Cognition and Event-Related Potentials

I. The Relation of Negative Potentials and Cognitive Processes

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INTRODUCTION

A variety of negative components have been identified that appear to reflect various aspects of information processing. These components vary in terms of the circumstances under which they are elicited, their scalp distributions, and the ways in which they are affected by stimulus parameters and instructional sets. The latency range encompassed by the various waves is extensive, varying from as early as 50 ms to as late as 3 or 4 s after the eliciting stimuli. Since the interpretation of the functional significance of the components often takes their relationships to each other into account, this paper will begin by briefly describing the various waves. In so doing, an

attempt will be made to provide just enough background as to when the components are elicited and how they respond to experimental manipulations, so that readers who do not work directly with these components can more easily follow the discussion of the issues.

Processing Negativity

For reviews, see Hillyard *et al.* (1978) and Näätänen and Michie (1979). Waves designated as processing negativity are generally obtained when two or more sets of stimuli are randomly interspersed and the subject is given a task (such as counting) with regard to one of the stimuli (the target). The waves, which are negative in polarity, are larger to target and nontarget stimuli processed in the same channel as the target, can begin 50 ms after the stimulus and last a few hundred ms. This negativity is relatively insensitive to stimulus probability, is modality specific in its scalp distribution, and includes the following waves.

Nd Wave

The Nd wave was previously called the N1 effect. Hillyard, Näätänen, and their respective colleagues, have proposed that this wave occurs when the set of stimuli that contains the target can be distinguished from the other set (or sets) of stimuli on the basis of simple stimulus characteristics or features, such as location and pitch (FIGURE 1).

Feature and Target Selection Negativities

Harter and colleagues have proposed that processing negativity may reflect many types of hierarchical serial and parallel selection processes, their number and nature depending on the complexity of the neural channels representing and processing the relevant and irrelevant stimuli. If the target is characterized by two or more features, feature selection occurs before target selection. The different types of selection processes are reflected by the difference in the amplitude, time course, and scalp distribution of the processing negativity associated with a given stimulus, due to a change in the nature of the target stimulus from one condition to the next. In FIGURE 2, for example, the increase in negativity following stimulus type 1 flashed to the left visual field when that stimulus was irrelevant (bottom, left column) compared to when it was relevant (top, left column) reflects two selection processes. The first was reflected by the increased negativity when the relevant stimulus was in the same (rows 1 and 2) rather than the opposite (row 3) visual field or location as the stimulus to which ERPs were recorded. This increase started at about 100 ms poststimulus and continued to about 275 ms poststimulus. It is similar to Nd in that it follows irrelevant stimuli in the same visual field as the relevant stimulus and usually contains the N1 wave (row 2). A second increase in negativity occurred in parallel with the first and was associated with relevant (row 1), rather than irrelevant (row 2), stimuli in the same visual field. It started at about 200 ms poststimulus and continued through about 275 ms. In addition to reflecting task relevance, this negativity also reflects the selection of the conjunction of features that define the relevant stimulus. These two
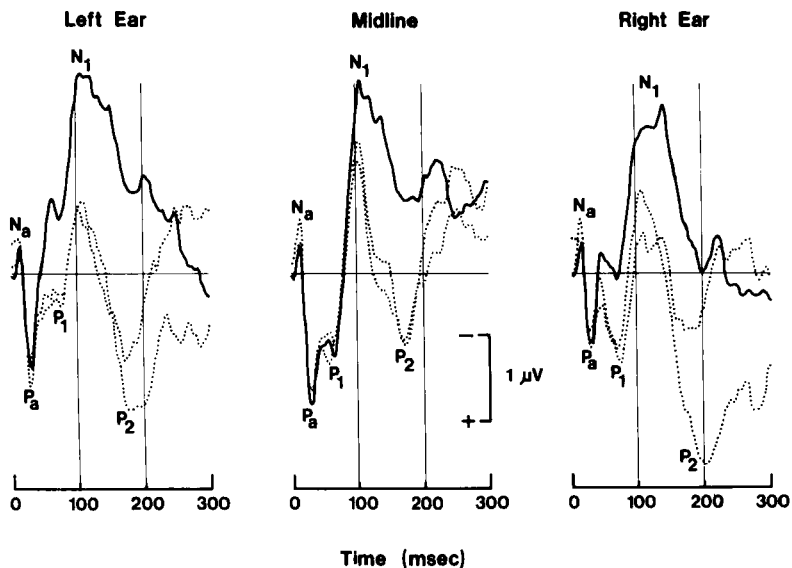
FIGURE 1. Vertex ERPs to left ear, midline (binaural) and right-ear stimuli when attended (solid line) and when unattended (dotted lines). Nd is reflected in the enhanced negativity associated with attending *versus* not attending the stimuli. [From Van Voorhis *et al.*, 1976 (unpublished); courtesy S. A. Hillyard.]

types of selection negativities, due, in this example, to interlocation cues, are also illustrated by the difference potentials shown in Harter *et al.* (this volume).
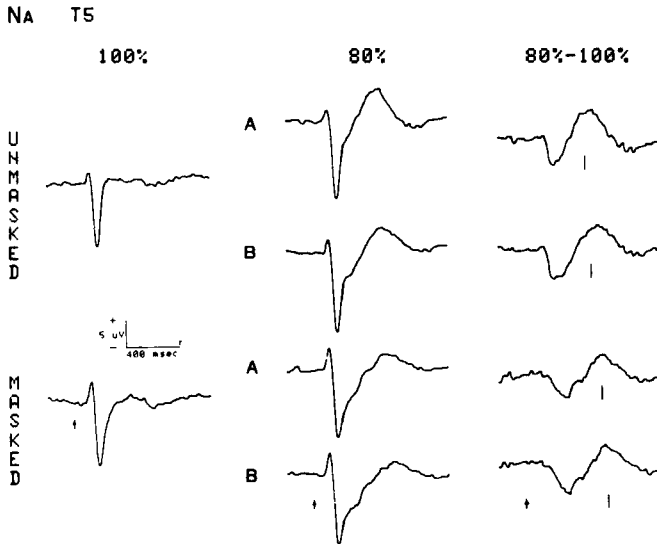
N_A

This component, based on experiments of Ritter, Simson, and Vaughan, has a constant onset latency for a given intensity of about 150 ms for visual stimuli and was obtained by subtracting the ERP associated with a stimulus presented in a simple RT task from the ERP associated with the same stimulus (or category of stimulus) when it was presented on 80% of the trials of a GO-NOGO or choice RT task. The peak latency of this component, which precedes the peak of N2, is related to the complexity of the stimulus presented and increases by about 70 ms with the introduction of a mask that makes it harder to perceive the stimuli (FIGURE 3).

N2 (N200, Mismatch Negativity)

Generally obtained when infrequent changes are randomly embedded in a train of stimuli, this component is inversely related in amplitude to stimulus probability and is modality specific in its scalp distribution. It is elicited by infrequent stimulus changes whether they are attended or ignored, and is followed by P3 (P300) when the changes are task relevant (FIGURE 4). For reviews, see Donchin *et al.* (1978) and Näätänen (1982).

CENTRAL VEPs

FIGURE 2. Two types of equiprobable stimuli were flashed randomly in either the left or right visual field. ERPs were obtained to a given stimulus flash (stimulus type 1 in this figure) under three types of attention conditions which differed in terms of which visual field and stimulus type was defined as task relevant: (1) A̲L̲T—type 1 in the left visual field was relevant (the ERP was to the relevant target stimulus), (2) A̲L̅T̅—type 2 in the left visual field was relevant (the ERP was to an irrelevant stimulus in the same visual field as the relevant stimulus), and (3) A̅L̅T̅—type 2 in the right visual field was relevant (the ERP was to an irrelevant stimulus in the opposite visual field as the relevant stimulus). The three superimposed tracings reflect replications of the same subject, each being an average of 64 individual responses. Note the main change in waveform due to attending the location of the flash (A̲L̲T vs. A̅L̅T̅ conditions) was an increase in negativity between about 100 and 275 ms poststimulus and an increase in positivity between about 300 and 450 ms. The main change in waveform due to attending the type of flash at a given location (A̲L̲T vs. A̲L̅T̅ conditions) was a further increase in negativity between about 200 and 275 ms and an increase in positivity between about 300 and 450 ms (P3 or P300 component or measure). (From Harter *et al.*, 1982.)

FIGURE 3. Grand mean ERPs averaged across subjects at T5 which had the largest N_A using electrodes Cz, Pz, Oz, T5, and left mastoid, referenced to nose tip. In the upper half of the figure, the stimuli were unmasked and, in the bottom half, the stimuli were masked. Left column: the letter F presented on all (100%) the trials of a simple RT task. Middle column: ERPs associated with stimuli that occurred on 80% of the trials of a choice RT task. Task A: subjects respond one way for letters (80% of trials) and another way for digits (20% of trials). Task B: subjects respond one way for four letters (20% of the trials) and another way for all other letters of the alphabet (80% of trials). Right column: Difference waveforms obtained by subtracting the waveforms in the left column from the waveforms in the middle column, separately for the unmasked and masked stimuli. Note that the onset of the negative wave in the difference waveforms, N_A, is constant across conditions, whereas the peak latency of N_A is affected by whether the stimuli are masked or unmasked. Arrow: stimulus onset. Vertical bar: RT averaged across subjects for the stimuli which occurred on 80% of the trials.

N400

This component was first observed in response to semantically anomalous words that completed sentences presented one word at a time (FIGURE 5). At parietal sites, a wave similar to N400 is also elicited when sentence stems are followed by pictures of contextually anomalous objects (*e.g.*, "I planted string beans in my . . ." followed by a line drawing of a car). For a review, see Kutas, in press.

Very Late Slow Negative Waves

These include the O wave, early CNV, slow negative wave, and negative afterwaves. There are two negative components in this complex, the first usually peaking between 600 and 800 ms, the second peaking beyond one second in latency and lasting as long as three or four seconds (FIGURE 6). The circumstances under which the

first two waves are elicited are quite broad, being obtained in passive conditions as well as in whatever conditions elicit N2 and P3. For reviews, see Gaillard (1978) and Loveless (1979).

PROCESSING NEGATIVITY

Nd Wave

In the original formulation of Hillyard and colleagues, this component was considered to reflect selection between channels (stimulus set), and the P3, which was
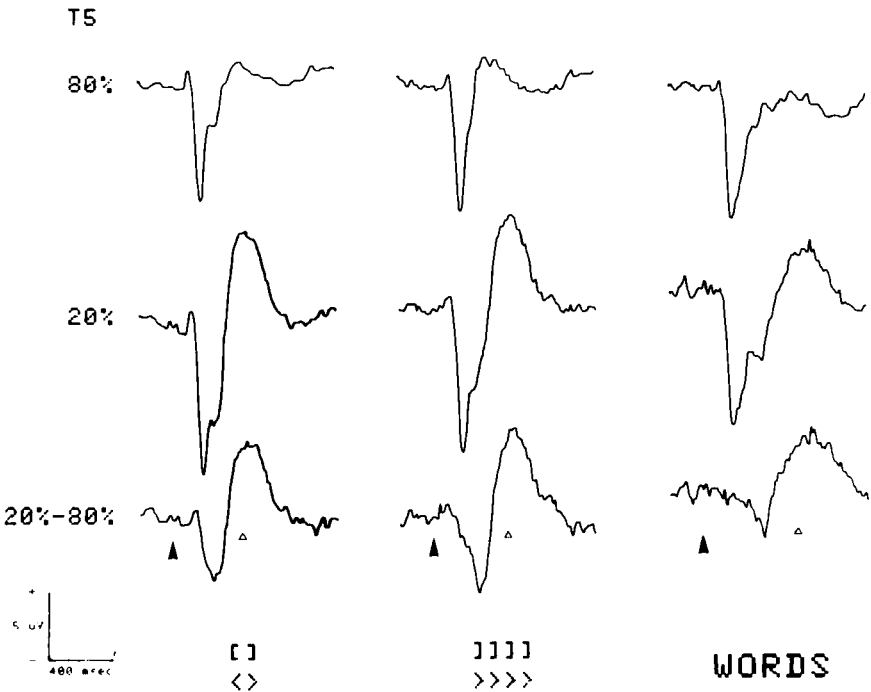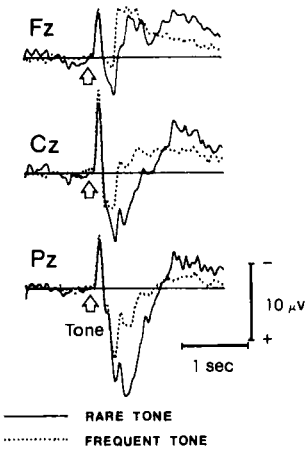

FIGURE 4. Grand mean ERPs averaged across subjects from three discrimination tasks. Left column: in 80% of the trials, two brackets, or two angles, faced each other, as illustrated on the bottom. On 20% of the trials, both brackets or angles reversed direction. Middle column: four brackets, or angles, all faced in the same direction, as illustrated, on 80% of the trials. On 20% of the trials, one of the four brackets or angles randomly changed. Right column: 80% of the stimuli were of one semantic category, *e.g.*, male names, and 20% of the stimuli were of another semantic category, *e.g.*, female names. In all conditions, subjects responded to the stimuli that occurred on 20% of the trials. Top row: ERPs associated with the frequent (80%) stimuli. Middle row: ERPs associated with the infrequent (20%) stimuli. Bottom row: difference waveforms obtained by subtracting the ERPs in the top row from the ERPs in the middle row for each condition. N2 is the negative wave in the difference waveforms. Arrow: stimulus onset. Open triangle: RT averaged across subjects.
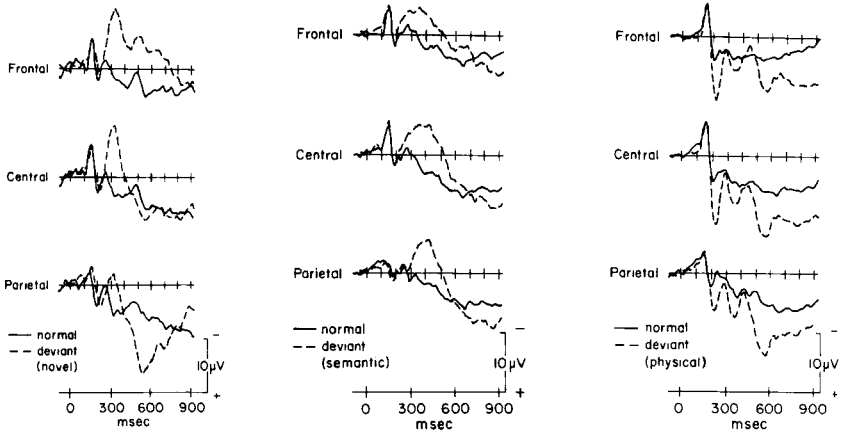
FIGURE 5. Column 1 shows the comparison of the grand average ERPs (across all subjects) to the normal, semantically congruent seventh words and the deviant novel slides. N = 40/subject for novels and 100–120/subject for words. Columns 2 and 3 show grand average waveforms to semantically and physically deviant words, respectively. See Kutas and Hillyard, this volume.

larger for the infrequent stimulus changes of the attended than unattended channel, to reflect response set. Hansen and Hillyard (1980), however, found that the onset of the Nd wave systematically increases in latency as the separation between channels is decreased. They therefore concluded that the onset latency of Nd is related to the duration of processing required to determine which channel a given stimulus belongs to. Thus, Nd does not reflect channel selection itself, but rather further processing of the stimuli determined to be in the relevant channel. In the Hansen and Hillyard study, reaction time to the infrequent stimuli of attended channels was analyzed as a function of separation between channels, but there was no change in RT across conditions. Thus, no relationship between the onset (or peak) latency of Nd and RT was found,

FIGURE 6. Grand mean ERPs averaged across subjects who silently counted the rare tones. 2000 Hz tones occurred on 75% of the trials and 1000 Hz tones occurred on 25% of the trials. The first component of the O wave peaks between 600 and 800 ms latency, is negative at Fz, and is positive at Pz. The second component of the O wave peaks around 1200–1300 ms in latency, is negative at all recording sites, but tends to be largest at Cz.

indicating that the time it took to differentiate the channels (as reflected by Nd onset latency) did not affect the time required to discriminate the infrequent from the frequent stimuli within a relevant channel. Hansen and Hillyard point out that "subjects might change from a sequential selection strategy" for larger channel separations, *i.e.*, first selecting the channel (by way of stimulus set) and then selecting the infrequent stimulus within a channel (by way of subsequent response set), to "a parallel strategy in which both dimensions are evaluated concurrently" (p. 288), *i.e.*, the dimensions separating the channels as well as the frequent and infrequent stimuli. However, the data are also compatible with an interpretation in which subjects process in parallel the dimensions that separate channels and separate frequent from infrequent stimuli within channels in all conditions. An N2 component of equal amplitude has been reported to be associated with the infrequent stimuli of both channels (Näätänen *et al.*, 1978), whereas Nd is larger for the stimuli of the attended channel. The onset of Nd could indicate the time it takes to determine that a stimulus is in the relevant channel and N2 could index infrequent stimulus changes, irrespective of channel. By putting the two pieces of information together (that a stimulus is in the relevant channel and that it is an infrequent change), a target would be identified. On this view, whichever of the two components has the longer latency would determine the earliest time that the two pieces of information could be put together. So long as the onset latency of Nd does not exceed the latency of N2 associated with the discrimination between the frequent and infrequent stimuli within channels, then Nd latency would not affect RT. This interpretation could explain the results of the Hansen and Hillyard experiment in which RT and Nd were not related. This interpretation is an embellishment of a position taken by Näätänen *et al.* (1978).

Näätänen and Michie (1979) suggest that processing negativity could reflect two processes: voluntary orienting to stimuli in the relevant channel (*vs.* involuntary orienting to the infrequent stimuli of both channels, as reflected in the N2 component) and further processing of stimuli ascertained to be in the relevant channel. This view, involving a dual role of processing negativity, receives support from the identification of two components associated with this negative activity by Hansen and Hillyard. While the latter investigators find Näätänen's suggestion of further processing plausible, they point out that "an increased negativity may follow attended channel stimuli even when there is no requirement for discriminating between targets and nontargets within the channel (Schwent, Hillyard and Galambos, 1976)" (Hansen and Hillyard, 1980, p. 288). Orienting to, and further processing of, relevant stimuli may occur even though there is no requirement for additional evaluation of the stimuli. At the present time, however, there are no data that directly test any particular interpretation concerning the nature of the processing reflected by either of the two components associated with processing negativity. A possible clue in this regard might be found in the positive relationship between the amplitude of Nd and target detection performance as measured by d' found in Hansen and Hillyard.

Feature and Target Selection Negativities

Harter, from an overview based on several studies (*e.g.*, Harter and Salmon, 1972; Harter and Previc, 1978; Harter and Guido, 1980; and work in progress), concluded that processing negativity can reflect many different selection processes. These were referred to as location selection, spatial frequency selection, orientation selection, conjunction selection, *etc.* In these studies, two or more equiprobable stimuli were presented randomly and one was designated task relevant. Selection negativities were

derived by comparing ERPs to a given stimulus when different types of target stimuli were task relevant. Given that different types of stimuli are selectively processed by different exogenous neural information channels, the selection negativities are presumed to reflect the priming (or suppressing) effects of selective attention on the ability of these channels to process information. They are modality specific for vision.

When multifeatured stimuli are designated task-relevant targets, selection negativity reflects a hierarchical series of overlapping selection processes. The early negativities, which may start as early as 100 ms poststimulus for location selection, reflect selection in neural channels processing the different features of the target stimulus. They follow both the target stimulus and nontarget stimuli having features in common with the target stimulus. Their onsets are poorly correlated with behavioral RTs and depend on the features contained in the target stimulus. The following sequence of selection negativities was proposed: location (100 ms), contours (130 ms), color or spatial frequency (150 ms), and orientation (200 ms). Less selectivity of attention effects is indicated by these early negativities than by behavioral measures. The later negativity reflects selection in the neural channels processing the conjunction of features or the relevant target stimulus *per se*. The selection of conjunctions begins at about 250 ms and the selection of simple words at about 300 ms. The latest negativity reflects the same degree of selectivity as behavioral measures of attention and its termination is correlated with the latency of behavioral responses. (Latencies are approximations and will vary with stimulus and task variables.) Recent data indicate that the selection of conjunctions of features is greater over the left hemisphere, regardless of the nature of attended information (verbal *vs.* spatial) and hand of response (left *vs.* right). The time course of the different types of selection negativities corresponds roughly with that suggested by neurophysiological data from animals in terms of the level of the nervous system at which various types of information are represented and coded: precortical (location, color, and contrast) and visual cortex (spatial frequency and orientation).

Note that the selection negativities are sequential only in terms of their onset. Since each selection process has considerable duration (100 to 400 ms or more depending on the time of the behavioral response), successive processes overlap in time and are active in parallel.

N_A

Ritter *et al.* (1983) found that, whereas N_A onset was constant across conditions, its peak latency became longer as stimulus complexity increased. The N2 component began after the onset but before the peak of N_A. Thus, these waves had successive but overlapping timing, which is similar to what Harter reported for processing negativities. Increases in peak latency of N_A were associated with delays of N2 and subsequent RT. In another study (Ritter *et al.*, 1982) the peak latencies of N_A and N2 were manipulated independently. Employing visual stimuli, a classification task was kept constant, while the difficulty of perceiving the stimuli was altered by introducing a mask. The onset of N_A was constant for mask and no-mask conditions, but the peak latency of N_A was about 70 ms longer under the mask conditions (FIGURE 3). The time from the peak of N_A to the peak of N2 was not affected by whether or not the mask was used. By contrast, the time interval between the peak latencies of N_A and N2 became greater when the complexity of the classification task was increased. The latter was true both for conditions where no mask was used and for conditions where the stimuli were masked. Taken together, these two studies indicate that the peak latency of N_A is

affected by stimulus complexity and difficulty of perceiving the stimuli, whereas the relative timing of N2 is affected by the complexity of the classification task. N_A is interpreted as related to pattern recognition and N2 considered related to the process of stimulus classification.

N2 (N200, Mismatch Negativity)

There appeared to be a consensus that N2 reflects some aspect of the process of discrimination. Ford suggests that N2 has the properties of a mismatch detector and Näätänen suggests that this component be called mismatch negativity. By contrast to the previous discussion of processing negativity, N2 has been shown to correlate in latency with RT (*e.g.,* Ritter *et al.,* 1979; Renault and Lesevre, 1979).

Näätänen points out that N2 by itself may not reflect target selection. He and colleagues have found that N2 is similar in amplitude to infrequently occurring stimuli that are targets and equally infrequent nontarget stimuli in the same run. Moreover, N2 is associated with infrequent target stimuli that subjects fail to detect (Näätänen *et al.,* 1982). Thus, whereas N2 reflects the registration of a mismatch, it may not reflect detection of a target. These data extend the results of Squires *et al.* (1975), who showed that infrequent tones elicit an N2 (and P3), whether the subject counts (treats as targets) the infrequent or the frequent stimuli. In the latter study, it was also found that infrequent tones elicited N2 (without P3) when subjects ignored the stimuli. Taken together, these findings for N2 have led Näätänen to support the suggestion of Snyder and Hillyard (1976) that N2 reflects the neuronal mismatch process associated with the orienting reflex, adding that N2 reflects an automatic process which is not under voluntary control. Näätänen points out that, by contrast, processing negativity is under voluntary control. This dichotomy between the two components can be illustrated in a situation where there are two channels (*e.g.,* dichotic stimulation) and embedded within each channel are infrequent stimulus changes. Subjects can voluntarily direct their attention to either channel in an effort to detect its infrequent changes. The processing negativity will be larger for the stimuli of the channel to which attention is directed, but an N2 of equal amplitude is elicited by the infrequent changes of both channels, irrespective of the direction of attention. Ford and Hillyard (1981) have recorded a negative peak that is sensitive to mismatches as well as attention and, thus, this peak may be a combination of mismatch negativity and processing negativity. In their study, the deviant events were tones that occurred out of pace (early) in a sequence of otherwise regular events. These early tones elicited a large negative component at about 130 ms, which they called N_E. Like the mismatch negativity, N_E is an obligatory response, since it was elicited even when the early tones were not task relevant. However, N_E also has an element of processing negativity, since it was larger when early events were task-relevant. It is interesting that the mismatch negativity component of N_E is not present in the visual ERP to early light flashes recorded in an analogous visual paradigm (Ford *et al.,* 1982). This may be due to differences between the auditory and visual systems and the characteristics of a compelling stimulus in each modality. However, the processing negativity component of N_E is present to early light flashes.

Data collected by Ritter *et al.* (1983) indicate that N2 might be under voluntary control in some circumstances and not others. In one condition, words were presented visually from two semantic categories (*e.g.,* male and female names) and subjects required to respond differentially. A larger N2 component was associated with the

semantic category occurring on 20% than with that occurring on 80% of the trials (FIGURE 4). When the same stimuli were presented and subjects instructed to respond in the identical way to all of the words (as in a simple RT task), no N2 component was observed. In these conditions, the processes underlying N2 appear to be under voluntary control. Were subjects asked to categorize a set of words in different ways on separate runs (*e.g.*, nouns *vs.* verbs; singular *vs.* plural, *etc.*), it would appear likely that N2 would shift its maximal amplitude to different subsets of words. On the other hand, when two stimuli that differed only in physical characteristics were presented with probabilities of 80 and 20 percent, N2 was observed when subjects responded selectively (FIGURE 4), as well as when all stimuli were responded to in an identical manner (as in simple RT). In the latter condition, N2 appeared to reflect an automatic response. It is possible that, when N2 is under voluntary control, it is sufficient to produce detection of targets.

Renault *et al.* (1982) distinguished two related negative components: (1) an N2 that is modality specific and correlates in duration with the duration of perceptual processing and with RT and (2) a modality nonspecific N2 (vertex N250), which is constant in duration, probably associated with orienting, and overlaps the later portion of the modality specific N2. For Renault, these results support the idea that orienting (reflected by the nonspecific N2) is dependent on stimulus identification and related to template matching (reflected by the earlier modality specific N2). Harter supported Renault's view that there are two related negative components, calling the modality-specific N2 "selection negativity" and the later nonspecific fronto-central component "orienting negativity." Rohrbaugh contends, however, that the absence of modality specificity would rule against a wave's candidacy for reflecting orienting. There are strong modality influences in the orienting response: vasoconstrictive and heart rate components of the orienting response are greater for auditory than for visual stimuli, the orienting response habituates more slowly to auditory than visual stimuli, *etc.* Renault points out that the effect of stimulus modality on the vertex N250 has not actually been studied systematically, the term "nonspecific" only being related to the apparent lack of variation in the scalp distribution of this wave with stimulus modality.

N400

The main focus of discussion on this negative wave concerned whether N400 and N2 are the same or different components, which, in turn, led to consideration as to how components should be defined. Kutas lists three criteria that are likely to be included in differentiating components, each of which has problems. Latency was one criterion, although Kutas points out that Nd, N2 and P3 have all been shown to vary in latency as a function of task variables. She questions, however, how much latency variability can be tolerated for either the psychological or physiological processes a given component might represent. In this case, the negative wave interpreted as N2 by Ritter and colleagues for the semantic category discriminations, described above, has virtually the same latency as the N400 found in Kutas and Hillyard (1980).

The scalp distribution of N400, a second criterion, is different from that of N2 when both are elicited by visual stimuli but N400 is associated with anomalous completions of sentences and N2 with physical changes. The scalp distribution of P300 varies both between subjects and across conditions and nevertheless is generally labeled the same component. Kutas believes that similar variations in the topography of negative components can be found. Kutas questions, however, the wisdom of considering P300 to be the identical component over a wide range of tasks, latencies and scalp distributions.

A third criterion is experimental manipulation. The decision about the N400-N2 identity would be easier to determine if more were known about the effect of modality, task instructions, the effect of stimulus probability, *etc.*

Presently, Kutas believes that N400 and N2 are distinct brain processes that differ in function and that it is too soon to specify how. The N400 appears to be a composite of at least two negative components, the first (around 200–300 ms) possibly being N2. She is uncertain whether N400 overlaps N2 or whether there are several components within the 200–600 ms range each affected by semantic deviancy.

Polich described data collected with Vanesse and Donchin, still being analyzed, which he feels indicates that N400 and N2 are the same component. One of the reasons for differentiating the two components originally given in Kutas and Hillyard (1980) was that N400 in their study was not followed by P300, as generally occurs when N2 is elicited by attended stimuli. Polich found, however, that the late negative wave in his data is followed by P300 if the anomalousness of the sentence completions is made task relevant. It was also found that this late negative wave was not dependent on the presentation of sentences. For example, sequences of seven words were presented visually, where the first six words belonged to the same category and subjects had to determine whether or not the seventh word belonged to the same category. Seventh words that did not belong to the category from which the first six were selected elicited the late negativity (again followed by P300, presumably due to the task-relevant nature of the judgment concerning the category of the seventh word). Thus, if Polich's contention that this late negativity and N400 are the same component is true, then anomalousness may not be a necessary ingredient in the elicitation of N400. The N400 obtained in sentences can be conceived of as being elicited by words that are not members of a subset of probable words established by the context of the preceding portion of the sentence and as being elicited by words that render the meaning of a sentence anomalous. In this regard, Polich suggests that N400 can be thought of as reflecting a categorical mismatch detector, analogous to the physical mismatch of stimulus parameters discussed above for N2 associated with nonlanguage stimuli.

The negative waves obtained with language stimuli by Kutas, Polich, Ritter, and their respective colleagues, all had peak latencies around 400 ms. Given the data that are currently available, the scalp distributions of these waves appear to be grossly similar, although Kutas (in press) has found that N400 is larger over the right than the left hemisphere. In Ritter *et al.*, a significant difference was found between the topography of N2 associated with physical and that associated with semantic discriminations (all stimuli were visual). On the basis of topography, taken by itself, all the negative waves associated with language stimuli might be considered variations around the same component, separate from the N2 associated with nonlinguistic stimuli. Topography alone, however, does not provide sufficient grounds to differentiate components. (Motor potentials vary in scalp distribution as a function of which limb is moved, but are not designated as being different components on that account.) No member of the panel expressed any reservations about N2 being modality specific in its distribution. The reason why components might be considered the same, despite substantial differences in topography, is that they appear to reflect comparable functional activities. In the study by Ritter and colleagues, the latency of N2 associated with physical discriminations had about the same temporal relationship with RT as did the N2 associated with semantic discriminations. Since N2 has been shown to vary in latency as a function of discrimination difficulty, it does not seem unreasonable that N2 could have a latency of about 400 ms associated with semantic discriminations.

Another basis for distinguishing between the negative waves obtained with language *versus* nonlanguage processing is the presumed differences in physiological mechanisms associated with them. On this argument, the N2 component associated

with auditory discriminations should be considered different from the N2 component associated with visual discriminations, since the physiological mechanisms that accomplish auditory discriminations (*e.g.*, pitch), are likely to be different from those associated with visual discriminations (*e.g.*, a vertical *versus* a horizontal bar). It is thus possible to end up with a different component for virtually any kind of discrimination that can be experimentally associated with N2. As far as is known, however, ERP components may not reflect the fine-grained physiological mechanisms related to particular cognitive processes, but rather only some general aspect of cognitive functioning. Kutas believes that the concepts of function we generally use are too vague to provide adequate grounds for defining components. While it is true that our concepts are vague, they are no better than the range of experimental manipulations that can be shown to modify the negative waves discussed by this panel. Thus, the successful use of a greater variety of task variables should simultaneously refine the concepts of function we employ and aid in identifying and distinguishing the components being studied.

Very Late Slow Negative Waves

These include the O wave, early CNV, slow negative wave, and negative afterwaves. Rohrbaugh believes that the first component of the O wave (SNW1) may be identical to the SW initially reported by Squires *et al.* (1975). The second component (SNW2), which is largest at the vertex, can last as long as three or four seconds. Both components are responsive to stimulus probability, though in other respects they appear to vary independently. Rohrbaugh remarked that those circumstances where true CNVs are found (*i.e.*, where there are long S_1–S_2 intervals and no required motor responses) can usually be accounted for by the long duration of the second component. In order to demonstrate that a wave is contingent, he points out, it is necessary that the wave disappear when the contingency is removed. In removing the contingency, though, some attempt must be made to mimic the signal value of the warning stimulus. Rohrbaugh has found that, when this is done, the O wave still appears. He also points out that the signal value of a stimulus can vary as a function of the task associated with S_2. The O wave might thereby assume different appearances, but these changes reflect changes imparted by the task to the warning signal's role and not what is expected at the end of the foreperiod.

According to Rohrbaugh, the SNW1 is modality specific in its scalp distribution, whereas the SNW2 is not (although it is larger in amplitude for auditory than visual stimuli). He thinks these characteristics of the O wave are related to a variety of behavioral differences associated with modality, these differences reflecting the nature of orienting functions.

Gaillard reiterated a number of arguments (from Gaillard, 1980) that support a relationship between the terminal CNV (the negativity that occurs before S_2 when the interval between S_1 and S_2 is three or more seconds) and the readiness potential. In brief, these are based on the morphological and topographical similarities between the terminal CNV and the readiness potential, the relationship between the terminal CNV and the mechanics of the motor response, its dependency on foreperiod duration and variability, and its attenuation or absence when no response is required.

The SNW1 peaks at about the same latency as the SW of Squires *et al.* (1975) and they have often been considered the same component. In most instances, both waves are affected in the same way: Each is enhanced for rare or novel stimuli and for stimuli that are relevant, attended, and contain information. Gaillard, however, points out that

there are some instances where the SNW1 is affected and the parietal maximum SW is not. For example, if S_1 in an S_1–S_2 paradigm indicates that a speeded response is to be made to S_2, the SNW1 is enhanced, but the parietal SW is not, compared to when S_1 indicates a delayed response should be made to S_2 (Gaillard and Perdok, 1980).

Gaillard proposes that the SW reflects the last stage of the stimulus evaluation process, whereas the SNW1 and 2 reflect processing that is more related to responding and may represent, for example, counting or resetting for a response. This is consistent with topography, the SW being largest over the parietal region and the SNW1, though modality specific in its distribution, having a more frontal maximum. These scalp distributions fit with Luria's model of the functional organization of the brain, in which the parietal association region performs the last stage of processing on sensory input and in which the function of the frontal lobes is to organize behavior.

CONCLUSIONS

There were a number of controversial issues concerning most of the negative components encompassed by this panel. They include: how to label components, the manner in which components should be defined, the interpretation of the fuctional significance of and the relationship between the various components, and the manner in which competing hypotheses might best be put to empirical test.

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