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Feedback processing as parallel task in P300 conditioning

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Abstract. Previous reports on conditioning P300 amplitude indicated that downtraining produced a stronger effect than uptraining. This asymmetry can be due to the effect of drain on processing resources of the brain produced by the attempts to use feedback information (parallel task effect). Such a drain should reduce P300 amplitude regardless of the direction of training. The aim of the experiment was to demonstrate this effect. Event-related potentials (ERPs) evoked by light stimuli in a standard odd-ball procedure were recorded from Fz, Cz and Pz scalp sites. Subjects were instructed to enlarge or to reduce the P300 amplitude. The first 30 presentations of the target stimulus were analyzed during which the effect of learning should be negligible and processing of feedback information should be intensive. ERPs recorded during uptraining and downtraining were compared with the no-feedback recordings. As predicted, downtraining significantly reduced the P300 amplitude even in the first session of learning. Unexpectedly, uptraining recordings did not differ from no-feedback ERPs but differed significantly from downtraining waves. Such results support the prediction that feedback procedures involve a number of processes that alter the P300 amplitude even before the effects of learning can be expected. But if the hypothesis of the parallel task is to be accepted there must be another instantaneous process that compensates for P300 amplitude reduction during uptraining.

Key words: P300, feedback, parallel task

INTRODUCTION

Experimental techniques employing feedback information are used rather rarely. They are difficult in animal experiments where the manipulation of the experimental task is usually more effective. It seems, however, that in experiments with humans where the exchange of information is rapid and efficient, these techniques offer unexplored possibilities. Among the other applications they can be used in studying the functional significance of event-related potentials (Rosenfeld et al. 1984). Late components of these potentials, such as P300 waves, are particularly interesting since they probably represent advanced levels of information processing that can be subjected to conscious, voluntary control (Donchin and Coles 1988, Verleger 1988).

Relatively few studies devoted to the problem of self--control of P300 component produced surprising results. Shabsin (1982) reported no effects of rewarding children for large P300 potentials evoked in visual tasks. In contrast, Miltner, Larbig and Braun (1986) reported the differential effect of training for increases and decreases of amplitude of late ERP components evoked by visual target stimuli. Up- and downtraining produced differences in P300 amplitude but from this experiment it was impossible to infer whether the difference was due to the enhancement in uptraining, the reduction in downtraining or the combination of both. Sommer (1987) confirmed the finding that training produced the differences in P300 amplitudes for auditory stimuli. He also reported the very interesting fact that P300 amplitudes diminished with downtraining but uptraining did not produce any difference. This finding was in keeping with the earlier negative result of Shapsin's (1982) uptraining attempts. The experiment of Sommer and Schweinberger (1992) - also with auditory stimuli - was specifically designed to test if uptraining can increase P300 amplitude. The amplitude increased above the level obtained with random reinforcement. In this experiment the effect of downtraining was not tested but the comparison with previously mentioned data (Sommer 1992) indicated that, even if uptraining produced a significant effect it was still much smaller and required longer training than the effect of downtraining.

One of the simplest explanations of the difference between the effects of up- and downtraining is the interaction of two processes: one - such as conditioning - enlarges or reduces P300 amplitude in a more or less symmetrical way; the other reduces P300 amplitude regardless of the direction of training. There is a well documented, strong effect that can modify the results of feedback experiments: it was shown that P300 amplitude was very sensitive to any parallel activity competing for brain processing resources with the main experimental task (Donchin et al. 1986, Polich 1989). It can be assumed that processing feedback information and the attempts to control brain potentials constitute a substantial drain on processing resources of subject's brain. Such a drain should limit the resources available for the main task of mental counting of target stimuli and should suppress the P300 amplitude regardless of the direction of training.

The aim of the present study was to demonstrate the effect of a parallel task in feedback experiments. To separate this effect from any possible effects of learning, alterations of event - related potentials were measured during the initial stage of training. Mental load should be particularly large at this stage but the effects of learning should be negligible.

METHODS

Subjects

Before the experiment each participant was asked to evaluate his/her level of anxiety and mood state on a ten-point scale. The "normal" level of anxiety and the "neutral" mood corresponded to value 5 on the scale. Fourteen volunteers of both sexes (4 males and 10 females), aged 29-48 years, participated in the experiment. They all showed an anxiety level and mood state between 4 and 6. Informed consent was obtained from all participants.

Recording

Disc electrodes were glued on the scalp at the Fz, Cz and Pz positions, according to the 10-20 system. Linked mastoids were used as a reference. Eye movements were monitored with vertical and horizontal EOG. All signals were digitized and stored with Elmiko Paperless EEG system. Each channel was sampled with 2048 Hz frequency, 12 bit resolution, digitally filtered 0.16-30 Hz and reduced to 256 Hz by averaging the adjacent points. Data were stored in epochs containing 250 ms before and 1 s after the stimulus onset. Epochs were rejected by the computer program if EOG amplitude exceeded 40 µV.

Flashes of spatially overlapped arrays of red and yellow LED diodes (2 deg x 2 deg of the visual angle, 10 cd/m^2 luminosity on 1 cd/m^2 background, 100 ms duration) were used as stimuli in a standard odd-ball procedure. Subjects were asked to mentally count the yellow flashes (target stimuli) and report their number at the end of the recording. Red flashes (non-target stimuli) were ignored. If the error in counting target stimuli was bigger than 20% the data were rejected. Stimuli were presented at intervals of 2.5 s. The probability of occurrence of the target stimulus was 0.12. If epochs were rejected because of artifacts they were replaced. The minimal number of good target stimulus repetitions was 30.

Procedure

ERPs recorded during the initial stages of up- and downtraining were compared with the no-feedback condition. To increase the amount of resources necessary for processing, feedback information was provided by spoken words. The words "small", "medium" or "big" were pronounced by the experimenter 1 s after each presentation of target stimulus, i.e., immediately after the recording of the EEG epoch was completed. An indicator on the computer screen was used to provide the timing. The evaluation of the P300 amplitude was based on the observation of the computer screen. The word "small" was used if the experimenter could not see the P300 wave.

The recordings were done in the following sequence:
1. control recording with no feedback,
2. feedback with the preceding instruction to change the P300 amplitude in one direction (down or uptraining randomly selected),
3. control recording with no feedback,
4. feedback with the preceding instruction to change the P300 amplitude in the other direction,
5. control recording with no feedback.

Data analysis

Waveform processing was done using Elmiko software package. Artifact-free epochs of EEG recorded in each session were averaged, stored and printed. Difference curves were computed for each pair of target and non-target ERPs. Grand-averaged waveforms were computed by averaging data for all subjects in each experimental condition. Statistical analysis followed two basic strategies:
1. amplitudes and latencies of peaks on target ERPs, non-target ERPs and difference curves were measured using the cursor on the computer screen and the data were transferred to SYSTAT program for multi-factor analysis of variance (ANOVA),
2. within the regions of visible differences corresponding points of grand-averaged curves were expanded into sets of paired data (points of individual difference curves) and compared with Student *t*-test.

Student *t*-test did not duplicate ANOVA results. Amplitudes measured for ANOVA were "latency corrected", i.e., the highest value within the specified region was selected disregarding its latency. In the process of grand-averaging, on the other hand, points of the same latency were added together, without any corrections, to form the final curve. The analysis of corresponding points evaluated the statistical significance of differences between such curves.

RESULTS

Figure 1 shows the responses to target stimuli grand-averaged over all subjects. Three sets of curves represent the data recorded from Fz (top), Cz (middle) and Pz (bottom) electrodes. Dotted lines show the waveforms obtained in the experiments with feedback and the instruction to enlarge P300 component. Solid lines show the recordings obtained with feedback and the instruction to reduce P300 wave. Dashed lines show the results of control recordings with no feedback and no instruction. Potentials recorded with feedback and the instructions to reduce P300 wave suggest the reduction of this component. But the instruction to enlarge P300 wave did not produce any clear differences from the control recordings without feedback. The effects of the feedback procedures seem to be limited to P300 waves. Earlier P200 components, although well developed in all recordings, are practically unaffected.

For statistical analysis P300 peak was identified as the most positive value between 250 ms and 400 ms after the stimulus onset. The P200 peak was identified as the most positive value between 150 ms and 290 ms after the stimulus onset. Amplitudes measured in individual ERPs, relative to 250 ms pre-stimulus baseline, were analyzed with two way ANOVA (electrode x feedback). There were significant differences in P300 amplitude due to the type of feedback ($F_{2,168} = 7.45$, $P<0.001$). Bonferroni test showed that the amplitudes of P300 waves recorded with feedback and the instruction to reduce them were significantly smaller than P300 waves recorded with feedback and the instruction to enlarge

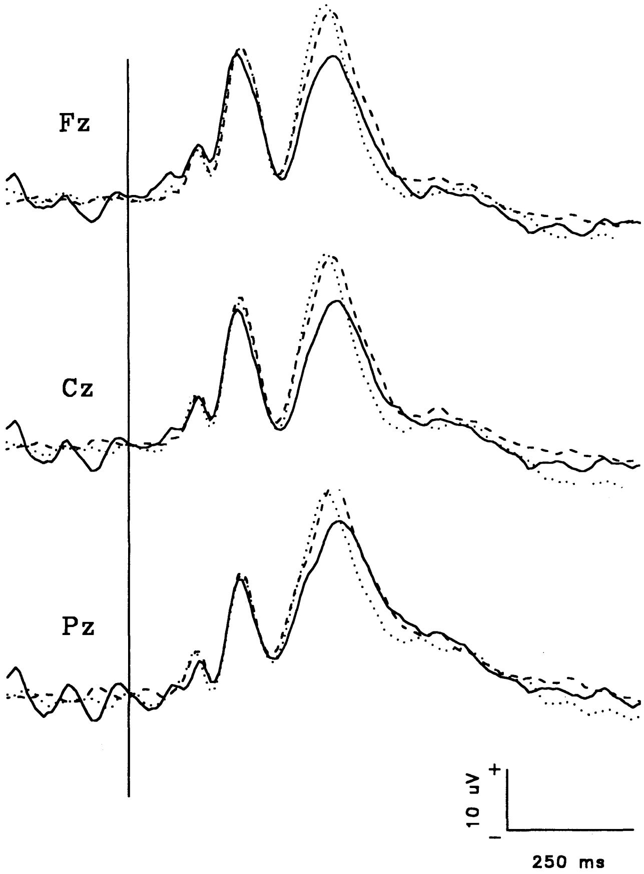

Fig. 1. Grand-averaged ERPs evoked by target stimuli. Potentials were recorded with Fz (top), Cz (middle) and Pz (bottom) electrodes. Dashed lines show the ERPs recorded without feedback. Dotted lines show the ERPs recorded with the feed-back and the instruction to enlarge the P300 amplitude. Solid lines show the ERPs recorded with feedback and the instruction to reduce the P300 amplitude.

them ($P<0.008$) or the waves recorded without the feed-back ($P<0.001$). In contrast, the amplitudes of P200 waves were not significantly affected by any of these procedures.

Latencies of individual P300 and P200 peaks were analyzed with an analogous two way ANOVA (electrode x feedback). Neither P300 nor P200 latencies differed significantly between uptraining, downtraining and no-feedback conditions.

Table I shows the mean amplitudes and latencies of P300 and P200 components. Interestingly, the data indicate that uptraining (like downtraining) reduced rather than enlarged the amplitudes of P300 components in comparison with the no-feedback condition.

Figure 2 shows the grand-averaged potentials evoked by non-target stimuli. Figure conventions are the same as in Fig. 1. Recordings from all electrodes show well-developed P200 waves and only the remainders of P300. Comparison of Figs. 2 and 1 shows that training affected non-target responses much less than target ERPs. However, the small remainders of P300 waves, visible in non-target responses, show some amplitude changes: amplitudes recorded without the feedback are slightly higher than those recorded in the other two conditions. Unfortunately, in the individual recordings these remainders of P300 waves were too small to identify and measure reliably and the statistical analysis could not be done. The amplitudes and latencies of P200 components were also measured in non-target responses and analyzed with two way ANOVA (electrode x feedback). Differences produced by the feedback type were clearly insignificant.

TABLE I

The effect of up- and downtraining on the parameters of P300 and P200 components of potentials evoked by target stimuli. Standard deviations are shown in parentheses beneath the mean values

	P300		P200	
	amplitude (μV)	latency (ms)	amplitude (μV)	latency (ms)
downtraining	19.5	388.3	15.76	200.9
	(8.2)	(28.0)	(5.2)	(12.3)
uptraining	25.7	381.7	17.9	207.0
	(7.6)	(21.4)	(6.0)	(11.3)
control	26.3	392.6	18.2	206.7
	(9.4)	(28.8)	(5.9)	(12.9)

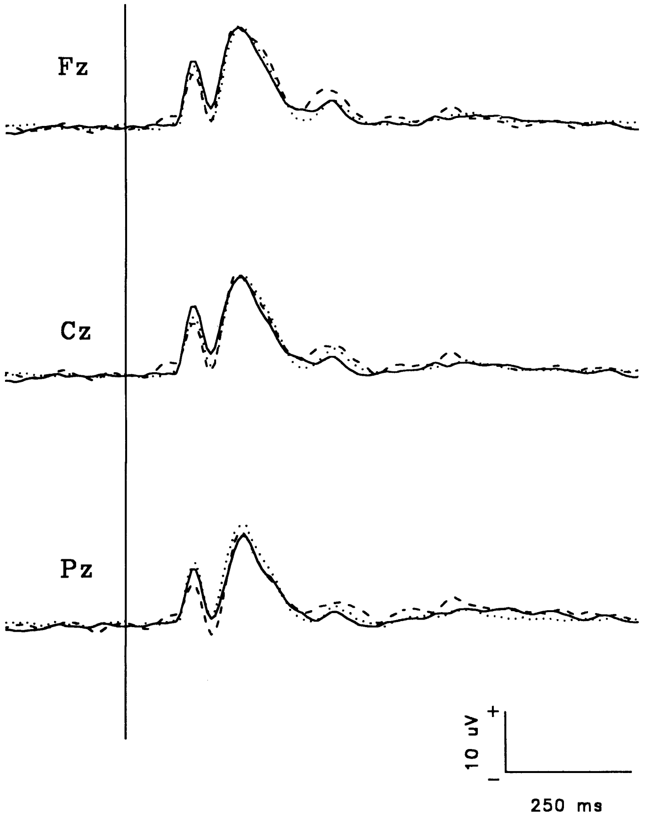

Fig. 2. Grand-averaged ERPs evoked by non-target stimuli. Figure conventions are the same as in Fig. 1.

P300 components were present almost exclusively in target responses but P200 waves appeared in both target and non-target ERPs with clearly different amplitudes. To separate components specific for target responses, difference curves were computed by subtracting ERPs evoked by non-target stimuli from those evoked by target stimuli. Figure 3 shows these difference curves, grand-averaged for all subjects. Figure conventions are the same as in Figs. 1 and 2. Two clear peaks within the P300 and P200 regions indicate that both components reflect endogenous processes. It is apparent that, like in target ERPs, feedback affected P300 component much more than P200 and that the effect was highly asymmetrical: downtraining (solid lines) clearly reduced P300 amplitude whereas uptraining (dotted lines) produced only very small deflections from control data recorded without feedback (dashed lines).

Table II shows the amplitudes and latencies of P300 and P200 components measured in the difference waves. Two way ANOVA (electrode x feedback) showed significant differences in P300 amplitude due to the type of feedback ($F_{2,168} = 13.848$, $P<0.001$). Bonferroni test showed that the amplitude of P300 wave recorded with feedback and the instruction to reduce it was significantly smaller than the same amplitude recorded with feedback and the instruction to enlarge it ($P<0.001$). Downtraining also produced a significant reduction of P300 amplitude when compared with the no-feedback condition ($P<0.001$). But uptraining did not produce a significant difference when compared with the control recordings without feedback.

The analysis of the difference curves revealed that feedback type produced significant differences also in P200 amplitudes ($F_{2,150} = 3.832$, $P<0.024$). Bonferroni test showed that downtraining significantly reduced the P200 component when compared with no-feedback control ($P<0.026$). The difference between P200 amplitudes

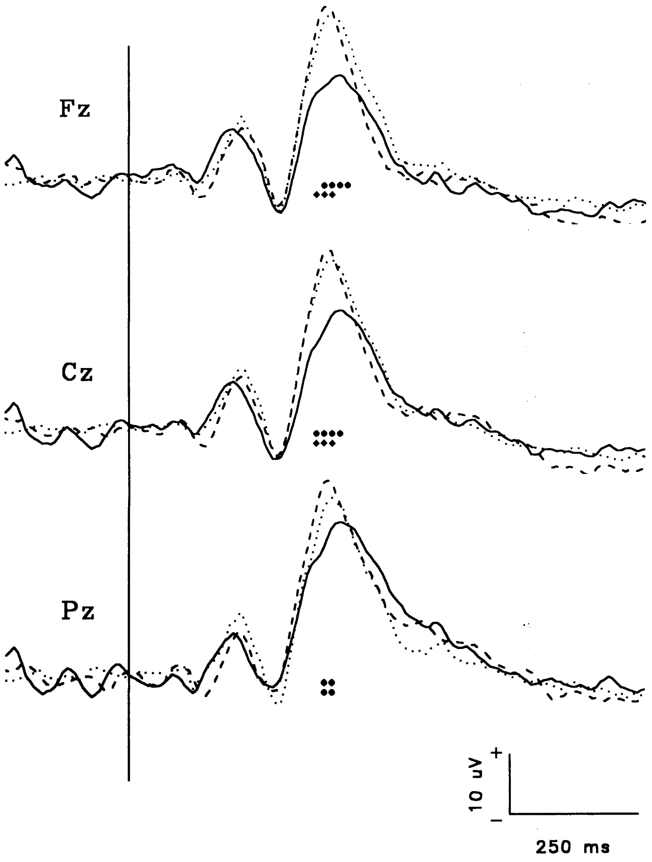

Fig. 3. Grand-averaged difference curves computed by subtracting ERPs evoked by non-target stimulus from ERPs evoked by target stimulus. Figure conventions are the same as in Fig. 1. Black circles beneath the curves show the points where the waveforms obtained with uptraining (dotted lines) and downtraining (solid lines) differed significantly. Black diamonds indicate the points of significant differences between the downtraining (solid lines) and the control no-feedback curves (dashed lines).

TABLE II

The effect of up- and downtraining on the parameters of P300 and P200 waves computed as a difference between potentials evoked by target and non-target stimuli. Standard deviations are shown in parentheses beneath the mean values

	P300		P200	
	amplitude (μV)	latency (ms)	amplitude (μV)	latency (ms)
downtraining	16.5	386.7	5.2	190.8
	(8.0)	(33.5)	(3.2)	(18.7)
uptraining	25.8	381.4	7.4	196.7
	(7.1)	(30.3)	(4.5)	(18.6
control	24.6	391.9	7.5	194.3
	(8.8)	(32.6)	(4.0)	(19.6

recorded in the up- and downtraining sessions was close to the level of statistical significance but did not reach this level ($P<0.066$).

All the differences in latencies of P300 and P200 components measured in difference curves were insignificant.

Difference curves were also used for the complementary statistical analysis. Within the range of 102 ms to 586 ms, every 24 ms, the corresponding points of grand-averaged difference curves were expanded into a sets of paired data (points of individual difference curves) and compared with Student *t*-test. Filled circles in Fig. 3 indicate the regions of significant differences ($P<0.05$) between curves obtained with up- and downtraining. All the circles are clearly located within the P300 region. Black diamonds mark the regions of significant differences ($P<0.05$) between the downtraining and the control, no-feedback curves. Again, all the diamonds are located within the P300 region. No significant differences were found between uptraining and control curves.

DISCUSSION

The results of downtraining experiments seem to support the working hypothesis: during the first 30 presentations of the target stimulus (the minimum number necessary to produce an acceptable averaged potential) P300 amplitude was already significantly reduced. In contrast, the effect of uptraining was clearly different: P300 amplitude was similar to the amplitude measured without the feedback and significantly different from the amplitude measured during downtraining.

The simplest explanation of such results may be some kind of saturation. Since the odd-ball procedure has been designed to produce robust P300 waves, the effects of this type can not be excluded. There could be just more room to reduce P300 waves than to enlarge them. In future experiments it would be interesting to test similar feedback procedures in the experimental situation that produces small P300 waves. Non-target responses could be an interesting candidate for such conditioning. But it is still puzzling why the effects of parallel drain could not be demonstrated. It was expected that, at the initial stages of learning, the effect of drain on processing resources of the brain would dominate. According to subject's reports the strategies used to control the P300 amplitude included the activities such as:

1. The attempts to analyze the internal states of the brain before and during the last target stimulus presentation,
2. The attempts to correlate these states with the received feedback information,
3. The elaboration of the decision whether to reproduce or avoid these states in the future,
4. The repetitive verification and modification of these decisions.

In comparison with the primary task of mental counting of target stimuli all these processes were vastly complex and should use a lot of brain processing resources. Therefore the resources available for the primary task should be significantly reduced.

The clear reduction of P300 amplitude by the parallel task was observed in a large number of experiments with different designs (Israel et al. 1980a,b, Donchin et al. 1986a,b, Kramer et al. 1987, Polich, 1989). Even "parallel activity" of a very general nature, such as perceiving tonic pain or stress, clearly suppressed the P300 amplitudes (Rosenfeld and Kim 1991, Rosenfeld et al. 1993, Michalski 1998a,b). The effect of the parallel task was always instantaneous, therefore it should reduce P300 amplitude in the first session of downtraining. It is difficult to explain why feedback procedures should be excluded from this rule.

At this stage of research it seems reasonable to assume that the effect of a parallel task actually reduced P300 amplitudes in both up- and downtraining experiments. This implies the existence of another process that compensated this reduction in uptraining but not in down-training. One obvious candidate is learning. But can it be so fast? The results of the earlier experiments support the initial assumption that during the first 30 repetitions of a target stimulus the effect of learning should be negligible (Sommer and Schweinberger 1992). It is safer to conclude that the "real feedback effects", i.e., processes of learning did not interfere in the present experiment.

The presence of asymmetrical processes, other than parallel drain, was indicated by the results of the experiment where random feedback was used as a reference (Sommer 1987). In this experiment the drain on processing resources should be similar in both feedback and control recordings. But the effect of downtraining was stronger than the effect of uptraining. Why should learning to increase the P300 amplitude be more difficult than learning to decrease it? It should be stressed that the difference was observed after long training, therefore it can not be directly compared with the present results. But the direction of the asymmetry was opposite to the direction required to explain the present results: rather than the enhancement during uptraining (needed to compensate the parallel task effect) stronger suppression was found during downtraining.

Conscious attempts to suppress the brain potentials could result in a kind of general "negative attitude", the specific brain state linked with emotions and/or altered attention levels. There are no reasons to believe that the attempts to enlarge brain potentials should produce the exactly complementary effects. It can not even be excluded that emotional states were produced by the experimenter himself. Since feedback was given in the form of spoken words, feedback information could contain an emotional component. In spite of conscious effort to avoid it, the experimenter could communicate his disappointment or satisfaction. In this case, however, the experimenter should be equally satisfied with the reduction of P300 waves during downtraining and with their enhancement during uptraining. Thus, this effect can not explain the observed asymmetry.

The absence of P300 wave was an extreme case and the difference between medium and large P300 could be much smaller than the difference between medium and small. This asymmetry does not seem to be crucial because most of the subjects treated the medium signal as inconclusive. The task was very difficult and the common strategy was to reduce the amount of information and concentrate on the two extreme cases. However, the numbers or the relative frequency of the large and small signals depended on both the general efficiency of the odd-ball procedure to produce the large P300 waves and the experimenters ability to detect small waves in the unprocessed EEG signal. This relative frequency could produce unspecific emotional states and could explain the asymmetric results because the effect could depend on whether or not the more frequent signal was the required one. In this paper the relative frequency of different feedback signals was not recorded. It was analyzed in the separate experiment in which the process of learning was entirely eliminated by using random feedback and the impression of success or failure was created by manipulating the proportions of required and not required feedback signals (Michalski 1999). The amplitudes of P300 potential were significantly reduced in the "failure" situation whereas "success" did not produce significant differences from the no-feedback control.

It can be concluded that feedback procedures can be useful in studying the phenomena such as the effects of parallel drain or even emotions. The experiment revealed that a task as complicated as the attempt to use external information to modify ones own brain potentials involves a number of processes, some of them little understood. At this stage several potentially interesting experiments can be designed even without solving the main controversy whether or not the conscious control of brain potentials is possible.

It should be also noted that the initial stages of feed-back training affected not only P300 but also P200 component. Unlike the P300 wave, P200 component was present in both target and non-target responses but with different amplitudes. This supported the earlier findings that P200 also reflected endogenous processes (Hillyard and Picton 1979, Miltner et al. 1989). Interestingly, P200 alterations were significant only in difference curves, suggesting that the same component of P200 wave that was specific to target responses was also sensitive to feedback manipulations. The alterations of P200 waves were found in spite of the fact that "odd ball" procedure was designed to elicit P300 component and that the subjects were specifically asked to control the P300 not P200 amplitude. This could be a further indication of the unspecific nature of the observed effects.

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