	0.48829
			c x l	14, 266	2.42	0.003	0.33994
			L: l		3.99	0.001	0.57467
			R: c		7.46	0.002	0.90901
			l		25.45	<0.001	0.44804
			c x l		3.99	<0.001	0.26866
			Z: c		2.77	0.075*	0.98456
			l		21.04	<0.001	0.48369
			c x l		2.87	<0.001	0.31193
(4) Targets vs all nontargets	ne3 vs (ne1+ ne2) /2	ANOVA	A: c	1, 19	8.12	0.010	
			l	7, 133	20.02	<0.001	0.46990
			L: l		3.58	0.001	0.58546
			R: c		7.67	0.012	
			l	7, 133	24.78	<0.001	0.44429
			c x l		2.03	0.055*	0.36163

(5) Targets vs nontarget subtypes	ne3 vs ne1; ne3 vs ne2	ANOVA	A: c	1, 19	14.00	0.001	
			l	7, 133	16.09	<0.001	0.44260
			L: l		2.90	0.008	0.62141
			R: c		19.56	<0.001	
			l		19.01	<0.001	0.39909
			c x l	7, 133	5.02	<0.001	0.44405
			A: l		22.79	<0.001	0.50354
			c x l		2.08	0.050*	0.36117
			L: l		3.87	0.001	0.53987
			c x l		2.05	0.053	0.71010
			R: l		29.01	<0.001	0.49126
			Z: l		22.15	<0.001	0.49629
			c x l		2.09	0.048	0.35490
(6) Nontarget subtype vs nontarget subtype	ne1 vs ne2	ANOVA	A: c	1, 19	4.56	0.046	
			l	7, 133	20.84	<0.001	0.53436
			c x l	7, 133	4.05	<0.001	0.44898
			L: l		4.07	<0.001	0.57382
			R: c		7.26	0.014	
			l		23.01	<0.001	0.45057
			c x l		6.96	<0.001	0.38854

			Z: c		4.56	0.046	
			l		20.84	<0.001	0.53436
			c x l		4.05	<0.001	0.44898
Across conditions							
(1) All subcategories	nc1, nc2, ne1, ne2, ne3	ANOVA	A: c	4, 76	30.70	<0.001	0.70280
			l	7, 133	43.84	<0.001	0.48618
			c x l	28, 532	12.71	<0.001	0.23365
			L: c		3.09	0.021	0.56591
			l		6.28	<0.001	0.61137
			c x l		1.80	0.008	0.33655
			R: c		41.45	<0.001	0.71836
			l		47.08	<0.001	0.44550
			c x l		19.40	<0.001	0.20049
(7) Simple vs complex targets	nc2 vs ne3	ANOVA	A: c	1, 19	35.91	<0.001	
			l	7, 133	45.60	<0.001	0.44677
			c x l	7, 133	21.10	<0.001	0.43889
			L: c		9.43	0.006	
			l		4.07	<0.001	0.60802
			R: c		50.87	<0.001	
			l		50.09	<0.001	0.46681
			c x l		28.60	<0.001	0.40163

			Z: l c x l		40.21 8.07	<0.001 <0.001	0.44835 0.45554
(8) Nontarget subtype similar to both conditions	nc1 vs ne2	ANOVA	A: l c x l	7, 133 7, 133	31.86 2.00	<0.001 0.060*	0.44698 0.45765
			L: l c x l		7.11 2.70	<0.001 0.012	0.53628 0.45361
			R: l c x l		32.86 3.83	<0.001 0.001	0.38169 0.44445
			Z: c l c x l	1, 19	13.80 31.96 3.90	0.001 <0.001 0.001	 0.44168 0.44699

Note. This table designates a number in brackets to each comparison performed. Separate analyses were completed for each dependent variable: 1) amplitude data, 2) latency data, 3) area data, and 4) normalized amplitude data - 1), 2) and 4) from the latency window of 399 to 597 ms and 3) from 400 to 599 ms post-stimulus onset. Within subject factors (n = 20) assessed included 1) comparison, and 2) location (Fz, Cz, Pz, Oz, P3, P4, T3, T4). All ANOVAs performed here were of the repeated-measures type. A=amplitude, L = latency, R = area, c= comparison, l= electrode location, z = normalized amplitude, * = approached significance. Experiment 1 simple condition subcategories: NC1, 2; complex condition subcategories: NE1 - 3. See Table 1 for a summary of stimulus subcategory abbreviations.

Table 7

Behavioral Data: Statistical Analyses for Experiment 2

Within conditions									
Subcategory comparison factor	Subcategory comparison abbreviation	Statistical test performed	*df*	RT (ms)			ER (%)		
				F or *t*	*p*	ϵ	*F* or *t*	*p*	ϵ
Simple condition									
(2) All subcategories in the condition	sc1, sc2, sc3, sc4	repeated-measures ANOVA	3, 51	124.75	<0.001	0.366155	10.99	<0.001	0.36442
(3) Targets vs all nontargets	sc2 vs (sc1+ sc3+ sc4)/3	*t*-test	17	11.44	<0.001		3.38	0.004	
(4) Between subcategories	sc1, sc2, sc3, sc4	one-way ANOVA & HSD	3, 68	16.2318	<0.001		10.6883	<0.001	
Complex condition									
(5) All subcategories in the condition	se1, se2, se3, se4, se5, se6	repeated-measures ANOVA	5, 85	115.11	<0.001	0.44643	16.44	<0.001	0.34957

(6) Targets vs all nontargets	se2 vs (se1+ se3+ se4+ se5+ se6)/5	*t*-test	17	7.91	<0.001		3.05	0.007	
(7a, b) Targets vs nontarget subtypes	se2 vs (se1+ se3)/2; se2 vs (se4+ se5+ se6)/3	*t*-test	--	--	--		--	--	
			17	11.89	<0.001		9.46	<0.001	
(8) Nontarget subtype vs nontarget subtype	(se1+ se3)/2 vs (se4+ se5+ se6)/3	*t*-test	17	-13.57	<0.001		9.46	<0.001	
(9) Between subcategories	se1, se2, se3, se4, se5, se6	one-way ANOVA & HSD	5, 102	78.9845	<0.001		16.2540	<0.001	
Across conditions									
(1) Both conditions, all subcategories	sc1, sc2, sc3, sc4, se1, se2, se3, se4, se5, se6	repeated-measures ANOVA	9, 153	159.28	<0.001	0.35430	19.01	<0.001	0.20759
(10) Simple vs complex targets	sc2 vs se2	*t*-test	17	-15.15	<0.001		-5.13	<0.001	
(11) Nontarget subtype similar to both conditions	(sc1+ sc3+ sc4)/3 vs (se4+ se5+ se6)/3	*t*-test	17	-5.62	<0.001		--	--	

ᵃ The comparison factor was within-subject (n = 18). This table designates a number in brackets to each comparison performed. All analyses listed were performed separately on RT and ER data. ms = milliseconds; RT = reaction time; ER = error rate. Dashes indicate statistical non-signigicance. Experiment 2 simple condition subcategories: SC1 - 4; complex condition subcategories: SE1 - 6. See Table 1 for a summary of stimulus subcategory abbreviations.

Table 8

Electrophysiological Data: Statistical Analyses for Experiment 2

Within Conditions							
Subcategory comparison factor	Subcategory comparison abbreviation	Statistical test performed	Dependent variable	*df*	*F*	*p*	ϵ
Simple condition							
(2) All subcategories in the condition	sc1, sc2, sc3, sc4	ANOVA	A: c	3, 51	48.89	<0.001	0.47696
			l	7, 119	33.13	<0.001	0.47519
			c x l	21, 357	9.76	<0.001	0.32973
			L: c		8.22	<0.001	0.66878
			l		3.66	0.001	0.49542
			R: c		51.17	<0.001	0.43105
			l		32.72	<0.001	0.33722
			c x l		14.96	<0.001	0.15213
			Z: c		3.60	0.020	0.69238
			l		30.18	<0.001	0.48600
(3) Targets vs all nontargets	sc2 vs (sc1+ sc3+ sc4)/3	ANOVA	A: c	1, 17	59.18	<0.001	
			l	7, 119	38.82	<0.001	0.45538
			c x l	7, 119	15.78	<0.001	0.52839

			L: c		13.39	0.002	
			l		2.62	0.015	0.43046
			c x l		2.34	0.028	0.55021
			R: c		59.35	<0.001	
			l		35.39	<0.001	0.33417
			c x l		17.65	<0.001	0.35273
			Z: c		5.17	0.036	
			l		36.51	<0.001	0.46314
			c x l		2.40	0.024	0.56508
(4) Within subtype	sc1, sc3, sc4	ANOVA	A: l	7, 119	23.50	<0.001	0.51071
			L: l		4.14	<0.001	0.54130
			R: l		25.62	<0.001	0.34433
Complex condition							
(5) All subcategories in the condition	se1, se2, se3, se4, se5, se6	ANOVA	A: c	5, 85	14.72	<0.001	0.38075
			l	7, 119	26.25	<0.001	0.50813
			c x l	35, 595	3.61	<0.001	0.19641
			L: c x l		1.74	0.006	0.23534
			R: c		20.54	<0.001	0.40102
			l		25.77	<0.001	0.40672
			c x l		5.87	<0.001	0.12060

(6) Targets vs all nontargets	se2 vs (se1+ se3+ se4+ se5+ se6)/5	ANOVA	A: c	1, 17	15.29	0.001	
			l	7, 119	20.82	<0.001	0.50941
			c x l	7, 119	3.87	0.001	0.56556
			R: c		13.61	0.002	
			l		22.19	<0.001	0.41596
			c x l		4.27	<0.001	0.40343
			Z: c		8.19	0.011	
			l		18.38	<0.001	0.51193
			c x l		2.41	0.024	0.56184
(7a, b) Targets vs nontarget subtypes	se2 vs (se1+ se3)/2; se2 vs (se4+ se5+ se6)/3	ANOVA	A: l	7, 119	11.76	<0.001	0.52290
			R: l		12.77	<0.001	0.40599
			c x l	7, 119	2.37	0.027	0.46679
			A: c		18.14	0.001	
			l		26.60	<0.001	0.50840
			c x l		5.19	<0.001	0.53430
			R: c	1, 17	20.70	<0.001	
			l		26.89	<0.001	0.42050
			c x l		5.93	<0.001	0.40057
			Z: c		11.43	0.004	
			l		22.98	<0.001	0.51296
			c x l		2.08	0.051	0.54406

(8) Nontarget subtype vs nontarget subtype	(se1+ se3)/2 vs (se4+ se5+ se6)/3	ANOVA	A: c	1, 17	20.40	<0.001	
			l	7, 119	24.57	<0.001	0.52092
			c x l	7, 119	6.40	<0.001	0.49504
			L: c x l		3.66	0.001	0.63465
			R: c		38.54	<0.001	
			l		24.62	<0.001	0.40402
			c x l		8.79	<0.001	0.38863
			Z: c		20.40	<0.001	
			l		24.57	<0.001	0.52092
			c x l		6.40	<0.001	0.49504
(9a, b) Within subtype	se1 vs se3; se4, se5, se6	ANOVA	A: l	7, 119	10.05	<0.001	0.57513
			L: c x l	7, 119	2.08	0.051*	0.40779
			R: l		11.45	<0.001	0.40623
			A: c	2, 34	4.74	0.015	0.94801
			l	7, 119	29.90	<0.001	0.48731
			L: l		2.90	0.008	0.46737
			R: c		3.60	0.038	0.93872
			l		26.19	<0.001	0.40764
			c x l	14, 238	2.31	0.005	0.51567

Across conditions							
(1) Both conditions, all subcategories	sc1, sc2, sc3, sc4, se1, se2, se3, se4, se5, se6	ANOVA	A: c l c x l	9, 153 7, 119 63, 1071	25.49 34.55 6.92	<0.001 <0.001 <0.001	0.39849 0.53183 0.15517
			L: c c x l		11.39 2.18	<0.001 <0.001	0.56159 0.16894
			R: c l c x l		28.49 32.53 9.86	<0.001 <0.001 <0.001	0.39855 0.36805 0.11176
(10) Simple vs complex targets	sc2 vs se2		A: c l c x l	1, 17 7, 119 7, 119	84.60 33.11 24.76	<0.001 <0.001< <0.001	0.515290. 52262
			R: c l c x l		85.48 30.62 26.34	<0.001 <0.001 <0.001	0.34176 0.37267
			Z: c l c x l		3.55 26.34 6.12	0.077* <0.001 <0.001	0.54462 0.53347

(11) Nontarget subtype similar to both conditions	(sc1+ sc3+ sc4)/3 vs (se4+ se5+ se6)/3		A: c	1, 17	33.33	<0.001	0.50847
			L: c c x l	7, 119	57.39 7.89	<0.001 <0.001	0.54963
			R: c l	7, 119	3.27 31.79	0.088* <0.001	0.39124

Note. This table designates a number in brackets to each comparison performed. Separate analyses were completed for each dependent variable: 1) amplitude data, 2) latency data, 3) area data, and 4) normalized amplitude data - 1), 2) and 4) from the latency window of 299 to 597 ms and 3) from 299 to 599 ms post-stimulus onset. Within subject factors assessed included a) comparison, and b) location (Fz, Cz, Pz, Oz, P3, P4, T3, T4). All ANOVAs performed here were of the repeated-measures type. A=amplitude, L = latency, R = area, c= comparison, l= electrode location, z = normalized amplitude, * = approached significance. Experiment 2 simple condition subcategories: SC1 - 4; complex condition subcategories: SE1 - 6. See Table 1 for a summary of stimulus subcategory abbreviations.

Table 9

<u>Electrophysiological Data: Statistical Analyses Comparing Experiments 1 and 2</u>

Subcategory comparison factor	Subcategory comparison abbreviation	Statistical test performed	Dependent variable	*df*	*F*	*p*	ϵ
Simple condition							
(1) Experiment 1 simple condition targets vs Experiment 2 simple condition targets	nc2, sc2	repeated-measures ANOVA	Z: c l c x l	1, 17 7, 119 7, 119	7.37 76.36 5.00	0.015 <0.001 <0.001	 0.41712 0.37897
Complex condition							
(2) Experiment 1 complex condition targets vs Experiment 2 complex condition targets	ne3, se2	repeated-measures ANOVA	Z: l	7, 119	19.96	<0.001	0.43736

<u>Note.</u> This table designates a number in brackets to each comparison performed.The dependent variable was the normalized amplitude data for analyses of interest from the latency window of 399 to 597 ms and 299 to 597 ms post-stimulus onset for experiments 1 and 2, respectively. Within subject factors assessed included a) comparison and b) location (Fz, Cz, Pz, Oz, P3, P4, T3, T4). Z = normalized amplitude, c= comparison, l= electrode location. Experiment 1 simple condition subcategories: NC1, 2; complex condition subcategories: NE1 - 3. Experiment 2 simple condition subcategories: SC1 - 4; complex condition subcategories: SE1 -6. See Table 1 for a summary of stimulus subcategory abbreviations.

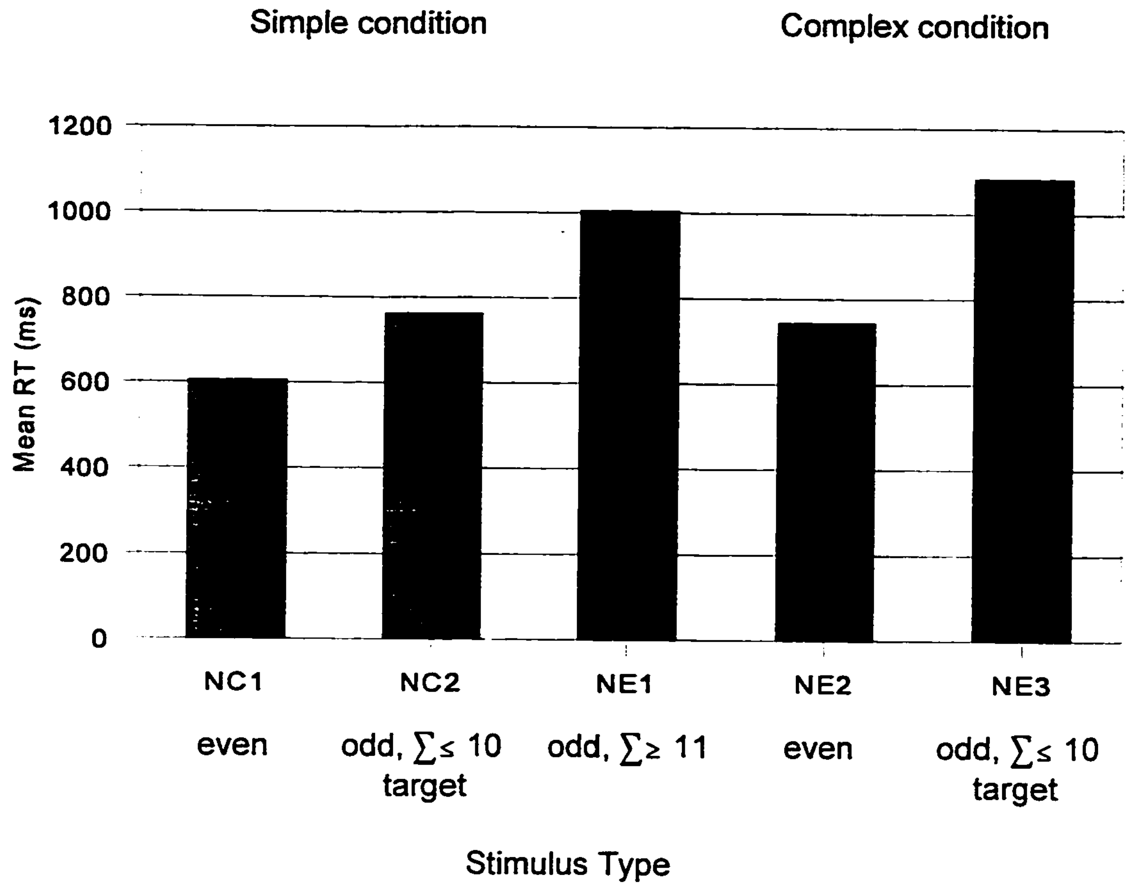


Figure 1. Bar graph of reaction times (RTs) for different stimulus subcategories of the simple and complex conditions of experiment 1. Simple condition subcategories: NC1, 2 (shaded bars); complex condition subcategories: NE1 - 3 (solid bars). ms = milliseconds.

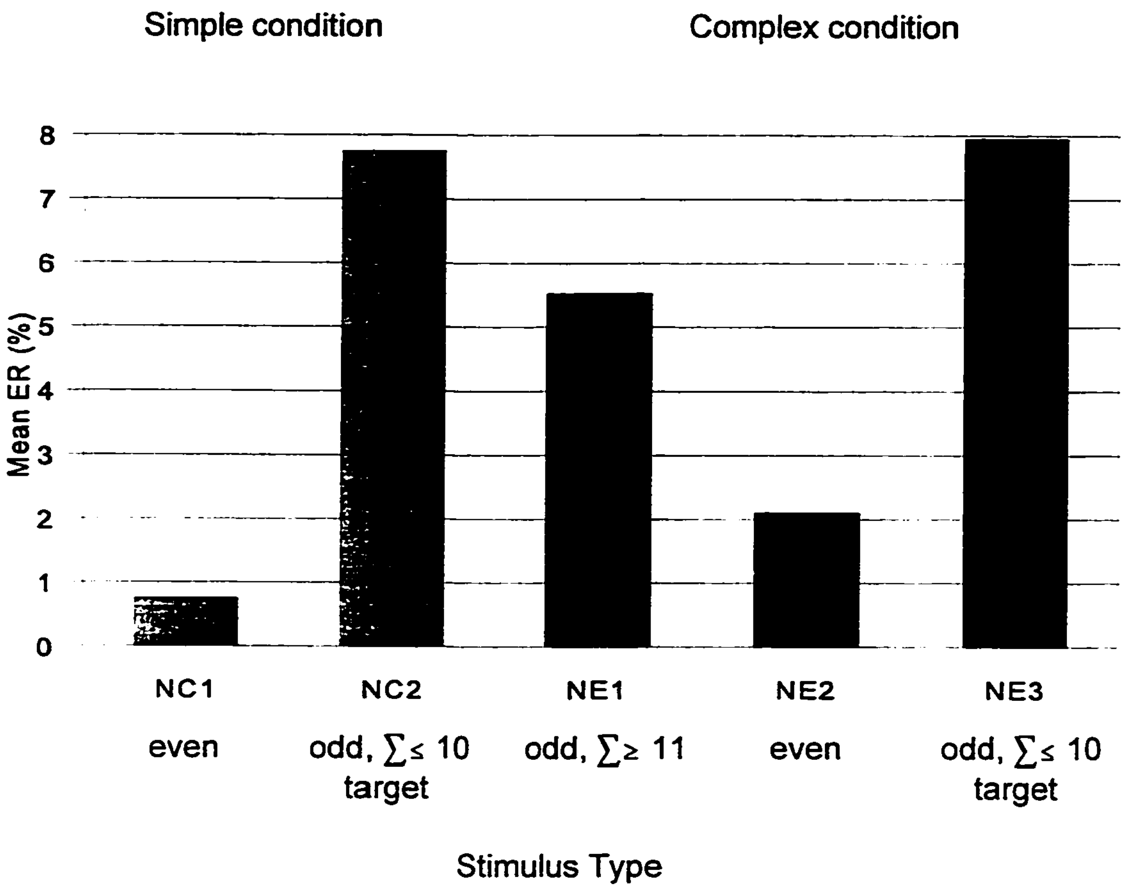


Figure 2. Bar graph of percent error rates (ERs) for different stimulus subcategories of the simple and complex conditions of experiment 1. Simple condition subcategories: NC1, 2 (shaded bars); complex condition subcategories: NE1 - 3 (solid bars).

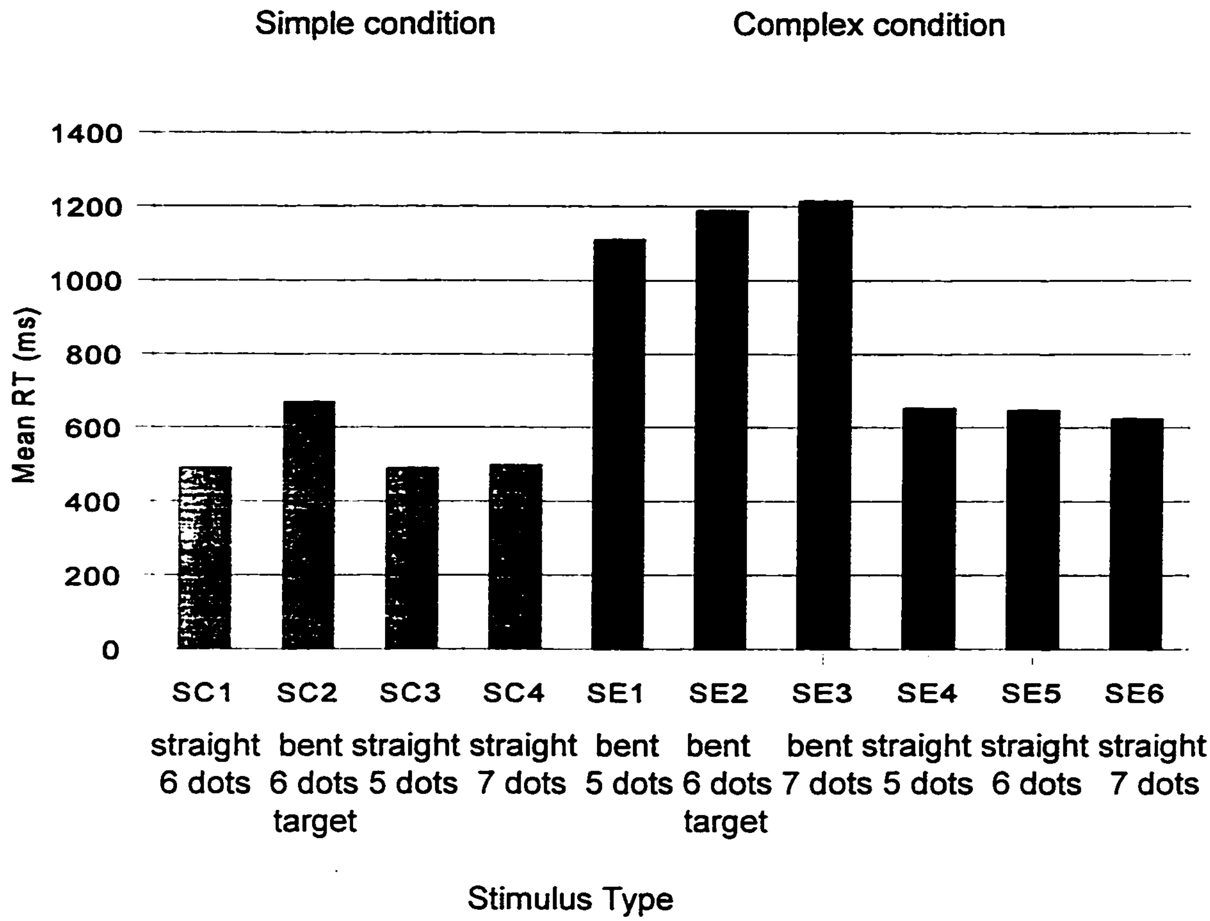


Figure 3. Bar graph of reaction times (RTs) for different stimulus subcategories of the simple and complex conditions of experiment 2. Simple condition subcategories: SC1 - 4 (shaded bars); complex condition subcategories: SE1 - 6 (solid bars). ms = milliseconds.

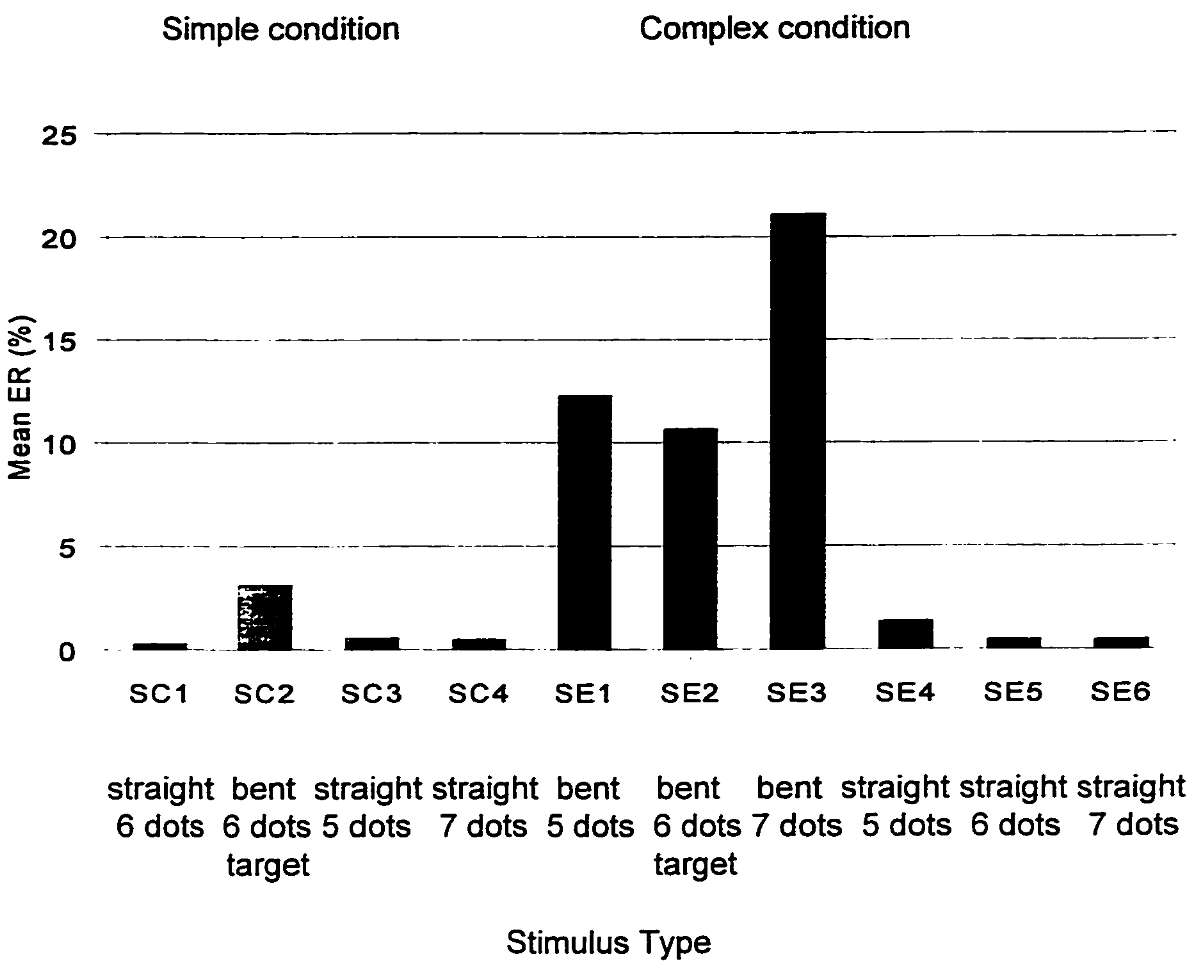


Figure 4. Bar graph of percent error rates (ERs) for different stimulus subcategories of the simple and complex conditions of experiment 2. Simple condition subcategories: SC1 - 4 (shaded bars); complex condition subcategories: SE1 - 6 (solid bars).

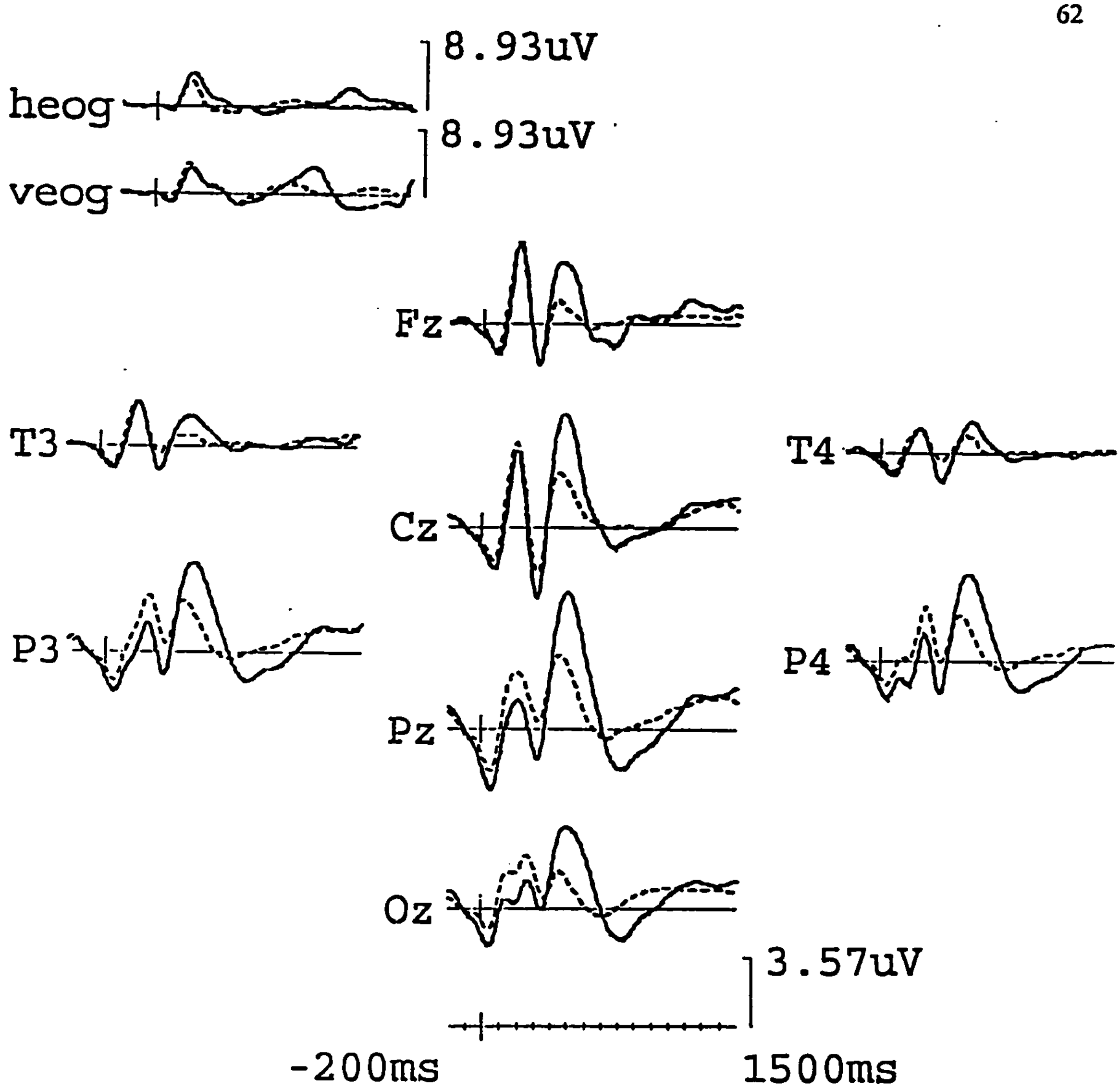


Figure 5: ERP averages: Simple condition of experiment 1 (numerical stimuli). heog = horizontal eye oculogram; veog = vertical eye oculogram.

- - - - - even
———— odd, $\sum \leq 10$ (targets)

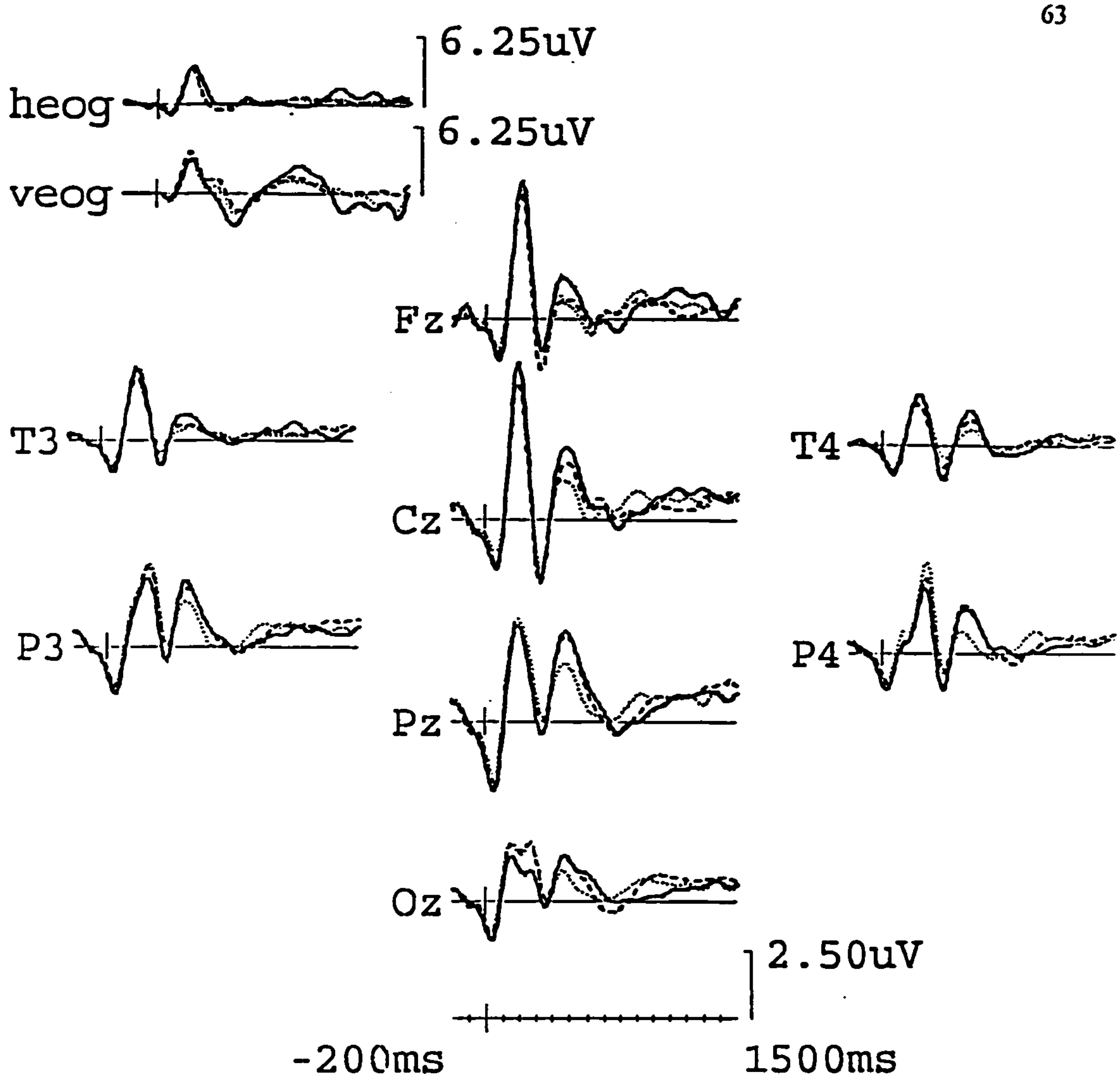


Figure 6: ERP averages: Complex condition of experiment 1 (numerical stimuli). heog = horizontal eye oculogram; veog = vertical eye oculogram.

.... odd, $\sum \geq 11$
– – – – – even
———— odd, $\sum \leq 10$ (targets)

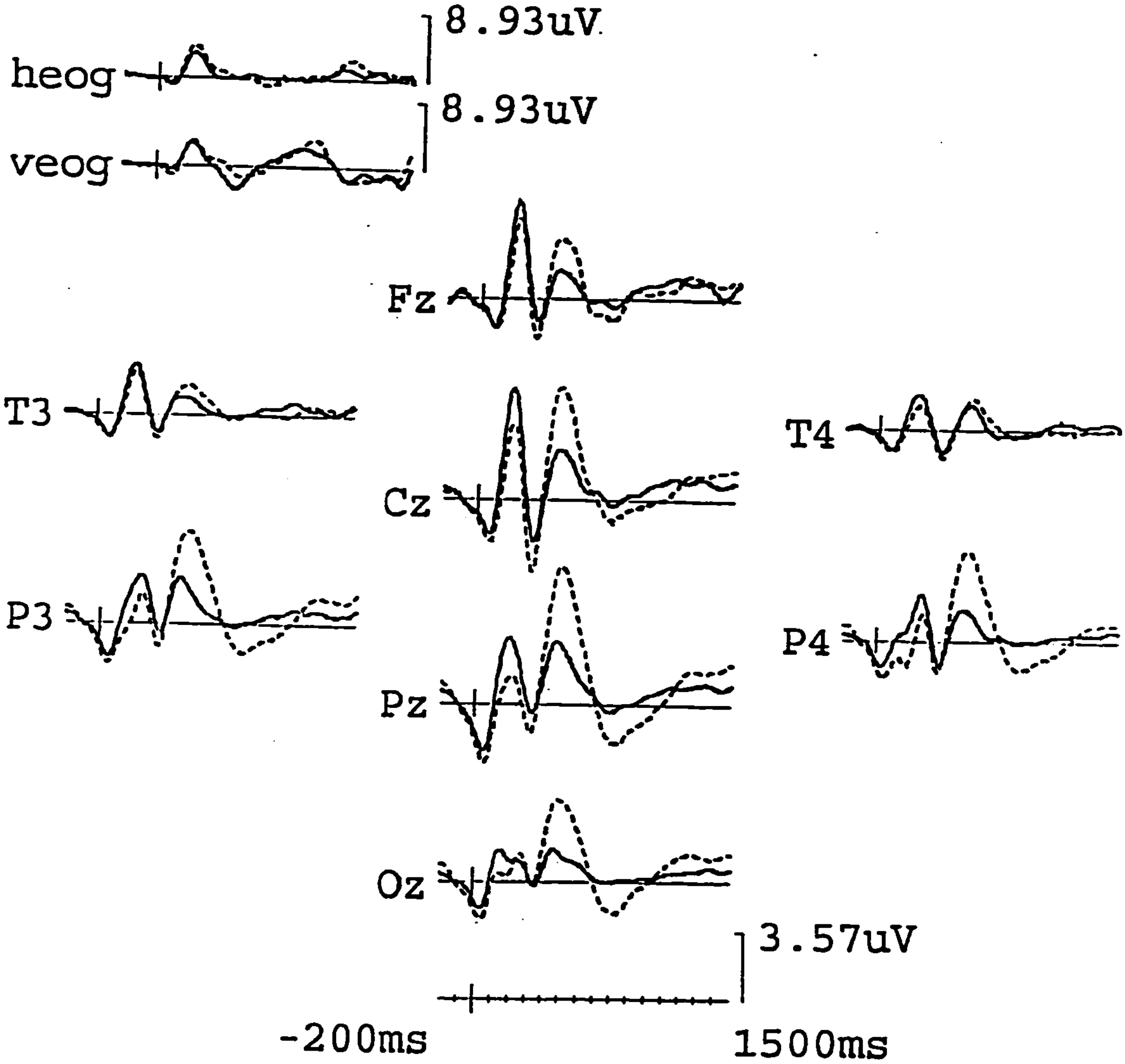


Figure 7: Target ERP averages: Simple versus complex condition of experiment 1 (numerical stimuli). heog = horizontal eye oculogram; veog = vertical eye oculogram.

- - - - - odd, $\sum \leq 10$ (targets) Simple condition
———— odd, $\sum \leq 10$ (targets) Complex condition

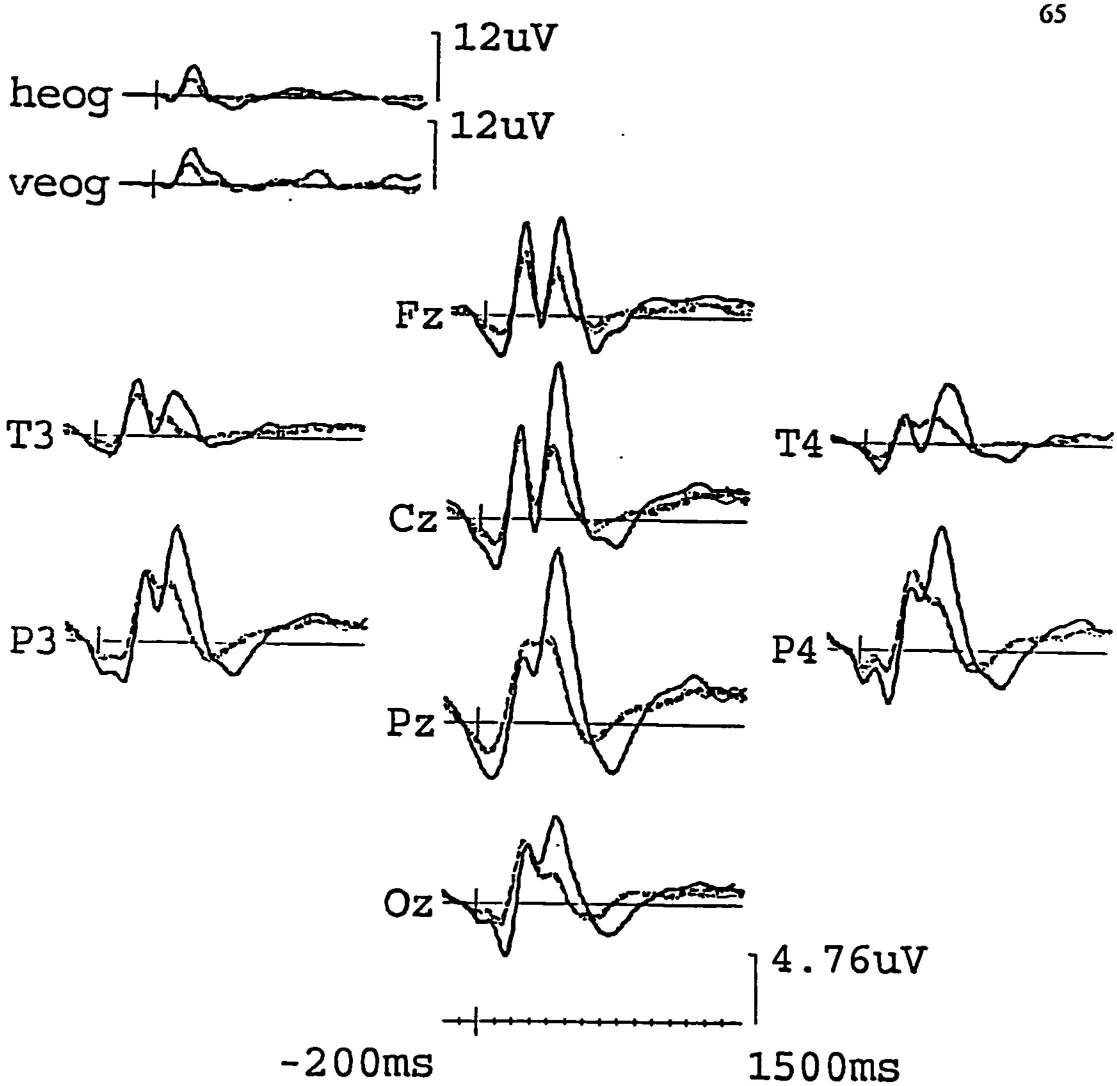
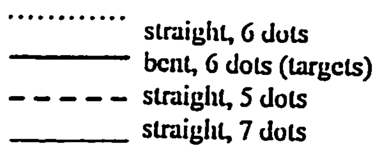


Figure 8: ERP averages: Simple condition of experiment 2 (line stimuli). heog = horizontal eye oculogram; veog = vertical eye oculogram.



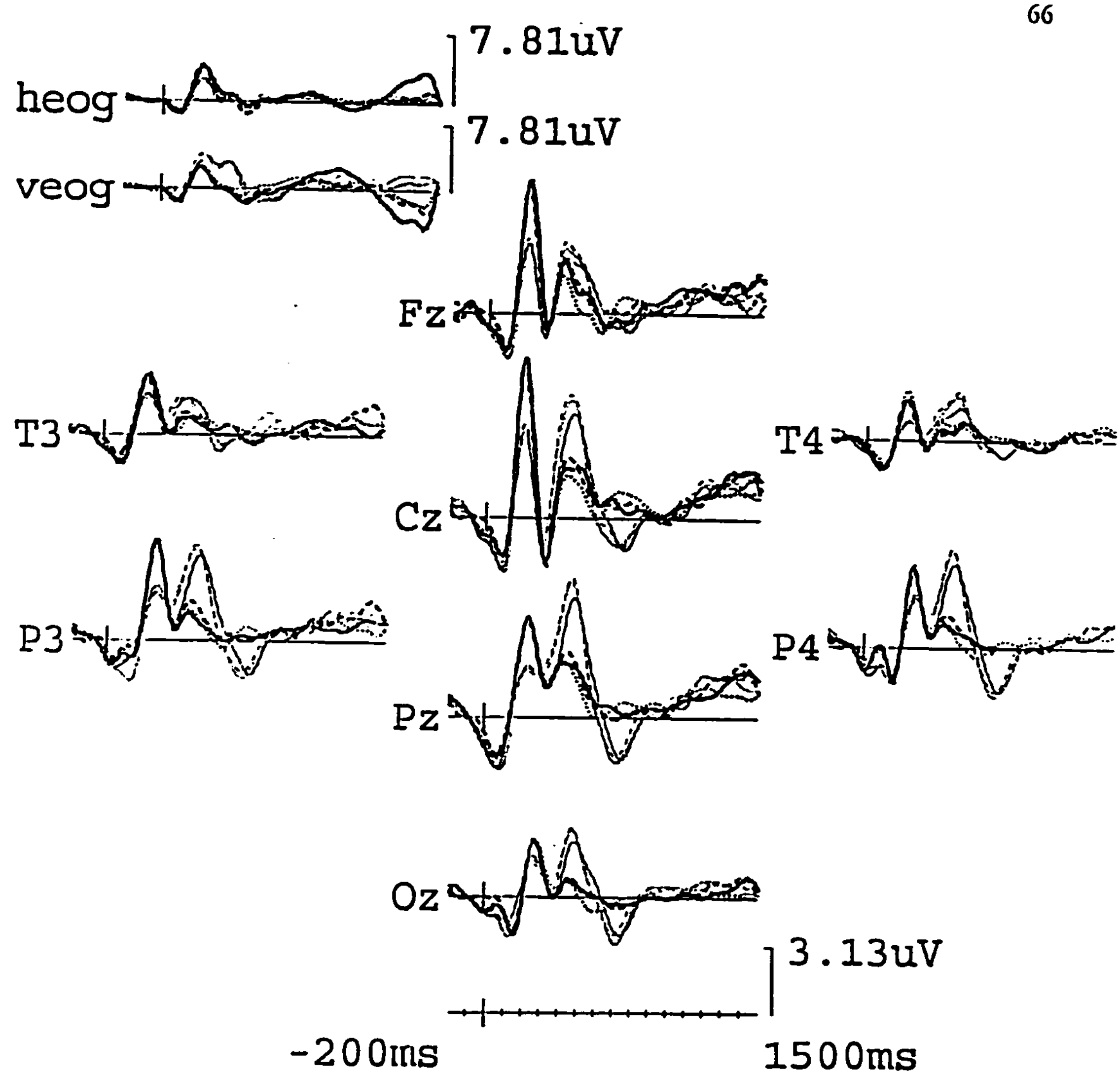


Figure 9: ERP averages: Complex condition of experiment 2 (line stimuli). heog = horizontal eye oculogram; veog = vertical eye oculogram.

....	bent, 5 dots	————	straight, 5 dots
————	bent, 6 dots (targets)	....	straight, 6 dots
- - - - -	bent, 7 dots	- - - - -	straight, 7 dots

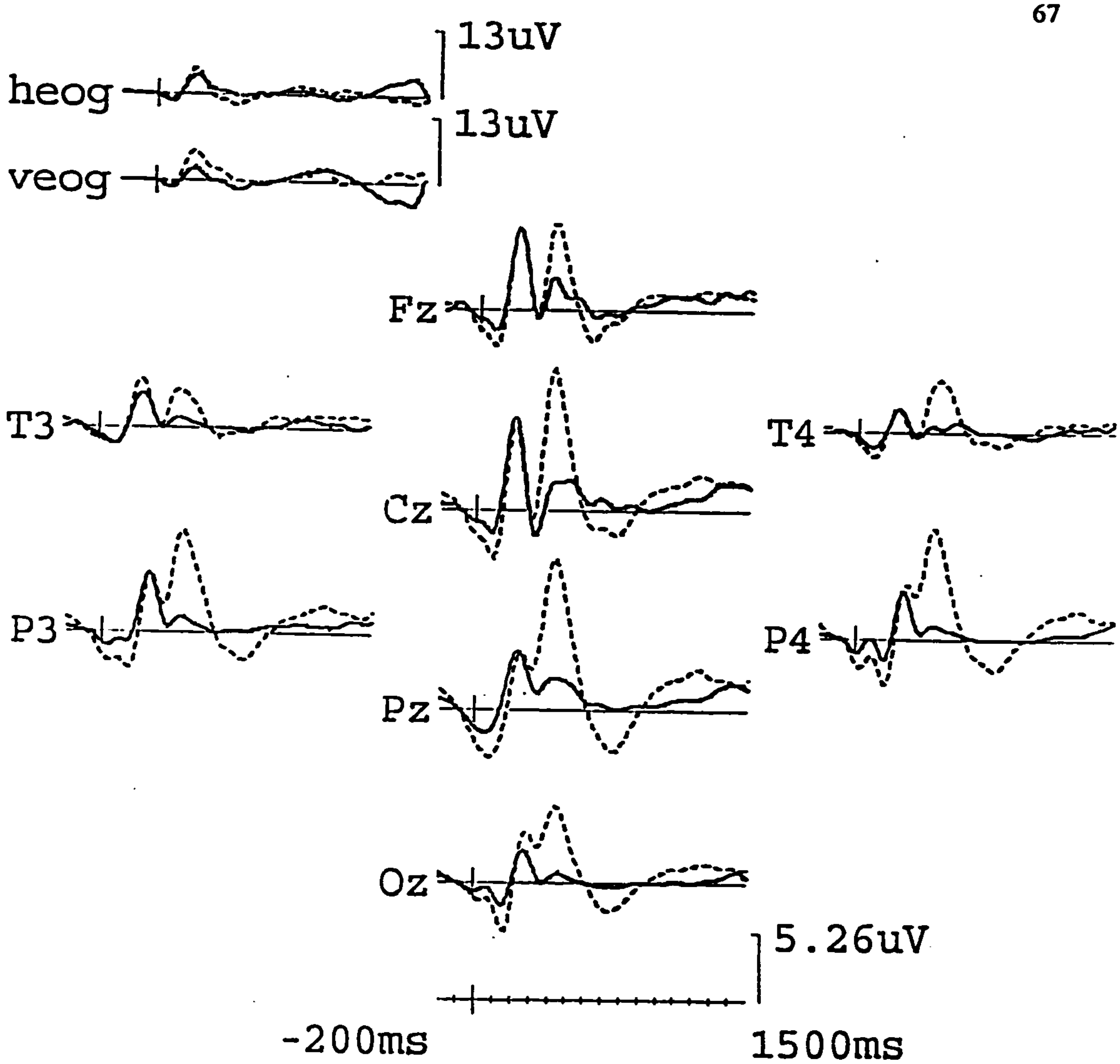


Figure 10: Target ERP averages: Simple versus complex condition of experiment 2 (line stimuli). heog = horizontal eye oculogram; veog = vertical eye oculogram.

- - - - - bent, 6 dots (targets) Simple condition
———— bent, 6 dots (targets) Complex condition

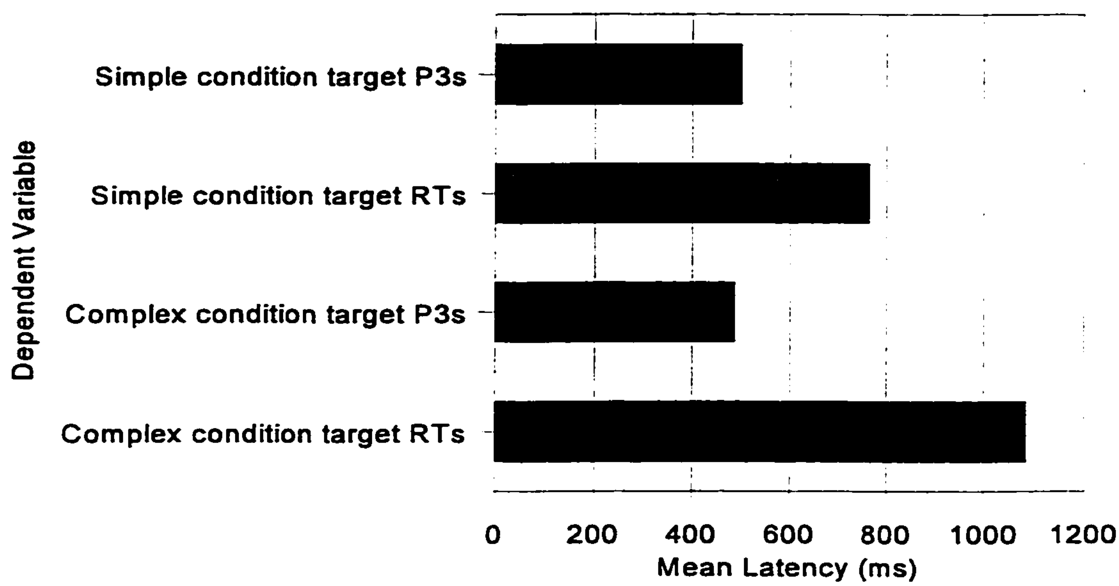


Figure 11. P3 latency and reaction time (RT) to targets of the simple (shaded bars) and complex (solid bars) conditions of experiment 1. ms = milliseconds.

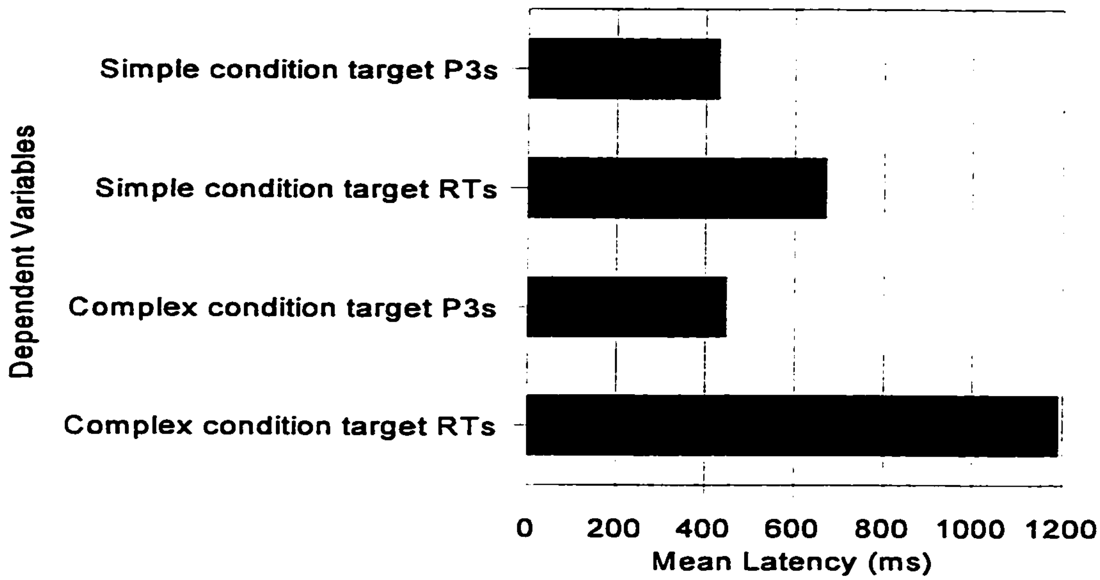


Figure 12. P3 latency and reaction time (RT) to targets of the simple (shaded bars) and complex (solid bars) conditions of experiment 2. ms = milliseconds.

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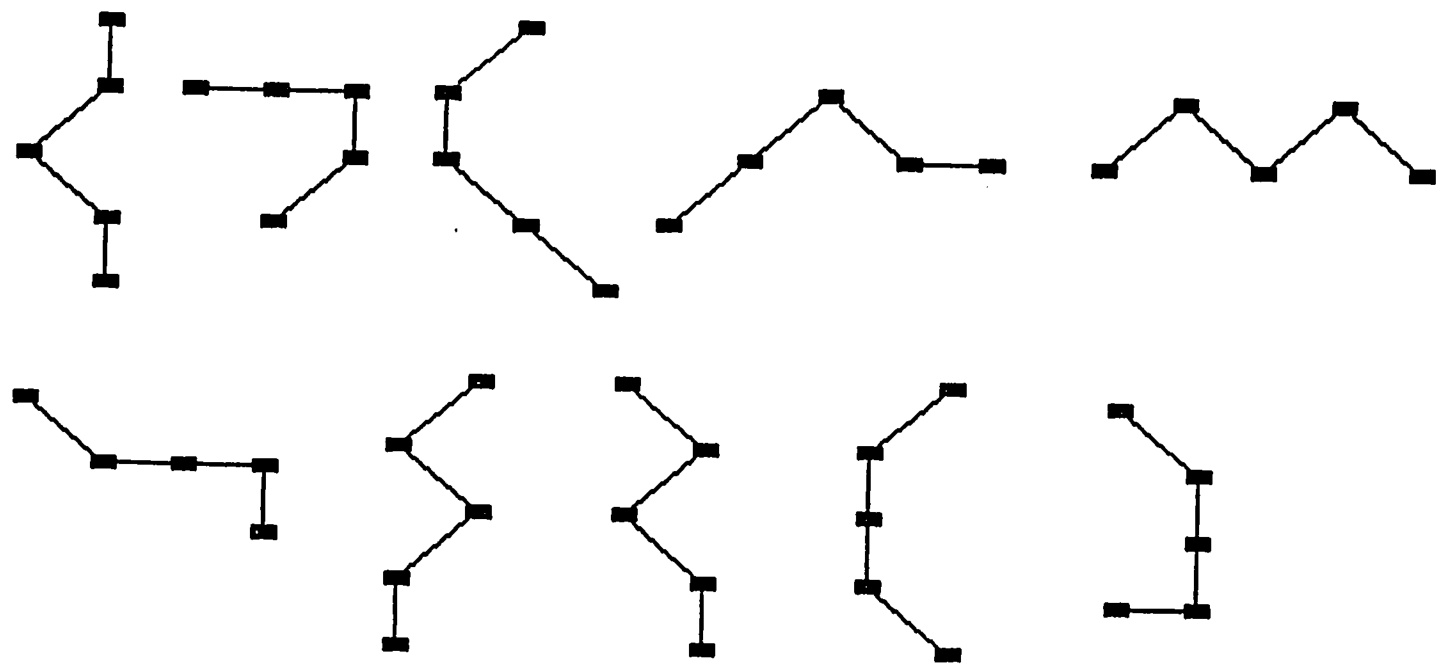
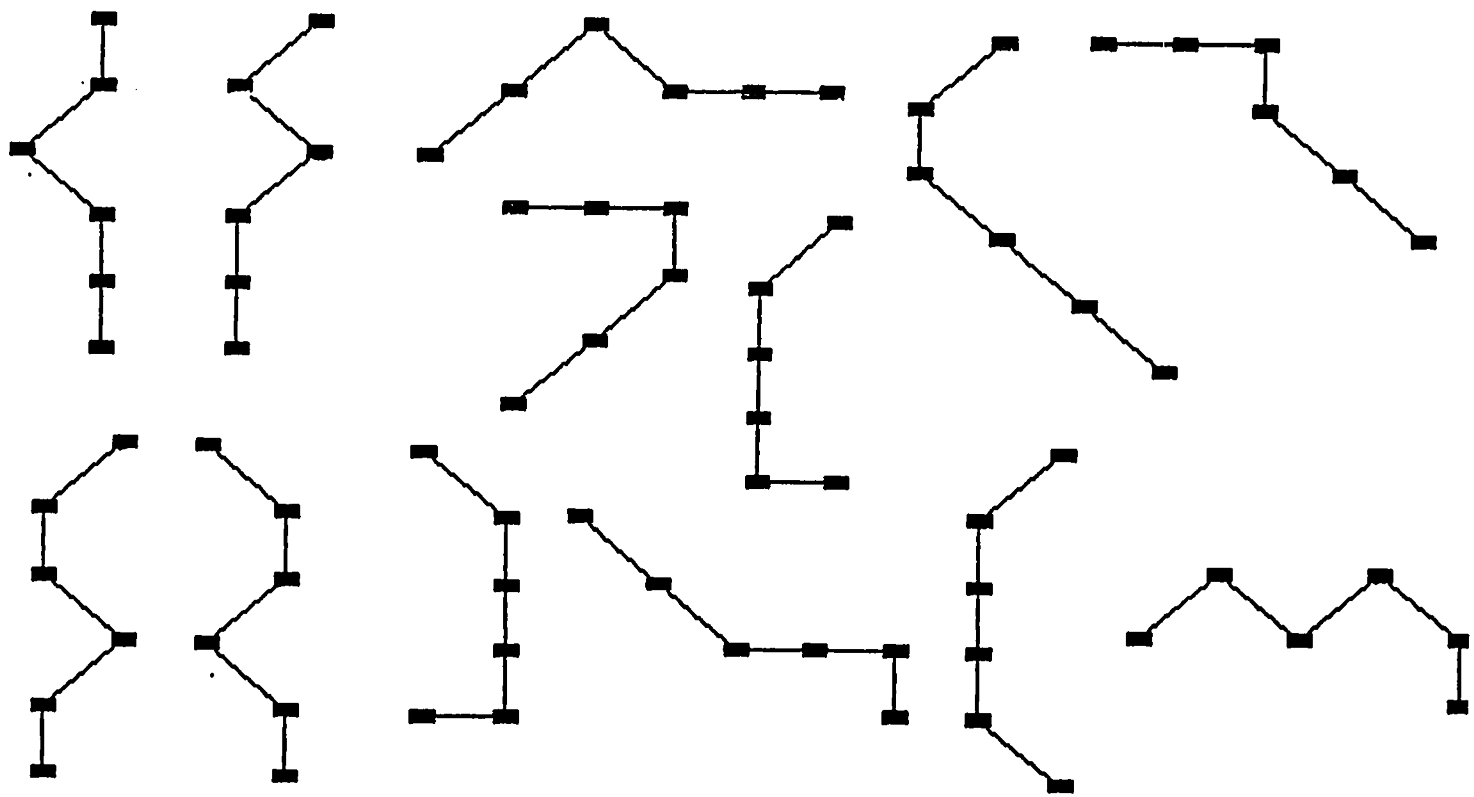
APPENDIX A

Line stimuli used in experiment 2. Subcategory: bent, 5 dot length.



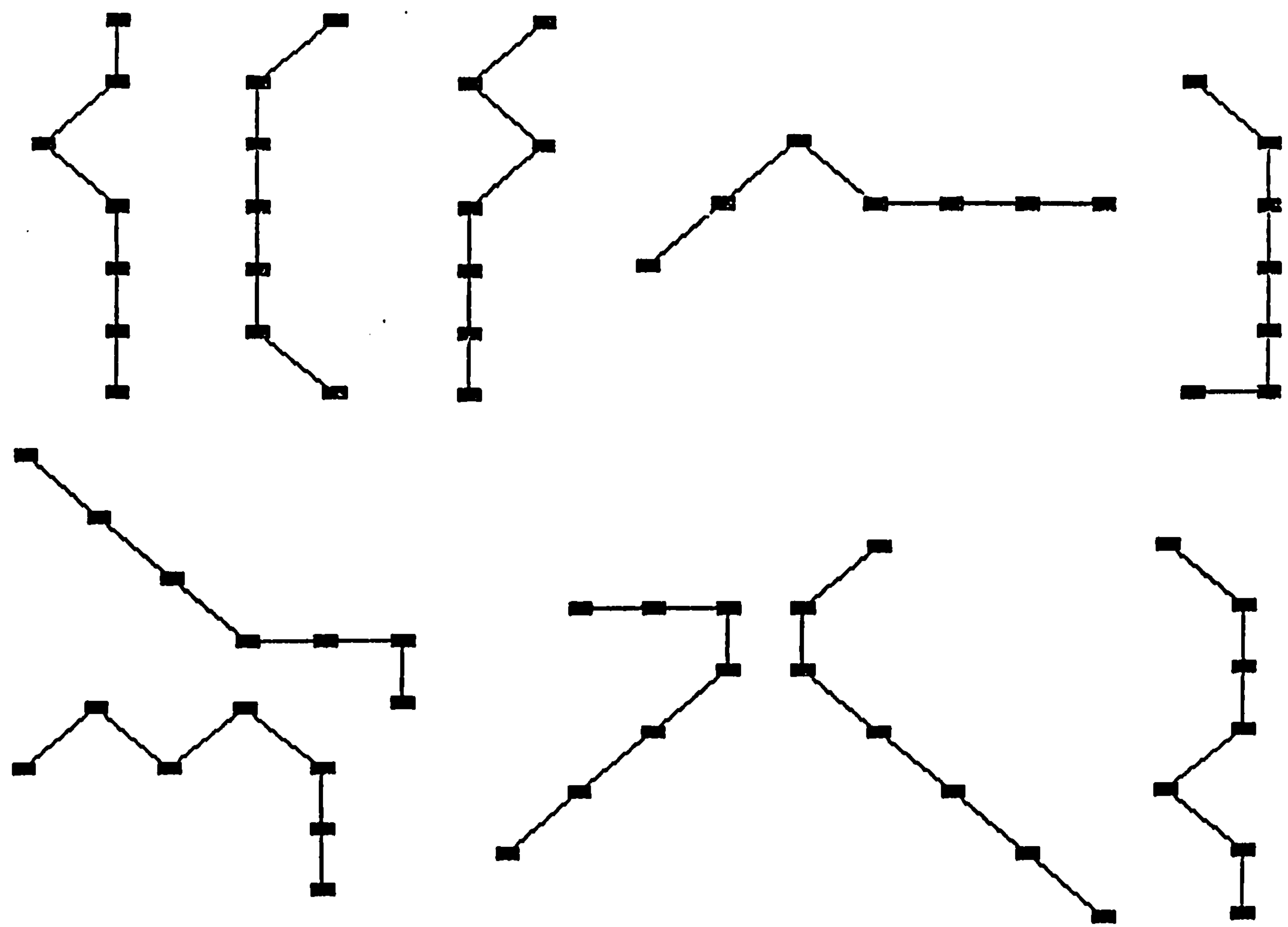
APPENDIX B

Line stimuli used in experiment 2. Subcategory: bent, 6 dot length (target).



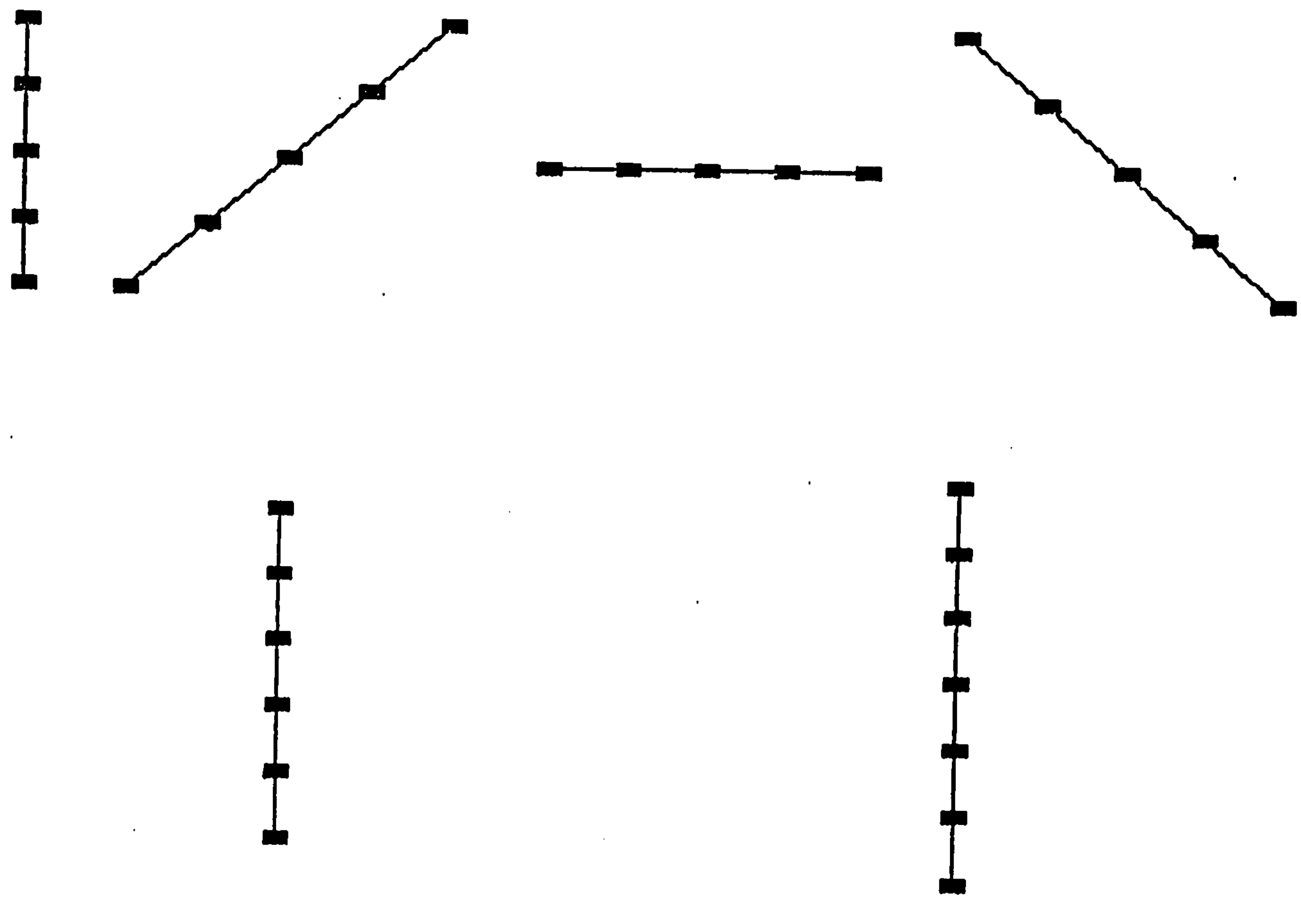
APPENDIX C

Line stimuli used in experiment 2. Subcategory: bent, 7 dot length.



APPENDIX D

Line stimuli used in experiment 2. Subcategories: straight, 5, 6 and 7 dot lengths. The first row demonstrates a straight, 5 dot line in each of the 4 possible rotations.

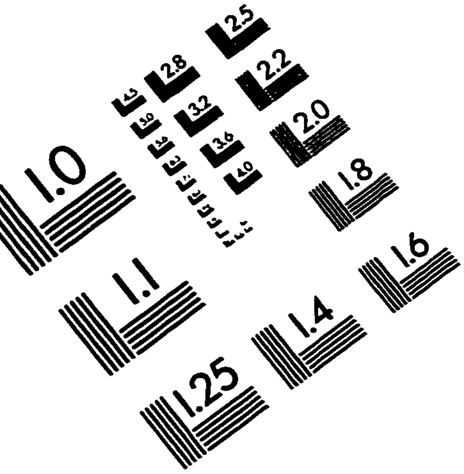


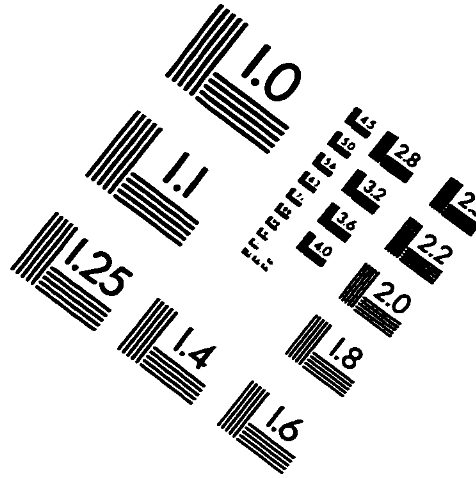
APPENDIX E

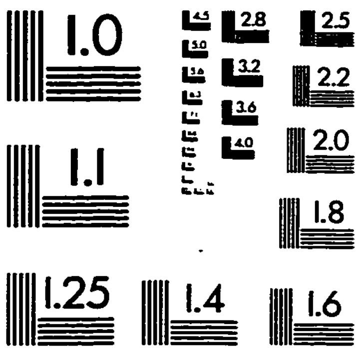
McCarthy-Wood formula:

$$MW = \frac{x - min}{max - min}$$

IMAGE EVALUATION TEST TARGET (QA-3)

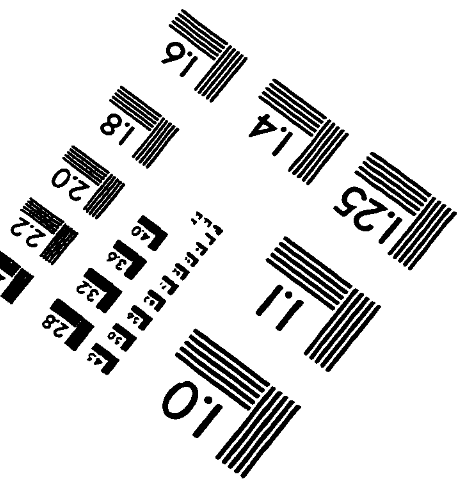


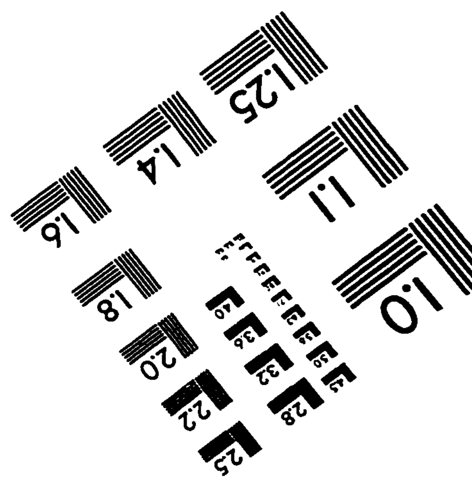




150mm

6″





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