

Perceptual context and the selective attention effect on auditory event-related brain potentials

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Abstract

Two experiments examined the effect of the perceptual context established through tonal grouping on neuroelectric responses during selective listening. Subjects monitored one of the extreme pitches in four-pitch tone sequences and detected rare longer tones of the designated pitch. In the first study, tonal grouping was manipulated by changing the tonal separation between the extreme pitches and their nearest neighbor, keeping the extreme pitches constant. Grouping increased the negativity of the attended–unattended difference potential. A second study examined the effect of grouping on the attention-related negativity when it opposed the effect of physical similarity. The proximity of extreme pitches varied, keeping the middle pitches constant. The effect of grouping on event-related potentials (ERPs) for the middle pitches was varied according to the tone being attended. ERPs for the middle tone adjacent to the attended tone became more negative with grouping, whereas ERPs for the distant middle tone became less negative with grouping. These effects suggest that the attention-related negativity is sensitive to contextual information.

Descriptors: Selective attention, Evoked brain potentials, Stimulation context, Tonal grouping, Pitch discrimination

The auditory selective attention effect refers to the influences of behavioral goals on the differential processing of various aspects of auditory input. These influences can occur at several levels in the nervous system and at several moments before and after the externally observable stimuli and responses. When sounds are part of a sequence, the attention-related processing difference can be based upon information provided by the physical features of the incoming stimulus and also upon contextual information contained in the relations between the stimulus and its predecessors. The present studies explored the influence of perceptual context on the auditory selective attention effect.

Besides overt performance, the neuronal population activity recorded in cerebral event-related potentials (ERPs) provides one of the simplest observations of the selective attention effect. In selective listening tasks, ERPs for tones designated to be monitored are more negative than ERPs for similar tones that are not monitored (for reviews, see Näätänen, 1990; Woods, 1990). Also, unattended tones in auditory monitoring tasks produce more negative ERPs than do similar tones heard during the execution of a concurrent task such as reading (Alho, Töttölä, Reinikainen, Sams, & Näätänen, 1987b).

The negative shift in the ERP surely reflects only part of the brain activity related to the selective attention effect. Compared to overt performance, however, ERP measures permit direct comparisons of responses to attended and unattended stimuli and thus provide a useful tool for the study of the perceptual basis of the selective attention effect.

The ERP auditory attention effect is often examined as a difference potential between ERPs for the same stimulus when it is to be attended and when another stimulus is to be attended. In surface recordings, the resulting slow negative difference wave (Nd) appears to have at least two distinct temporal portions, an early and a late component (Nd_e and Nd_l), that peak at about 200 ms and 400 ms, respectively, following tone onset (Hansen & Hillyard, 1980).

The Nd_e has an earlier onset and a larger amplitude when the tonal or spatial separation between attended and unattended tones is larger (Alho et al., 1987a; Alho, Paavilainen, Reinikainen, Sams, & Näätänen, 1986a; Alho, Sams, Paavilainen, & Näätänen, 1986b; Alho et al., 1987b; Hansen & Hillyard, 1980). The amplitude of Nd_l also increases with the tonal separation between attended and unattended stimulus sequences (Hansen & Hillyard, 1980).

Little is known of the central nervous system operations underlying the attention-related negativity. Hillyard and colleagues (Hansen & Hillyard, 1980, 1983; Hillyard, Hink, Schwent, & Picton, 1973; Hillyard & Picton, 1988) suggested that the Nd_e reflects an early stimulus selection based upon easily discriminable information distinguishing relevant from irrelevant stimuli (i.e., stimulus set, Broadbent, 1971). From this perspective,

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stimuli are accepted or rejected on the basis of their dominant relevant physical attributes, and further perceptual analysis is contingent on this early selection. Hillyard and colleagues also proposed that the Nd_1 could reflect a late selection of target from nontarget stimuli within the attended channel based upon less discriminable cues.

Näätänen (1982, 1990) proposed a more specific hypothesis in which the Nd_e reflects an early selection of stimuli that is based upon a gradual comparison process between the sensory input and a memory trace. The memory trace refers to a temporary neuronal representation of the distinctive physical features of the attended tones that is actively formed and maintained during selective listening and serves to recognize the stimuli that must be further processed for a possible response. According to Näätänen, all incoming stimuli are compared to the memory trace, the comparison process generates a surface negative potential (the processing negativity), and the duration of the comparison process depends on the similarity between each incoming stimulus and the memory trace. In this perspective, the Nd reflects the difference between the processing negativities elicited by the comparison processes executed on matching (attended) and nonmatching (unattended) stimuli.

In experimental situations involving only two types of stimuli (one attended and one unattended), the obvious perceptual information upon which processing segregation can be based is that provided by the differences in physical features of the two types of stimuli. However, realistic listening situations contain information on continuity and other interstimulus relationships that could also be used for processing segregation. Thus, the perceptual basis of the selective attention effect could depend on the listening situation or perceptual context.

In vision, the perceptual context of neighboring stimuli affects selective performance (Driver & Baylis, 1989; Duncan, 1984; Kahneman & Henik, 1981; Pomerantz, 1981). In audition, the stimulation context within which an acoustic event is embedded can have a strong influence on its processing (Handel, 1989, chap. 9). Bregman and Rudnicki (1975) and Jones, Kidd, and Wetzel (1981) have shown that order judgments may be improved by a context that facilitates the segregation of sounds into separate streams. They presented two different target tones that were flanked by two identical lower pitch distractors. In all conditions, the target tones and the distractors remained constant while additional *captor* tones of still lower pitch, preceding and following the block of four tones, varied in tonality. They noted that order judgments on the target tones improved with the reduction of the pitch separation between the captor and the distractor tones. This result was interpreted as compatible with the stream segregation phenomenon, the close captor inducing a process that segregates the targets and distractors into separate streams thereby facilitating the processing of the targets.

These studies suggest that the effect of distractors on performance does not depend solely on their individual physical features but may also depend on the set of relationships that they have with each other and with targets. The perceptual context seems to provide information to the processing system that can alter the processing of an incoming stimulus.

If contextual information is used by the system to segregate the processing of attended and unattended stimuli, it may also affect the attention-related potential. An effect of context on the attention-related negativity would imply that the selective processing that it reflects can use information from interstimulus relations and not only that contained in the similarity

between individual stimuli and a representation of the attended stimulus.

Two experiments were designed to examine the effect of context on ERPs during selective listening to tone sequences. Context was varied through manipulations of the pattern of tonal separation between the four different pitches in the sequence. In one experiment, context was manipulated by changing the separation between the two middle pitches, keeping the extreme pitches constant. A second experiment varied the separation of extreme pitches while keeping the middle pitches constant. When the pitches are grouped, the relative proximity of pitches within each pair provides contextual information (pair membership) that may be available to the auditory system to facilitate the selective monitoring of one pitch out of the four present.

Experiment 1

The first study examined whether tonal grouping could affect the attention-related negativity (Nd) in selective listening. The experiment tested whether the Nd could be enhanced by grouping the four pitches in a tone sequence into two pairs as compared with a baseline condition in which they were evenly spaced in tonality (see Figure 1A).

Attention was directed to either of the constant extreme pitches. If Nd is not sensitive to context but only to the physical proximity of the attended pitch and the incoming tone, there should be no difference between the Nds for the extreme tones in the two conditions because the extreme pitches remained constant across conditions. However, if Nd is sensitive to contextual information, it should be enhanced when the four pitches are grouped into two pairs as compared with when they are

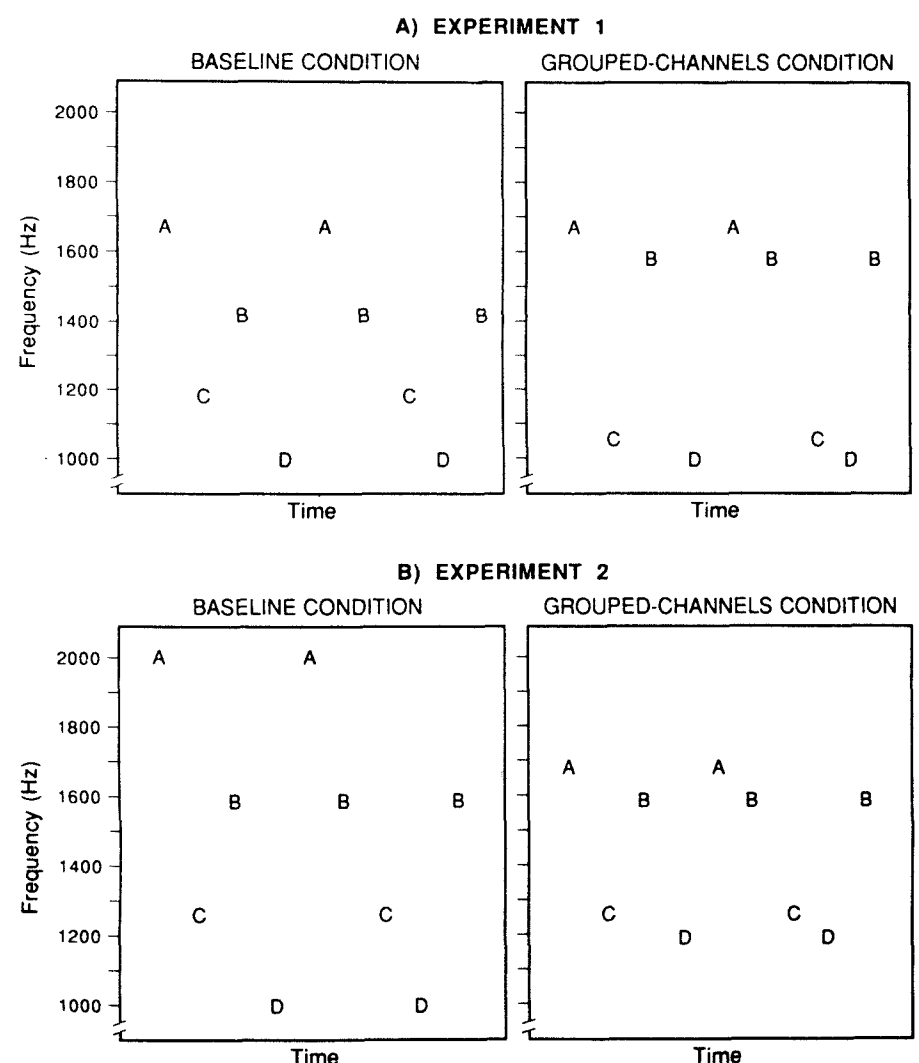


Figure 1. Stimulus sequences (A-D) used in the two conditions of Experiment 1 (A) and Experiment 2 (B).

evenly spaced because grouping provides additional information to differentiate the attended and unattended extreme tones.

Method

Subjects. Ten women between 20 and 37 years of age participated in this study. Five additional volunteers did not qualify for the experimental session because of their poor performance during the training session (more than 50% misses in the training sequences). Three of the subjects had previous experience with evoked potential studies but none with similar paradigms. None of the 10 subjects reported any history of a hearing disorder. All subjects received an honorarium for their participation.

Stimuli. Tone frequencies of 1,000, 1,059, 1,189, 1,414, 1,587, and 1,682 Hz were used. All tones were produced from sine waves digitized on 12 bits, at 20 kHz, with 10-ms rise and fall times. Digitized tones were presented through a 386 personal computer and a Data Translation digital-to-analog interface. The analog output was bandpass filtered (0.4–3 kHz, Rockland model 1000F), amplified by a standard audio amplifier, and presented binaurally through headphones at 60 dB SPL. Within each pitch, frequent short duration tones ($p = .85$, 60 ms) and rare long duration tones ($p = .15$, 130 ms) were presented.

Recording. The electroencephalogram (EEG) (Grass polygraph, bandpass 0.1–35 Hz) was sampled continuously at 200 Hz (12-bit digitization) from three midline scalp Ag/AgCl electrodes (Fz, Cz, and Pz) referenced to linked mastoids. Eye movements were recorded with a left infraorbital and a right supraorbital electrode. Impedance was always below 8 kohms between electrooculogram (EOG) electrodes and below 5 kohms between scalp and reference electrodes.

Procedure. Each subject was tested in two experimental conditions presented on separate days. In the two conditions, stimulus sequences consisted of 320 tones of four different pitches delivered at random intervals uniformly distributed between 200 and 500 ms. In the baseline condition, the four pitches were equally spaced by three semitones (1,000, 1,189, 1,414, 1,682 Hz). In the grouped-channels condition, the 1,189- and 1,414-Hz tones were replaced by two others separated from the extreme pitches by one semitone (1,000, 1,059, 1,587, 1,682 Hz). In both conditions, the attended pitches were alternately 1,000 or 1,682 Hz. We refer to tones of the lowest two pitches in both conditions as low-pitch tones and to the other tones as high-pitch tones. In each sequence, the tones were presented in random order with two restrictions: (a) Three consecutive presentations could not contain more than two low-pitched or high-pitched tones, and (b) at least five short tones were interspersed between infrequent long duration tones.

Subjects were seated in a sound-attenuated room and were asked to fixate a cross placed on a panel 1.5 m in front of them. Before the recording sessions, subjects received four training sequences on the appropriate condition for that day (grouped channels or baseline), that is, two sequences for each attended pitch. Following practice, they received five consecutive sequences in which the same pitch was attended (1,000 or 1,682 Hz). Each sequence of 320 tones lasted nearly 2 min, and a pause of about 30 s separated consecutive sequences. A 10-min pause was given midway into the session, at which time the subject was instructed to switch attention to the other extreme pitch. The subjects were

asked to press a button as soon as possible when they heard rare longer tones of the designated pitch (targets), while trying to make as few errors as possible. After each sequence, the subject was given a verbal feedback on her error rate and mean response time. The order of conditions and of attended pitches was randomly assigned for each subject.

Data analysis. Behavioral measures of response time and accuracy were scored by computer. Correct responses were defined as a button press within 200–800 ms after a target was presented. Responses at any other time were classified as false detections. Performance data were compared across conditions for the 1,000- and 1,682-Hz tones using two-way analyses of variance (ANOVAs).

EEG epochs of 800 ms, including a 200-ms prestimulus baseline, were extracted off-line and averaged separately for each stimulus type in each condition. For each epoch, the mean amplitude of a 200-ms prestimulus baseline was subtracted from all data points. The individual ERPs were inspected visually without knowledge of evoking stimulus, and those containing eyeblinks or muscular artifacts were excluded from the averages. In addition, because evidence suggests that the attention effect on the ERP is not present at the beginning of a sequence (Donald & Young, 1982; Hansen & Hillyard, 1988), the first 10 ERPs of each sequence were also excluded from the averages. Difference waves (Nd) were constructed for the extreme short and long tones in each condition by subtracting the ERPs for a given tone when it was not attended from the ERPs for the same tone when it was attended.

The mean amplitude of ERPs was computed for five consecutive 40-ms intervals beginning at 5 ms after stimulus onset (i.e., 5–40, 45–80, 85–120 ms, etc.). The amplitudes were compared across conditions separately for each 40-ms interval, each electrode, and each tone duration using ANOVAs for repeated measures, with grouping condition and pitch (1,000 or 1,682 Hz) as variables.

Results

Performance. Grouping was used to facilitate differentiation of the two pairs of tones. However, grouping was expected to increase discrimination difficulty within each pair because of the increased proximity between the attended pitch and its nearest neighbor in the grouped-channels condition. Table 1 shows group averages for response time and errors. Subjects made more false detections in the grouped-channels than in the baseline condition, $F(1,9) = 9.0$, $p = .01$. No difference was detected between conditions in the number of misses and response time. The effects of pitch and the Pitch \times Condition interactions were not significant.

Table 1. Means (SD) of Behavioral Measures in Experiment 1

	Response time	Misses	False detections
Baseline	470 (39)	9.3 (5.6)	3.8 (2.9)
Grouped channels	492 (66)	14.7 (9.1)	11.8 (9.8)

Note: An average of 60 targets were presented for each attended pitch.

To evaluate whether the increased false detection rate in the grouped-channel condition could be attributed to the increased proximity of the middle tone adjacent to the attended tone, we examined the type of tone presented 300–700 ms before each false detection. In the baseline condition, 23% of false detections involved tones that were adjacent in pitch to the targets, whereas this proportion increased to 41% in the grouped-channels condition. This increase in the proportion of false detections was not observed for any other tone.

ERPs for extreme tones. Figure 2 shows the group average ERPs for the frequent extreme tones in the two conditions when they were attended and when they were unattended, as well as the attended–unattended difference potentials (Nds). The N1 and P2 components peaked at an average of 110 and 200 ms, respectively. The Nds overlapped the N1–P2 complex and were largest at Fz and Cz. At Fz, Nds showed distinct early and late

components (Nd_e and Nd_l) that peaked at about 200 ms and 350 ms, respectively.

The ANOVAs revealed a significant difference in Nd amplitude between the grouping conditions only during the 85–120-ms interval at Fz, $F(1,9) = 6.4$, $p = .03$, and at Cz, $F(1,9) = 9.7$, $p = .01$, as well as a trend for the 45–80-ms interval at Fz, $F(1,9) = 4.6$, $p = .06$. No difference was detected during any other interval.

To examine whether the effect of context on Nd could be attributed to an enhanced negativity for the attended tones or to a decreased negativity for the same tones when they were unattended, ANOVAs were performed on the average ERP waveforms for attended and unattended tones using the mean amplitude of consecutive 40-ms intervals, with pitch and grouping condition as variables. For unattended tones, grouping produced a slight decrease in negativity during the 45–80-ms interval at Fz, $F(1,9) = 4.55$, $p = .06$, and during the 85–120-ms interval at Fz, $F(1,9) = 3.67$, $p = .09$, and Cz, $F(1,9) = 4.11$, $p = .07$. Grouping produced a decreased negativity in ERPs for attended tones only between 5 and 40 ms at Pz, $F(1,9) = 2.57$, $p = .03$, but this difference is probably artifactual because it was not repeated at later intervals. No difference was detected between the two conditions for attended tones at any other electrode or interval before 200 ms poststimulus. In all cases, the interaction of pitch and condition was not significant.

The Nd waveforms recorded at Pz show a positivity at late latencies that appears to be due to a positivity in the ERP for attended tones in the grouped-channels condition partially overlapping with a later negativity in the ERP for unattended tones. To evaluate the effect of grouping on this late difference, post hoc analyses were performed on the mean amplitude of five 40-ms intervals beginning at 245 ms poststimulus at all electrodes. The only significant effect of grouping was detected at Pz during the 325–360-ms interval, $F(1,9) = 7.47$, $p = .02$. Analyses were also performed on the mean ERP amplitude in the same late intervals for attended and unattended tones. The ERPs for attended tones showed a significant Pitch \times Condition interaction during the 325–360-ms interval at Cz, $F(1,9) = 6.92$, $p = .03$, and at Pz, $F(1,9) = 6.16$, $p = .04$. For the attended 1,000-Hz tones, the ERPs for frequent stimuli were more negative in the grouped-channels condition during the 325–360-ms and the 365–400-ms intervals at Cz, $t(9) \geq 2.84$, $p \leq .02$, and all intervals from 285 to 440 ms at Pz, $t(9) \geq 2.37$, $p \leq .05$. For the attended 1,682-Hz tones, the ERPs for frequent tones did not differ between the two grouping conditions. In addition, when the tones were unattended, no late difference was found between the two conditions at any electrode ($p > .10$). The late positivity in Nd thus appears to be due mainly to a general negativity in the ERPs for unattended tones and a specific positivity in the ERP for the attended 1,000-Hz tone in the grouped-channels condition.

Target tones elicited the usual negative–positive complex (N1–P2) followed by an additional negative component peaking at about 250 ms and a late positive wave (N2–P3). The P3 component was quantified at Pz as the highest peak in the interval of 300–600 ms poststimulus. The amplitude of P3 was larger in the baseline than in the grouped-channels condition, $F(1,9) = 8.59$, $p = .02$. No difference was detected for the latency of the peak of P3.

ERPs for middle tones. Figure 3 shows the group ERPs for the frequent middle tones in the two conditions when they were

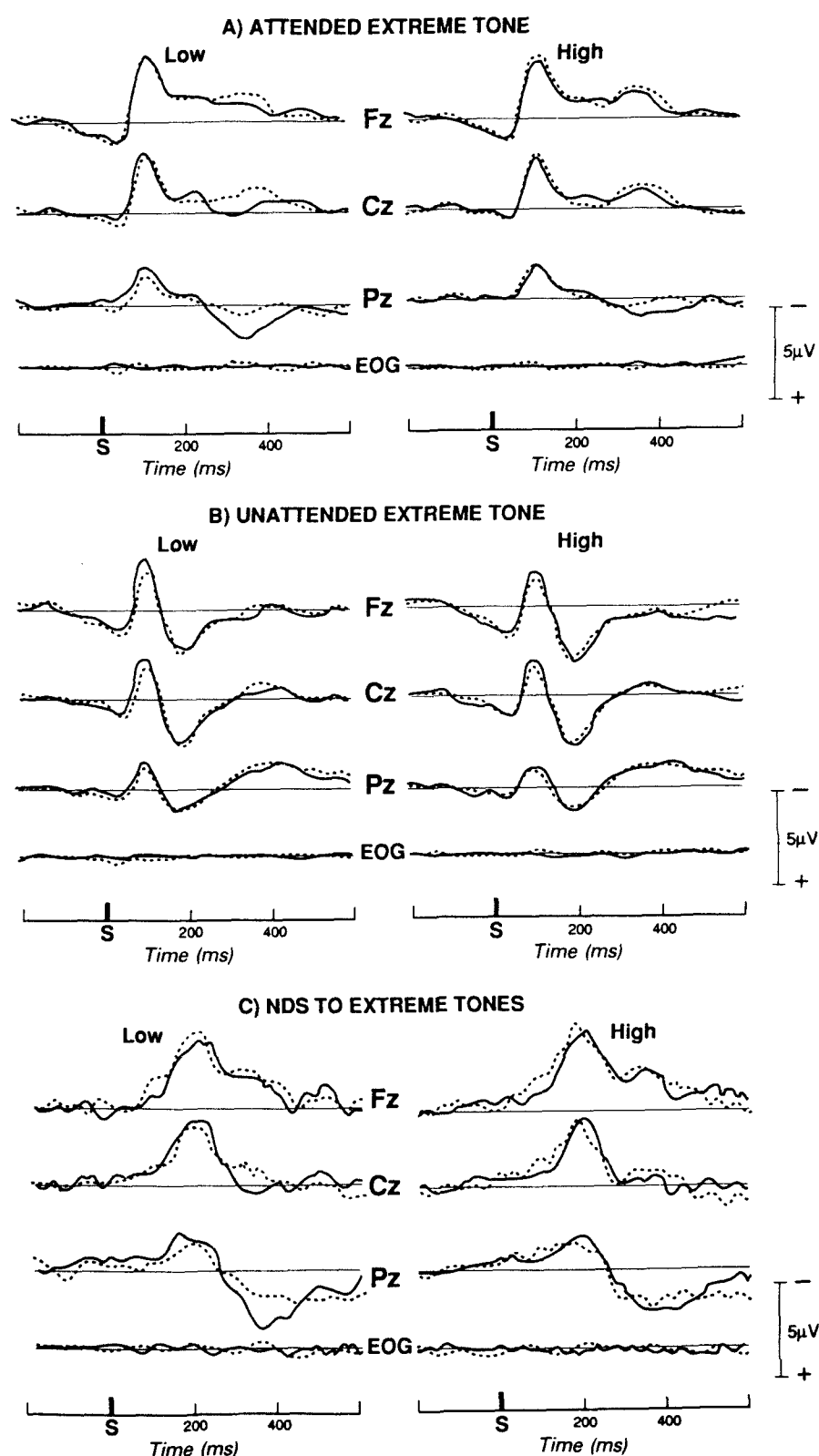


Figure 2. Group average ERPs for attended (A) and unattended (B) extreme tones in the baseline (solid) and grouped-channels (dotted) conditions of Experiment 1. C. Average attended–unattended difference potentials (Nds) from the ERPs in A and B.

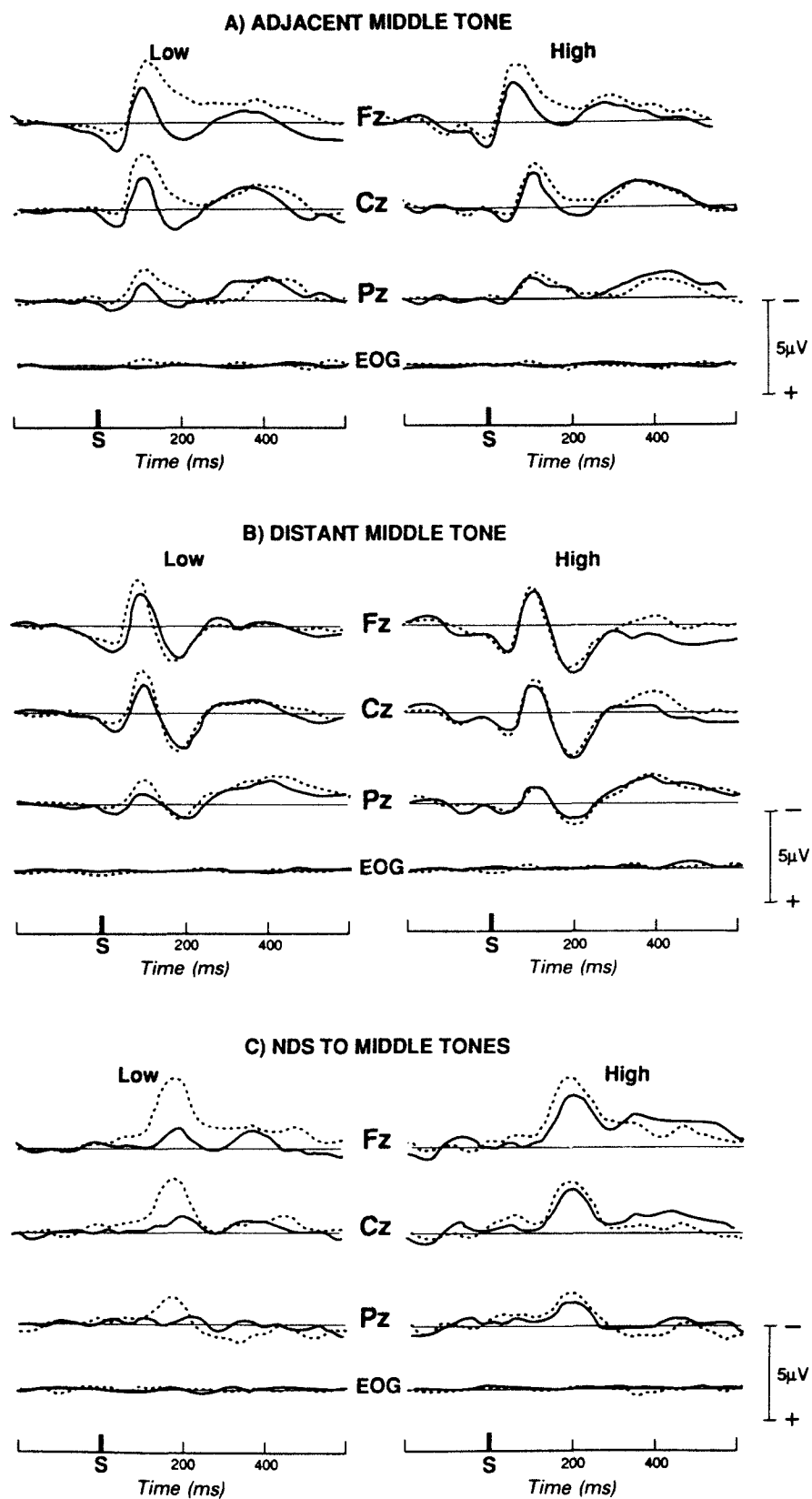


Figure 3. Group average ERPs for middle tones when the attended pitch was adjacent (A) and when it was distant (B) in the baseline (solid) and grouped-channels (dotted) conditions of Experiment 1. C. Adjacent-distant difference potentials (Nds) derived from the ERPs in A and B.

adjacent to or distant from the attended tone and the attention-related difference potentials computed as the difference in the ERPs for a particular tone when attention was directed to the adjacent pitch and when it was directed to the distant pitch (here called Nd for middle tones).

Grouping enhanced the Nds for the middle tones in the intervals between 125 and 200 ms at all three electrodes, all $F(1,9) > 6.5$, $p < .05$, and during the 45–80-ms interval at Cz, $F(1,9) = 6.2$, $p < .05$. This Nd effect is linked to selective effects on the ERPs. Grouping enhanced the negativity of ERPs adjacent to the attended tone in the intervals between 125 and 240 ms at Fz and Cz, all $F_s > 5.2$, $p < .05$, and during the 85–120-ms interval at Fz, $F(1,9) = 5.2$, $p = .05$. The Pitch \times Condition interactions were not significant except between 125 and 200 ms at

Cz. Grouping did not significantly affect the ERPs for middle tones distant from the attended tone.

Discussion

The data indicate that grouping enhanced the attention-related Nd potential for the extreme tones and that this effect was mainly due to a decreased negativity for the tones when they were unattended. Because the extreme tones did not differ between the two conditions, the grouping effect on Nd cannot be explained by the physical proximity between the incoming stimulus and the attended pitch. Grouping may have produced some effects because of the decreased separation between extreme tones and their nearest neighbors, as exemplified by the increased false detection rate for the tone adjacent to the attended tone. However, such effects could not have selectively decreased the negativity of unattended tones.

In addition to the usual early negativity, the Nds for the extreme tones also contained a late positivity at Pz that was also affected by grouping. The ERPs underlying this difference potential were positive for some attended tones and negative for unattended tones. This late difference may point to a late processing difference between the two conditions that may be related to the increased within-pair discrimination difficulty in the grouped-channels condition.

Grouping also enhanced the Nd for the middle tones, affecting the ERP for the tone adjacent to the one being attended. Because these tones differed in the two conditions, this result could be explained by a number of factors, including grouping and physical similarity.

The effect observed on the ERPs for extreme tones suggests that the attention-related negativity is sensitive to the contextual information contained in tonal grouping and this ERP effect parallels behavioral effects of context on selective responding. If this effect is generalizable, it would imply that the attention-related negativity can reflect more than physical comparison processes. A mechanism restricted to the comparison of features of each incoming stimulus to a fixed memory trace of the target stimulus would not show the effect observed here because the target stimuli were constant across conditions. Comparison processes are most probably involved in any selective monitoring or target detection task, and they are most probably partly based on some cognitive specification that will facilitate recognition of the targets. However, this specification does not appear to be fixed and determined by the physical parameters of the target alone. Instead, it appears to be adaptable at least to the extent that it is sensitive to the context created by the presence of neighboring tones. Grouping may affect a postulated trace by making it stronger or narrower and no longer only defined by the physical characteristics of the target (Näätänen, 1990, 1991), but this hypothesis only shifts the problem of explaining selectivity mechanisms to the processing origin of this strength or narrowness. This post hoc enlargement of the previously well-defined concept of trace weakens its explanatory power, and there is a risk that it may become synonymous with all central nervous system (CNS) effects of selective processing instructions.

Selective monitoring instructions most probably have multiple effects on the CNS, and probably only a portion of them are associated with mechanisms based on physical similarity to targets. However, these effects or traces cannot be studied directly because ERPs only reflect how these traces interact with the incoming stimulus. The present data indicate that this interaction is at least partly dependent on the stimulation context. In

the present experiment, context effects appeared when physical similarity effects were controlled. However, it is not clear if context information could prevail in a situation in which the effects of physical proximity and context are opposed.

Experiment 2

Behavioral evidence suggests that grouping information can affect the attention-related processing segregation of stimuli despite physical separation effects (Driver & Baylis, 1989). If the attention-related negativity can show the same effects, this finding would be further evidence that context can override physical similarity as the major influence on the selective processing mechanisms reflected in this physiological measure.

A situation in which grouping produces an effect opposite to physical separation can be achieved by having grouping produce a decreased tonal separation. In the monitoring task involving four-pitch tone sequences, grouping was achieved by decreasing the separation between the extreme tones, keeping the middle tones constant (see Figure 1B). In this task, grouping decreases the physical separation between all unattended tones and the attended tone. The reduced physical separation should thus produce an enhancement in the negativity of ERPs for both middle tones with grouping, whereas group membership information should decrease the negativity of the tone that is not grouped with the attended tone.

Method

Subjects. Fifteen women between 22 and 33 years of age participated in this study. Five additional volunteers were excluded from the experimental session because of their poor performance during the training session (more than 50% misses) or because of abundant eyeblinks. Two of the subjects had previous experience with evoked potential studies but none with similar paradigms. None of the subjects had any history of hearing disorder. All subjects received an honorarium for their participation.

Stimuli. Tones were produced in the same manner as in Experiment 1. At each frequency, tone sequences included frequent short tones ($p = .85$, 60 ms) and infrequent long tones ($p = .15$, 130 ms). In the baseline condition, the four pitches were equally spaced by four semitones (1,000, 1,260, 1,587, 2,000 Hz). In the grouped-channels condition, the extreme pitches were replaced by two others separated from the middle pitches by only one semitone (1,189, 1,260, 1,587, 1,682 Hz).

Recording. As in Experiment 1, the EEG was sampled at 200 Hz from three midline scalp electrodes (Fz, Cz, and Pz) referenced to linked mastoids, and EOG was recorded.

Procedure. Each subject was tested under the two experimental conditions on the same day. Within each condition, stimulus sequences consisted of 320 tones of four different pitches delivered at intervals varying randomly between 200 and 450 ms. Subjects monitored one of the two extreme pitches. Stimulation sequences were composed of tones in the four pitches presented in random order with the same restrictions as used in Experiment 1.

Before the recording session, each subject received eight training sequences (two sequences for each attended pitch in each condition). Following practice, each subject listened to six

consecutive sequences in each condition, three for each attended pitch. The order of conditions and attended pitches was randomly determined for each subject.

Results

Performance. Table 2 shows the group averages of the behavioral measures in the two conditions. Subjects made more false detections, $F(1,14) = 10.95$, $p < .01$, and misses, $F(1,14) = 18.64$, $p < .01$, in the grouped-channels than in the baseline condition. Moreover, response time increased significantly with grouping, $F(1,14) = 7.50$, $p < .05$. No significant effects of pitch or Condition \times Pitch interaction were detected.

In the baseline condition, 19% of false detections involved tones that were adjacent in pitch to the targets, whereas this proportion increased to 41% in the grouped-channels condition. This increase in the proportion of false detections was not observed for any other tone.

ERPs for middle tones. Figure 4 shows the group-averaged ERPs elicited by the middle tones in the two conditions when the attended pitch was adjacent or distant, as well as the adjacent-distant difference potentials (Nd). Grouping enhanced the Nd for middle tones between 85 and 200 ms at Fz and Cz, all $F_s(1,14) > 5.1$, $p < .05$, and during the 165–200-ms interval at Pz, $F(1,14) = 7.9$, $p < .02$. No significant effects of pitch or Condition \times Pitch interactions were noted.

The effect of tonal grouping on ERPs for middle tones varied depending on whether or not the attended pitch was adjacent or distant. When the attended pitch was distant, grouping produced significantly less negative ERPs in the 85–120-ms interval at Cz and Pz, all $F_s(1,14) > 5.0$, $p < .05$, and during the 165–200-ms interval at all electrodes, all $F_s(1,14) > 5.2$, $p < .05$. No significant effects of pitch or Condition \times Pitch interaction were detected. When the attended pitch was adjacent, grouping produced significantly more negative ERPs in the 165–200-ms interval at Fz, $F(1,14) = 7.4$, $p < .02$, and during the following interval at both Fz and Cz, all $F_s(1,14) > 5.3$, $p < .05$, but not during earlier intervals. No other difference was found between the conditions.

The grouping effect on middle tones was also evaluated at late latencies. When the attended pitch was distant, grouping produced less negative ERPs between 300 and 420 ms at Fz and Cz, $F(1,14) = 6.7$ – 23.1 , $p < .05$ for all comparisons. A grouping effect was also detected between 345 and 460 ms at Pz, $F(1,14) = 9.4$ – 17.6 , $p < .01$ in all cases. The interaction of pitch and condition was not significant. When the attended pitch was adjacent, the only significant effect of grouping at late latencies was an increased negativity during the 465–500-ms interval at Cz, $F(1,14) = 5.94$, $p < .05$.

Table 2. Means (SD) of Behavioral Measures in Experiment 2

	Response time	Misses	False detections
Baseline	498 (55)	5.3 (4.0)	5.0 (4.2)
Grouped channels	520 (55)	9.7 (5.6)	12.3 (8.9)

Note: An average of 72 targets were presented in each condition.

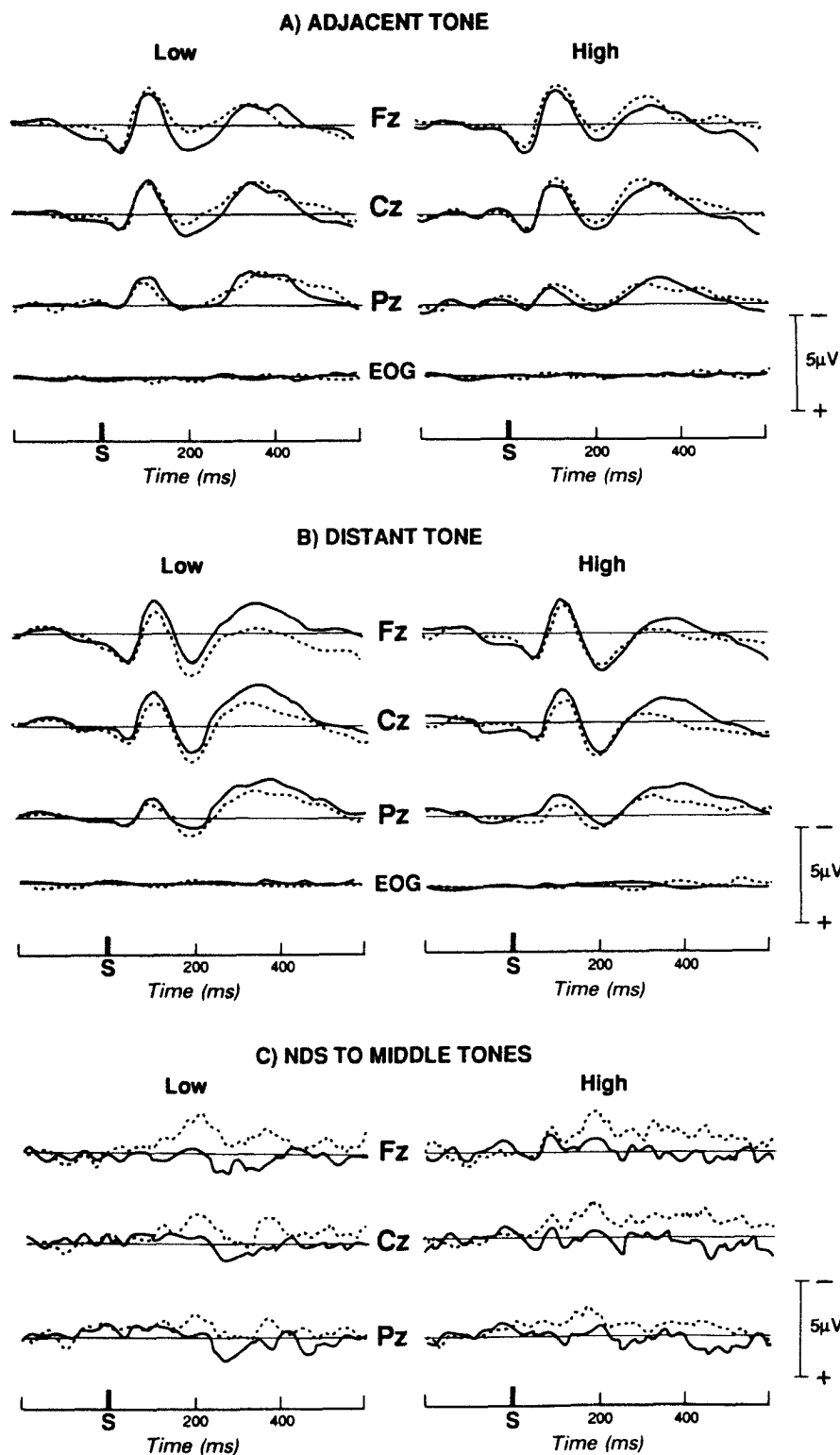


Figure 4. Group average ERPs for middle tones when the attended pitch was adjacent (A) and when it was distant (B) in the baseline (solid) and grouped-channels (dotted) conditions of Experiment 2. C. Adjacent-distant difference potentials (Nds) derived from the ERPs in A and B.

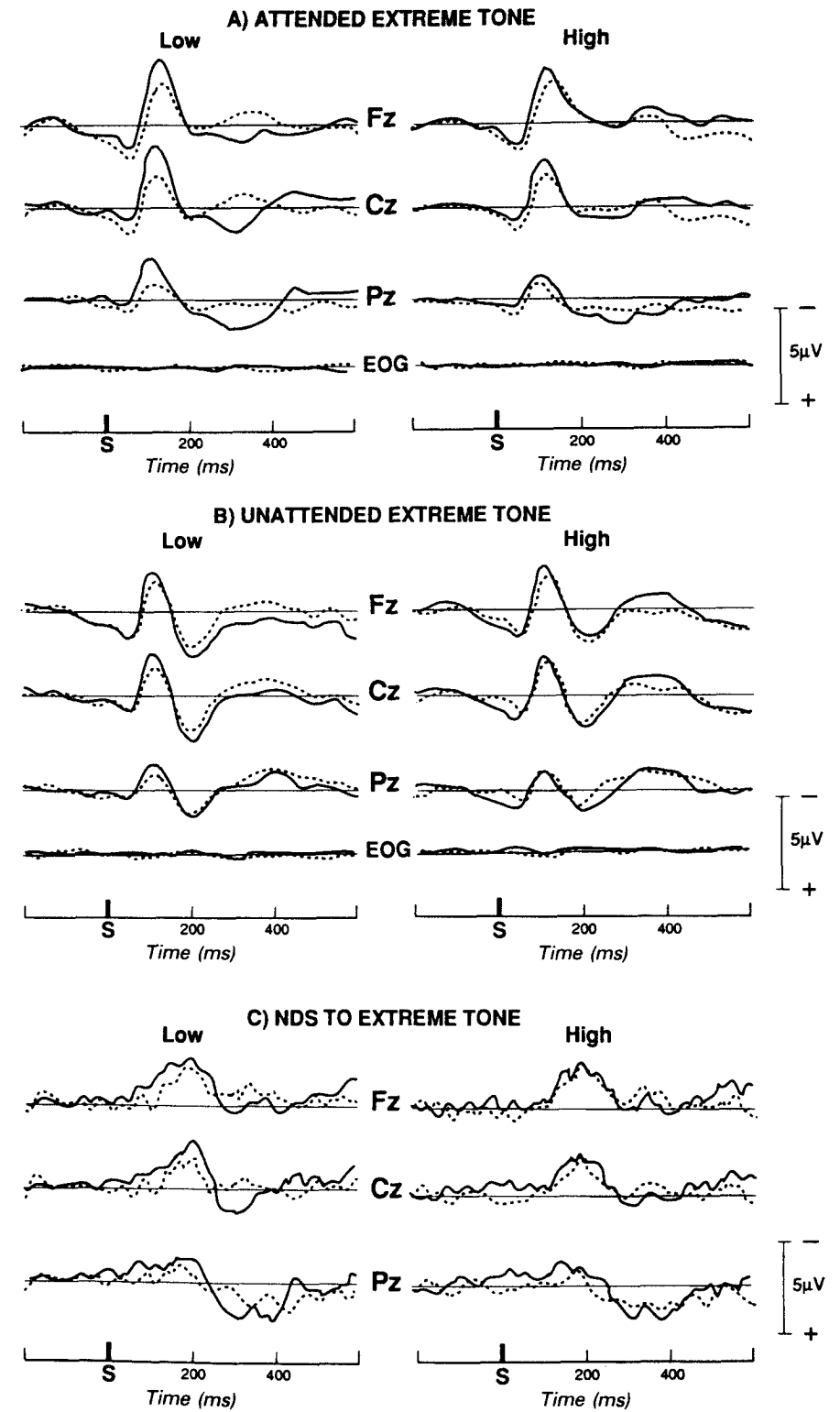


Figure 5. Group average ERPs for attended (A) and unattended (B) extreme tones in the baseline (solid) and grouped-channels (dotted) conditions of Experiment 2. C. Average attended-unattended difference potentials (Nds) from the ERPs in A and B.

ERPs for extreme tones. Figure 5 shows the group-averaged ERPs for frequent extreme tones and associated Nd potentials. The Nds show an early component peaking at about 200 ms following tone onset and at Fz a late component peaking at about 380 ms poststimulus.

Grouping decreased the amplitude of Nds for extreme pitches between 85 and 160 ms at Fz and in the 45–80-ms interval at Cz and during the 85–120-ms interval at Pz, all $F_s(1,14) > 4.7$, $p < .05$. For the ERPs for attended tones, grouping produced a significant decrease in negativity in the intervals between 45 and 120 ms at all electrodes, all $F_s(1,14) > 4.4$, $p < .05$, and during the 125–160-ms interval at Fz, $F(1,14) = 10.2$, $p < .01$. Grouping also decreased the negativity of ERPs to unattended tones in the 85–120-ms interval at Fz and Cz, all $F_s(1,14) > 7.4$, $p < .05$, but also decreased the positivity in the 205–240-ms interval at Cz and Pz, all $F_s(1,14) > 10.5$, $p < .01$. No effects of pitch

or Pitch \times Condition interaction were detected during any of the intervals.

ERPs for target tones. Target tones followed by a correct response elicited the usual negative–positive complex (N1-P2) followed by an additional negative component peaking at about 250 ms and a late positive wave (N2-P3). We expected P3 amplitude to differ between the two conditions because of the known effect of discrimination difficulty on P3 (Fitzgerald & Picton, 1983). P3 amplitude was measured at Pz as the highest peak in the interval of 300–600 ms poststimulus. Two subjects were excluded from this analysis because they did not show a clear P3 component in both conditions. The amplitude of P3 was smaller in the grouped channels than in the baseline condition, $F(1,12) = 5.38$, $p < .05$. No difference was detected between the grouping conditions for the peak latency of P3.

Discussion

In this experiment, tonal grouping produced opposite effects on ERPs for unattended middle tones depending on whether attention was directed to a tone in the same group or not. Because grouping was accompanied by a decreased separation between the attended tone and all unattended tones, these effects suggest that group membership information influenced the attention-related negativity of unattended stimuli.

These effects cannot be predicted by assuming that the negativity is only dependent on the physical similarity between incoming stimuli and a representation of the attended stimulus, because when the attended pitch was distant, grouping decreased the negativity for the middle tones despite the fact that it was more similar to the attended pitch in the grouped-channels condition. The opposite effect would have been predicted if physical similarity information was the main influence on the attention-related negativity. This effect on the distant unattended tone did not appear in Experiment 1. However, in Experiment 1 the grouping manipulation increased the separation between the two tone pairs, an effect that may have masked the grouping effect.

Because the grouping effect is in opposite directions for distant and adjacent middle tones, the results cannot be explained by general effects of the proximity of neighboring stimuli. The present data suggest that context can differentially affect the negativity of stimuli even when it opposes the physical similarity effect.

Grouping may have modified some of the processing segregation strategies or mechanisms set up by the selective listening instructions. Some of these modifications could also affect a postulated attended-stimulus trace. However, if this trace is only used for physical comparison, it should affect all tones that are made more similar to it in the same manner. The differential effect of grouping suggests that at least some of the modifications underlying the ERP selective attention effect can be dissociated from simple trace matching.

Grouping also affected the ERPs for extreme tones, decreasing the Nd. This effect is opposite to that obtained in Experiment 1. In the present experiment, the grouping manipulation reduced the separation between the two extreme tones from 12 to 6 semitones, whereas in Experiment 1, extreme-tone separation was kept constant at 9 semitones. The reduction in the Nd for extreme tones may be related to this reduction in separation and in this sense would replicate the well-known effect of physical separation on Nd. However, the ERPs composing the Nds indicate that in the present experiment grouping decreased the negativity of ERPs for attended tones, an effect that is not predicted by the trace matching hypothesis. Thus, the ERPs for the extreme tones may have been affected by the physical separation effect produced by the experimental design, but the underlying effect is unclear. However, the present experiment was not designed to examine the effects of grouping on the extreme tones, and this issue will be addressed in future studies.

General Discussion

The results of both studies suggest that the selective attention effect on ERPs is sensitive to contextual information. In selective listening to sound sequences, contextual information seems to permit some segregation of the processing of task-relevant and task-irrelevant stimuli that can even successfully oppose information conveyed by the physical features of individual

stimuli. From this perspective, selective processing may occur at a number of levels of perceptual processing, depending on the available information in the listening situation.

For these rapid tone sequences, the contextual information could have been provided by an early process whose role would be to automatically organize the auditory input into separate streams (Bregman, 1990). At certain stimulation rates, the tonal separation pattern can affect the extent to which tones can be organized in distinct streams, and the tones that are similar in frequency will tend to be grouped together (Bregman, 1990). The tonal pattern used in the grouped-channels condition could favor the perceptual grouping of pitches, based upon the tonal similarity between the pitches within a pair. This arrangement may facilitate a rapid categorization of the tones as low or high using an emergent feature provided by tonal grouping. Perceptual streaming is only one explanation for the contextual information used by the system in the present tasks, and more work will be needed to elucidate the mechanism of this effect.

Results of previous studies on the attention-related negativity may also be consistent with an effect of interstimulus relations information. One such result is the early attention effect recorded for two gradually changing stimuli. Using highly trained subjects, Okita (1979, 1987) reported an early attention effect beginning at about 50 ms during selective listening to one of two sources of tone pips gradually and concurrently changing in spatial location and pitch. Näätänen (1990) explained these results by postulating that a memory trace can be voluntarily modified to extrapolate the continuous stimulus change. This explanation is difficult to reconcile with the portion of the trace matching model that postulates that a memory trace is built from repeated exposure to the relevant tones. However, Okita's results can easily be interpreted from the perspective of interstimulus relationships. The predictable trajectories of the two stimulus streams in Okita's experiments provided information that was not carried by each stimulus but by the relative changes from previous stimuli, that is, interstimulus relationship information.

Another result that may need reevaluation from the perspective of context effects is the earlier attention effect at shorter interstimulus intervals (ISIs) (Hansen & Hillyard, 1984; Hillyard et al., 1973; Parasuraman, 1980; Schwent, Hillyard, & Galambos, 1976). The ISI effect can be explained with the trace matching hypothesis by postulating that the memory trace decays gradually as a function of the temporal separation between two attended tones. In this regard, the shorter ISIs could help keep the memory trace clearer or more complete, thereby facilitating the matching process. The ISI effect can also easily be explained by the interstimulus relationships. When the tonal separation between the tones remains constant, the reduction of ISI increases the segregation of the two sounds into separate streams (Bregman, 1990; Bregman & Campbell, 1971). This effect may be due to grouping by proximity; the high tones tending to group with the previous high tones when they are close enough in time, as previously suggested (Bregman, 1990). Thus, the earlier attention effect with shorter ISI could be due to the perceptual context established by the stimulation speed that could provide information for selective processing mechanisms.

In conclusion, the present data and data from other paradigms are consistent with a perspective that allows the attention-related negativity to reflect selective processing that is based on information other than the physical similarity of individual stimuli such as the perceptual context in which these stimuli are embedded.

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