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Amplitude changes in components of the auditory evoked potentials during a reward-associated counting task

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Auditory evoked potentials (AEPs) were recorded while subjects were instructed to count each of a series of clicks as they were presented via earphones. Reward was made available following a response after the 20th click. AEPs to these clicks were computed separately for five successive time windows during these series. Four waves of the AEP were examined for systematic change in amplitude. The earliest wave (N92) did not change, but the following three waves (P171, N240, and P339) showed gradual increasing amplitudes as the reward approached. However, more complex changes, such as a sudden postreward decrement or prereward enhancement, which are often associated with the fixed-interval reinforcement schedules, were not clearly observable.

Most counting behaviors are associated with reward at the end of the counting. Usually the reward is in the form of acquired information. In addition, when counts of certain length are repeated, the subject may show differences in the responses during the count sequences for the periods immediately before and after the presentation of the reward. Such effects may be expected when the reward is made available on a consistent fixed interval. The present study examined human auditory evoked potentials (AEPs) during a counting task and the differential neurophysiological outputs accompanying the behavioral responses.

METHOD

Eleven young adult subjects were used. They were seated in a semiacoustically shielded chamber, fitted with earphones for both ears, and given a hand-held pushbutton. A click train, which also served as a trigger for the AEP, was presented at a fixed interstimulus interval of one click every 2 sec. The subject was instructed to operate a response button, which, after the 20th click, would produce reward. A "payoff" in the form of variable amounts of monetary reinforcement (1-9 cents) was displayed for 6 sec on a screen directly in front of the subject (see Figure 1). The subject was instructed to write down the amount earned each time, but he was asked to do so only during the display period. He was also instructed to count silently. These measures were taken in order to avoid myogenic contamination to the AEP record. The next counting trial started as soon as the display disappeared. Forty reinforcements were delivered in an experimental session. Thus a subject earned

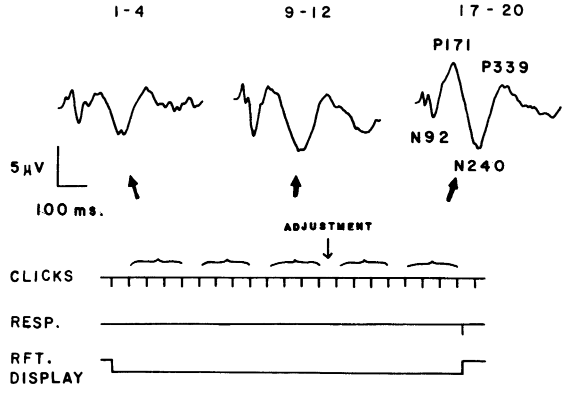

Figure 1. Experimental design is shown on the bottom. See text for explanation. The response waveforms from a single subject are shown on the top. The three illustrated responses were obtained by averaging the first window of four clicks (left), the third window of four clicks (middle), and the fifth window of four clicks (right). The correspondences between the response and the location of the interreinforcement windows are indicated by arrows as well as the numbers 1-4, 9-12, and 17-20. The AEP from the second and fourth windows are not shown. Four waves labeled N92, P171, N240, and P339 were analyzed. Upward displacement of the reinforcement display marker shows reward display.

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about $2 in a session. The click presentation, reinforcement display, AEP averaging for each of five separate time windows, and recording of the pushbutton responses were all controlled by a PDP-12 computer. Occasionally, subjects failed to respond immediately after the 20th click, in which case provision was made for inclusion of the latest AEPs. If the responses were made after the 21st click, an adjustment (see Figure 1) was made between the third (9-12 clicks) and the fourth (13-16 clicks) averaging windows. The adjustment was achieved by storing the AEP recorded in the first three windows; then the PSP-12 started to record the AEP to the next eight clicks in a ringstorage mode. When a response was made, these eight AEPs were frozen, rearranged, divided into two blocks of four AEPs each, and stored in the memory as the fourth and the fifth windows. This ring was kept circling by continuously discarding the oldest AEP, which was replaced by the latest one until the response was made. A schematic of the design is given in Figure 1.

The clicks were 1 msec long and had an intensity of 92 dB SPL (re: .0002 dyne/cm^2). The AEP was recorded between the vertex (C_Z) and the linked earlobes. An electrode placed over the right inner canthus monitored eye movement. These electrophysiological data were recorded from a Beckman Type R Dynograph with a band pass of 1-150 Hz. The analysis time of the AEP was 512 msec, and the averaging was kept separate for the click stimuli presented at five successive windows of four clicks since reinforcement.

RESULTS

The AEP waveforms are shown in Figure 1 with the associated experimental conditions. Four of the AEP components were selected for amplitude measurement. They are indicated in Figure 1 as Waves N92, P171, N240, and P339. The N or P indicates polarity, and the numbers are the mean peak latency. No apparent eye movement was recorded in association with click presentation. Generally, the AEP recorded under the present experimental conditions had a slightly shorter latency and somewhat smaller amplitude compared with the AEP to passive listening of clicks with comparable parameters (Goff, Matsumiya, Allison, & Goff, 1977), but these measures were roughly the same as those found with task-associated listening (Wilkinson & Morlock, 1967). Analysis of variance revealed significant intersubject variability on all AEP components ($p < .01$), although the significant differences found between waveforms (Figure 2) were characteristic of each of the individual records.

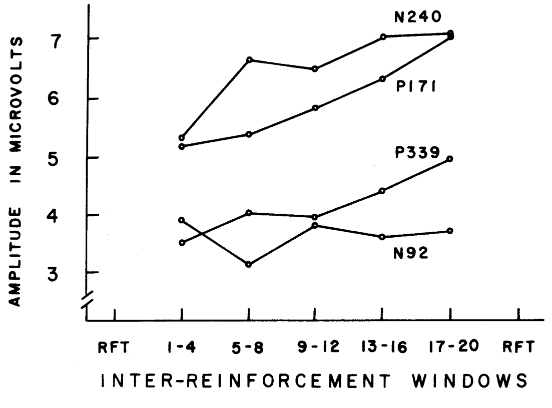

Figure 2. Amplitude changes of four AEP waves as a function of the location in the interreinforcement window. Mean value of 11 subjects.

Figure 2 shows the changes of the AEP amplitude as a function of its position in the interreinforcement period. Wave N92 does not show any systematic amplitude changes. Wave P171 shows a significant linear increase in amplitude [$F(4,40) = 4.86$, $p < .01$]; the points of Waves N240 and P339, although not linear, also have a significant overall difference [$F(4,40) = 2.91$, $p < .05$, and $F(4,40) = 2.67$, $p < .05$, respectively]. No significant latency shifts were noted in the AEP.

DISCUSSION

The defined task for the subject in this experiment was to count, and since counting behavior in the human adult subject has already been overlearned, it is reasonable to consider that this procedure would reflect effects created by periodical rewards rather than by acquisition, transition, or extinction processes of temporal conditioning. This was later confirmed when the first half and the second half of the session were compared. There was no difference between the two sessions. The incorporation of specific instructions and the selection of the filtering system that was used in the design of the experiment preclude an explanation of the findings by contaminants such as motor potentials, eye movement, CNV, and so on.

It is of interest that Wave N92 did not respond to the present paradigm, showing no effect of an anticipated reward. This wave is known to change in some studies as a function of attention level (Schwent & Hillyard, 1975; Wilkinson & Morlock, 1967). It is possible that the amount of unexpectedness, which is minimal in the present study, is responsible for the differences between the studies. The other three waves change as a function of position in the counting sequence, showing a gradual increase in amplitude as reward is approached. The nature of the change is mostly linear in Wave P171. The present experimental paradigm resembles the fixed-interval (FI) schedules of reinforcement to the extent that both paradigms include estimation of elapsed time associated with the fixed position of the reward. Therefore, it was expected that the present AEP might show postreinforcement amplitude decrement and prereinforcement increment. However, the only tendency that conformed partially to such a prediction was Wave N240, for which the total amplitude difference of 1.77 microV between the first window (Clicks 1-4) and the last window (Clicks 17-20) was found. The difference between the first and the second (Clicks 5-8) window of this wave was 1.34 microV; thus it accounts for 75% of the total change. This ogive-like form of amplitude change is suggestive of the postreinforcement response decrement found in conventional conditioning experiments.

In animal experiments, when an external counter is added to the interreinforcement interval, the responses come to be restricted to the last, reinforced trials (Ferster & Zimmerman, 1963), but no comparable AEP change was found (i.e., no marked prereinforcement amplitude increment with otherwise low amplitude waveforms). In a sense, human AEP changes are more undifferentiated than animal behavior. It is possible that the first 340 msec of AEP is reactive but is rather undifferentiated to the effects caused by a fixed position of reward, and the more differentiated form, such as seen in FI-type behavior, is associated with activities occurring after 340 msec, such as may be represented by CNV.

Interpretative explanations from the data to possible underlying decision or expectancy processes are both tempting and probably premature at this time. The systematic variations in amplitude for the separate components suggest, however, that the present design offers considerable promise in integrating AEP outcomes with behavior generated under conditions of attention, orienting reactions, and reinforcement schedules.

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