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P300 and Uncertainty Reduction in a Concept-Identification Task

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ABSTRACT

The relationship between the amplitude of P300, the mean amplitude of the Slow Wave, and uncertainty reduction after (dis)confirmation of hypotheses was studied in a Concept-Identification task. The subjects had to categorize stimuli according to a conceptual rule (joint denial or exclusion) and to rate the confidence that their classification was correct. Three types of feedback were distinguished: confirming (subject's categorization was correct), disconfirming (subject's categorization was incorrect), and non-informative feedback. The EEG was averaged separately according to the three types of feedback and the two confidence ratings (low, high).

The data showed the predicted interaction between type of feedback and confidence level. A larger P300 amplitude turned up after confirming feedback when the subject was less confident, than when he was more confident. The reverse was found after disconfirming feedback. The P300 amplitude after non-informative feedback was not influenced by confidence. The mean amplitude of the Slow Wave showed approximately the same interaction pattern.

The results were interpreted in terms of changes in the probability of hypotheses which subjects use to categorize stimuli in a Concept-Identification task.

DESCRIPTORS: Concept Identification, Feedback, Confidence level, P300, Slow Wave.

Influential theories of Concept-Identification behaviour state that subjects are testing hypotheses to learn concepts (e.g. Bruner, Goodnow, & Austin, 1956; Levine, 1975). This thesis implies that a subject selects a hypothesis and classifies stimuli according to this hypothesis. If the classification turns out to be incorrect (disconfirmation) the subject rejects the hypothesis and selects another one. In case of correct classifications (confirmations) the subject stays with his hypothesis. Many studies have shown that subjects perform according to this strategy 'reject your hypothesis only after disconfirmation' (e.g. Falmagne, 1970; Coltheart, 1973; White, 1974; De Swart & Das-Smaal, 1976, 1979a).

Bayes' theorem offers a model to describe the change in subjective probabilities after confirmation and disconfirmation in a deterministic Concept-Identification task, given the strategy 'reject your hypothesis only after disconfirmation.'

Several Concept-Identification studies revealed data which are in agreement with the Bayesian predictions about changes in subjective probabilities

(Trabasso & Bower, 1968; Falmagne, 1970; De Swart & Das-Smaal, 1976, 1979a, 1979b).

Sokolov (1969) used Bayes' theorem in his model of the orienting reflex to evaluate the quantitative change in the probabilities of the neural models. This change resulted from a combination of information from the outside world and the prior probabilities of the models. De Swart and Das-Smaal (1976, 1979a, 1979b) argued that Sokolov's model is a neural analogue of the cognitive process of hypothesis testing. The authors (1979b) found that the amplitude of the Skin Conductance Response (SCR) was higher when the feedback confirmed a low-confidence classification than a high-confidence classification. Disconfirmation revealed the opposite result: SCR was higher after a high-confidence classification than after a low-confidence classification.

A vast number of studies demonstrated that the amplitude of the late positive component (P300) of the cortical event-related brain potential (ERP) is inversely related to the 'expectancy' or subjective probability of a task relevant stimulus. In these studies subjective probability was conceived to result from the prior probability of the stimulus and the specific sequential structure of preceding stimuli

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(Squires, Wickens, Squires, & Donchin, 1976; Duncan-Johnson & Donchin, 1977). More precisely, Donchin suggested that 'P300 is related to the process whereby the nervous system continuously generates hypotheses about the environment, which are then validated against the input information. The hypotheses . . . might be 'strongly held' (that is, the organism has a clear expectation as to what should happen). . . . The disconfirmation of such hypotheses does yield a P300. Alternatively, if the hypotheses . . . are weak, in the sense that several alternate hypotheses might be entertained with relatively equal probability, the confirmation of either of these hypotheses . . . will yield a P300' (Donchin, 1975, p. 213; see also Donchin, Ritter, & McCallum, 1978, p. 386). These results were obtained in non-learning tasks. Furthermore, the experimental paradigm did not permit a direct estimation of the expectancy about or confidence in the hypothesis under test.

Recently, Stuss and Picton (1978) investigated P300 following feedback stimuli in a Concept-Identification task in which subjects learned an affirmation. They found that the P300 amplitude was larger in the trials before the affirmation was learned than in those after it was learned. Stuss and Picton interpreted their results in terms of the difference in uncertainty before and after the subject had learned the concept. Clearly, these results corroborate the notion that the P300 amplitude is a function of the discrepancy between stimulus information and expectancies about or confidence in hypotheses under test. However, Stuss and Picton did not have a direct measure of the subjects' confidence in their hypotheses.

The current study investigates the effects of different types of feedback (i.e. confirmation, disconfirmation and non-informative feedback) on P300 during a task which required the subjects to learn difficult concepts and during which confidence was measured directly. It was hypothesized that when confirming feedback followed a classification, the P300 amplitude would be larger when the subject was less confident about his classification than when he was more confident. When disconfirming feedback followed a classification, the P300 amplitude would be larger when the subject was more confident than when he was less confident. When non-informative feedback followed a classification, the P300 amplitude would not differ as a function of degree of confidence.

The strategy 'reject your hypothesis only after disconfirmation' assumes that subjects classify stimuli according to the hypothesis under test. Hence, a confidence rating that the classification of a stimulus is correct, can be taken as an index for the subjective

probability or expectancy that the hypothesis under test is true.

Testing the relationship between P300 and (dis)confirmation of hypotheses differing in prior probability in a Concept-Identification task offers some problems. Neither the number of learning trials, the (subjective) prior probabilities, nor the number of (dis)confirmations can be directly controlled by the experimenter; they are subject-dependent. The data of De Swart and Das-Smaal (1979a) revealed that about 160 trials are necessary to test the hypothesis about the relationship between type of feedback and confidence level. No single Concept-Identification task can provide this number of trials. De Swart and Das-Smaal (1979a) suggested that two exclusions and two joint denials with 40 learning trials for each conceptual rule would provide a sufficient number of trials within each category of the interaction between type of feedback and confidence level to compute the averaged ERP waveforms.

A further complication is to distinguish between an explanation of the results in terms of (dis)confirmation of hypotheses differing in probabilities and an explanation in terms of the probability of the different feedback stimuli. In the present study, three feedback stimuli were employed: a) feedback indicating that the presented stimulus belongs to the concept (positive category), b) feedback indicating that the presented stimulus does not belong to the concept (negative category), and c) feedback without information about the correct category ('unknown'). Each feedback stimulus was presented about equally often. Any explanation of the data in terms of the probability of the feedback stimuli is therefore ruled out. The subject has to deduce (assuming that he is testing hypotheses to identify concepts) from the feedback stimuli, whether his hypothesis is (dis)confirmed or—in the case of 'unknown'—that the feedback does not inform him about the correctness of his hypothesis. The data of De Swart and Das-Smaal (1979a) revealed a larger number of confirming than disconfirming feedback stimuli. If the same difference turns up in the present study the 'probability' explanation predicts that the P300 amplitude will be smaller following confirmation than following disconfirmation.

With respect to the latency of P300 no systematic effects were expected. Stuss and Picton's (1978) data revealed no systematic variations. It has been shown that P300 latency depends primarily upon stimulus-evaluation time (Kutas, McCarthy, & Donchin, 1977). In our paradigm (as in Stuss and Picton's (1978) experiment) the evaluation of the information of the feedback stimuli is rather simple. Therefore, the P300 latencies are

not expected to vary as a function of the different feedback stimuli.

Method

Tasks

The subjects participated in two tasks, a Listening task and a Concept-Identification task. In the Listening task the subjects were required to listen to a series of two tones and a burst of white noise, presented in random order. The aim of the Listening task was to determine the influence of the three stimuli on P300, independently of the factors in the Concept-Identification task. In the Concept-Identification task, each subject was required to learn to categorize stimuli (slides) into positive and negative categories according to conceptual rules. The rules were an exclusion and a joint denial. An exclusion is defined as $A \cap \bar{B}$, i.e. an instance belongs to the positive category if characteristic A (e.g. square) is present and characteristic B (e.g. +) is absent. A joint denial is defined as $\bar{A} \cap \bar{B}$, i.e. an instance belongs to the positive category if characteristic A and characteristic B are both absent. Each subject had to learn two exclusions and two joint denials in four different Concept-Identification tasks.

Subjects

Sixteen male university students, who were paid at a flat hourly rate, served as subjects. The subjects were divided into four different groups corresponding to four different orders of the two exclusions and two joint denials, constructed according to a diagram-balanced latin square (Wagenaar, 1969).

Stimulus Material

In the Listening task the stimulus material consisted of three 85dB (SPL) stimuli of 100 msec duration: white noise, a 2000 Hz tone, and a 500 Hz tone.

In the Concept-Identification task the stimulus material consisted of slides showing geometrical figures, identical to those used in the De Swart and Das-Smaal (1979a) study. Four three-valued dimensions were used. Each slide contained a value of each dimension: shape (square, circle or diamond), shading within the shape (horizontal, vertical or diagonal), location on the slide (high, middle or low), and sign in the middle of the shape (+, - or ×). Thus, the stimulus population consisted of 81 different slides. In each of the four experimental tasks a selection of 40 slides was presented. Twenty of these slides belonged to the positive and 20 to the negative category, the order was random.

After the categorization response of the subject one of the feedback stimuli was presented: a 2000 Hz tone or a 500 Hz tone, meaning that the preceding slide belonged to the positive or negative category, respectively, or a burst of white noise meaning 'no information about the correct category is given' ('the category is unknown'). It should be emphasized, that the feedback tones indicated the correct category of the preceding stimulus and not the correctness of the categorization response of the subject. The subject had to infer the correctness of his response by comparing his own classification to the classification indicated by the

feedback. In case of the white noise, this comparison could not be made. Each tone was presented 14 times, the white noise 12 times. The order was pseudorandom.

Apparatus

The experimental room was soundproof and dimly illuminated. A tachistoscope was located outside the room. The visual stimuli were presented on a frosted glass window in front of the subject. The visual stimuli had to be assigned to either the positive or the negative category. Subjects responded by pressing a right or left button to indicate that the slide belonged to the positive or negative category, respectively. In addition to the buttons there was a lever to indicate the confidence in the categorization. The confidence ratings were measured on a continuous scale that varied between -2 Volts (lowest lever position) to +2 Volts (highest lever position). Lowest and highest lever positions denoted the lowest and highest confidence levels, respectively. The buttons and the lever were fastened to the arm of the subject's chair within reach of his preferred hand. The responses were recorded automatically with the aid of a Beckman 8-channel polygraph (type R411 Dynograph).

The EEG was recorded from three electrode sites (F_z , C_z and P_z) referred to linked mastoids with Ag-AgCl electrodes. The time constant was 10 sec and the high frequency cut-off filter was set at 35 Hz. The electrode impedance never exceeded 5 KOHms. The EOG was measured with Beckman electrodes placed above and below the right eye. For the Listening task analysis the EEG was digitized off-line by the PDP 15 computer for a 1.4-sec interval, beginning 1 sec prior to the onset of the feedback stimuli, at a rate of 370 samples/sec. For the Concept-Identification task analysis the EEG was digitized off-line at a rate of 256 samples/sec for a 2.0-sec interval, beginning 1.0 sec prior to the onset of the feedback stimuli.

Procedure

After the subject had been informed about the experimental equipment, the recording leads were attached and the subject was seated in the experimental room. He was then instructed to listen to a series of 150 stimuli, consisting of a random presentation of the 500 Hz and 2000 Hz tones and white noise, each stimulus occurring 50 times. The duration of each stimulus presentation was 100 msec with an intertrial interval of 4 sec. The subject was instructed to listen to the stimuli and not to make a response. In the Listening and the Concept-Identification tasks the subject was asked to refrain from making body movements, eye movements or eye blinks and to fixate a spot in front of him during the interval starting 1 sec before onset until at least 1 sec after offset of the auditory stimulus.

Following the Listening task, the subject was instructed about the nature of the Concept-Identification task, the responses required (i.e. the categorization and confidence rating), and the meaning of the feedback stimuli presented by means of the same two tones and white noise used in the Listening task. The subject started with a training task, followed by a 5-min rest period during which the main points of the instruction were repeated. Then the 4 experimental tasks were presented in succession, sepa-

rated by rest intervals of approximately 3 min duration. Each task was terminated after 40 trials. At the beginning of each task the subject was told which conceptual rule was applicable, and that his task was to learn to classify the slides in the correct category by identifying the relevant values of the dimensions. It was emphasized to respond accurately and as quickly as possible.

The trials of the Concept-Identification task were composed as follows: stimulus presentation (11 sec), after which the subject gave his categorization response (positive or negative) immediately, as well as his confidence rating; 7 sec after stimulus offset, feedback was presented (100 msec). After a 7-sec rest interval the next slide was presented. The order of presentation of the slides within each task was the same as in De Swart and Das-Smaal's (1979a) study.

Data Collection

For the Concept-Identification task, the confidence ratings of the subjects were dichotomized into two levels of confidence: $<.50$ and $>.50$, corresponding to ratings in the lower half and upper half of the confidence rating scale, respectively. Three types of feedback were distinguished: 'confirmation' (the category chosen by the subject and indicated by the feedback stimulus were the same), 'disconfirmation' (the category chosen by the subject and indicated by the feedback stimulus were different), and 'no-information about the correct category' which was always, and only, indicated by white noise.

The EEG was averaged separately according to each level of confidence and each type of feedback. The trials of each of these six categories were averaged across the four experimental tasks. A trial with an EOG, which exceeded 200 microvolts during the EEG analysis interval, was rejected from the analysis. Thus, the EEG was averaged over a number of trials, which depends on the number of EOG artefacts, the correctness of the subject's categorization, and the confidence level ($<.50$ and $>.50$).

A computer programme measured the amplitude and latency of P300 by finding the maximal value of the averaged waveform in a fixed latency range. The peak latency range that was chosen after visual inspection of the averaged individual waveforms for P300 was 250–375 msec. A separate statistical analysis verified that there was no systematic variation in the average EEG in the 1-sec period prior to the feedback stimuli as a function of the two confidence levels and the three types of feedback. Therefore, these values were chosen as baselines and subtracted from the amplitude values.

In most of the averaged individual waveforms, that were elicited by the feedback stimuli in the Concept-Identification task, a large prolonged wave that followed P300 could be observed. The amplitude of this wave, hereafter referred to as Slow Wave, was measured as the mean value in the range 400–995 msec.

For the Listening task averages were computed over the trials of each of the stimulus categories separately. After rejecting the trials with EOG artefacts from the analysis, the EEG in each stimulus category (2000 Hz, 500 Hz and white noise) was averaged over the residual number of trials. The amplitude and latency of P300 were

measured according to the method described above. Since the duration of the poststimulus analysis interval was only 400 msec, no separate measurement of the Slow Wave was taken for these data.

Results

After eliminating eye movements and eye blink artefacts, only 8 of the subjects produced enough data (no empty categories). These data were analyzed with ANOVAs. Significant main and interaction effects were further analyzed by Duncan's New Multiple Range Test (Edwards, 1960).

Listening Task

In the Listening task about 18% of the trials were eliminated from the analysis because of eye movements and eye blinks. This percentage was about the same for each feedback stimulus (2000 Hz: 17%; 500 Hz: 20%; white noise: 17%).

Figure 1 shows the averaged waveforms for the three stimuli (2000 Hz and 500 Hz tones and white noise, respectively) from one representative subject in the Listening task at the parietal electrode site. Visual inspection of the data showed that: 1) the P300 amplitude was smallest at F_z and the C_z and P_z amplitudes were similar to each other, and 2) the white noise resulted in a larger P300 amplitude than the 2000 Hz and 500 Hz tones (see Figure 1).

ANOVAs (completely repeated two-factor designs) were performed on the P300 amplitude and P300 latency, with Scalp Distribution (F_z , C_z and P_z) and Stimulus (2000 Hz, 500 Hz and white noise) as factors. The ANOVA on the P300 latencies re-

Figure 1. Average event-related potentials recorded from P_z for subject 4 in the Listening task.

vealed that neither Scalp Distribution, nor Stimulus, nor the Scalp Distribution $\times$ Stimulus interaction influenced the latency. The ANOVA performed on the P300 amplitude data showed significant Scalp Distribution and Stimulus effects ($F(2/14) = 5.64$, $MS_e = 7072.25$ and $F(2/14) = 29.07$, $MS_e = 4257.63$, respectively). The Scalp Distribution $\times$ Stimulus interaction did not significantly affect P300 amplitude. Duncan's test revealed a significantly smaller P300 amplitude at F_z than at C_z or P_z ($p < .01$ and $p < .05$, respectively); no significant difference was found between C_z and P_z . Furthermore, the analysis showed that the significant Stimulus effect resulted from the white noise, causing a larger P300 amplitude than the two tones; P300 amplitude did not differ between the 2000 Hz and 500 Hz tones.

Concept-Identification Task

Table 1 presents the percentage of trials in the Concept-Identification task (indicated by N) for each type of feedback (confirming, disconfirming, no information), categorization response (positive, negative), feedback stimulus (2000 Hz, 500 Hz, white noise), and confidence level ($<.50$, $>.50$). This table summarizes also the percentage of trials, that remained for averaging after eliminating eye movements, eye blink artefacts, and the first trial in

each of the four identification tasks (indicated by A). The first trial was rejected from analysis because a subject could not have formulated a hypothesis before the first feedback stimulus in each identification task was presented. Table 1 shows that there was little difference between the percentages before and after elimination of the eye movements, eye blink artefacts, and the first trial of each identification task. Furthermore, Table 1 reveals that: 1) the confirming type of feedback occurred more often than the disconfirming type of feedback (51% and 19%, respectively); 2) the subjects chose the positive and negative categories about equally often (49% and 51%, respectively); 3) the 2000 Hz and 500 Hz tones were presented equally often for confirming and disconfirming feedback (25% and 10%, respectively); and 4) an equal percentage of trials occurred in each confidence level.

Figure 2 reveals the mean confidence ratings as well as the percentage confirmations as a function of successive trial blocks, both averaged over subjects and identification tasks. The data demonstrate that the subjects' confidence and the number of confirmations increased during the identification tasks.

TABLE 1
Percentage of trials ($N = 1280$) in the Concept-Identification task for each type of feedback (confirming, disconfirming, no information), categorization response (positive, negative), feedback stimulus (2000 Hz, 500 Hz, white noise), and the two confidence levels (low, high)

Types of Feedback	Percentages of Trials			
	Low Confidence Level		High Confidence Level	
	N ^a	A ^a	N	A
	10	9	15	16
	11	11	14	15
	7	7	3	3
	5	5	5	5
	9	9	5	5
	9	8	7	8

^aN indicates the percentage of trials for each type of feedback and confidence level ($\Sigma N = 100\%$); A indicates the percentage of trials for each type of feedback and confidence level after elimination of eye movements, eye blink artefacts, and the first trial of each identification task ($\Sigma A = 100\%$).

Figure 2. Mean confidence ratings (upper panel) and percentage confirmations (lower panel) plotted against 8 successive trial blocks of the Concept-Identification task (averages of 8 subjects and 4 different tasks).

Figure 3 shows the grand average waveforms for each type of feedback, superimposed for the two confidence levels. Figure 4 illustrates the grand average waveforms for each confidence level, superimposed for the three types of feedback. Figure 3 reveals that the P300 amplitude was larger after confirmation when the subject was less confident about his categorization, than when he was more confident. The opposite tendency was observed after disconfirmation. Little difference could be observed between the two levels of confidence after non-informative feedback. Figures 3 and 4 demonstrate also, that the P300 amplitude was smaller after informative than after non-informative feedback. Separate ANOVAs were performed on P300 amplitude, P300 latency, and mean amplitude of the Slow Wave, with Scalp Distribution (F_z , C_z and P_z), Confidence ($<.50$, $>.50$), and Type of Feedback (Confirmation, Disconfirmation and No-Information) as factors. The analysis revealed that the P300 latency data were not significantly influenced by any of the factors or the interactions. The P300 amplitude data were significantly influenced by Scalp Distribution and Type of Feedback ($F(2/14) = 24.44$, $MS_e = 16469.97$ and $F(2/14) = 3.95$, $MS_e = 38550.90$). Confidence did not influence the P300 amplitude in a significant way. However, the Confidence $\times$ Type of Feedback interaction was a significant determinant of the P300 amplitude ($F(2/14) = 9.90$, $MS_e = 5840.47$). None of the other interactions involving the P300 amplitude data were significant. Duncan's test showed significant differences between the three electrode positions. At the

Figure 4. Across subjects averages of the event-related potentials recorded from P_z , as a function of the two confidence levels. The waveforms are superimposed for the three types of feedback. Time-points of the waveforms represent averages of 40-msec periods.

F_z location the P300 amplitude was lower than at the C_z location ($p < .01$) which, in turn, was lower than at the P_z location ($p < .01$). The significant F -value for Type of Feedback was the result of the 'No-Information' condition which resulted in a significantly larger P300 amplitude than the other two types of feedback ($p < .05$). Confirmation and disconfirmation did not result in a difference in the P300 amplitude data. Duncan's test also revealed a significant difference in P300 amplitude within the confirming and disconfirming types of feedback between the low and high confidence levels ($p < .05$ and $p < .01$,

Figure 3. Across subjects averages of the event-related potentials recorded from P_z , as a function of confirming feedback, disconfirming feedback, and no-information (unknown). The waveforms are superimposed for the two confidence levels. Time-points of the waveforms represent averages of 40-msec periods.

respectively). The direction of the difference was, however, different for the two types of feedback. After 'confirming feedback,' P300 amplitude was larger when the subject was uncertain than when he was certain; after 'disconfirming feedback,' P300 amplitude showed the opposite tendency. Within the 'non-informative' type of feedback no significant P300 amplitude difference between the two confidence levels was observed. These effects are illustrated in Figure 5. The ANOVA performed on the mean amplitude of the Slow Wave also revealed significant effects due to Scalp Distribution, Type of Feedback, and the Confidence $\times$ Type of Feedback interaction ($F(2/14) = 110.6$, $MS_e = 789300.67$; $F(2/14) = 16.17$, $MS_e = 971244.81$; and $F(2/14) = 4.33$, $MS_e = 350964.65$, respectively). 'Confidence' and all other interactions affected the mean amplitude of the Slow Wave in a nonsignificant way. Duncan's test showed that the mean amplitudes of the Slow Wave differed significantly between all electrode locations ($p < .01$), being negative at F_z , positive at C_z , and strongly positive at P_z . Furthermore, the mean amplitude of the Slow Wave did not differ significantly after 'confirming' versus 'disconfirming' feedback. After 'no-information' the mean amplitude of the Slow Wave was significantly larger than after 'confirmation' or 'disconfirmation.' Analysis of the significant Confidence $\times$ Type of Feedback interaction showed that: 1) after 'confirming' feedback, the mean amplitude of the Slow Wave did not vary significantly as a function of Confidence (although the difference was in the predicted direction); 2) after 'disconfirming' feedback, the mean amplitude of the Slow Wave was larger

when the subject was certain than when he was uncertain about his hypothesis; and 3) within the 'non-informative' feedback there was no significant difference between low and high confidence levels. These effects are illustrated in Figure 5.

Difference between the Listening and Concept-Identification Tasks

The data suggested that the P300 latency and amplitude differed between the Listening and Concept-Identification tasks. To test this suggestion, ANOVAs were performed on P300 amplitude and P300 latency with Task (Listening and Concept-Identification) and Scalp Distribution (F_z , C_z and P_z) as factors. The analysis revealed that no difference in the P300 latency data could be systematically ascribed to any of the sources or to any of the interactions between sources. With respect to the P300 amplitude, it was found that the amplitude was significantly larger in the Concept-Identification task than in the Listening task ($F(1/7) = 55.91$, $MS_e = 24150.32$). A significant difference between the two tasks was noted with respect to Scalp Distribution ($F(2/14) = 10.11$, $MS_e = 3436.64$). Duncan's test showed that during the Concept-Identification task the P300 amplitude at each electrode location was significantly larger than during the Listening task ($p < .01$). As already mentioned, the P300 amplitude in the Concept-Identification task differed significantly between all scalp locations, being minimal at F_z and maximal at P_z . During the Listening task no difference was found between C_z and P_z ; however, the P300 amplitude was lower at F_z than at C_z and P_z ($p < .01$ and $p < .05$, respectively).

Figure 5. Confidence by type of feedback interaction patterns for P300 and Slow Wave measures as a function of three different electrode positions (F_z , C_z , P_z). C=Confirmation, D=Disconfirmation, U=Unknown (no-information).

Discussion

Many previous studies have shown that the amplitude of P300 varies inversely with expectancy. In these studies expectancy was inferred from the *a priori* probability of a stimulus or the sequence of preceding stimuli (Tueting, Sutton, & Zubin, 1970; Squires et al., 1976; Roth, Ford, Lewis, & Kopell, 1976; Duncan-Johnson & Donchin, 1977). The present study did not investigate the magnitude of the amplitude of P300 as a function of the probability of stimuli, but as a function of the relationship between the amplitude of P300 and the subjective probability or confidence in the hypothesis under test. The subjective probability ratings were used to classify stimuli. It was assumed that Bayes' theorem offers a model to describe the changes in confidence in a deterministic Concept-Identification task, given the strategy 'reject your hypothesis only after disconfirmation.' It was predicted that the P300 amplitude would be a function of the confidence of the subject in his hypothesis and the type of feedback. The data revealed that the P300 amplitude after confirming feedback was larger when the subject was less confident, than when he was more confident about his hypothesis under test. After a disconfirmation the reverse tendency was observed: the amplitude of P300 was larger when the subject was more confident than when he was less confident about his hypothesis. The P300 amplitude after non-informative feedback did not vary as a function of the degree of confidence. These results are in accordance with the predictions, with Stuss and Picton (1978), and with De Swart and Das-Smaal (1979b). The latter authors found the same relationship in a Concept-Identification task using GSR as the dependent variable. Similar results were found by Chesney and Donchin (1979) in a prediction task. They showed that when subjects predicted stimulus repetition, disconfirmation evoked a larger P300 amplitude than confirmation. However, when stimulus alternation was predicted, confirmation elicited a larger P300 amplitude than disconfirmation. Even more relevant are the data of Horst, Johnson, and Donchin (1979). In a paired associate learning task they inferred, similar to the present experiment, the expectancy on each trial of the task, and found that P300 amplitude was a function of the interaction between level of confidence and the effect of feedback stimuli by which the subject was informed about the correctness of his response.

Recently, Campbell, Courchesne, Picton, and Squires (1979) found, in a time estimation task, that the amplitude of P300 to auditory feedback varied with the probability of the stimulus and was unaffected by the meaning of the feedback. It is impor-

tant to note, that in this experiment the pitch of the feedback stimulus denoted whether the response of the subject was correct or incorrect. In our experiment the feedback stimuli indicated to which category the geometrical figures actually belonged. By comparing the category information of the feedback with his own response the subject had to infer whether he was correct or incorrect. The number of feedback stimuli (i.e. 1000 Hz, 500 Hz and white noise) were presented about equally often. So, an explanation of the P300 amplitude in terms of a difference in 'simple' probabilities of the feedback stimuli was ruled out. Furthermore, the (more frequent) confirming feedback and the (less frequent) disconfirming feedback did not cause a difference in P300 amplitude. Hence, it seems reasonable to exclude an explanation of our results in terms of the probability of the meaning of the feedback stimuli and to conclude, that the amplitude of P300 indicates uncertainty reduction or expectancy violation about the hypothesis under test.

Our data are also consistent with the notion that the P300 amplitude reflects 'surprise' (Duncan-Johnson & Donchin, 1977; Donchin, 1979). The surprise value of the feedback increases, when the feedback violates prior expectancies. This occurs when: a) the subject's confidence, or expectancy to be correct, is low and the feedback shows, that he is in fact correct; and b) the subject's confidence to be correct is high and the feedback reveals that he is incorrect.

The present experiment suggests that sorting the data according to confidence ratings may lead to a better understanding of the effects of confirming and disconfirming feedback on P300 amplitude. It may explain why earlier studies, in which the P300 amplitudes were averaged according to confirming and disconfirming feedback, have yielded inconsistent results. For instance, some studies reported a larger P300 amplitude to disconfirming than to confirming feedback stimuli, while other studies revealed no significant difference or even a larger P300 amplitude to confirming feedback stimuli (Sutton, Braren, Zubin, & John, 1965; Tueting et al., 1970; Levitt, Sutton, & Zubin, 1973; Leifer, Otto, Hart, & Huff, 1976; see also Donchin, 1979). Also the present study revealed no difference in P300 amplitude between the two types of feedback. Horst et al. (1979) and the present results showed that the amplitude of P300 was a function of the interaction between type of feedback and the confidence of the subject in the hypothesis under test, rather than a function of the type of feedback per se.

The 'expectancy' explanation of the results of the present study is also in accordance with the notions of Sokolov (1969), Bernstein (1969, 1973), and

Bernstein and Taylor (1979). Sokolov (1969) employed Bayes' theorem to evaluate at the neural level the change in the likelihood of neural models which represent a system of hypotheses. The formulation of Donchin (1975), cited in the introduction, is quite close to—if not identical with—Sokolov's (1969) formulation (cf. Kok, 1978). Bernstein's concept of the significance of the information for the subject (Bernstein, 1969, 1973; Bernstein & Taylor, 1979) and Pribram and McGuiness' (1975) 'context updating' could also be easily (re)formulated in terms of the Bayesian parameters (see also Donchin, 1979).

At the cognitive level, Bayes' theorem is frequently used to study the revision of opinion (or expectation) about states of affairs (i.e. hypotheses) in the light of new information (e.g. Slovic & Lichtenstein, 1971; De Swart, 1972). Recently, Donchin (1979) suggested that '... no index, other than the subject's overt predictions, is available to assess his expectations ... Perhaps P300 amplitude might serve as an objective measure of subjective probability' (p. 63). The present study showed that P300 amplitude is sensitive to changes in likelihood of hypotheses. To what extent the amplitude of P300 is a more reliable measure of subjective probability than the subject's overt predictions or than indirect measures of subjective probability (e.g. lotteries) is, however, an open question at this moment.

A substantial difference in P300 amplitude between the Listening and the Concept-Identification tasks was observed, being at each electrode position larger in the latter task. It is rather obvious to ascribe this difference to the difference in meaning of the stimuli between the two tasks. In the Listening task, the stimuli were meaningless; the subjects were simply asked to listen to three different tones. However, in the Concept-Identification task the stimuli conveyed meaning with respect to the correct classification of the stimuli. Within the context of our experimental paradigm meaning is equivalent to task relevance. In the Concept-Identification task the confirming and disconfirming types of feedback were task relevant, since the different types of feedback played a distinct role in the information processing activities of the subject, given he applied the strategy 'reject your hypothesis only after disconfirmation' (cf. Donchin et al., 1978). There is an abundance of literature showing that task relevance is a necessary condition for eliciting P300 (Courchesne, Hillyard, & Galambos, 1975; Squires, Donchin, Squires, & Grossberg, 1977; Duncan-Johnson & Donchin, 1977; Johnson & Donchin, 1978).

The result that non-informative feedback (white noise) elicited the largest P300 amplitude in the

Concept-Identification task was unexpected and is in conflict with the notion that task relevance is an important determinant of P300 amplitude. A possible explanation of this result might be that the subjects classified the feedback stimuli into two categories: informative and non-informative stimuli with *a priori* probabilities of .70 and .30, respectively. Several studies have shown that P300 amplitude is determined rather by the probability of the stimulus category, than by the probability of individual stimuli. Courchesne, Hillyard, and Courchesne (1977) demonstrated that homogeneous as well as heterogeneous background stimuli (single and all letters of the alphabet, respectively) caused in a letter counting task small and similar P300 waves, despite the lower probabilities of the stimuli in the heterogeneous series. Also Johnson and Donchin (1980) reported a marked similarity between P300 waves to background stimuli in stimulus series, which consisted of either two or three equiprobable tones. The subjects had to count one of these tones. Although the *a priori* probability in the three tones condition was .33, the data suggested that the subjects treated each uncounched stimulus as if its probability were .67.

The Listening and Concept-Identification tasks differed with respect to the pattern of the P300 amplitude at the different recording electrodes. In the Listening task the amplitude of P300 for each tone was largest at C_z , but not significantly different from P_z , and had its significantly lowest value at F_z . During the Concept-Identification task, the P300 amplitudes after the feedback differed significantly from each other, being largest at P_z and lowest at F_z . This difference can be attributed to the difference in meaning of the tones in the two tasks.

The mean Slow Wave showed, in a less pronounced way, the same picture as P300 amplitude with respect to Confidence, Type of Feedback, and Confidence $\times$ Type of Feedback, although the first two sources caused a nonsignificant *F*-value. Hence, it was concluded that uncertainty reduction affected the amplitude of P300 and the mean amplitude of the Slow Wave in an almost similar fashion. The Slow Wave showed a clear frontal-parietal shift in polarity: at F_z it was negative, at C_z it was positive, being largest at P_z . This confirms the findings of Squires et al. (1977).

None of the independent variables significantly influenced the P300 latency either in the Listening task or the Concept-Identification task. This finding is in agreement with the results of Stuss and Picton (1978) and Campbell et al. (1979). These studies did not reveal an effect of feedback meaning on P300 latency either. Reaction time studies have shown that P300 latency depends primarily on evaluation or en-

coding of stimulus characteristics (Squires et al., 1977; Kutas et al., 1977; Gomer, Spicuzza, & O'Donnell, 1976; Kok, Note 1). In the Concept-Identification task of the present study, the feedback stimuli were easy to discriminate, familiar, not complex, and not presented in a degraded way. In other words, none of the known variables that could

influence stimulus evaluation and P300 latency were present. Therefore, P300 latency was not expected to differ systematically as a function of feedback stimuli, types of feedback, or the interaction between confidence and type of feedback. The results were in accordance with this prediction.

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