

## EARLY SELECTIVE-ATTENTION EFFECT ON EVOKED POTENTIAL REINTERPRETED\*

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In a dichotic listening situation stimuli were presented one at a time and at random to either ear of the subject at constant inter-stimulus intervals of 800 msec. The subject's task was to detect and count occasional slightly different stimuli in one ear. In Experiment 1, these 'signal' stimuli were slightly louder, and in Experiment 2 they had a slightly higher pitch, than the much more frequent, 'standard', stimuli. In both experiments signals occurred randomly at either ear. Separate evoked potentials from three different locations were recorded for each of the four kinds of stimuli (attended signals, unattended signals, attended standards, unattended standards). Contrary to Hillyard et al. (1973), no early ( $N_1$  component) evoked-potential enhancement was observed to stimuli to the attended ear as compared with those to the unattended ear, but there was a later negative shift superimposed on potentials elicited by the former stimuli. This negative shift was considered identical to the  $N_1$  enhancement of Hillyard and his colleagues which in the present study was forced, by the longer inter-stimulus interval used, to demonstrate temporal dissociation with the  $N_1$  component. The 'Hillyard effect' was, consequently, explained as being caused by a superimposition of a CNV kind of negative shift on the evoked potential to the attended stimuli rather than by a growth of the 'real'  $N_1$  component of the evoked potential.

In an impressive series of experiments, Hillyard and his colleagues (for a comprehensive review, see Hillyard and Picton 1978) have shown that all stimuli within an attended channel (one ear, certain pitch easily

\* The experiments were carried out in the Institute for Perception TNO, Soesterberg, in the summer of 1975 when S. Mäntysalo worked there as a visiting scholar, supported by Suomen Tiedeakatemia (The Finnish Academy of Science and Letters). Please send requests for reprints to A. W. K. Gaillard, Institute for Perception TNO, Kampweg 5, Soesterberg, The Netherlands.

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discriminable from that of other stimuli, etc.) under certain conditions engender an enhanced  $N_1$  component of the evoked potential (EP) in comparison to that elicited by the stimuli of unattended channels. This finding is the first valid demonstration of a selective-attention effect on EP with such a short latency (around 100 msec from stimulus onset, sometimes even less). Earlier similar claims are based on data from experimental settings in which the subject has had some possibility for predicting the order of presentation of the relevant and irrelevant stimuli beyond the chance level (see Karlin 1970 and Näätänen 1967) or in which some other methodological reasons make the interpretation of the results equivocal (for a review, see Näätänen 1975).

The experimental situation used in the original Hillyard et al. (1973) study involved a dichotic listening task in which one tone pip at a time was randomly delivered to either ear of the subject. One of these tone pips was occasionally replaced by a slightly higher tone pip in either ear and the subject's task was to try to detect and count these 'signal' or 'target' stimuli in one ear. (The other, much more numerous, stimuli were called standard stimuli.) That was the way to direct the subject's attention to one ear at a time. The main result was that the  $N_1$  component of the EPs of the attended ear (signals and standards alike) was enhanced compared to that of the EPs of the unattended ear.

In achieving this early selective-attention effect, the authors themselves emphasized the following features of their experimental design: (1) the relevant and irrelevant stimuli differed from one another both in spatial localization and pitch attributes, making them easily distinguishable; (2) the fast rate of presentation of the stimuli – on an average, there were at least two stimuli per second – which made it impossible to discriminate stimuli in one ear and fully appreciate the stimuli to the other ear at the same time; and (3) the difficulty of the task which ensured that the subject really had to be selectively attentive in order to cope with the task requirements.

Because of the short latency of this selective EP effect, the authors interpreted it as indicating an early 'input selection', or 'channel selection', or 'stimulus set' mode of attention based upon simple physical cues rather than a late selection process occurring after complete evaluation of all stimuli. Among other things, the authors wrote that "the early latency of the attention effects upon  $N_1$  (evident at 60 to 70 msec in most subjects) suggests that the underlying attentional process is a tonically maintained set favoring one ear over the other

rather than an active discrimination and recognition of each individual stimulus" (Hillyard et al. 1973: 179). On the other hand, it was suggested by Näätänen (1975: 286) that, irrespective of the short latency of this effect, it can reflect a very fast processing effort to discriminate between a target and a standard after the input was found to be on the attended side. According to him, there still was time enough for a rapid discrimination to intervene between the stimulus onset and the effect on the  $N_1$  component and, therefore, it would be premature on the basis of these data to suggest the operation of a tonically maintained set favoring one ear over the other.

In the Hillyard et al. (1973) study, signal stimuli delivered to the attended ear evoked a large late positive wave ( $P_3$  or  $P_{300}$ ), but no earlier differences between the signal and standard stimuli within the attended ear were observed,<sup>1</sup> consistently with their afore-given interpretation. If such differences in the  $N_1$  component were also observed, then the idea of the  $N_1$  enhancement as reflecting the 'stimulus set' mode of attention, a fast preliminary analysis of simple physical stimulus attributes in order to choose certain kinds of stimuli for further, and more profound, processing, would run into problems (if this enhancement could not be totally accounted for by refractory factors). The finer discrimination, that between the signal and standard stimulus within the attended channel, should, according to this explanation, occur – or be reflected in EP – post  $N_1$ . In fact, the latter discrimination was suggested as reflecting the 'response set' mode of attention (Broadbent 1970),  $P_3$  reflecting "the selective recognition of the higher pitched tones in the attended channel by a response set mechanism which is coupled with an appropriate cognitive response (counting)" (Hillyard et al. 1973: 180).

In the following, data from two rather similar experimental situations (using, however, a constant ISI), suggesting a reinterpretation of the Hillyard et al. (1973) effect, will be reported.

<sup>1</sup> In their later work, published since the present study was started, differences between the EPs to signals and standards were occasionally found already in the  $N_1$  component, but these findings did not seem to evoke much of the attention of the authors.

## Experiments 1 and 2

### Method

#### *Subjects and apparatus*

Five highly experienced Ss (age 22–33 yr) were used in a sound-attenuating, electrically shielded test room (Amplifon). The EEG was recorded with chlorided silver-silver disc electrodes from the vertex ( $C_2$ ) and temporal ( $T_3$  and  $T_4$ ) positions referred to the right mastoid. Vertical eye movements were recorded from above and below the right eye. An electrode attached to the left ear served as a ground. After a.c. amplification (time constant 6 sec) the EEG and EOG signals were stored on magnetic tape (Philips Analog 14). Timing of the signals, including the trigger, was carried out by the PSARP equipment (Van Doorne and Sanders 1968).

#### *Procedure*

With constant intervals of 800 msec, either ear of the S (in random order) received a 'standard' stimulus which was occasionally<sup>2</sup> replaced by a 'signal' stimulus slightly differing from the standard. The stimuli were given via earphones (Sennheiser HD-414), all in a single random sequence. The S's task was to detect and count silently the signals, either in the left ear or in the right ear, and report their number after each run. No feedback was given.

After a training session of 3200 trials (on a separate day), the Ss participated in two experiments. To reduce eye movements, the Ss were trained during the practice session to fixate a red cross at a distance of 70 cm which was also used during the experiments.

In each session, 16 stimulus series with short breaks were given. The number of the signals varied from 0 to 9% both in the attended and the unattended ear for each series. Both the attended and the unattended ear received 80 signal stimuli and 3120 standard stimuli altogether in a session.

In the first experiment, both the standard and the signal were tones of 1000 Hz with a duration of 31 msec, whereas the intensity was either 70 dB (standard) or 80 dB (signal). This experiment consisted of six sessions per S, which were carried out on separate days.

In the second experiment, the difference between the standard and the signal was in pitch: the standard was a 1000 Hz tone and the signal a 1140 Hz tone. They were of equal intensity (70 dB) and duration (31 msec). This experiment consisted of 2 sessions per S.

The EEG signals were analyzed with a PDP-8 computer. The analysis period was 720 msec (sample frequency 250 c/sec). The EPs of each site were separately averaged for the 4 stimulus categories and for the left and right sides.

EP amplitudes were measured in two ways. Firstly, the peak-to-peak amplitudes of  $P_1-N_1$ ,  $N_1-P_2$ ,  $P_2-N_2$ , and  $N_2-P_{300}$  were taken. Secondly, the peak amplitudes of  $P_1$ ,  $N_1$ ,  $P_2$ ,  $N_2$  and  $P_{300}$  were measured with reference to the baseline (BL). The

<sup>2</sup> The positions of the signal stimuli were random with the limitation that a signal never was the first stimulus after the alternation of the ear stimulated.

latter was determined by measuring the mean potential during the period of 50–0 msec before the onset of the stimulus. The amplitude data were subjected to an analysis of variance.

## Results

### I. Vertex-lead data

*Attended vs. unattended standards.* Attending vs. non-attending to one ear had no effect on the amplitude of the  $N_1$  component ( $BL-N_1$ ) of the standard EPs (fig. 1 and table 1). The only difference between these EPs was a slight but systematic negative displacement of the EP to the attended standards relative to the EP to the unattended standards, which result held for both experiments (fig. 1).<sup>3</sup> This displacement usually started during the downward slope of the  $N_1$  component.

*Signals vs. standards.* The analyses of variance performed show a statistically significant difference in the amplitude of the  $N_1$  component: the  $N_1$  to signals was always larger than that to standards (fig. 1 and tables 1 and 2). This was the case for both  $P_1-N_1$  and  $BL-N_1$  measures. As to  $P_1-N_1$ , in Experiment 2, in which the signals and standards differed only in pitch, the average percentage by which the signal EPs were larger than the standard EPs was 76 for the attended ear and 48 for the unattended ear. The corresponding percentages for  $BL-N_1$  were 86 and 47, respectively.

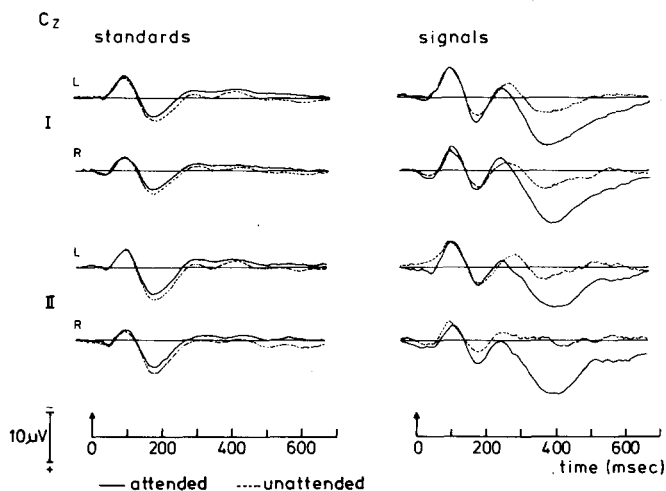


Fig. 1. Vertex EPs (averaged across Ss) to standards and signals separately for the left (L) and right (R) ear when attended and when unattended. I refers to Experiment 1, II to Experiment 2.

<sup>3</sup> In Exp. 1, this effect in  $C_z$  was statistically significant according to the sign test for all the latency values used in this test (200, 300, 400, 500, 600, 670 msec post-stimulus). The same test was performed for  $T_3$  and  $T_4$  and a statistically significant difference was obtained in most cases.

Table 1  
Means of different vertex EP amplitudes in  $\mu V$ s (measured from the averaged data of individual sessions) separately for left and right signals and standards when attended and when unattended

	BL-P <sub>1</sub>	BL-N <sub>1</sub>	BL-P <sub>2</sub>	BL-N <sub>2</sub>	BL-P <sub>3</sub>	P <sub>1</sub> -N <sub>1</sub>	N <sub>1</sub> -P <sub>2</sub>	P <sub>2</sub> -N <sub>2</sub>	N <sub>2</sub> -P <sub>3</sub>	P <sub>2</sub> -P <sub>3</sub>
	Att. Unatt.	Att. Unatt.	Att. Unatt.	Att. Unatt.	Att. Unatt.	Att. Unatt.	Att. Unatt.	Att. Unatt.	Att. Unatt.	Att. Unatt.
Experiment 1										
Left										
Signal	2.2 1.8	6.3 6.0	7.7 6.3	2.3 3.1	13.2 7.6	8.6 8.0	14.2 12.4	10.2 9.4	15.6 10.8	5.4 1.3
Standard	0.8 0.8	4.8 4.5	5.2 6.1	- -	- -	5.8 5.4	10.1 10.7	- -	- -	- -
Right										
Signal	2.7 2.2	4.3 5.2	6.7 5.7	3.3 2.5	14.5 6.8	7.1 7.2	11.2 11.0	10.2 8.3	17.8 9.2	7.7 1.1
Standard	1.4 1.4	3.3 3.0	5.1 5.8	- -	- -	4.6 4.5	8.3 8.9	- -	- -	- -
Experiment 2										
Left										
Signal	1.3 0.9	6.4 5.3	4.3 5.1	2.6 3.6	9.7 4.3	7.8 6.3	10.8 10.6	7.1 8.8	12.3 7.9	5.1 -0.8
Standard	0.9 0.7	3.7 3.7	6.4 7.4	- -	- -	4.6 4.5	10.1 11.2	- -	- -	- -
Right										
Signal	2.3 2.2	4.6 4.2	4.9 3.7	3.1 3.9	13.2 4.3	7.0 6.5	9.6 7.7	9.3 7.5	16.3 8.1	8.1 0.7
Standard	1.5 1.3	2.2 2.7	6.6 6.8	- -	- -	3.8 4.1	8.8 9.5	- -	- -	- -

Table 2

Summary of the *F*-values (*df*: 1, 4) of the analyses of variance on some amplitude measures of the vertex EP for the factors: signals vs. standards and attended vs. unattended ear (the latter analysis was carried out on the signals only).

Experiment	Signals/standards				Attended/unattended (signals only)		
	BL-P <sub>1</sub>	P <sub>1</sub> -N <sub>1</sub>	BL-N <sub>1</sub>	N <sub>1</sub> -P <sub>2</sub>	N <sub>2</sub> -P <sub>3</sub>	P <sub>2</sub> -P <sub>3</sub>	BL-P <sub>3</sub>
1	15.2*	29.3*	12.6*	11.8*	25.8**	22.8**	13.3**
2	2.68	21.3**	29.7**	<1	24.4**	13.3**	21.3**

\**p* < 0.05

\*\**p* < 0.01

Also P<sub>1</sub> (BL-P<sub>1</sub>) appears to be larger for signals. According to the analysis of variance, this effect was significant only for Experiment 1 in which the mean of the signal P<sub>1</sub> was considerably larger than that of the standard P<sub>1</sub>, both for the attended (by 123%) and unattended (by 82%) ear. The respective percentages for Experiment 2 were 50 and 55.

As to the later components, N<sub>1</sub>-P<sub>2</sub> and BL-P<sub>2</sub> showed no statistically significant difference in the analysis of variance. No further comparisons were carried out as the standard EPs had no later component than P<sub>2</sub>. Contrary to signal EPs, there was no P<sub>300</sub> in the standard EPs – they even seem to be slightly negative (relative to BL) during that latency range. Also, a discernible N<sub>2</sub> component was observed in signal EPs (fig. 1).

*Attended vs. unattended signals.* The picture is very systematic and clear, as shown by table 2, the only significant difference being the much larger late positivity in the EPs to attended signals (see also fig. 1). In both experiments, this difference is significant for the following measures: N<sub>2</sub>-P<sub>3</sub>, BL-P<sub>3</sub>, P<sub>2</sub>-P<sub>3</sub>. In Experiment 1 the mean late positivity (BL-P<sub>3</sub>) of EPs to unattended signals was 7.2 µV and to attended signals 13.9 µV. The corresponding values for Experiment 2 were 4.3 µV and 11.5 µV, respectively.

## II. Temporal-leads data

The temporal data were very consistent with the vertex data. This is illustrated by fig. 2 in which the T<sub>3</sub> data corresponding to the C<sub>z</sub> data shown in fig. 1 are represented. The T<sub>4</sub> data were very similar (fig. 3).

## III. Errors

The error rate calculated on the basis of the differences between the number of signals reported by the *S* and the correct number was 7.7% for Experiment 1 and 10.2% for Experiment 2. Most of the errors were of the type of omission.

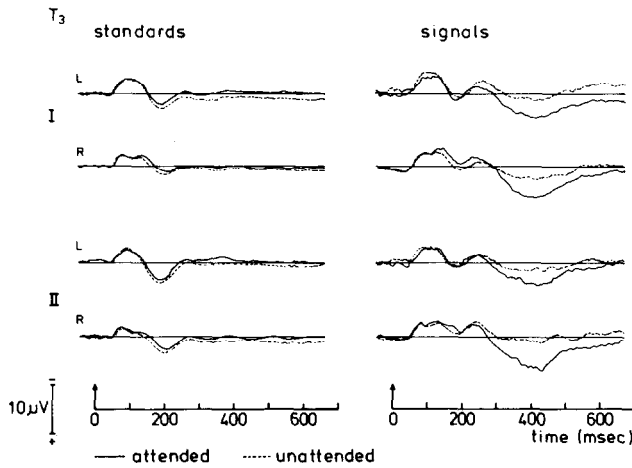


Fig. 2. Temporal (T<sub>3</sub>) EPs (averaged across Ss) to standards and signals separately for the left (L) and right (R) ear when attended and when unattended. I refers to Experiment 1, II to Experiment 2.

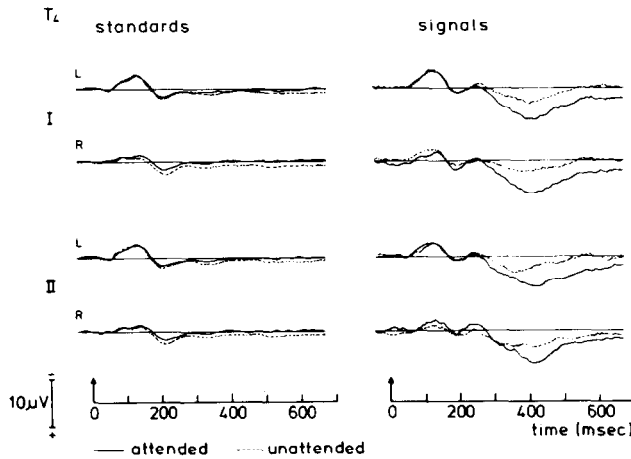


Fig. 3. Temporal (T<sub>4</sub>) EPs (averaged across Ss) to standards and signals separately for the left (L) and right (R) ear when attended and when unattended. I refers to Experiment 1, II to Experiment 2.



## Discussion

The results showed no difference in the amplitude of the  $N_1$  component between EPs elicited by stimuli delivered to the attended and the unattended ear. There was, however, a later negative displacement of the EP to the attended standards with reference to that to the unattended standards (see figs. 1–3). This effect was small but very systematic, commencing usually during the downward slope of the  $N_1$  component (i.e., at a latency of some 150 msec) and lasting at least 500 msec, possibly until the delivery of the next stimulus. (The ISI was constant at 800 msec and the analysis period, shown in figs. 1–3, 720 msec.) It is suggested that the present finding represents another manifestation of the same effect as that demonstrated by Hillyard et al. (1973). This implies that their finding actually involved no enhancement of the 'true'  $N_1$  component but was rather caused by a superimposition on it of a fast CNV-kind of negative wave of perhaps quite a different origin and functional significance. This was suggested by Näätänen (1975: 286) as follows: "It might be that some of the cerebral tissue whose activity is recorded via the vertex electrode, reacted fast enough to the first 'experience' (or to its physiological correlate) of, or related to, task relevance (in this case to the 'left tone' or 'right tone' depending on which side is relevant). Such a fast reaction might perhaps be rapidly increased excitability or impulse activity related to preparation for, or performance of, the difficult pitch-discrimination task involved and this (rather than differences in afferent inflow between relevant and irrelevant standard stimuli) might be reflected by the enhanced  $N_1$  component."

Such an explanation implies, of course, that the discrimination between the ears is a very fast process. Recently, using a disjunctive reaction-time (RT) paradigm, it was shown by Näätänen et al. (1977) that the discrimination between two similar tones presented to different ears results in considerably shorter RTs than the (monaural) discrimination between two tones with even a very large frequency difference, such as that between 250 Hz and 8000 Hz. Moreover, the discrimination between the two similar tones delivered to different ears was not speeded when, in addition, a considerable frequency difference was introduced between them.

Hence, although an effect measurable from the amplitude of the  $N_1$  component is lacking from the present results, they are not regarded as

being at variance with those of Hillyard's group. The present effect is only somewhat delayed and of a smaller amplitude, but it has a longer duration.

This difference may relate to the temporal aspects of the stimulus delivery: because of the constant ISI of 800 msec used in the present study, the *S* had ample time for processing each stimulus and, therefore, he did not have to expedite his processing activities up to their maximal speed. In contrast, Hillyard et al. (1973) employed shorter and irregular ISIs to give the *S* as little time for 'unnecessary processing' as possible (see also Hartley 1970). Under such conditions, the stimulus processing is presumably speeded in order to avoid being caught by the next stimulus during processing the previous one and, as a result, the '*processing negativity*' overlapped an EP component of as short a latency as  $N_1$ . In keeping with this interpretation, using mean ISIs of 350, 960 and 1920 msec, Schwent et al. (1976a) were able to produce a clear effect on the amplitude of the  $N_1$  component only with the shortest mean ISI.<sup>4</sup>

Some may regard it as somewhat problematic to suggest that such a fast phenomenon as that involved in the ' $N_1$  effect' is, in fact, a CNV kind of negative shift. There exists, however, plenty of data demonstrating that under certain conditions the rise of such a shift may be exceptionally fast. For instance, Karlin et al. (1970) have shown that, when  $S_2$  requires (a simple RT task) or can require (a disjunctive RT task) a fast motor response,  $N_1$ ,  $P_2$  and  $N_2$  components of the EP are negatively shifted (compared to a control condition). See also Debecker and Desmedt (1971), Posner and Wilkinson (1969), and Gaillard and Näätänen (1973). These studies strongly support the view that under some experimental conditions the enhancement of the  $N_1$  component in EP elicited by the relevant stimuli may simply be due to its summation with a negative shift rapidly developing because of the task the stimulus introduces (Näätänen 1975: 254).

<sup>4</sup> The lack of the effect on the amplitude of the  $N_1$  component in the present results is not due to the fact that we delivered physically similar standard stimuli to both ears while, for example, Hillyard et al. (1973) had a considerable inter-ear pitch difference (the respective Hz values being 800 and 1500 Hz). This was ascertained by the results of a separate experiment (to be reported elsewhere) with a comparable Hz difference between the standard stimuli to the attended and the unattended ear. Nor does the relative easiness of the discrimination task of the present study seem to explain the delay of the discussed effect as the enhancement of the  $N_1$  amplitude has even been produced by merely counting easily discriminable tones (Schwent et al. 1976b).

The onset latency of the negative shift, varying as a function of the temporal requirements of the task, and, particularly, its long duration as demonstrated by the present study, render it impossible to equate this effect with a stimulus-set or channel-selection kind of operation. Rather a *sequelae* of such a selection process is observed here as well as in earlier related studies; the negative shift involved is probably caused by operations carried out *after* the decision related to the ear of input ('right' or 'wrong' ear) was made. This implies that this negative shift, in fact, is associated with the processing of the stimulus dimension on which a target differs from the standards rather than the ear of entry of the input as such.

Because of the long latency (some 150 msec) and duration of the negative shift in the present study, this shift may reflect such discrimination-related activities as rehearsal of the sensory input and its recombination against the template. Such a negative shift did not occur for the standards on the unattended side as these activities, presumably, were not started when the input was detected to be on the 'wrong' side, making it possible for the *S* to regard the stimulus as a non-target with full confidence.

It is, however, possible that this negative shift in the present study as well as in those of Hillyard's group simply reflects the *S*'s recognition of the fulfillment of the current input of one of the criteria for the target, in this case, that the stimulus comes from the task ear. This possibility is supported by Schwent et al's (1976b) finding that the effect could even be produced by mere counting easily discriminable tones.<sup>5</sup>

<sup>5</sup> It is difficult to say whether such a negativity might reflect to some extent orienting kinds of processes in the brain. This is, however, not very likely because then half the stimuli should have been of an orienting nature and there was nothing new or unexpected in them. Moreover, the duration of the present effect was perhaps somewhat longer than what could be expected on the basis of this explanation, which also would have predicted some peaking rather than a steady flat shift. This possibility could be further explored by a detailed topographical mapping of the scalp distribution of the negative enhancement, as it is known that the negativity related to orienting has a more anterior focus than the other kinds of slow negative shifts (Loveless and Sanford 1975; Gaillard 1976).

Nor is it likely that the negative shift was a sign of anticipation of, or preparation for, the next stimulus selectively following the stimulus on the attended side (the repetition expectancy). If it were, the morphology of this wave should have been different, with a later onset and demonstrating some increase of the amplitude as the moment of the next stimulus was approached.

There was a large difference in early negativity between EPs to signals and standards within both the attended and the unattended ear. Fig. 4 represents subtraction curves in which the corresponding time points of the EP to standards were subtracted from the EP to signals, separately for each ear and each electrode position. In comparison to standard EPs, signal EPs show a systematic negative enhancement, with an onset prior to the peak of the  $N_1$  component and lasting up to the  $N_2$  component (with an approximate duration of 200 msec).<sup>6</sup> This was followed (mainly for the attended ear) by a  $P_{300}$ -kind of positivity. The negative process involved may reflect a step-by-step process by which the  $S$  ends up with subjective certainty of some degree that something deviating (template mismatch) with regard to the stimulus background composed of the frequent standards has happened. In case of standards, this phase of processing presumably terminates with an early match.

An interesting analogy is provided by Gould (1967; for corroborating evidence, see Gould and Dill 1969; Gould and Peebles 1970) who found that the duration of the eye fixation to target stimuli (identical to the model target shown prior to the task) was longer than to non-target stimuli and the fixations to the former were more numerous than to the latter. Moreover, the duration of fixation to a non-target was the longer the more similar a non-target was to the target. These data made him suggest a comparison process that terminates upon the detection of a critical difference between the actual and the memorized patterns.

It is, however, possible that the initial part of the negativity concerned is due to the signal stimuli activating, because of the (slight) difference in intensity (Exp. 1) or in pitch (Exp. 2), such afferent fibers that are not activated by the standards. If this were the case it could, naturally, directly account for only that phase of the negative shift which corresponds to the latency of the  $N_1$  component and perhaps of the  $N_2$  component (see fn. 6).

It may well be that a physiological mismatch process caused by a sensory input deviating from the memory trace ('template') formed by a frequent 'background' stimulus is such an automatic basic process

<sup>6</sup> This negative enhancement was more even for the temporal than for the vertex data, the latter often showing a 'trough' around the latency of the  $P_2$  component suggesting that some component-specific ( $N_1$  and  $N_2$ ) enhancement took place. This may be related to refractory factors to which vertex EPs are known to be much more sensitive than EPs recorded over sensory-specific areas.  $N_2$  in signal EPs may also represent some kind of alerting effect.

that it takes place irrespective of the intentions of the experimenter and the *S*, perhaps even unmodified by the latter. This view is supported by the fact that the mismatch negativity was similarly observed both for the attended and the unattended sides. Hence, we may here be dealing with a *deviation* effect rather than *relevance* effect, whereas the much larger  $P_{300}$  in the EPs to the attended signals than to the unattended signals certainly represents a relevance effect.<sup>7</sup>

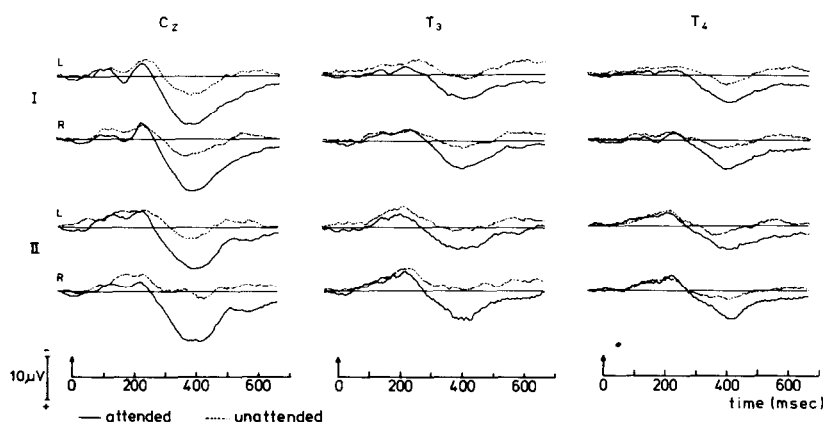


Fig. 4. The difference between EPs to signals and standards (averaged across *Ss*) for the three electrode positions separately for the left (L) and right (R) ear when attended and when unattended. These difference curves were obtained by subtracting the corresponding time points of the EP to standards from the EP to signals. I refers to Experiment 1, II to Experiment 2.

<sup>7</sup> On the other hand, the *S* may for some reason have adopted the strategy of first searching for a template mismatch – irrespective of the ear – rather than of listening to stimuli delivered to the instructed ear. (For a discussion of the *S*'s very flexible decision-making strategies in such tasks, see Näätänen 1975: 287–291.) This kind of strategy appears possible in view of the fact that, while the mismatch negativity commenced at some 100 msec post-stimulus, the EPs to the relevant standards started to differ from those to the irrelevant standards at 150 msec. This, however, is no strong evidence for the above inferences as to the strategy of the *S* as the initial part of the mismatch negativity may simply be due to release from refractory factors and the long latency and duration of the reflection of the stimulated ear may be related to the negative shift involved as being associated with some process taking place well after the ear discrimination, such as rehearsal of the sensory input and its recomparison to the template. Such a change in strategy would also be consistent with the similarity of the mismatch negativity for the attended and unattended signals but not with the long duration of the mismatch negativity (see fig. 4).

The mismatch negativity was more notable in the temporal-lead data in relation to the vertex data than what could have been expected from the lateral distribution of the CNV amplitude (fig. 4). On an average, this negativity in the lateral data was of about the same size in  $\mu\text{Vs}$ <sup>8</sup> as that in the vertex data, although generally, the EPs of the former data were of a considerably smaller amplitude than those in the vertex data (figs. 1–3). This suggests that the mismatch negativity reflects specific auditory stimulus discrimination processes taking place in the auditory primary and association areas.

Interestingly, this result is to some degree analogous to the recent data of Simson et al. (1976), involving the topographical distribution of the negative component elicited by a missing click in a long series of clicks delivered with short regular intervals. According to the authors, this topography "can be considered to reflect the sum of activity generated within the cortex of the supratemporal plane which is projected to the surface in the central region and a field overlying auditory association cortex on the lateral surface of the superior temporal gyrus" (Simson et al. 1976: 40). Also their negative component reached its peak relatively late (some 275 msec from the 'onset' of the missing stimulus) and in many of the instances demonstrated a long gradual increase.

To sum up the present results, it is suggested that first there was a fast discrimination as to whether the input was on the attended side (and this discrimination process *as such* was not reflected by the data). If the stimulus was a signal, physiological processes leading to the experienced template (formed by the frequent standards) mismatch were at a relatively early phase, perhaps even parallelly, under the process of being built up. If the mismatch and the detection of the stimulus as being on the task side were associated with the same stimulus, the *S* experienced as having detected a target and a large  $P_{300}$  usually found in connection of target detection resulted. In case of a standard stimulus, the comparison process of the incoming sensory input with the template resulted in no mismatch negativity. If such a template match was associated with the experience of the stimulus being on the attended side, such discrimination-related activities as rehearsal of the

<sup>8</sup> The amplitude of the mismatch negativity was measured from the data of individual *Ss* for Experiment 2. The mean value for this negativity over *Ss*, sessions and conditions was  $3.25 \mu\text{V}$  for the vertex data, whereas the corresponding figure for  $T_3$  was  $3.6 \mu\text{V}$  and for  $T_4$   $2.58 \mu\text{V}$ .

sensory input and its recomparison against the template were possibly carried out and reflected by the slight long-lasting negative displacement as observed in the present data. (Such a negative shift did not occur for the standards delivered to the unattended side as these activities, presumably, were not at all started; the detection of the input as being on the 'wrong' side made it possible for the *S* to regard the stimulus as a non-target with full confidence.)

Another interpretational alternative for this negative shift simply is its being a reflection of the input having been recognized as fulfilling one (the spatial) criterion of a target.

## General conclusions

(1) The  $N_1$  effect of selective attention first demonstrated by Hillyard et al. (1973) on EPs is no real  $N_1$  effect (an enhancement of the  $N_1$  component of the EP) but represents a summation of a negative shift, herein called '*processing negativity*', on the EP wave form. This is known, provided that the present negative shift and the ' $N_1$  effect' represent the same phenomenon, from temporal dissociation which, under some conditions such as those of the present study, can be produced between this effect and the  $N_1$  component. The former, evidently, is very sensitive in reflecting ISI and task-demand effects. Topographical studies might show differences between the scalp distribution of the  $N_1$  component and the ' $N_1$  effect'.

(2) This effect is not related to channel selection as such but it rather reflects stimulus processing selectively carried out on certain stimuli on the basis of a preceding selection process. It is also possible that, more simply, this negativity is associated with the subject's observation that the stimulus meets one criterion for a target. In this case, this negative shift reflects relevancy (closeness to the target) rather than stimulus processing.

(3) A negative shift superimposed on the EP wave form, herein called '*mismatch negativity*', can be observed when a deviating stimulus is delivered among much more numerous, 'standard', stimuli. The relatively high amplitudes of this negativity over the temporal areas suggest that it reflects specific auditory stimulus-discrimination processes. The latter processes are suggested to be largely automatic, beyond the control of will, instructions, etc., and may be closely related to the orienting

response. On the other hand, the processing negativity (if this interpretation is correct) would reflect such processing which can be directed to different stimuli by instructions, will, attention, preset criteria, templates, etc. and is, therefore, to a great extent under the subject's control.

(4) The development of mismatch negativity was not dependent on the outcome of the discrimination of a faster and more easily detectable difference between stimuli (the two ears), on the basis of which they may initially be divided into relevant and irrelevant stimulus categories. Consequently, such a stimulus-processing model is not supported which suggests an initial selection process to choose stimuli belonging to a certain easily discriminable category for a further and more profound processing. It is possible, however, that the results would in this respect have been very different had we used such a fast stimulus rate as usually employed in the experiments of Hillyard's group to force out all the initial stimulus selectivity the subject may be capable of.

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