EVENT-RELATED BRAIN POTENTIALS RECORDED DURING
PERFORMANCE OF A PERCEPTUAL-MOTOR TASK

by

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This thesis examined the event-related brain potentials recorded while subjects perform a continuous involvement perceptual-motor task. It was found that potentials associated with psychological processes of anticipation and selective attention could be reliably measured. A post-stimulus negative shift observed in response to attended stimuli was found to be composed of two types of electrocortical activity. The first and earliest to appear was sensitive to the difference between channels (i.e. ears) carrying relevant and irrelevant auditory information. The second was sensitive to the direction in which subjects oriented their attention during the task. Between 200 msec and 300 msec after stimulus onset, these two activities or processes interacted such that the electrocortical effect of selective attention became largest in the cerebral hemisphere contralateral to the direction of orientation. Predicted relationships between brain potentials and task performance on a trial-to-trial basis were not found. The results are discussed in terms of the current understanding of the electrophysiology of human attention.
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I. Introduction

This thesis provides a qualitative and quantitative description of the electrocortical phenomena associated with performance of a perceptual-motor task. The task differs from most others which have been used to study these phenomena in that it continuously engages the interest of the subject and provides him with a realistic information load (Sabat, 1978). The electrocortical events recorded in this research are known as event-related potentials (ERPs) and are closely associated with psychological processes of anticipation and selective attention. The aims of this project were twofold. The first was to demonstrate that ERPs could be reliably recorded in a perceptual-motor task, and that these ERPs compare favourably with those which have been observed in the more austere paradigms of previous investigations of anticipation and attention. The second was to suggest a functional interdependence between anticipatory and attentional electrocortical systems. Traditionally in ERP studies, the basic distinction between anticipation and selective attention is that between electrocortical activity measured prior to and consequent to a given event. Slow negative shifts in the ERP are usually considered "anticipatory" if they are associated with preparatory processes. These processes may be stimulus-oriented and preparatory to information processing, or else response-oriented and preparatory to effective motor responding (Rockstroh, Elbert, Birbaumer and Lütkemeier, 1982). Poststimulus negative electrocortical activity, first observed in the ERP waveform at around 100 msec, has been related to selective attention. The word "selective" is meant to imply that stimuli designated as being relevant
are processed more effectively than irrelevant stimuli, and in the ERP one observes greater negativity in response to attended, relevant stimuli (Hillyard, 1982). More specific information about electrocortical negativities will be provided in the following introduction to ERP terminology.

ERPs can be recorded from many locations on the scalp surface. They are usually quantified by taking the averaged response to many identical stimuli and then measuring the difference in amplitude (in microvolts) between each post-stimulus peak or trough and the average level of prestimulus activity. This baseline-to-peak method is preferred over trough-to-peak or peak-to-trough techniques which measure amplitude differences between adjacent ERP components. The main reason for the preference is the substantial body of evidence showing the independence of successive components in terms of sensitivity to experimental manipulation and generator source (Desmedt and Debecker, 1979; Knight, Hillyard, Woods and Neville, 1980; Tueting and Sutton, 1973; Wilkinson, Morlock and Williams, 1966). ERPs are classified according to whether they are strictly evoked by the physical properties of stimuli (referred to as "exogenous" ERPs), emitted in conjunction with some internal cognitive process (referred to as "endogenous" ERPs),
or constitute a compromise between these two situations (Hillyard and Picton, 1979).

An abrupt acoustic stimulus will evoke an ERP over the central scalp region with a negative peak at about 100 msec poststimulus. This peak, called N1 or $N_{100}$, is an example of a compromise or "mesogenous" ERP component. Its amplitude is not only related to stimulus properties such as pitch or intensity (Picton, Hillyard, Krausz and Galambos, 1974), but also to the amount of attention paid to the stimulus or to all events in the channel (e.g., the ear) carrying the stimulus (Hillyard and Picton, 1979; Hink, Hillyard and Benson, 1978; Parasuraman, 1978; Schwent and Hillyard, 1975). Selective attention experiments in which the subject is required to attend to stimuli in one channel, say the right ear, and to ignore stimuli in the other ear usually show a larger N1 response to information in the attended channel. This effect is more pronounced under conditions of high information load, and has been shown to be independent of nonspecific factors such as fluctuations in general arousal (Hillyard and Picton, 1979). It was originally proposed that N1 was an electrocortical index of Broadbent's (1970) "stimulus set", that is, channel selection based upon analysis of simple stimulus attributes (Hillyard and Picton, 1979). More recent research suggests that the effect of selective attention on N1 is not simply an increase in the amplitude of the exogenous component, but rather a modulation of the entire ERP by the superimposition on it of an endogenous slow negative shift (Hansen and Hillyard, 1980; Okita, 1981, Parasuraman, 1980; see Nummenen, 1982, for a thorough review). This work questions the interpretation of N1.
as reflecting some simple early filter or gating mechanism in selective attention. A neuroanatomical dissociation between N1 and endogenous negativity was reported by Knight, Hillyard, Woods and Neville (1981) who showed that lesions of frontal cortex attenuated the attention-related negative shift without altering N1 amplitude.

Two other important endogenous ERPs are the contingent negative variation (CNV) and the readiness potential (RP). Both are negative potentials which are emitted in anticipation of a sensory and/or motor event. The CNV, sometimes called the expectancy wave (E wave), is a large slow potential change occurring in the interval between a warning stimulus and an imperative stimulus to which a response is required (Walter, Cooper, Aldridge, McCallum and Winter, 1964), although the strict pairing of stimuli is not always necessary for its production (McCallum, 1980). The RP, or Bereitschaftspotential (BP), is a smaller potential which builds just prior to the initiation of voluntary limb movement (Deecke and Kornhuber, 1977). The CNV is usually larger over frontal than over central scalp regions and is bilaterally symmetrical, while the RP is more prominent centrally and is asymmetrically distributed, being larger over the hemisphere contralateral to the responding limb (Becker, Iwase, Jurgens and Kornhuber, 1976; Deecke, Becker, Grozinger, Scheid and Kornhuber, 1973; Gerbrandt, 1978; Hillyard, 1973; Hink, Kohler, Deecke and Kornhuber, 1982). CNV amplitude is enhanced by active attention to stimuli.
(Picton, Hillyard, Galambos and Schiff, 1971) and reduced by
distraction during the interval between warning and imperative
stimuli (Hillyard, 1973; Tecce and Hamilton, 1973). Larger amplitudes
and slower rates of habituation are associated with good performance
and higher levels of task motivation (McCallum, 1976; Walter, 1965;
Walter et al., 1964).

RP amplitude is generally higher prior to slow movements than to
rapid movements (Becker et al., 1976), and increases with muscular
effort (Brunia and Vingerhoets, 1981). There seems to be a general
agreement that at least one component of the RP reflects the subject's
intention to act (Hink et al., 1982; Deecke, 1978; Libet, Wright and
Gleason, 1982), while another is sensitive to the demands made on
the subject's attention (Deecke and Kornhumber, 1977; Grunewald-

Traditional distinctions between the CNV and the RP have been blurred
somewhat in recent years by research which has isolated CNV compon-
ents described as "early" or "late", depending on when they reach peak
amplitude (Gaillard and NHHtHnen, 1976; Tecce, 1971). The early CNV
seems to be especially sensitive to arousal and attention, while the
late CNV is generally indistinguishable from the RP (Gaillard, 1980;
Rohrbaugh, Syndulko and Lindsley, 1976). The RP too has been found
to have a bilateral CNV-like component as well as a lateralized negative shift more closely related to response initiation (Grunewald-Zuberbier et al., 1981; Kutas and Donchin, 1977). This supports the notion that the CNV and the RP are both members of the same family of endogenous negative waves (Kutas and Donchin, 1977), and that they likely overlap in task situations involving short inter-stimulus internals (Rohrbaugh et al., 1976). In this thesis the family of prestimulus negative shifts will be referred to by the general label, anticipatory potentials (APs).

In most electrocortical investigations of selective attention the amplitude of the poststimulus N1 component has been the dependent measure. Although it was suggested some time ago that APs and the N1 might be "signs of the same functional system, one representing a more tonic, the other a more phasic activity" (Järvilehto and Fruhstorfer, 1970, p 315), very little is known about the relationship of APs to selective information processing (Hansen and Hillyard, 1980; Hillyard and Picton, 1979). In recognition of the fact that selective attention need not be uniquely indexed by any single physiological variable (Hillyard, 1973), there is a need to study both prestimulus and post stimulus ERPs in a given experimental context. The problem is nicely illustrated by reference to an example of research in which the dual-variable approach might have been helpful.
Jutai and Hare (1983) studied ERPs and selective attention in groups of psychopathic and non psychopathic prison inmates. Binaural repetitive tone pips were presented through stereo headphones while subjects played different types of video skill games. The tones were irrelevant to video events and subjects were instructed to ignore them. For nonpsychopaths, it was found that improvement in game performance across trials was accompanied by smaller N1 responses to the irrelevant tones. The psychopathic group showed N1 responses smaller than those of the other group throughout the game trials and yet they were unable to sustain the levels of performance achieved by nonpsychopaths. The intrinsically interesting nature of the video game task (reported by all subjects) helped eliminate the possibility that group differences in motivation contributed to the findings. The results were interpreted as providing support for the hypothesis that psychopaths effectively ignore stimuli which are not of immediate interest to them. Since ERPs were not recorded to stimuli coincident with video events, it could not be determined whether psychopathic subjects were also less efficient than nonpsychopaths at distributing attentional resources among these events. For example, had APs been recorded they might have shown that psychopaths had greater difficulty anticipating important video events, which may or may not have been related to their ability to attend selectively.

The research described in this thesis also used a video game as the basic experimental task because it requires of the subject that
he both anticipate and selectively attend to stimuli. Furthermore it avoids the artificial nature of the typical CNV paradigm in which "small islands of S1-S2 (i.e., warning stimulus-imperative stimulus) activity are separated by periods of inactivity during which the subject's psychological and behavioural state is relatively poorly controlled" (McCallum, 1976, p. 46), by making continuous demands on attention. Also, since the task is intrinsically motivating and relatively simple to learn to play, it should be possible to use it to study ERPs in a wide range of subjects. Investigators have often commented on the failure of conventional stimuli like tones and light flashes to engage the interest of subjects such as children and clinical patients - subjects whose attentional abilities or disabilities might be of critical importance to these investigators (Tecce, 1971). The use of uninteresting stimuli can inflate estimates of distractibility in these subjects and might actually increase the likelihood of physiological artifacts resulting from random eye movements (Tecce, 1971).

Like the experiment by Jutai and Hare (1983) subjects in the present studies were required to play video games while listening to tone pips through stereo headphones. Only the tone pips in one ear were coincident with salient events shown on the video screen. Like the experiment by Jutai and Hare (1983) subjects in the present studies were required to play video games while listening to tone pips through stereo headphones. Only the tone pips in one ear, however, were irrelevant to the task. Those in the other ear were coincident with salient events shown on the video screen. The stimuli in both ears were physically identical. Prestimulus and poststimulus ERPs associated with tones in both
ears were measured. Two experiments established that genuine AP and N1 phenomena are reliably recorded in this type of experimental situation. A third experiment explored relationships among the various types of ERPs and further dissociated ERP effects from those attributable to eye movement or muscular artifact. Two major hypotheses were tested in this experiment. The first was that electrocortical signs of anticipatory readiness and selective attention are interrelated by virtue of their being dependent to some extent on the direction in which a subject orients his attention during task performance. The second was that the amplitudes of these ERPs are positively correlated with task performance.

II. Experiment 1: Qualitative description of ERPs

This preliminary study was designed to examine the nature of the various ERPs which could be recorded in a paradigm such as that described above. It was important to ascertain whether extra-cerebral physiological artifacts, such as eye movements, might obscure the interpretation of observed ERP phenomena.

Method

Subjects

Eleven right-handed males between the ages of 18 and 29 (mean = 21.45, SD = 2.81) served as paid volunteers. All subjects were in good general health at the time of study, and had normal
vision and hearing. These subjects represented a wide range of previous experience with video games although none had played the particular game used in this study. None had prior experience as a subject in an ERP experiment. Subjects were informed of the general nature of the study, but specific hypotheses were not discussed until after the experimental session. Technical and procedural modifications resulted in five subjects out of the original eleven experiencing the procedure as it is outlined below. The data described below, therefore, pertain to these five subjects.

Only right-handed subjects were studied since results obtained with left-handers tend to be highly variable when measures of prestimulus, anticipatory ERP activity are used (Kutas and Donchin, 1977).

Apparatus

The experimental task was a video squash game generated by a Ridgewood Gamatic 7600 video game system, and was presented on an 18cm X 23cm black and white television screen. Figure 1 depicts the general experimental layout. Three of the four boundaries of a regular squash court were displayed as white lines against a black background on the T.V. screen. Lines representing the two side walls ran along the top and bottom of the screen. The back (or service) wall extended along the far left side of the screen. The view thus presented to the subject was of a squash court as seen from above. The subject's squash racquet appeared as a small white bar which could be moved along an invisible vertical axis located about
Figure 1. General layout of the video game task (see text for details)
one-quarter of the way across the screen from the right. The racquet control mechanism was housed in a small, lightweight plastic box held in the left hand. Control was effected by dialing a knob on the box with the fingers and thumb of the right hand; very little effort was required to execute these movements. The squash ball (a small white dot) was served automatically, always from the service wall, and would rebound upon contact with the racquet or any of the three court walls. The subject's task was to keep the ball in play within the court for as long as possible during each game trial. A 'miss' occurred when the ball escaped contact with the racquet and passed into the area on the far right of the screen, at which time another ball was served. The number of misses was displayed as a running total at the upper left corner of the screen.

The subject wore a pair of AKG 140 stereo headphones. In one ear he heard the live audio portion of the game he was actually playing. This consisted of 500 Hz, 1000 Hz and 2000 Hz tones which coincided exactly with wall bounces, racquet hits and misses, respectively. In the other ear the subject heard the same stimuli carried on the pre-recorded audio portion of a game which had been played by an associate of the experimenter. Thus, one earphone presented auditory information relevant to experimental task performance
while the other carried information which was potentially distracting since it was rarely (and then, only by chance) associated with activity on the T.V. screen. The assignment of relevant or irrelevant auditory information to the left or right ear was counterbalanced across subjects. Only the 500 Hz and 1000 Hz tones were used as triggers in subsequent ERP analyses. These were 40 msec in duration with 10 msec rise and fall times included. The intensity of the tones was 70 dB SPL delivered against a continuous background of 50 dB white noise. The average inter-tone interval per ear channel was 1.5 sec. The 2000 Hz 'miss' tone was omitted from data analysis for two reasons. First, it was not synchronous with the precise point in time at which the ball passed by the racquet; it actually followed the event by about 1 sec. Second, on average it occurred too infrequently within a game trial to permit an adequate artifact-free sample size for ERP averaging.

A Beckman Type R 711 polygraph was used to record EEG, eye movement (EOG) and muscular activity (EMG). Monopolar EEG recordings were obtained from Beckman EEG electrodes placed over C3 and C4 sites, referenced to linked earlobes. C3 and C4 refer to left hemisphere and right hemisphere recording sites, respectively. Each lies 20% of the distance from the center (or "vertex") of an
imaginary line extending from ear to ear at right angles to a line extending from nasion to inion. These positions overlie left and right portions of the Rolandic fissure. Central sites were used since the slow negative potentials which anticipate limb movement are recorded maximally over these areas (e.g., Deecke and Kornhuber 1977), especially when the subject knows in advance the nature of the required movement (Loveless, 1979). The linked-ears reference is preferred among investigators of slow potentials (Donchin, Gallaway, Cooper, Desmedt, Goff, Hillyard and Sutton, 1977), primarily because of its relative electrical indifference (Vaughan, Costa and Ritter, 1968), and because it seems to eliminate the artifactual contribution to scalp recordings of horizontal eye movements (Gerbrandt, 1978). In order to monitor gross eye movement an EOG recording was made with Beckman miniature electrodes placed above and on the outer canthus of the right eye. Both EEG and EOG signals were fed into Type 9806A A.C. couplers with bandpass set at 0.16 Hz to 30 Hz (3 dB rolloff). Given the interstimulus interval used in this study, the low frequency cutoff (time constant = 1 sec.) would ensure minimal distortion of the slow ERPs (Cooper, 1976; Donchin, 1973; Gerbrandt, 1978). EMG activity was recorded with miniature electrodes placed midway between the wrist and the elbow of the right arm, over the flexor and extensor muscles. This placement was found to be the one most sensitive to control-knob rotation
in both directions. A Type 9852 coupler with bandpass set at 0.80 to 30Hz was used to produce an integrated EMG signal. All electrode sites were prepared by rubbing with Redux paste, and impedances were kept under 5 Kilohms. The EEG, EOG, EMG and signal marker data were recorded and stored on magnetic tape.

Procedure

The experiment was conducted in a sound-proofed and electrically shielded chamber. The subject was seated comfortably at an eye-level distance of 136 cm from the center of the T.V. screen. At this distance the maximum vertical and horizontal eye movements required to perform the task were $8^\circ$ and $10^\circ$ respectively.

The subject was given a brief overview of the experiment and a description of the nature and function of the electrodes. Electrodes were then attached and the subject completed several short consent forms and a handedness questionnaire. Maximum vertical and horizontal eye movements were calibrated on the polygraph, and a check was made on the sensitivity of the EMG recording to control-knob rotations. Task instructions were then given.

The subject was told that there would be a series of short game trials, each lasting several minutes, and that he should concentrate on
minimizing the score on the T.V. screen (i.e., the number of misses) by keeping the ball in play in the squash court. Manipulation of the control knob was carefully demonstrated and the subject instructed to restrict voluntary muscular activity to the execution of this response. The subject was informed that tone pips would be presented through the headphones throughout each trial, and was told that no behavioural response was required to these tones and that attention should be focussed on the T.V. screen. No information was provided about relationships between tone pips and video events.

The subject then played a set of ten 4-minute game trials with a 30-sec pause between trials. The games were followed by a 4-min period in which the subject listened with eyes closed to a binaural presentation of pre-recorded game activity, and was required to keep a mental count of the number of occurrences of the 2000 Hz tone. Afterward, the total count was reported to the experimenter. This control condition was used to examine ERPs to the 500 Hz and 1000 Hz tones in a single channel, focused attention situation.

The entire session lasted about 90 minutes.
Data quantification and analysis

The electrophysiological signals were analyzed offline by a microcomputer. The sampling epoch extended from 500 msec pre-stimulus to 1000 msec following stimulus onset. The computer sampled at a rate of 200/sec, retaining 500 msec's worth of data until trigger onset at which time every second data point in the prestimulus portion of the epoch was discarded. This resulted in effective pre- and poststimulus digitization rates of 100/sec and 200/sec, respectively. This procedure was used because of data storage limitations on magnetic floppy disks. Although a 100 Hz sampling rate is adequate for the measurement of slow potentials, resolutions of latency components in the prestimulus period cannot be expected to be quite as good as that for poststimulus components. The computer was programmed to reject trials on which EOG and EMG amplitudes exceeded individually determined criterion ranges, in a period extending from 500 msec before to 500 msec after trigger onset. For the EMG, this procedure was designed to discard only those trials in which very large amplitude transients occurred. These are artifacts usually associated with gross body movements. The EOG and EMG were averaged and plotted over the same epoch as the EEG. The success of artifact rejection procedures was verified by visual inspection of the averaged EOG and EMG tracings.
Averaged ERPs were computed for the first 25 epochs free of artifact in each of the 10 game trials, and were triggered on tone onset. Four passes of the data on each trial were required, one for each combination of tone frequency (500 Hz, 1000 Hz) and ear channel (live audio, pre-recorded audio). In each pass the computer automatically rejected trials in which another tone event, including the designated trigger, occurred in the same 1000 msec period used for rejection of physiological artifact. Thus each average was free of EOG-, EMG- and non-trigger- and double-trigger EEG artifact for a 500 msec period before and after trigger onset.

Results

Event-related potentials

Figure 2 shows the group averaged prestimulus ERPs associated with 1000 Hz tone (racquet hit) of the subject's game soundtrack. Relative to poststimulus activity (see Figure 3), these ERPs display considerable electrocortical negativity. A negative component rises steeply over both C3 and C4 from about -450 msec to about -350 msec. The peak latency of this 'early component' seems to vary from trial to trial. Beyond this point in time, dramatic differences emerge between C3 and C4 waveforms. Negativity at C3 either continues to
Fig. 2. Group averaged prestimulus ERPs associated with 1000 Hz tone on relevant channel, for trials 1-10.
Fig. 3. Group averaged poststimulus ERPs associated with 1000 Hz tone on relevant channel, for trials 1-10.
build or else levels off about 100 msec before stimulus onset, while at C4 negativity is waning. The amplitude of the early component depicted in Figure 2 ranges from $3\mu V$ to $7\mu V$. The difference between C3 and C4 ERPs at stimulus onset varies from $2.5\mu V$ to $6\mu V$.

Figure 3 presents the poststimulus portions of the waveforms shown in Figure 2 (note the change in time scale). C3 and C4 tracings are aligned such that the amplitudes of the small positive deflection appearing between 50 msec and 100 msec poststimulus are equivalent. This emphasizes differences between C3 and C4 in the size and latency of the N1 component. The general effects of the larger prestimulus negativity on poststimulus components recorded at C3 relative to C4 are a retardation of component peak latencies by about 15 msec, an attenuation of N1 amplitude and greater positivity in portions of the waveform extending beyond 200 msec from stimulus onset. For both C3 and C4 there are noticeable fluctuations in N1 latency across trials.

Group averaged ERPs recorded in response to the 1000 Hz tones on the pre-recorded soundtrack are shown in Figure 4. There was no appreciable negative buildup in the prestimulus period, hence only poststimulus waveforms are depicted. An N1 component is prominent in each trial, and C3 appears to exhibit slightly more negativity
Fig. 4. Group averaged ERPs to 1000 Hz tone on irrelevant channel, for trials 1-10.
than C4 in early and later portions of the waveforms. A comparison of Figures 3 and 4 highlights the distortions of the ERP when it has been preceded by a prestimulus negative shift. These include attenuation of N1 amplitude and enlargement of the N1-P2 peak-to-peak difference, where P2 in the positive deflection occurring immediately after N1. These findings however should not be understood to imply that prestimulus negativity strictly determines the form of the poststimulus ERP. Recall that N1 is often referred to as a "mesogenous" component, sensitive to both physical and psychological manipulation. It is conceivable that N1 could be directly affected by the same psychological process which gives rise to the prestimulus shift. Of course such an effect is not easily distinguishable from distortion produced by the temporal overlap of pre- and poststimulus activity. Nonetheless, direct manipulation of N1, independent of mediation by prestimulus negativity, has been demonstrated in the past (see review by Naatanen, 1982) and was visible in the analysis of ERPs to 'wall bounce' tones.

Figures 5 and 6 present ERPs associated with 500 Hz 'wall bounce' tones recorded at C3 and C4, respectively. There was no appreciable negativity in the prestimulus wave-forms. In most trials and across both recording sites there is a sizeable difference in N1 amplitude between responses to stimuli in the relevant
Fig. 5. Group averaged ERPs to 500 Hz tone on relevant (GAME) and irrelevant (TAPE) channels, for site C3.
Fig. 6. Group averaged ERPs to 500 Hz tone on relevant (GAME) and irrelevant (TAPE) channels, for site C4.
and irrelevant audio channels. Moreover, ERPs to relevant tones demonstrate greater negativity throughout most of the waveform on each trail. There seems to be considerable trial-to-trial variability in the difference in overall ERP negativity between channels.

ERPs recorded during the single sensory channel control condition are displayed in Figure 7. N1 amplitude seems to be larger at C4 than at C3, and P2 appears larger in response to 500 Hz tones than to 1000 Hz tones. In this focused attention condition the N1 component was generally larger than it was while subjects played the video game. There is little evidence of the late negativity which dominates many of the ERP tracings of Figures 5 and 6.

Physiological artifact rejection

On the average, 1 out of every 4 sampled epochs was discarded because of eye movement artifact. Although it may be high by the standards of some other ERP studies, this rejection ratio is not unacceptable given the complexity of the experimental task used. The percentages of trials rejected (out of the total required for 25 clean averages) for averaged ERPs associated with 1000 Hz 'hit' and 500 Hz 'wall bounce' in first the relevant,
Fig. 7. Group averaged ERPs recorded during control condition.
then the irrelevant channels were 21.53, 25.37, 27.16 and 24.59. The success of the EOG rejection strategy is verified by inspection of Figures 8-12. Figure 8 presents averaged EOG waveforms which were concurrent with the ERPs to 'hit' tones in the relevant channel. A racquet hit was invariably associated with left-to-right eye movement immediately before the hit, followed by a right-to-left deflection as the ball rebounded from the racquet. For the purpose of artifact rejection it was necessary to keep the sampling epoch free of movements which did not conform to this invariant pattern. These included blinks and unusually large or sudden eye rotations. EOG artifact control was achieved in the remaining experimental and control condition epochs as shown in Figures 9-12.

The number of EMG artifacts was negligible, averaging only a few percent for any single ERP epoch. Apparently subjects had little difficulty restricting limb activity to only those finger movements required for control-knob manipulation.

Event-related EMG

Group averaged EMG waveforms associated with the 1000 Hz tone ERPs in the relevant channel are displayed in Figure 13
Fig. 8. Group averaged EOG associated with 1000 Hz tone on relevant channel, for trials 1-10. (0=stimulus onset)
Fig. 9. Group averaged EOG associated with 1000 Hz tone on irrelevant channel, for trials 1-10.
Fig. 10. Group averaged EOG associated with 500 Hz tone on relevant channel, for trials 1-10.
Fig. 11. Group averaged EOG associated with 500 Hz tone on irrelevant channel, for trials 1-10.
Group averaged EOG recorded during control condition.

*Fig. 12. Group averaged EOG recorded during control condition.*
Prestimulus activity follows a ramp-like course, peaking between 50 msec and 200 msec before tone onset. This suggests that, in general, the initiation and completion of preparatory muscular activity was confined to this period. Thus, on the average, subjects had properly positioned the racquet so as to intercept the ball at least 50 msec prior to the tone. Following the stimulus the waveform returns to baseline within 200 msec. A comparison of Figures 2 and 13 reveals an overall similarity between the EMG and the ERP recorded at C3, i.e. over the hemisphere contralateral to finger movement. Note that during the prestimulus period negativity recorded at C4 was decreasing at a time when EMG was peaking. In general, the ERP activity peaked earlier than the EMG. Furthermore, there appeared to be no burst of EMG activity concurrent with the peak of the 'early component' observed in the ERP.

Intersubject variability in ERPs

In order that the reader might assess the adequacy of the electrophysiological recording techniques used in this study, a sampling of a single subject's waveforms recorded during Trial 1 is provided in Figure 14. It should be apparent from the figure
Fig. 13. Group averaged EMG associated with 1000 Hz tone on relevant channel, for trials 1-10. ($\Theta =$ stimulus onset)
Fig. 14. Electrophysiological waveforms for Subject 7, during trial 1:
A, prestimulus ERP to 1000 Hz tone on relevant channel;
B, prestimulus EMG to 1000 Hz tone on relevant channel;
C, ERP to 1000 Hz tone on irrelevant channel;
D, postimulus ERP to 1000 Hz tone on relevant channel;
E, ERP to 500 Hz tone on relevant (GAME) and irrelevant (TAPE) channels, for site C3;
F, ERP to 500 Hz tone on relevant (GAME) and irrelevant (TAPE) channels, for site C4.
that the essential features of the ERPs described for group data are readily observable in the data of Subject 7.

Behavioural data

Performance data were not of prime importance to this preliminary investigation. Nonetheless, Figure 15 present the group mean trend in game scores across trials. There was a gradual improvement in performance (i.e., decline in number of misses) throughout the first half of the trial set. Scores peaked between trials 4 and 6 and then began to fluctuate. Intersubject variability was quite large.

Discussion

The results of this experiment suggest that a variety of interesting ERPs can be reliably recorded in this paradigm. The most important of these are ERPs which might reflect selective attention and psychomotor preparation/anticipation.

Anticipatory ERPs

The prestimulus negativity observed in the ERPs to 1000 Hz 'hit' tones in the relevant auditory channel has features in common with the CNV and RP phenomena described in the literature. Like the 'Type A' or 'early' CNV, this waveform is characterized by a relatively large and sudden initial negative shift (Deecke and
Fig. 15. Group averaged game performance across trials 1-10.

Like the readiness potential, the later portion of this ERP is asymmetrically distributed, being a few microvolts larger in recordings made over the hemisphere contralateral to the responding hand (Becker et al., 1976; Deecke et al., 1973; Gaillard, 1980; Hink et al., 1982; Kutas and Donchin, 1977). This study differed from most RP studies, however, in that feedback did not immediately follow upon execution of the required motor response. On the average there was at least 50 msec between termination of the preparatory motor response and onset of the feedback or 'hit' stimulus. This means that one could well expect some anticipatory negativity not associated with motor readiness to have carried on beyond the peak of motor preparedness to stimulus onset. It has been shown, for example, that sustained prestimulus negativity can occur while a subject waits for feedback, even though the feedback does not require a response (Weinberg, 1973). In fact the structure of the entire negative waveform observed in this study is remarkably similar to that of the "goal-directed movement potential" (GDMP) described by Grunewald-Zuberbier et al. (1981). These authors examined the ERPs which accompany skilled slow positioning movements. Subjects were required to initiate particular positioning movements and terminate them when a target position was reached. They reported that a slow negative shift (BP) precedes EMG onset of the positioning movement. It
begins symmetrically over both hemispheres but, prior to EMG onset, it becomes significantly more negative at the recording site contralateral to the moving hand. This pre-EMG negativity continued to increase, past EMG onset, until the target position was attained. Grunewald-Zuberbier et al. (1981) suggested that the GDMP represented more than just motor activity, that it was sensitive to the attentional demands of the task. The ERP in this study might similarly be composed of an early, BP-like wave which anticipates a motor response and a late, GDMP which anticipates the racquet hit. I shall henceforth refer to these two anticipatory components as API and AP2, respectively.

ERPs and selective attention

Despite the fact that subjects were not given specific information about the nature of the auditory stimuli, and were not required to overtly respond to stimuli in either ear channel, a dramatic difference appeared between ERPs to relevant and irrelevant tones. Relative to ERPs to 500Hz 'wall bounce' tones in the irrelevant channel, relevant 'bounce' ERPs seemed to be characterized by a 'processing negativity', the modulation of the exogenous ERP by an endogenous slow negative wave (Hansen and Hillyard, 1980; Okita, 1981; Parasuraman, 1980). This suggests that auditory information which is coincident with attended visual events
automatically receives more attention than information which is not.

ERPs and focused attention

A comparison of ERPs to 'wall bounce' tones with ERPs to tones in the focused attention (count tones) condition further specifies the type of attention associated with processing negativity. Neither ERPs to passively-attended, irrelevant 'bounce' tones nor ERPs to actively-attended tones during focused single-channel attention evidenced the degree of negative shift observed in ERPs to relevant 'bounce' tones. In fact, during focused attention processing negativity was almost entirely absent. This suggests that processing negativity is indeed peculiar to the selective aspect of multi-channel sensory information processing and not simply due to greater expenditure of attentive effort.

Implications for further study

The results clearly suggest that ERP measures of anticipation and selective attention can be obtained from a continuous involvement, perceptual-motor task. Negative shifts in the pre-stimulus ERP appear to represent anticipation of, or preparation
for, a racquet hit. Poststimulus 'processing negativity' seems to characterize the ERP to stimuli which are the objects of selective attention, such as 'wall bounce' tones in the relevant auditory channel. Despite the complexity of the task as compared to more traditional laboratory paradigms, ERP recordings were not badly disrupted by the more common sources of EOG artifact such as blinks and random eye movements. This supports Tecce's (1971) notion that the use of interesting, intrinsically motivating stimuli can reduce distractibility in subjects and decrease the likelihood of EOG artifact. However, there may still be other sources of difficulty in the interpretation of the ERP waveforms. Although it is extremely unlikely that eye movement potentials contributed artifactually to the asymmetry in ERPs observed in anticipation of a racquet hit, the maintenance of a rightward orientation of visual attention might have produced this effect. Asymmetry might also have been enhanced by an effect of somatosensory reaference on recordings made at C3, the recording site contralateral to the responding hand. This would have had its greatest impact on the AP2, N1 and P2 components. A final point of concern is that the ERP effects attributed to selective attention might have instead been the result of bisensory (auditory plus visual) stimulation. A predominantly negative-going ERP associated perhaps
with the visual event of a wall bounce might have been superimposed upon the auditory ERP to the simultaneous 500 Hz tone. Issues involving the direction of orientation and somatosensory reaference are discussed in some detail in Section IV. Experiment 2 examines the possibility of bisensory stimulation.
III. Experiment 2: Examination of visual ERP activity

Andreassi and Greco (1975) demonstrated that bisensory (auditory and visual) stimulation produced larger amplitude ERPs than did unisensory stimulation in either modality, and produced faster reaction times to stimuli. This seemed to support the idea that information processing can be facilitated by sensory interaction occurring in the central nervous system. The second experiment was designed to ascertain whether there were ERPs produced in response to the salient events in the visual display - ERPs which could possibly combine with ERPs to coincident auditory tones.

Method.

Subjects

The subjects were five right-handed males between the ages of 18 and 31 (mean = 23.0, SD = 5.15). They were volunteers, and were paid $5.00 each for their participation. All were in good general health and had normal vision and hearing. The previous experience of these subjects with video games and ERP experiments was similar to that of the subjects in the first experiment.
Apparatus

The nature of the experimental task and the physiological recording apparatus were as described in Experiment 1 with two exceptions. In order to reduce the magnitude of gross eye movements associated with the task a smaller T.V. screen was used. The new video display measured 8 cm × 10 cm. Maximum vertical and horizontal eye movements were 3° and 4° respectively, at a viewing distance of 152 cm. Also, although the subject wore a pair of headphones during the session no auditory stimuli were presented. The headphones served only to permit communication with the subject once the experimenter left the chamber.

Procedure

The procedure was as outlined in Experiment 1 with the exception that no instructions were given to the subject about auditory stimuli. A 'count tones' follow-up task was not included.

Data quantification and analysis

The computer was triggered by the 500 Hz and 1000 Hz tones which were coincident with wall bounces and racquet hits, respectively.
Only two passes of the data were required since there was only one signal marker channel involved (live audio). In all other respects the data analysis was as described in Experiment 1.

Results

The group averaged ERPs associated with racquet hits on the video display during the first game trial are presented in Figure 16. The prestimulus waveforms are easily recognizable by their similarity to those obtained in Experiment 1 (Figure 2). Poststimulus waveforms, however, showed little trace of the exogenous $N_{100}$ component observed in the auditory ERP to racquet hit tones (see Figure 3).

Figure 17 shows the group averaged ERPs associated with wall bounces on the T.V. screen during the same trial. There is no evidence of visual ERP components coincident with those described earlier in auditory ERP tracings (Figures 5 and 6). Nor is there evidence of any sustained poststimulus negative trend in these waveforms.

The waveforms depicted in Figures 16 and 17 are entirely representative
Figure 16. Group averaged ERPs associated with racquet hit for trial 1.
Figure 17. Group averaged ERPs to wall bounce for trial 1
of those observed in trials 2-10. Single subject data for trial 1 is shown in Figure 18.

Discussion

It seems that bisensory stimulation cannot account for the difference in waveforms between ERPs to relevant and irrelevant 500 Hz tones in Experiment 1. Racquet hit and wall bounce occurrences on the T.V. screen do no appear to be discrete and intense enough to generate visual ERPs. Furthermore, sustained negativity associated with preparation for a racquet hit, on average, does not appear in the ERP which follows a wall bounce event for at least 500 msec. This suggests that the increased negativity of ERPs to relevant 500 Hz tones in the first experiment represents selective attentive processing of these particular auditory events and not anticipation of a subsequent racquet hit.

The following experiment attempted a quantitative analysis of ERPs obtained in this type of perceptual-motor task.
Figure 18. ERP waveforms for Subject 2 on trial 1
IV. Experiment 3: Quantitative analysis of ERPs

In addition to the quantitative analysis of the ERP waveforms observed in a replication of Experiment 1, this experiment examined the effect of direction of gaze on ERP asymmetry. Although it has been established that downward eye movements can produce a large negative shift in the CNV (Straumanis, Shagass and Overton, 1969; Hillyard and Galambos, 1970), it is extremely unlikely that eye movement potentials were responsible for the asymmetry in prestimulus ERPs observed in the first two experiments. First, vertical eye movements could not have produced an ERP asymmetry (Anderson, 1977). Second, horizontal eye movements do not contribute artifactually to ERP recordings when the linked-earlobes reference is used (Gerbrandt, 1978). While potentials preparatory to eye movements may appear over the cortex, they are quite specific to prefrontal regions and do not systematically influence central or occipital recordings (Rosen, Robinson and Loiselle, 1978). However, this evidence is not marshalled in order to deny an important relationship between orientation and ERPs, in which eye movements might play an integral role (Cratton, Coles and Donchin, 1983; Loveless, 1979). Good performance on the video games would have required anticipation of a racquet hit. It is reasonable to
expect that subjects would have directed a large proportion of their attentional resources to the right side of the video screen, where the racquet was located, in anticipation of a hit. While eye position can be important in the control of attention (Reisberg, Scheiber and Potemken, 1981), research also shows that orientation of attention can occur independently of the line of sight (Posner, Nissen and Ogden, 1978). It has been forcefully argued that attention can selectively activate one hemisphere (Kinsbourne, 1975), and Posner et al. (1978) further specify that when an attentional set is maintained at a given spatial location, it "... is mediated by a shift of attention to a position in the brain that would be contacted by the external event" (p. 143). In support of this idea, Roland (cited in Nuttinen, 1982) used regional cerebral blood flow (rCBF) measurement techniques to show that when attention is focused on some part of the skin on one side of the body, there is preparatory activation of relevant somato-topical cortex in the contralateral hemisphere. This might suggest that when subjects in the present study maintain an attentional set on the right side of the video screen, the left hemisphere is selectively activated, irrespective of eye movements. The result would be larger ERPs at C3. Doubtless some part of the prestimulus ERP asymmetry observed earlier is associated with contralateral (i.e., right hand) motor preparation. Nonetheless, by the reasoning developed thus far, one should expect the asymmetry to weaken or perhaps even reverse when
subjects are required to orient attention more to the left side of the screen. In order to test this hypothesis, two groups of subjects were tested. One group (Group N) played the video games in the usual way. For the second group (Group R), the flow of action on the screen was reversed, i.e., the racquet appeared on the left side and balls were served from the right.

It was expected that subjects in Group N would orient attention primarily to the right side of the T.V. screen, where racquet hits occurred. Anticipation of a racquet hit is accompanied by a prestimulus negative shift in the ERP (i.e. an AP). APs should be larger over C3 (left hemisphere) than over C4 (right hemisphere) for Group N if indeed preparatory cortical activation is greater in the hemisphere contralateral to the direction of orientation. Subjects in Group R should orient more to the left side of the screen, in which case APs should be larger over C4 than over C3. Although AP1 and AP2 might reasonably be expected to be sensitive to motor preparation and feedback anticipation, respectively, response and feedback variables were not manipulated in this experiment. It is difficult therefore to predict the correlation between these two prestimulus components.

The preparatory activation or priming of the contralateral hemisphere induced by orientation might have implications for stimuli other
than those directly associated with the anticipated racquet hit, such as 'wall bounce' tones, although a priori these are not clear. Directional orientation might prime the contralateral hemisphere to give larger ERPs in response to all other stimuli in the task environment, equally to both relevant and irrelevant 'wall bounce' tones for example. On the other hand, such priming might act selectively to enhance attention paid to relevant stimuli only. If this were true one would expect an ERP effect of selective attention (i.e., larger poststimulus ERP response to relevant bounce tones) to be greater for the primed hemisphere (i.e., the hemisphere with the larger AP). Note that prestimulus APRs and anticipation are discussed in connection with one type of event, a racquet hit, while poststimulus processing negativity (measured at P1, N1, P2 and N2 latencies) and selective attention are associated with entirely different events, namely wall bounces. If relevant 'wall bounce' tones were also reliably preceded by AP-like negative shifts, it would be incorrect to assume that a poststimulus negative shift reflected only selective, "processing negativity" and not some nonspecific, anticipatory process. Instead, it is suggested here that one type of event (racquet hits) might possibly be used to prime a hemisphere to respond selectively to different events (wall bounce tones) which are not anticipated.
Method

Subjects

Sixteen right-handed males between the ages of 18 and 36 (mean = 21.3, SD = 4.91) volunteered to serve as subjects. Each was paid $5.00 for his participation in the study. All subjects had normal hearing and normal or corrected-to-normal vision, and were in good general health. The subjects represented a wide range of previous experience with video games. None had prior experience as a subject in an ERP experiment.

Apparatus

The nature of the experimental task and the physiological recording apparatus were as reported in Experiment 1 with two exceptions. The T.V. screen set-up described in Experiment 2 was used, and, the left-right flow of video game activity was reversed for half of the subjects by inverting the T.V. screen.

Procedure

The same procedure outlined in Experiment 1 was followed excepting that subjects were randomly assigned to normal (Group N) and reversed (Group R) orientation groups. Also, subjects were instructed to ignore the changing score which appeared on the T.V.
screen and to concentrate instead on keeping the ball in play for as long a period as possible. This change in instruction was necessary since for Group R the score appeared inverted on the T.V. screen and might not therefore have been as effective a cue for Group R as for Group N. Scores could not be hidden from subjects since it was necessary for the experimenter to monitor and to record this information. Furthermore, subjects were specifically instructed as to the nature of tone stimuli presented to each ear.

Data quantification and analysis

Computer averaging and artifact rejection procedures were those used in Experiment 1. ERP components were scored in the following manner. Four components were scored for ERPs associated with 1000 Hz 'hit' tones in the relevant (live audio) channel. AP1 was taken to be the amplitude of the most negative point occurring between -400 msec and -300 msec relative to the amplitude at t = -500 msec. AP2 was the amplitude of the most negative point occurring between -150 msec and -50 msec, relative to the amplitude of the most positive point in the period immediately before t = -150 msec but after t = -300 msec. N1 was scored as the amplitude of the most negative point in the period extending from 70 msec to 150 msec poststimulus, relative to the point of maximum
positivity immediately prior to it. P2 amplitude was taken to be the difference in amplitude between N1 and the point of maximum positivity in the period extending from 200 msec to 300 msec poststimulus. This measure of P2 has been found not to spuriously inflate an inverse correlation between AP and P2 magnitudes and agrees well with P2-to-baseline type measures (Ruchkin and Sutton 1979). AP1-, AP2-, N1- and P2-type measures were also taken from the averaged EOG and EMG waveforms.

Four components were scored for ERPs associated with 500 Hz 'wall bounce' tones in the relevant channel and 500 Hz 'wall bounce' and 1000 Hz 'hit' tones in the irrelevant channel. All amplitudes were scored relative to the mean amplitude of the EEG 100 msec prior to tone onset. P1 was the point of maximum positivity in the period extending from 50 msec to 100 msec poststimulus. N1 was the point of greatest negativity subsequent to P1. P2 was the largest positive point after N1, and N2 was the point of maximum negativity following P2 up to 300 msec after tone onset.

The peak latencies for all components were also scored. In order to protect against type 1 error with so many variables being analyzed, multivariate analysis of variance (MANOVA) were used on the data.
Repeated measures MANOVAs were performed with a BMD programme (Dixon, 1981). The stepwise multivariate procedure described by Harris (1975, pp. 118-120) was followed; univariate tests of significance were considered only in the context of a statistically significant multivariate effect for all dependent measures. A Bonferroni adjustment was made to the rejection region associated with each of these tests such that the rejection probability was set at .05/p, where p equals the number of dependent variables.

Performance was assessed by means of repeated measures analysis of variance of the number of misses per trial using a BMD ANOVA program (Dixon, 1981).

Data obtained from the post-experimental 'count tones' condition are not relevant to the major hypotheses tested and were therefore excluded from analysis.

Results

Video game performance

The performance of Groups N and R is shown in Figure 19. There was a general improvement in scores across trials (F(9,126) = 15.59, p < .0001), with significant linear (F(1,14) = 83.43, p < .0001), quadratic (F(1,14) = 20.63, p < .0005) and cubic (F(1,14) = 5.88, p < .03) components of trend. Post hoc tests using the Tukey method (Kirk, 1968, pp. 88-90) revealed that performance on trial 1 was significantly poorer than each of trials 3 through 10, trial 2 was
Figure 19. Mean performance scores (number of misses) for subjects in normal (N) and reversed (R) orientation groups while playing video games.
poorer than each of trials 4 through 10, trial 3 poorer than trials 9 and 10, and trial 4 poorer than trial 10 \((q(10,135) = 4.47, p<.05)\). There was an overall difference between groups \((F(1,14) = 6.25, p<.03)\), but no significant Group X Trial interaction. Mean scores for Groups N and R were 26.13 and 39.46, respectively.

ERPs associated with racquet hit stimuli on relevant channel

Examples of averaged ERPs associated with the 1000 Hz 'racquet hit' tone on the relevant (live audio) channel for Groups N and R are presented in Figure 20 (prestimulus ERP) and Figure 21 (poststimulus ERP). Similar representations of single subject waveforms are shown in Figures 22 and 23.

The four dependent variables subjected to analysis of variance were AP1, AP2, N1 and P2. Mean amplitude and latency of these components for Groups N and R as a function of recording side are presented in Table 1.

The only significant effect to emerge from an analysis of component amplitudes was a Group X Hemisphere interaction \((F(4,11) = 4.51, p<.025)\). Univariate tests were significant for P2 \((F(1,14) = 12.06, p<.005)\) but not for AP1 \((F(1,14) = 3.98, p<.07)\) and AP2 \((F(1,14) = 3.65, p<.08)\). Though not statistically significant
Figure 20. Averaged prestimulus ERPs associated with 1000 Hz 'racquet hit' tone on relevant (live audio) channel for Groups N and R on trial 1.
Figure 21. Averaged poststimulus ERPs associated with 'racquet hit' tone on relevant channel for Groups N and R on trial 1
Figure 22. Averaged prestimulus ERPs associated with 1000 Hz tone on relevant channel for Subjects N3 and R6 on trial 1.
Figure 23. Averaged poststimulus ERPs associated with 1000 Hz tone on relevant channel for Subjects N3 and R6 on trial 1.
Table 1

Mean amplitude and latency of ERP components associated with 1000 Hz 'racquet hit' tone on relevant (live audio) channel for Groups N and R (standard error in parentheses)

<table>
<thead>
<tr>
<th>Component</th>
<th>Site</th>
<th>Group N</th>
<th></th>
<th></th>
<th>Group R</th>
<th></th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Amp.</td>
<td>Lat.</td>
<td>Amp.</td>
<td>Lat.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AP1</td>
<td>C3</td>
<td>-3.065</td>
<td>-348</td>
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<tr>
<td></td>
<td></td>
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<td>(6)</td>
<td>(0.298)</td>
<td>(6)</td>
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<tr>
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<td></td>
<td></td>
<td>(0.246)</td>
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<td>(0.410)</td>
<td>(6)</td>
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<tr>
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<td></td>
<td></td>
<td>(0.163)</td>
<td>(7)</td>
<td>(0.209)</td>
<td>(7)</td>
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<tr>
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<td>-4.350</td>
<td>-122</td>
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<td></td>
<td></td>
<td>(0.167)</td>
<td>(6)</td>
<td>(0.274)</td>
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<tr>
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<td></td>
<td>(0.185)</td>
<td>(2)</td>
<td>(0.123)</td>
<td>(2)</td>
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</tr>
<tr>
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<tr>
<td></td>
<td></td>
<td>(0.171)</td>
<td>(2)</td>
<td>(0.146)</td>
<td>(2)</td>
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</tr>
<tr>
<td>P2</td>
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<td></td>
<td></td>
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<td>(4)</td>
<td>(0.320)</td>
<td>(5)</td>
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<tr>
<td>P2</td>
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<td>247</td>
<td>12.280</td>
<td>268</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.434)</td>
<td>(4)</td>
<td>(0.354)</td>
<td>(5)</td>
<td></td>
</tr>
</tbody>
</table>
the API and AP2 results were nonetheless in the predicted direction and were certainly strong enough to warrant further examination. For each component Group N showed greater left-over-right hemisphere asymmetry while Group R showed the reverse (Figure 24). Differences between means were probed further using tests of simple main effects (Kirk, 1968, pp 179-182) since these are routinely computed by the BMD P4V program. API amplitude recorded at C4 was larger for Group R than for Group N (F(1,14) = 6.65, p<.03). Right vs. left hemisphere differences in AP2 and P2 amplitude were statistically significant for Group R only (F(1,14) = 5.86, p<.03; F(1,14) = 17.83), p<.001). There were no significant main effects or interactions involving the Trials factor. The API and AP2 results support the hypothesis that the hemisphere contralateral to the presumed direction of orientation (i.e., rightward for Group N, leftward for Group R) shows greater preparatory electrocortical activation or priming. Pearson correlations between prestimulus ERP component amplitudes, and between pre- and poststimulus amplitudes, are shown in Table 2. API and AP2 had a moderate positive correlation. Similarly, moderate positive correlations were found between each of these components and poststimulus P2 amplitude. Correlations with N1 were negligible.

An analysis of EOG activity coincident with the ERP components produced a main effect of Group (F(4,11) = 6.44, p<.007).
Figure 24. Mean AP1, AP2 and P2 amplitudes to 1000 Hz 'racquet hit' tones as a function of Group (N and R) and recording site (C3 and C4)
Table 2

Pearson correlations between prestimulus ERP component amplitudes, and between pre- and poststimulus amplitudes

<table>
<thead>
<tr>
<th>Variables</th>
<th>C3</th>
<th>C4</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP1, AP2</td>
<td>0.50*</td>
<td>0.51*</td>
</tr>
<tr>
<td>AP1, N1</td>
<td>-0.26</td>
<td>-0.19</td>
</tr>
<tr>
<td>AP1, P2</td>
<td>0.43</td>
<td>0.50*</td>
</tr>
<tr>
<td>AP2, N1</td>
<td>0.06</td>
<td>0.03</td>
</tr>
<tr>
<td>AP2, P2</td>
<td>0.34</td>
<td>0.47</td>
</tr>
</tbody>
</table>

*p<.05
The mean EOG amplitudes for Group R (mean API = 4.41, SD = 0.30; mean AP2 = 3.54, SD = 0.20) were larger than those for Group N (mean API = 2.60, SD = 0.31; mean AP2 = 2.53, SD = 0.17; however, these differences were not statistically significant. No significant results emerged from analyses of EMG waveforms.

There was a significant main effect of Hemisphere for ERP latency data $(6,9) = 27.07, p<.0001)$. Univariate tests were significant for AP2 $(F(1,14) = 12.36, p<.004)$, N1 $(F(1,14) = 117.91, p<.0001)$ and P2 $(F(1,14) = 26.36, p<.0002)$. Mean latencies are presented in Table 3. All ERP components peaked earlier in the right hemisphere than in the left.

ERPs associated with racquet hit stimuli on irrelevant channel

Examples of averaged ERPs associated with the 1000 Hz 'racquet hit' tone on the irrelevant (pre-recorded audio) channel for Groups N and R are shown in Figure 25. Single subject ERPs are represented in Figure 26.

Analysis of variance was performed on the four poststimulus components P1, N1, P2 and N2. Mean amplitude and latency of
Table 3

Mean latency of ERP components associated with 'racquet hit' tone on relevant channel, recorded over left ($C_3$) and right ($C_4$) hemisphere scalp locations (averaged across groups and trials) (standard error in parentheses)

<table>
<thead>
<tr>
<th>Site</th>
<th>Component</th>
<th>$C_3$</th>
<th>$C_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AP1</td>
<td>-346</td>
<td>-353</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td></td>
<td>AP2</td>
<td>-107</td>
<td>-115</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(5)</td>
<td>(5)</td>
</tr>
<tr>
<td></td>
<td>N1</td>
<td>118</td>
<td>109</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1)</td>
<td>(1)</td>
</tr>
<tr>
<td></td>
<td>P2</td>
<td>270</td>
<td>258</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3)</td>
<td>(4)</td>
</tr>
</tbody>
</table>
Figure 25. Averaged ERPs associated with 1000 Hz 'racquet hit' tone on irrelevant (prerecorded audio) channel for Groups N and R on trial 1.
Figure 26. Averaged ERPs associated with 1000 Hz tone on irrelevant channel for Subjects N3 and R6 on trial 1.
these components for groups N and R as a function of recording site are displayed in Table 4.

There was a statistically significant effect of Hemisphere on ERP amplitudes ($F(4,11) = 6.21, p < 0.008$). Univariate tests showed that right hemisphere amplitudes were larger than left hemisphere amplitudes for P2 ($F(1,14) = 25.56, p < 0.0002$), and to a lesser extent for P1 ($F(1,14) = 3.29, p > 0.05$). Mean C4 amplitudes for P1 and P2 were 0.82 mV (SD = 0.16) and 0.92 mV (SD = 0.21). Mean C3 amplitudes were 0.65 mV (SD = 0.15) and 0.47 mV (SD = 0.17), respectively. The hemispheres did not differ in N1 or N2 amplitude. There were no main effects or interactions involving Group or Trial factors.

ERP latencies were shorter for Group R than for Group N ($F(4,11) = 6.54, p < 0.006$). This was especially true for N1 ($F(1,14) = 13.59, p < 0.003$), P2 ($F(1,14) = 18.30, p < 0.0008$) and N2 ($F(1,14) = 10.67, p < 0.006$). Means are presented in Table 5. This finding suggests that Group R required less time than Group N to decide on the irrelevance of these tones. Latencies were shorter for the right hemisphere than the left ($F(1,14) = 24.55, p < 0.0001$). This was the case for all components; P1 ($F(1,14) = 42.65, p < 0.0001$), N1 ($F(1,14) = 49.56, p < 0.0001$), P2 ($F(1,14) = 63.03, p < 0.0001$) and N2 ($F(1,14) = 27.67, p < 0.0001$) (see Table 5). There were no significant effects involving the Trials factor.
Mean amplitude and latency of ERP components associated with 1000 Hz 'racquet hit' tone on irrelevant (prerecorded audio) channel for Groups N and R (standard error in parentheses)

<table>
<thead>
<tr>
<th>Component</th>
<th>Site</th>
<th>Group N</th>
<th>Group R</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Amp.</td>
<td>Lat.</td>
</tr>
<tr>
<td>P1</td>
<td>C3</td>
<td>0.776</td>
<td>81</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.213)</td>
<td>(2)</td>
</tr>
<tr>
<td></td>
<td>C4</td>
<td>0.905</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.223)</td>
<td>(2)</td>
</tr>
<tr>
<td>N1</td>
<td>C3</td>
<td>-2.503</td>
<td>137</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.224)</td>
<td>(2)</td>
</tr>
<tr>
<td></td>
<td>C4</td>
<td>-2.326</td>
<td>127</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.239)</td>
<td>(2)</td>
</tr>
<tr>
<td>P2</td>
<td>C3</td>
<td>0.650</td>
<td>204</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.271)</td>
<td>(3)</td>
</tr>
<tr>
<td></td>
<td>C4</td>
<td>1.099</td>
<td>191</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.276)</td>
<td>(3)</td>
</tr>
<tr>
<td>N2</td>
<td>C3</td>
<td>-1.532</td>
<td>259</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.288)</td>
<td>(4)</td>
</tr>
<tr>
<td></td>
<td>C4</td>
<td>-1.309</td>
<td>246</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.276)</td>
<td>(4)</td>
</tr>
</tbody>
</table>
Table 5

Mean latency of ERP components associated with 'racquet hit' tone on irrelevant channel for Groups N and R, and for recording sites C_3 and C_4 (standard error in parentheses)

<table>
<thead>
<tr>
<th>Component</th>
<th>Group N</th>
<th>Group R</th>
<th>C3</th>
<th>C4</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>78</td>
<td>75</td>
<td>80</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(1)</td>
<td>(1)</td>
</tr>
<tr>
<td>N1</td>
<td>132</td>
<td>121</td>
<td>132</td>
<td>121</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(2)</td>
<td>(2)</td>
</tr>
<tr>
<td>P2</td>
<td>198</td>
<td>172</td>
<td>191</td>
<td>179</td>
</tr>
<tr>
<td></td>
<td>(2)</td>
<td>(2)</td>
<td>(2)</td>
<td>(2)</td>
</tr>
<tr>
<td>N2</td>
<td>253</td>
<td>229</td>
<td>246</td>
<td>235</td>
</tr>
<tr>
<td></td>
<td>(3)</td>
<td>(3)</td>
<td>(3)</td>
<td>(3)</td>
</tr>
</tbody>
</table>
ERPs associated with wall bounce stimuli

Sample ERP waveforms associated with the 500 Hz 'wall bounce' tones in the relevant and irrelevant audio channels for Groups N and R are shown in Figure 27. EOG tracings are displayed in Figure 28. Single subject representations of the waveforms of Figures 26 and 27 are presented in Figures 29 and 30, respectively.

The four poststimulus ERP components P1, N1, P2 and N2 were analyzed as a function of Channel (relevant vs. irrelevant), Group, Hemisphere and Trial. Mean amplitudes and latencies of these components are contained in Table 6.

The Channel (or selective attention) effect was significant \( F(4,11) = 9.60, p < .002 \). Amplitudes were larger to stimuli in the relevant than in the irrelevant channel for N1 \( F(1,14) = 10.75, p < .006 \) and N2 \( F(1,14) = 37.35, p < .0001 \), but smaller for P2 \( F(1,14) = 29.11, p < .0001 \) (see Table 7). Since all measures were relative to a prestimulus baseline, these results attest to the negative shift in the poststimulus waveform of ERPs to the relevant tones. There was a significant Group X Hemisphere
Figure 27. Averaged ERPs associated with 500 Hz 'wall bounce' tone on relevant (live audio) and irrelevant (pre-recorded audio) channels for Groups N and R on trial 1.
Figure 28. Averaged EOG waveforms associated with 500 Hz tone on relevant and irrelevant channels for Groups N and R on trial 1.
Figure 29. Averaged ERPs associated with 500 Hz tone on relevant and irrelevant channels for Subjects N3 and R6 on trial 1
Figure 30. Averaged EEG waveforms associated with 500 Hz tone on relevant and irrelevant channels for Subjects N3 and R6 on trial 1.
Table 6

Mean amplitude and latency of ERP components associated with 500 Hz 'wall bounce' tone on relevant (live audio) and irrelevant (pre-recorded audio) channels for Groups N and R (standard error in parentheses)

<table>
<thead>
<tr>
<th>Channel</th>
<th>Component</th>
<th>C3</th>
<th>C4</th>
<th>C3</th>
<th>C4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relevant</td>
<td>P1</td>
<td>0.453 (0.174)</td>
<td>0.413 (0.197)</td>
<td>0.539 (0.186)</td>
<td>0.096 (0.249)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>83 (2)</td>
<td>78 (2)</td>
<td>86 (2)</td>
<td>79 (2)</td>
</tr>
<tr>
<td></td>
<td>N1</td>
<td>-3.489 (0.222)</td>
<td>-3.481 (2.242)</td>
<td>-2.771 (0.238)</td>
<td>-3.256 (0.264)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>147 (2)</td>
<td>135 (2)</td>
<td>137 (3)</td>
<td>126 (3)</td>
</tr>
<tr>
<td></td>
<td>P2</td>
<td>-0.646 (0.222)</td>
<td>-0.382 (0.278)</td>
<td>-0.917 (0.299)</td>
<td>-1.308 (0.319)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>209 (2)</td>
<td>197 (3)</td>
<td>181 (3)</td>
<td>171 (3)</td>
</tr>
<tr>
<td></td>
<td>N2</td>
<td>-4.039 (0.236)</td>
<td>-3.513 (2.265)</td>
<td>-3.884 (0.319)</td>
<td>-5.110 (0.357)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>288 (4)</td>
<td>272 (4)</td>
<td>260 (4)</td>
<td>249 (4)</td>
</tr>
<tr>
<td>Irrelevant</td>
<td>P1</td>
<td>0.425 (0.206)</td>
<td>0.659 (0.196)</td>
<td>0.743 (0.194)</td>
<td>1.026 (0.215)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>87 (2)</td>
<td>77 (2)</td>
<td>80 (2)</td>
<td>74 (2)</td>
</tr>
<tr>
<td></td>
<td>N1</td>
<td>-2.573 (0.194)</td>
<td>-2.355 (2.213)</td>
<td>-1.679 (0.251)</td>
<td>-1.784 (0.317)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>142 (2)</td>
<td>129 (2)</td>
<td>124 (3)</td>
<td>117 (3)</td>
</tr>
<tr>
<td></td>
<td>P2</td>
<td>0.623 (0.267)</td>
<td>0.915 (0.270)</td>
<td>0.763 (0.279)</td>
<td>0.940 (0.331)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>203 (3)</td>
<td>189 (3)</td>
<td>178 (4)</td>
<td>168 (4)</td>
</tr>
<tr>
<td></td>
<td>N2</td>
<td>-2.385 (0.271)</td>
<td>-2.156 (0.255)</td>
<td>-2.490 (0.264)</td>
<td>-2.472 (0.307)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>275 (4)</td>
<td>260 (4)</td>
<td>258 (5)</td>
<td>245 (5)</td>
</tr>
</tbody>
</table>
Table 7

Mean N1, P2 and N2 amplitudes to 500 Hz 'wall bounce' tone in relevant (R) and irrelevant (I) channels (standard error in parentheses)

<table>
<thead>
<tr>
<th>Component</th>
<th>Channel</th>
<th>R</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td></td>
<td>0.375</td>
<td>0.713</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.102)</td>
<td>(0.102)</td>
</tr>
<tr>
<td>N1</td>
<td></td>
<td>-3.249</td>
<td>-2.098</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.122)</td>
<td>(0.125)</td>
</tr>
<tr>
<td>P2</td>
<td></td>
<td>-0.813</td>
<td>-0.810</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.142)</td>
<td>(0.143)</td>
</tr>
<tr>
<td>N2</td>
<td></td>
<td>-4.136</td>
<td>-2.376</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.152)</td>
<td>(0.137)</td>
</tr>
</tbody>
</table>
interaction \((F(4,11) = 8.38, p<.003)\). Univariate tests verified an interaction for \(N2\) \((F(1,14) = 27.75, p<.0001)\) and to some extent for \(N1\) \((F(1,14) = 4.57, p>.05)\), which are depicted in Figure 31. Tests of simple main effects on \(N1\) amplitudes showed that right hemisphere responses were larger than left for Group R \((F(1,14) = 4.77, p<.05)\). \(N2\) amplitudes were larger over the left than the right hemisphere for Group N \((F(1,14) = 8.21, p<.013)\), but larger over the right than the left for Group R \((F(1,14) = 21.02, p<.0005)\). These results complement those presented in Figure 24 and suggest a general tendency for ERP amplitudes to be larger in the hemisphere contralateral to the presumed direction of orientation. A Channel X Hemisphere interaction was nearly significant \((F(4,11) = 3.15, p<.06)\). A univariate test was significant for \(P1\) \((F(1,14) = 13.44, p<.003)\) and was nearly so for \(N2\) \((F(1,14) = 5.62, p<.04)\). The effects are portrayed in Figure 32. Tests of simple main effects on \(P1\) amplitudes revealed that right hemisphere amplitudes were smaller than left to tones in the relevant channel \((F(1,14) = 5.30, p<.04)\), but were larger to tones in the irrelevant channel \((F(1,14) = 5.08, p<.05)\). In addition, channel separation was greatest in the right hemisphere \((F(1,14) = 5.39, p<.04)\). Responses to relevant tones produced larger \(N2\) amplitudes than those to irrelevant tones in both the left \((F(1,14) = 26.47, p<.0001)\) and the right hemispheres.
Figure 31. Mean N1 and N2 amplitudes to 500 Hz 'wall bounce' tones for recording sites C3 and C4 for Groups N and R
Figure 32. Mean P1 and N2 amplitudes to 500 Hz 'wall bounce' tones in relevant (R) and irrelevant (I) auditory channels for recording sites C3 and C4.
(F(1,14) = 40.62, p < .0001). Asymmetry in N2 amplitude in favour of the right hemisphere was significant only for responses to relevant tones (F(1,14) = 4.19, p < .06). A triple interaction of Group X Hemisphere X Channel (F(4,11) = 3.41, p < .05) proved to be significant by univariate test for N2 only (F(1,14) = 14.87, p < .002).

Figure 33 shows that a selective attention effect (i.e., responses to relevant stimuli were greater than those to irrelevant stimuli) was obtained within each hemisphere for each group, but it did vary in size. The effect appeared to be strongest for the hemisphere contralateral to the presumed direction of orientation of each group. Tukey tests were significant for the channel comparison in the right hemisphere for Group R (q(8,49) = 4.484, p < .05). Responses to irrelevant tones were only slightly larger in the left than in the right hemisphere for both groups. Responses to relevant tones were noticeably larger in the hemisphere contralateral to the presumed direction of orientation of each group. N2 amplitudes were comparable for the two groups in the left hemisphere but tended to be larger in the right for Group R, especially for responses to relevant tones. This N2 finding suggests that above and beyond a general effect of contralateral dominance, direction
Figure 33. Mean N2 amplitude to 500 Hz 'wall bounce' tones as a function of Group (N and R), Hemisphere (C3 and C4) and Channel (R=relevant, I=irrelevant)
of orientation appears to affect hemippheric asymmetry in the poststimulus ERP selective attention effect. The Trials factor produced no significant main effects or interactions.

ERP latencies were shorter for Group R than for Group N \( F(4,11) = 5.78, p<.01 \), especially for N1 \( F(1,14) = 8.88, p<.01 \), P2 \( F(1,14) = 24.22, p<.0002 \) and to a lesser degree for N2 \( F(1,14) = 8.12, p<.02 \). For all components, latencies were earlier in the right than in the left hemisphere \( F(4,11) = 77.53, p<.0001 \); P1 \( F(1,14) = 73.57, p<.0001 \), N1 \( F(1,14) = 156.13, p<.0001 \), P2 \( F(1,14) = 80.15, p<.0001 \) and N2 \( F(1,14) = 78.82, p<.0001 \). There were no significant effects involving Trials, nor were there any significant interactions between the other factors. It would appear then that direction of orientation, hemisphere of recording and selective attention have additive effects on response latency.

Rejection of physiological artifact.

On the average about 22% of trials were discarded because of eye movement artifact. This figure did not significantly vary across experimental conditions, and it is comparable to those percentages reported in Experiment 1. As was true for the first experiment, EMG artifacts were negligible, averaging only about 3% across
experimental conditions.

Discussion

The group differences in pattern of AP asymmetry cannot be easily explained by factors other than the orientation of attention. The groups did not differ in amplitude of EMG activity recorded both before and after a racquet hit. This argues against effects of general tension, somatic anxiety or muscular effort. It is true that somatosensory ERPs may be generated by the response to a stimulus in a task such as this (Loveless, 1979). These ERPs could conceivably affect electrocortical activity measured at AP2, N1 and even P2 latencies (Hink et al., 1982; Papakostopoulos, 1978). The lack of significant differences in EMG patterns between groups, however, makes it most unlikely that differential reafferent activity influenced the findings (see Papakostopoulos, 1978). Furthermore, reafference would not explain the opposite asymmetries shown by the two groups given that both used the same hand to respond.
The manipulation of orientation was partially verified by the direction of the averaged EOG associated with a racquet hit, which was rightward for Group N and leftward for Group R. Analysis of EOG showed that Group R tended to produce larger amplitude eye movements. However, evidence provided by other researchers against an effect of eye movements on centrally-recorded ERP asymmetry was cited at the beginning of this section.

ERP amplitudes are known to be sensitive to fluctuations in nonspecific arousal (Khachaturian and Gluck, 1969; Näätänen, 1982), but this too is an unlikely explanation of group differences in AP asymmetry. In this experiment ERPs associated with four different stimuli were measured concurrently. The responses of Group R were by no means consistently larger (or smaller) than those of Group N (see Tables 1, 4 and 6; McCallum, 1976).

The performance results suggest that Group R found the task to be more difficult than Group N. Although an attempt was made prior to experimentation to equate the two groups on level of previous experience with video games, only one subject in each group actually
claimed never to have played this type of game before. Thus subjects in Group R might have experienced greater difficulty with the unusual screen orientation presented to them. The inverted score might have contributed to this difficulty. Nevertheless, it is unlikely that task difficulty produced opposite AP asymmetries in Groups N and R. Variation within each group in performance across trials was at least as great as that between groups and yet respective patterns of asymmetry for the groups were invariant across trials.

The most satisfactory explanation seems to be that anticipatory electrocortical negativity is larger in the hemisphere contralateral to the direction of orientation. These physiological findings support the idea that readiness is indeed sensitive to attended location (Posner, Davidson and Snyder, 1980).

Explanations of group differences in the size of AP asymmetry might conceivably involve factors other than orientation. Greater mental effort, as might be required to perform a task of greater difficulty, has been shown to increase the amplitude of AP-type components without, however, influencing their lateralization
(Grunewald-Zuberbier et al., 1981; McCarthy and Donchin, 1978). The EOG results could reflect the greater expenditure of mental effort by Group R. It is also possible that individual differences in degree of asymmetry might be involved despite efforts to randomly allocate subjects to the two groups.

In Experiment 3 subjects in both Groups N and R were right-handed and performed the task using the preferred hand. Effects of handedness and of responding hand were not investigated. Nevertheless, based on previous research, it is possible to speculate on the possible importance of these two factors to the present findings. In a detailed report, Kutas and Donchin (1977) examined the readiness potential (RP) in groups of right- and left-handed subjects. In general they found less variability in the waveforms of right-handed subjects. Asymmetry in the RP favoured the hemisphere contralateral to the responding hand for right hand responses by both groups of subjects. For left hand responses contralateral dominance was present (although reduced) in right-handed subjects. Left-handers however, showed bilaterally symmetric waveforms when using the preferred hand. To the extent
to which the RP studied by Kutas and Donchin (1977) is similar
to the APs described in the present studies (and the similarity is
probably great for AP1), one could expect the AP results of
Experiment 3 to replicate when right-handed subjects use the
left hand. Results for left-handers are obviously less predictable
possibly due to greater heterogeneity in inter-hemispheric relations
in this population (Kutas and Donchin, 1977).

The moderate correlation between AP1 and AP2 amplitudes suggests that
these two components reflect a common process of psychomotor
preparation but at the same time do not provide completely redundant
information about this process (Järvilehto and Fruhstorfer, 1970).
Unfortunately Experiment 3 was unable to functionally separate these
two components. As with previous research (e.g., Smith, 1976)
there was a tendency for larger APs to be associated with greater
positivity in the poststimulus portion of the ERP. The asymmetry
in P2 amplitude which developed after a racquet hit could indicate
that P2 largely represented a phenomenon like CNV resolution,
in which the return to baseline of anticipatory negativity
depends upon the extent to which the imperative stimulus or manual
response completes the processing of task relevant information,
or otherwise "resolves" the situation (Weinberg, 1973; Wilkinson, 1976). Alternatively it could be argued that the P2 is much more of an independent event (Donald and Goff, 1973; Ruckin and Sutton, 1979), sensitive to detection of target stimuli. This means describing P2 as a $P_{300}$-like component, and suggesting that target detection has a greater impact on the hemisphere contralateral to the direction of orientation. This latter interpretation receives added support from the fact that $N_1$ amplitude, from which P2 measures were taken, was unrelated to the level of anticipatory negativity immediately preceding the stimulus (i.e., $A_{P2}$). In any event, moderate positive correlations between components and functional dissociation of components are not necessarily mutually exclusive phenomena (Tueting and Sutton, 1973).

A comparison of the poststimulus ERP associated with a relevant 1000 Hz tone and the ERP to an irrelevant 1000 Hz tone points out differences between ERPs preceded and not preceded by anticipatory negativity which appear to be highly reproducible. The distinguishing features of the former are a positive shift in all components which appear after about 50 msec, shorter $N_1$ latency, and smaller $N_1$ amplitude (Smith, 1976). Again, however, it must be noted that
anticipatory negativity itself need not have completely determined the poststimulus waveform of the ERP to a relevant 1000 Hz tone (see Experiment 1: Results).

The $P_{300}$ - like form of the P2 component in ERPs to racquet hit tones in the relevant channel does not appear to be specific to the physical qualities of a 1000 Hz tone. ERPs to 1000 Hz tones in the irrelevant channel showed no large post-N1 positive deflections. In fact these ERPs were very similar to those recorded in response to 500 Hz tones in the same channel, even though the 1000 Hz tones occurred less frequently. Thus neither relative rarity of occurrence nor physical similarity to target events (relevant 1000 Hz tones) - two situations often associated with the production of $P_{300}$ responses (Pritchard, 1980) - was sufficient to induce late positivity in the ERPs to irrelevant 1000 Hz tones. It is likely that the task used in this experiment, when coupled with the presentation of distracting tones, was difficult enough to require selective attention to relevant stimuli. Under such circumstances late positivity is only occasionally present in ERPs to deviant stimuli in an unattended channel (e.g. Hillyard, Hink Schwent and Picton, 1973).
The most compelling evidence of selective attention in this experiment resulted from comparisons between ERPs to 500 Hz tones presented in relevant and irrelevant ear channels. The former were characterized by a negative shift that is not explained by a difference between the tones in physical quality (they were identical in the two channels) or by eye movement artifact. Recall also the first two experiments which showed that bisensory stimulation, and the anticipation of racquet hits and relevant tones did not contribute to this effect (see also Figure 27 on the latter point). The shift likely represents the "processing negativity" associated with the identification of target features (Näätänen, 1982). It does not seem to be a sign that the relevant tones receive further processing because it emerged in this experiment, as in others (e.g. Schwent, Hillyard and Galambos, 1976), even though there was no requirement for tone discrimination. It is not clear from this study though whether the ERP differences were mediated more by spatial location (right or left ear) or by temporal correlation with visual events, since these factors were confounded. Selective attention does appear to have been an automatic process, at least in the sense that it was involuntary (Kahneman and Treisman, 1983). Subjects did not seem capable of ignoring tones presented on the relevant channel even when it might have worked to their advantage.
to ignore tones altogether and concentrate on the video screen, especially since no tone discrimination was necessary. Instead they made spatial location a target feature and selected as objects of attention any auditory event in a particular location (ear) which was coincident with a salient visual event.

The earliest ERP components to show a selective attention effect was P1, at about 80 msec, and this occurred only in the right hemisphere. Amplitudes were smaller in response to relevant 'wall bounce' tones than to irrelevant tones. This attenuation of the amplitude of a positive peak in the ERP is consistent with a "processing negativity" interpretation of the selective attention effect. That is, an endogenous slow negative shift develops in the ERP to selected information. This shift displaces the entire poststimulus waveform in a negative direction, enhancing the amplitude of negative components while attenuating those of positive components like P1. Selective processing may have begun earlier than 80 msec since P1 was simply the first component measured. In fact some attention-related auditory ERP effects have been observed as early as 15 msec poststimulus, although these did not appear to be lateralized (McCallum, Curry, Cooper,
Asymmetries in visual ERPs have been reported, but these emerge much later in the processing sequence, after about 200 msec (Kostandov, 1980), and after the bilateral appearance of a selection effect in central cortical areas (Harter, Aine and Schroeder, 1982). The finding is consistent with the notion of right hemisphere specialization for stimulus localization and analysis of spatial information (Heilman and Van Den Abell, 1980; Kolb and Whishaw, 1980, pp. 246-247, 266).

From about 120 msec to about 200 msec after stimulus presentation the selective attention effect was symmetrically distributed over the hemispheres, as shown by the N1 and P2 amplitude results. That is, N1 amplitude was larger and P2 amplitude smaller in response to relevant 'wall bounce' tones than to irrelevant tones, regardless of hemisphere. At about 120 msec another, apparently independent, process representing the effect of direction of orientation (the Group variable) on hemispheric asymmetry also began to develop and to continue on in parallel with the selective attention process. This was shown by the statistical independence of the N1 selection effect from the Group X Hemisphere interaction. Somewhere between 200 msec and 300 msec poststimulus the two processes interacted as revealed by the dependence of the size of the N2
selective attention effect on particular combinations of hemisphere and direction of orientation. At this time in the information processing sequence selection was maximal in the hemisphere contralateral to the direction of orientation. These findings provide strong support for a dual component model of the endogenous negative shift (Okita, 1981). One component reflects electrocortical activity associated with selective information processing and, in Experiment 3, was first observed in the ERP at about 80 msec poststimulus. The second component involves activity associated with orientation to the source of relevant information, and it was measurable later in the ERP at around 120 msec poststimulus.

This experiment demonstrated that the effect of having subjects orient in one direction or the other is to prime the hemisphere contralateral to that direction. When subjects expected important events like racquet hits to take place on either the left or the right side of their visual field, anticipatory negative shifts in electrocortical activity prior to these events were larger in the contralateral hemisphere. Unfortunately there was no behavioural evidence attesting to the benefits of this priming. There was
however, electrocortical evidence of the success of priming in the analysis of ERPs other than the anticipatory potentials. Selective attention effects observed in later components of ERPs to wall bounce stimuli were greatest in the primed hemisphere. Thus the electrocortical system, like the behavioural, is internally consistent in suggesting that priming enhances the ability to attend selectively. These results provide a hitherto missing link between the endogenous electrocortical negativities (Hansen and Hillyard, 1980; Hillyard and Picton, 1979).

Two final points deserve mention. First, virtually all ERP component latencies measured in this experiment were shorter in the right hemisphere than in the left, for both groups of subjects. This might indicate that in general ERPs are organized earlier in the right hemisphere (Kostandov, 1980), and it would be consistent with behavioural evidence that this hemisphere is an early information processor (Ser gent, 1982).

The second point concerns the failure to observe significant changes across trials in ERPs despite significant changes in performance. In many studies of reaction time and the CNV, reaction time reaches
an optimal level after a few trials and remains fairly constant at that level (e.g., McCallum, 1978). This seemed to be the pattern of the performance measure in this experiment. The CNV however, often shows a steady decline (Hillyard, 1973; McCallum, 1978; Weinberg, Curry and Peters, 1978). The decline has been attributed to overlearning as the subject's performance ceases to be focal ("scoepetic mode") and instead becomes automatic ("categoric mode") (Cooper, McCallum and Papakostopoulos, 1979). For some time now McCallum (1976; 1978) has been arguing that the typical CNV paradigm does not sufficiently motivate a subject to maintain involvement in the task, and that the steady decline in CNV amplitude could be arrested if the experimental task kept performance from becoming automatic. The video game used in the present experiment was chosen because it demanded continuous involvement on the subject's part and this might explain why the amplitude of the CNV-like anticipatory potentials (APs) failed to decline or otherwise change significantly with time on task. With respect to selective attention effects, the nonsychopathic subjects in the Jutai and Hare (1983) study gradually appreciated that all auditory stimuli were irrelevant and consequently devoted less attention to them, producing a steady drop in ERP amplitude.
Psychopaths made this assessment almost immediately and effectively ignored tones throughout game trials. In the present study, the need to attend selectively would have remained comparatively constant across trials since some but not all tones were relevant, thereby preventing a decrease in size of ERP selection effects. Correlations between behaviour and ERP components may well have emerged had more fine grained performance measures been employed, but it is not at all clear what form these measures should take. Poststimulus components like N1 are very difficult to correlate with reaction time to individual stimulus presentations because of the need for averaging. Although this is less of a problem for anticipatory potentials because of their much larger size and longer duration, reliable relationships with performance are elusive (Rebert and Tecce, 1973). Interpretation of correlations is not made easier by the fact that reaction time itself is multiply determined by motor and perceptual factors which limits it use as an index of any one particular psychological process (Hillyard, 1973).

Effort, independently of performance, seems to be the primary determinant of AP amplitude (Deecke, 1978), but efficiency of effort expenditure could be expected to predict performance (Picton,
Campbell, Barideau-Braun and Proulx, 1978). However, at present there is a lack of suitable techniques for the measurement of psychophysiological efficiency.
V. Brief summary of main findings

This thesis demonstrated that event-related potentials (ERPs) associated with psychological processes of anticipation and selective attention can be reliably recorded when subjects perform a continuous involvement perceptual-motor task. Anticipatory potentials (APs) consisted of slow negative shifts in the EEG which occurred during the 500-msec period prior to a racquet hit in the video game task. These APs likely represented both the psycho-motor preparation for a racquet hit and the anticipation of the feedback stimulus (1000 Hz tone) which signalled a successful hit. APs were found to have greater amplitude over the hemisphere contralateral to the primary direction of the subject's orientation. That is, APs were larger over the left hemisphere for subjects in Group N, and larger over the right for subjects in Group R.

Selective attention was measured by the difference in poststimulus ERP negativity between wall bounce tone presented in relevant and irrelevant auditory channels. Between 120 msec and 200 msec after stimulus presentation, ERP negativity was greater in response to relevant stimuli. At around 200 msec poststimulus it was shown
that this selective attention effect was greater in the hemisphere contralateral to the direction of the subject's orientation. This result suggested that orientation may have primed the contralateral hemisphere as evidenced by the AP asymmetries, and that the effect of this priming might be to enhance certain aspects of selective attention which are measured in the ERP at around 200 msec after stimulus onset.
References


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