Effect on numerosity judgment of grouping of tones by auditory channels

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Previous research suggests that numerosity judgments for sequences of tones improve when the sequence is structured such that equal and small groups of tones alternate between the ears. The present study systematically investigates the effects of the structure of tone sequences on number judgment. Tone frequency is chosen as the grouping principle instead of spatial location. In the first experiment, sequences with equal groups of 2, 3, 4, 5, 6, or 7 tones (groups alternating between 800 and 1,250 Hz) were compared with monotonous sequences. At a slow repetition rate of the tones (280 msec onset to onset), grouping the sequence deteriorated the numerosity judgment. At a fast repetition rate of the tones (100 msec onset to onset) grouping improved numerosity judgment, but only if the group size did not exceed 4 to 5 tones. In the second experiment, the equality of group size in the sequence as a necessary condition for the improvement was investigated. It was found that tone sequences comprised of equal groups were judged more accurately in number than sequences comprised of unequal groups. These results seem to give support for the existence of an auditory subitizing process. The results of this study are also compared with the results of studies in which sequences of tones, alternating one by one between locations or frequencies, had to be judged in number.

In a previous experiment, designed to study spatial attention switching (ten Hoopen & Vos, 1979), we found that the number of short tones in a sequence was reported more accurately if the sequence was structured such that small groups of tones (2, 3, 4, or 5) alternated between the ears, as compared to monaural presentation of the tones. In addition, if the alternating groups were not equal in size, the numerosity judgment deteriorated significantly. We therefore concluded that processes other than merely counting the tones one by one were invoked if the sequence alternated in small and equal groups between the ears.

In a tutorial chapter, Chase (1978, p. 63) discusses quantification processes and mentions three distinct mechanisms, following the classification of Klahr and Wallace (1976): subitizing, counting, and estimating. It is possible to explain our finding of the effect of auditory grouping by a three-stage process, consisting of (1) subitizing the number of tones in a group, (2) counting the number of groups, and (3) multiplying the two numbers. As far as we know, the subitizing process has been studied only with respect to visual presentation, although Woodworth (1938, p. 695) mentions that such a process might also be invoked when the number of auditory events has to be established. In the visual modality, the

subitizing process can be examined by means of chronometric techniques, which show that subitizing only works if the number of visual objects does not exceed four. Beyond this limit, subjects resort to counting (see Chase, 1978).

The chronometric paradigm can hardly be applied to the auditory counterpart, because the auditory events appear successively. So, for the time being, we shall investigate the effect of the number of tones in a group on the quality of numerosity judgment.

In our previous study (ten Hoopen & Vos, 1979), the tones were grouped with respect to location as auditory channel. Recently, evidence from related studies has shown that different frequencies can function as auditory channels, too (Bregman, 1978; Massaro, 1977; van Noorden, 1975). Hence, we considered it worthwhile to investigate the effects of grouping on numerosity judgment with respect to frequency channels.

EXPERIMENT 1

Two kinds of tone sequences were presented: either those comprised of tones of the same frequency (ungrouped sequences) or those comprised of equal groups of tones, groups alternating between frequencies (grouped sequences). A short stimulus onset asynchrony (SOA) between the tones was chosen at which subjects were unable to count the tones one by one; a long SOA was also chosen at which subjects were able to count the tones.

We predicted (1) that, at the long SOA, grouping

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and group size would have no effect on numerosity judgment, and (2) that at the short SOA, grouping should improve numerosity judgment, but should improve it more with smaller group sizes.

Method

Subjects. Twelve paid students, selected from first- and second-year psychology courses, participated in the experiment. Left- and right-ear thresholds were screened for pure tones of 750 and 1,500 Hz. The rejection criterion was a loss of 10 dB. All subjects passed this criterion.

Stimuli and Design. Sequences of sine tones of 40 msec duration were generated and recorded on tape (see ten Hoopen & Vos, 1979, for details). The SOA between the tones was 100 or 280 msec. The ungrouped sequences were comprised of tones of either 1,250 or 800 Hz. The grouped sequences were comprised of equal groups of tones, groups alternating between 1,250 and 800 Hz. The groups contained 2, 3, 4, 5, 6, or 7 tones. The number of groups varied, too, and hence the length of the sequence. The presented sequences are given in Tables 1, 2, 3, and 4. Nearly the whole range of number of tones between 4 and 25 is filled by 28 different sequences. A block consists of $2 \text{ (SOA)} \times 28 = 56$ different grouped sequences. The "grouped block" had two forms. In one block, all 56 sequences started with a group of 1,250-Hz tones. In the other block, all 56 sequences started with a group of 800-Hz tones. The "ungrouped block" had two forms, too. In one block, all sequences comprised 1,250-Hz tones. In the other block, all sequences comprised 800-Hz tones.

Of each of the four blocks, three versions were prepared by placing the 56 sequences in three different random orders.

Procedure. The 12 subjects first received training with feedback on 56 grouped and 56 ungrouped sequences. Two seconds before a sequence started, a warning tone of 400 Hz and 100 msec was given. All the tones were diotically presented at a comfortable listening level by means of Sennheiser headphones. The subjects were instructed to establish the number of tones in each sequence with 2.5 sec available to write down the response. The order of the four blocks was balanced three times according to Latin squares. Each Latin square, thus each four subjects, received a different version of the four blocks.

Results

For each type of sequence at each SOA, the mean numbers reported were computed (see Tables 1 and 2). The percentages of sequences correctly judged in number at each condition are displayed in Tables 3 and 4. Both variables, number reported and percentage correct, are dependent upon the length of the tone sequence. Long sequences are underestimated more in number and are judged less accurately than short sequences. From the tables, it can be seen that the length of the sequence (number of tones) is partly confounded with the structure of the sequence (number of groups $\times$ group size). Hence, if we are interested in effects of grouping and group size, differences in length of the sequences ought to be ruled out as much as possible.

For that reason, we selected two or three sequences at each level of group size such that the total number of tones of the selected sequences would be about equal for each level of group size. For the group sizes 2, 3, 4, 5, and 6, this procedure succeeded quite well. The selected sequences are marked by an asterisk in Tables 1, 2, 3, and 4. The total numbers of tones are 42, 45, 48, 45, and 42 for Group Sizes 2 to 6, respectively. In order to correct for the slight differences in length (42-48 tones), the ratio of the reported number of tones to the number presented in the selected sequences was taken as the dependent variable. For the ungrouped condition, the ratios were also calculated on the basis of the sequences of the same lengths, specified above.

The ratios were submitted to two ANOVAs, one at each SOA [2 (ungrouped vs. grouped) by 5 (group size), all repeated measures]. The pattern of results

Table 1
Mean Number of Tones Reported at the Stimulus Onset Asynchrony Between Tones of 100 Msec

	Tones per Group	Number of Groups in the Sequence					
		2	3	4	5	6	7
Number Presented		4	6	8	10	12*	14*
Grouped Sequences	2	3.96	5.88	7.77	9.96	11.25	12.54
Ungrouped Sequences		3.71	4.74	6.42	7.57	9.04	10.33
Number Presented		6	9	12*	15*	18*	21
Grouped Sequences	3	5.71	7.88	9.79	12.79	14.54	16.25
Ungrouped Sequences		4.74	6.83	9.04	10.63	13.13	14.36
Number Presented		8	12*	16*	20*	24	
Grouped Sequences	4	6.92	10.00	12.25	14.58	17.79	
Ungrouped Sequences		6.42	9.04	11.38	13.83	15.19	
Number Presented		10*	15*	20*	25		
Grouped Sequences	5	8.08	11.63	14.21	15.71		
Ungrouped Sequences		7.57	10.63	13.83	16.79		
Number Presented		12	18*	24*			
Grouped Sequences	6	9.00	12.50	15.79			
Ungrouped Sequences		9.04	13.13	15.19			
Number Presented		14	21				
Grouped Sequences	7	10.79	15.08				
Ungrouped Sequences		10.33	14.36				

*Sequences used for the ANOVAs.

Table 2
Mean Number of Tones Reported at the Stimulus Onset Asynchrony Between Tones of 280 Msec

	Tones per Group	Number of Groups in the Sequence						
		2	3	4	5	6	7	8
Number Presented		4	6	8	10	12*	14*	16*
Grouped Sequences	2	4.08	6.04	7.83	10.00	11.33	13.17	14.46
Ungrouped Sequences		4.00	6.14	8.33	10.02	11.83	14.02	15.70
Number Presented		6	9	12*	15*	18*	21	24
Grouped Sequences	3	6.21	8.63	11.92	14.13	16.83	19.67	22.79
Ungrouped Sequences		6.14	9.04	11.83	14.79	17.88	20.17	23.60
Number Presented		8	12*	16*	20*	24		
Grouped Sequences	4	8.00	12.13	15.29	20.17	21.92		
Ungrouped Sequences		8.33	11.83	15.70	19.46	23.60		
Number Presented		10*	15*	20*	25			
Grouped Sequences	5	10.04	14.38	18.54	23.05			
Ungrouped Sequences		10.02	14.79	19.46	24.46			
Number Presented		12	18*	24*				
Grouped Sequences	6	11.71	17.33	22.92				
Ungrouped Sequences		11.83	17.88	23.60				
Number Presented		14	21					
Grouped Sequences	7	13.63	20.17					
Ungrouped Sequences		14.02	20.17					

*Sequences used for the ANOVAs.

Table 3
Percentages of Tone Sequences Correctly Judged in Number at the Stimulus Onset Asynchrony Between Tones of 100 Msec

	Tones per Group	Number of Groups in the Sequence						
		2	3	4	5	6	7	8
Number Presented		4	6	8	10	12	14	16
Grouped Sequences	2	87.5	62.5	66.7	33.3	41.7	4.2	12.5
Ungrouped Sequences		54.2	18.8	20.8	12.5	4.2	2.1	4.2
Number Presented		6	9	12	15	18	21	24
Grouped Sequences	3	62.5	29.2	25.0	12.5	16.7	8.3	12.5
Ungrouped Sequences		18.8	8.3	4.2	.0	2.1	.0	.0
Number Presented		8	12	16	20	24		
Grouped Sequences	4	33.3	25.0	8.3	4.2	16.7		
Ungrouped Sequences		20.8	4.2	4.2	.0	.0		
Number Presented		10	15	20	25			
Grouped Sequences	5	12.5	4.2	.0	4.2			
Ungrouped Sequences		12.5	.0	.0	.0			
Number Presented		12	18	24				
Grouped Sequences	6	12.5	4.2	4.2				
Ungrouped Sequences		4.2	2.1	.0				
Number Presented		14	21					
Grouped Sequences	7	.0	.0					
Ungrouped Sequences		2.1	.0					

is shown in Figure 1. At the SOA of 100 msec, it can be seen that the number of tones is reported better with the grouped sequences than with the ungrouped [$F(1,11) = 11.96$, $p < .006$]. The difference is largest for groups of two tones and is reduced to nothing with increasing group size. This interaction between type of sequence (grouped vs. ungrouped) and group size is significant [$F(4,44) = 4.69$, $p < .004$].

At the SOA of 280 msec, a totally different pattern of results emerged. There was also a main effect of

type of sequence (grouped vs. ungrouped), but in the other direction: grouped sequences were significantly underestimated in number relative to ungrouped sequences [$F(1,11) = 17.87$, $p < .002$]. There were no main or interaction effects of group size ($p > .33$).

The accuracy data, based on the selected sequences, is given in Figure 2. At the short SOA, the improving effect of grouping on numerosity judgment ceases if groups are comprised of more than four to five tones. At the long SOA, sequences with alternating

Table 4
Percentages of Tone Sequences Correctly Judged in Number at the Stimulus Onset Asynchrony Between Tones of 280 Msec

	Tones per Group	Numbers of Groups in the Sequence						
		2	3	4	5	6	7	8
Number Presented		4	6	8	10	12	14	16
Grouped Sequences	2	95.8	95.8	95.8	83.3	62.5	50.0	58.3
Ungrouped Sequences		83.3	83.3	79.2	83.3	80.2	79.2	72.9
Number Presented		6	9	12	15	18	21	24
Grouped Sequences	3	91.7	66.7	66.7	62.5	54.2	45.8	66.7
Ungrouped Sequences		83.3	75.0	80.2	79.2	64.6	60.4	73.6
Number Presented		8	12	16	20	24		
Grouped Sequences	4	91.7	83.3	83.3	75.0	70.8		
Ungrouped Sequences		79.2	80.2	72.9	68.8	73.6		
Number Presented		10	15	20	25			
Grouped Sequences	5	75.0	66.7	66.7	54.2			
Ungrouped Sequences		83.3	79.2	68.8	54.2			
Number Presented		12	18	24				
Grouped Sequences	6	79.2	70.8	70.8				
Ungrouped Sequences		80.2	64.6	73.6				
Number Presented		14	21					
Grouped Sequences	7	62.5	45.8					
Ungrouped Sequences		79.2	60.4					

groups of two or three tones are counted less accurately than ungrouped sequences.

Discussion

One might wonder why the main effect of grouping is in a different direction at the long SOA. At the short SOA (100 msec), counting the tones one at a time is impossible, and grouping the tones should help establish the number: subitize the number of tones in a group, count the number of groups (possible because the SOA *between groups* is at least 200 msec but mostly longer), and multiply the two numbers.

At the long SOA (280 msec) and with ungrouped sequences, it is possible for the subjects to keep up with the speed of the sequence (see Figure 1).

The number reported nearly equals the number presented. Figure 2, however, shows that the *accuracy* of the report is only 75%. When the tone sequence at 280 msec SOA alternates in groups between the frequencies, the counting process appears to be hampered. Subjects cannot keep up with the speed of the sequence (see Figure 1). In addition, they judge the number of tones *less* accurately (see Figure 2). This performance deterioration is most pronounced when the group size is two or three tones.

Thus, the results at the SOA of 100 msec conform to our second prediction, that grouping should improve numerosity judgment, especially with smaller group sizes. The results at the SOA of 280 msec, however, contradict our first prediction. We expected grouping and group size to have no effect on numer-

Figure 1. Ratios of the reported number of tones to the presented number of tones in the sequence as a function of stimulus onset asynchrony (SOA) between the tones and kind of sequence.

Figure 2. Percentage of tone sequences correctly judged in number of tones as a function of stimulus onset asynchrony (SOA) between the tones and kind of sequence.

osity judgment. This expectation was based on studies in which tones were alternated one by one between the ears (Guzy & Axelrod, 1972; Massaro, 1976, first experiment). These studies indicated that at SOAs shorter than about 250-280 msec, numerosity judgment of alternating sequences deteriorated in comparison to those not alternating. At about 250-280 msec SOA, numerosity judgment was perfect at both presentations.

In the present experiment, at 280 msec SOA between the tones, the alternations occur after each 560 msec when the group size is two tones and after each 840 msec when the group size is three tones. Thus, even with the long periods between frequency alternations, counting performance is hampered.

Massaro (1977) found that sequences of tones, alternating *one by one* between frequencies were counted less accurately than sequences of tones at the same frequency. Even at the longest SOA of 275 msec, used in his study, counting accuracy for tones alternating between 440 and 998 Hz was only 84%, while counting accuracy for tones of the same frequency was 99%.

Does the counting accuracy data of Massaro (1977), gathered in a SOA range of 45 to 275 msec, provide information about accuracy beyond 275 msec SOA? Plotting counting accuracies against SOA is indicated by the curve displayed in Figure 3. One sees that the "virtual" accuracy curve reaches 85% at 560 msec SOA and 87 % at 840 msec SOA. In the present study, counting accuracy at these SOAs (between alternation) is even more diminished (60%). This is due to two facts: (1) We used longer tone sequences, and (2) in our sequences more tones were presented between frequency alternations.

Figure 3. Counting accuracy as a function of stimulus onset asynchrony (SOA) and kind of sequence (same vs. alternating frequency). The solid parts of the curves are based on data from Massaro, 1977 (frequency alternations between 440 and 998 Hz). The dashed parts of the curves are extrapolated. The estimated counting accuracies at the SOAs of 560 and 840 msec are inserted, which are the SOAs between alternating groups of two, respectively three tones in the present sequences.

EXPERIMENT 2

The first experiment clearly demonstrated that the number of tones in rapid sequences is better established when tones are presented in groups of 2, 3, 4, or 5 tones alternating between frequencies, as compared to establishing the number of tones of the same frequency.

To see whether the equality of group size in the alternating sequences is a requirement for the improvement in numerosity judgment, an experiment was designed in which sequences comprised of groups of equal size were compared with unequally grouped sequences.

Method

Subjects. Twenty paid students (who did not participate in Experiment 1) were tested. Ear thresholds were screened at 750 and 1,500 Hz. All subjects passed the rejection criterion of 10 dB hearing loss.

Stimuli and Design. The frequency, duration, and intensity of the presented tones were the same as in Experiment 1. The alternating groups of tones in a sequence were either equal or unequal in size. The group size in the "equal group sequences" was held constant at 3 tones, but the number of groups varied between three and seven, so that sequences of 9, 12, 15, 18, and 21 tones was the result. In the corresponding "unequal group sequences" of the same lengths, the group size varied between 2, 3, and 4 tones within the sequence.

To keep subjects from discovering the values of number of tones in the experimental sequences, we added dummy sequences. Experimental and dummy sequences, both with equal and unequal groups, are specified in Table 5.

Equal group and unequal group sequences were kept apart in blocks. Each sequence could start with a group of 1,250- or 800-Hz tones and was presented at a SOA of 100 or 280 msec between tones. Thus, a block comprised 14 (5 experimental and 9 dummy sequences) $\times$ 2 (1,250 or 800 Hz start) $\times$ 2 (SOA) = 56 sequences. For each kind of block, "equal group" and "unequal group," two versions were prepared by placing the 56 sequences in two different random orders.

Procedure. Ten subjects were assigned to the two "equal-group" blocks and the other 10 subjects were assigned to the two "unequal-group" blocks. Before commencing, the subjects received training with the 56 sequences in a different random order. Other procedural situations were the same as in Experiment 1.

Results and Discussion

The numbers reported were analyzed by an ANOVA, equal vs. unequal grouped sequences as a between-subject variable, other variables within subject. The effect of "equal" vs. "unequal" was not significant [$F(1,18) = 1.12, p > .30$]. None of the interactions was significant ($p > .28$). With regard to "number reported," we found no effect of equal vs. unequal group size. It might be that "number reported" is a rather insensitive measure for differences between numerosity judgments for the sequences used. The data were therefore reanalyzed for *accuracy* of report. Having four reports of each subject for each sequence presented, we counted how many of

Table 5
Grouped Tone Sequences Presented in Experiment 2

N	Equal Groups	Unequal Groups
Experimental Sequences		
9	3, 3, 3	2, 4, 3
12	3, 3, 3, 3	3, 2, 4, 3
15	3, 3, 3, 3, 3	2, 3, 4, 2, 4
18	3, 3, 3, 3, 3, 3	4, 3, 2, 2, 4, 3
21	3, 3, 3, 3, 3, 3, 3	2, 4, 3, 4, 2, 3, 3
Dummy Sequences		
8	2, 2, 2, 2	1, 2, 2, 3
8	4, 4	3, 5
10	2, 2, 2, 2, 2	3, 1, 2, 3, 1
14	2, 2, 2, 2, 2, 2, 2	1, 3, 2, 1, 2, 3, 2
16	2, 2, 2, 2, 2, 2, 2, 2	1, 3, 2, 1, 2, 3, 1, 3
16	4, 4, 4, 4	3, 4, 4, 5
20	2, 2, 2, 2, 2, 2, 2, 2, 2, 2	2, 1, 3, 1, 2, 3, 1, 3, 2, 2
20	4, 4, 4, 4, 4	3, 4, 5, 3, 5
22	2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2	1, 3, 2, 2, 3, 1, 3, 1, 2, 1, 3

Note—Groups of tones alternated between 800 and 1,250 Hz.
N = number of tones in the sequence.

these 40 reported numbers equaled the exact number presented.

The pattern of accuracy results is given in Figure 4. This pattern reveals that sequences with equal groups give rise to more accurate numerosity judgments. At the long SOA, an improvement in accuracy of equal over unequal grouped sequences is seen for sequences of all lengths used (9 to 21 tones). At the short SOA, this improvement holds only for the sequences of 9, 12, and 15.

Figure 4 also suggests that at both SOAs equal grouped sequences of 12 tones (4 groups of 3 tones) were judged more accurately in number than sequences of 9 and 15 tones, which means 3 and 5 groups of 3 tones. Wilcoxon tests revealed that the differences in accuracy between the 12- and 9-tone sequences and between the 12- and 15-tone sequences were both significant at .05 (one-tailed). An explanation for this could be that the frequency patterns ... and ... are repeated once in the case of 12 tones, giving the subject the opportunity to double the number of tones in the pattern, a strategy which is impossible with the sequences of 9 and 15 tones.

GENERAL DISCUSSION

In Experiment 1, ungrouped sequences were contrasted with equally grouped sequences, while in Experiment 2, equally grouped sequences were contrasted with unequally grouped sequences. It is possible to compare the accuracy of numerosity judgments for the three kinds of sequences used. The percentages correct from Experiment 1 (see Figure 2) for Group Size 3 are based on sequences of 12, 15, and 18 tones. These data are therefore comparable with the percentages correct measured at the levels of 12, 15, and 18 tones from Experiment 2 (see Figure 4).

At the SOA of 280 msec, ungrouped sequences were counted most accurately (75%, Experiment 1), equally grouped sequences less accurately (59%, average data from Experiments 1 and 2), and unequally grouped sequences least accurately (33%, Experiment 2). This rank order shows that the frequency alternations between groups interfered with the counting process, especially when they occurred irregularly. At the SOA of 100 msec, a totally different accuracy rank order emerged. Equally grouped sequences were judged more accurately (25%) than unequally grouped sequences (11%), the latter ones being judged more accurately than ungrouped sequences (3%). Thus, at the short SOA, the frequency alternations between groups improved the numerosity judgment, particularly if alternations marked equal groups of tones.

Present findings and those reported by ten Hoopen and Vos (1979) suggest that the numerosity judgment of rapid auditory sequences can be maximally improved on the conditions that: (1) the sequence is structured into groups of two, three, or four events, and (2) the groups are of equal size throughout the sequence. These conditions hold for grouping by location as well as for grouping by frequency, and it is conceivable that they also hold for grouping by intensity and timbre. It should be emphasized, however, that the present effects cannot be explained by the phenomenon of streaming. Listening to grouped sequences does not result in the experience of fission or streaming as described by Bregman (1978) and van Noorden (1975). At the present conditions, the shortest SOA between the frequency alternating groups is 200 msec (groups of 2 tones $\times$ 100 msec). The frequency separation is 450 Hz, which amounts to nearly 8 semitones. Inspecting van Noorden's (1975) Figure 2.9 reveals that the present values of these parameters do not result in an inevitable sensation of fission. Auditory sequences can be organized

Figure 4. Percentage of tone sequences correctly judged in number of tones as a function of stimulus onset asynchrony (SOA) between the tones and kind of sequence.

into groups of sounds coming from different sources in the "attribute space"—location, frequency, intensity, and timbre. We would like to call auditory sequences organized along these attributes "ambient auditory patterns." Similar conceptualizations have been put forward by Bregman (1978), Deutsch and Roll (1976), and Massaro (1977). Future research should focus on three issues.

First, the effects on numerosity judgment of the amount of, e.g., frequency separation and angular separation between groups of tones should be investigated. The interaction between amount of separation and repetition rate of the alternating groups should be studied in addition. A second question is whether these effects differ across attribute spaces. Third, more information is needed about the effects on numerosity judgment when the groups of tones alternate between multiattribute sources (for instance between a high-frequency left and a low-frequency right). Answering these issues contributes to (1) the study of numerosity judgment and (2) the formulation of the conditions that evoke "channels" or "streams" in auditory space.

Under the present conditions, the ambient organization of auditory sequences improves numerosity judgment (provided that the sequences are rapid). Similar effects have been demonstrated in the visual modality. Beckwith and Restle (1966) found that numerosity judgments for simultaneously presented dots improved when the dots were grouped with respect to spatial location in the display or grouped with regard to the color of the dots. These authors propose that "The S might . . . subitize each group and add the result to a running total" (p. 443).

Klahr (1973) studied subitizing—the rapid and accurate determination of number—for the visual modality extensively. Reaction time paradigms revealed that the subitizing process is involved as a quantification mechanism when the number of objects is four or less. The subitizing speed is about 40 msec per object, and hence much faster than the counting speed (Chase, 1976). The authors are not aware of any existing studies which give evidence for subitizing in the quantification of auditory events.

In the present study, *groups* of tones alternated back and forth between frequencies. In other studies (Guzy & Axelrod, 1972; Harvey & Treisman, 1973; Massaro, 1976, 1977) rapid tone sequences were presented such that the tones alternated *one by one* between locations or between frequencies. For this con-

dition, the number of tones was underestimated in comparison to the monaural and monotonous presentation, respectively. This phenomenon is often assigned to the observer's inability to redirect attention fast enough between channels to follow the tone sequence.

In a previous study (ten Hoopen & Vos, 1979), it was estimated that shifting attention between the ears takes about 30-50 msec. Hence, less time is available to count the tones. Such time-consuming shifts may also appear with alternating groups of tones. Nevertheless, grouped sequences are judged more accurately in number than are ungrouped. Thus, it seems that the loss of time is amply compensated for by the appliance of another quantification process, presumably the fast process of subitizing.

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