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HEMISPHERIC ASYMMETRY FOR AUDITORY PERCEPTION OF TEMPORAL ORDER

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Abstract—Two psychophysical methods were employed to examine the role of the left cerebral hemisphere for the auditory discrimination of temporal order. Subjects were asked to report either the order or the simultaneity of two clicks when each was presented to a different ear. The results showed that the threshold for temporal order was smaller when the right-ear click preceded the left-ear click compared to the opposite order of presentation. These results were discussed in relation to an hypothesis which suggests that the left hemisphere is the location for temporal processing in this task.

THE PURPOSE of the present experiment was to investigate brain asymmetry for the auditory discrimination of temporal order in a sample of normal subjects. EFRON [1] showed that the visual and tactile discrimination of temporal order occurred most efficiently within the left cerebral hemisphere, but did not investigate temporal order perception in the auditory modality. A demonstration of hemispheric asymmetry for decisions of auditory temporal order would have implications for the description of information transmission in the auditory system. As well, it would provide an important addition to the collection of studies which attribute superiority of temporal function to one hemisphere [2–7].

METHOD

Subjects

Two independent samples of 10 right-handed college students, within an age range of 18–25 yr, participated in threshold determinations using the method of limits or the method of constant stimuli. Their pure-tone thresholds for the left and right ears were determined with the Békésy audiometer. The resulting audiograms showed that no subject had a difference in threshold of more than 5 dB between ears for frequencies spanning 750 Hz–4000 Hz. Handedness was assessed with a questionnaire consisting of six items. The skills represented were those found by ANNETT [8] to be actions consistently performed with the preferred hand.

Apparatus

The output of a Tektronix waveform generator was used to trigger two Tektronix pulse generators, each of which produced a square wave pulse of 1 msec duration which the subject heard through stereophonic headphones. Each pulse could be delayed relative to the other by means of a control on the pulse generator. A Grason-Stadler white-noise generator was used to provide a background for the click pair. Calibration of the pulse characteristics and the delay was performed immediately prior to an experimental session using a Hewlett-Packard oscilloscope.

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Procedure

Pairs of successive clicks were presented to the subjects such that on each trial one member of the pair was delivered to the left ear and the other member of the pair was delivered to the right ear. The interval of time separating the onsets of the paired clicks was varied to include intervals at which their temporal order could be resolved easily as well as intervals at which the temporal distance between stimuli was too small to allow a ready discrimination of temporal order. In the latter case, subjects were instructed to call the stimuli "simultaneous", as in EFRON's [1] procedure, indicating that the two clicks were heard as occurring together in time. This judgment necessarily included the range of successiveness for which two stimuli may be identified even though their order cannot be. When subjects made successive-order judgments, they were instructed to report the ear which received the first click of the pair.

The method of limits and the method of constant stimuli were used to obtained thresholds for the perception of successive order. In both methods, the trials with one ear leading were presented in a blocked sequence. This paradigm was used to minimize effects due to attentional biases such as the law of prior entry would predict [9].

Method of limits. Each subject received a total of 10 descending runs presented in a prearranged random sequence; five with the click to the left ear leading and five with the click to the right ear leading. The initial separation between clicks in a run varied from 80 to 100 msec with a step size of 5 msec. A background of white noise was superimposed in both ears during presentation of the click pairs to facilitate the use of crossed auditory pathways. AITKEN [10] measured right and left hand reaction time to monaural tones with and without contralateral noise. He reported that crossed reaction time (right ear–left hand) was significantly longer than uncrossed reaction time (left ear–left hand) in the presence of white noise, but obtained no difference between conditions in the absence of contralateral noise. He concluded that the presence of white noise favored the transmission of stimulus information via contralateral pathways. The intensity level of the noise was set at a value estimated by the subject to be equal to the click which was 70 dB SL.

A run was terminated when the subject reported simultaneity for two successive trials and a trial was repeated as many times as necessary for the subject to make a judgment. Two practice runs were given to each subject prior to the experimental ones. The position of the headphones was reversed for one-half of the subjects to control for any asymmetries in the audio channels.

Method of constant stimuli. A click was delivered to the left or the right ear and, after a randomly-chosen interval, the other ear received a click. Five intervals were used (10, 20, 30, 40 and 50 msec) and each interval was presented 20 times in a right-first condition and 20 times in a left-first condition. A total of 240 trials were given in the experiment, with 20 practice trials and 100 test trials per day. One half of the subjects received the right-first trials on their initial day.

The instructions given to each subject were similar to those for the method of limits except that the subject made a manual response with the right hand to indicate successive order or simultaneity, prior to orally reporting which ear received the first click in the case of a successive-order judgment. It was assumed that the use of the right hand did not influence measurement of the threshold since the obtained value was based on the time interval between the first and the second click, and the response occurred after the second click.

RESULTS

Method of limits

The mean value of the interval within which together judgments occurred was calculated for runs in which the right-ear click was delivered first and for runs in which the left-ear click was delivered first. The mean threshold of temporal order for the right-first runs was 54.9 msec and for the left-first runs was 60.6 msec yielding a difference of 5.7 msec between conditions. A matched pairs t-test on these data indicated the ear difference to be significant at the 0.01 level [$t(9) = 4.19$]. As shown in Table 1, a lower threshold of temporal order in right-first runs was obtained for each of the 10 subjects tested.

Method of constant stimuli

In order to eliminate attentional asymmetries, left-first or right-first presentations occurred in blocks. Subjects, who were instructed to describe the perceived relationship between the clicks, seemed to successfully heed those instructions since reports at all inter-click intervals included judgements of "simultaneous", "left first" and "right first". The results indicate that the percentage of correct responses showed a gradual increase as temporal separation

Table 1. Mean threshold values (msec) for individual subjects following right-first and left-first conditions of stimulus presentation. Different groups of subjects were tested by the two methods

	Method of limits		Method of constant stimuli	
	Left-first	Right-first	Left-first	Right-first
	16	14	48.0	36.7
	83	74	35.6	40.0
	65	61	27.9	25.0
	73	57	42.0	35.0
	63	56	40.0	36.7
	54	48	23.8	25.0
	59	57	46.2	43.3
	39	35	28.6	25.4
	72	70	30.0	25.7
	82	77	32.0	28.8
Mean	60.6	54.9	35.3	32.2
Standard deviation	19.42	18.01	7.95	6.61

was lengthened. At the briefest intervals, nearly all reports were "simultaneous", whereas at the 50 msec separation, subjects reliably described the correct order.

The temporal gap for which subjects were correct on half of the trials approximates the threshold for successiveness under the conditions of this experiment (for a separation of 24 msec, 50% of the judgments were "simultaneous"). A longer separation, however, is needed for the subjects to consistently report the correct temporal order. By definition they could do this faultlessly when the percentage correct was 100. An estimation of the threshold for temporal order was obtained by taking the point at which correct judgments were made on 75% of the trials.

The value at which a correct order judgment was obtained on 75% of the trials was derived for each subject using linear interpolation. The mean threshold across subjects was 35.3 msec for left-first trials and 32.2 msec for right-first trials. The difference of 3.1 msec was significant at the 0.05 level of confidence [$t(9) = 2.4206$]. The individual thresholds shown in Table 1 indicate that eight of the ten subjects tested showed a lower threshold for right-first trials.

The smaller mean threshold estimate obtained with this second method may be due to the different psychophysical technique as well as the greater number of trials delivered. However, it is the relative difference between left- and right-ear thresholds, rather than the absolute value of the threshold, which is pertinent to the hypothesis of the experiment and the two techniques provided similar estimates of this difference.

DISCUSSION

The results of the present study demonstrate that the threshold for temporal order is lower when the right-ear stimulus precedes the left-ear stimulus compared to the opposite order of presentation. These findings are in agreement with those of EFRON [1] who found a lower temporal-order threshold for visual and cutaneous stimuli when the right-side stimulus was delivered first. Efron's interpretation of these data suggested that the comparison of temporal order and the decision of simultaneity occurred within the left cerebral hemisphere.

He assumed that information about each visual or cutaneous stimulus was initially directed to the contralateral hemisphere and primarily used contralateral sensory pathways. Consequently, information concerning the left-side stimulus required more time to reach the left hemisphere than was required for the right-side stimulus. The higher-temporal order threshold which was found for the left-first condition included this additional transmission time, assumed to reflect the callosal transfer of temporal information from the right to the left hemisphere.

In the auditory modality, the same rationale may be developed to account for the threshhold difference providing the assumption of contralateral transmission is warranted. Physiological data [11, 12] have indicated that the contralateral system is functionally superior to the ipsilateral during both monaural and dichotic stimulation, although some ipsilateral contribution remains. The literature on ear differences in dichotic and monaural tasks [13–15] is based upon the assumption of superiority of contralateral pathways coupled with an asymmetry in the central processing of auditory inputs.

The concept of a timing mechanism based in the left hemisphere leads to a model, shown in Fig. 1, specifying the relationship between psychophysical temporal order thresholds and neural events. The behavioral data can be used to determine the interhemispheric transfer time, which equals one-half of the difference between thresholds obtained for the left-first and right-first conditions.

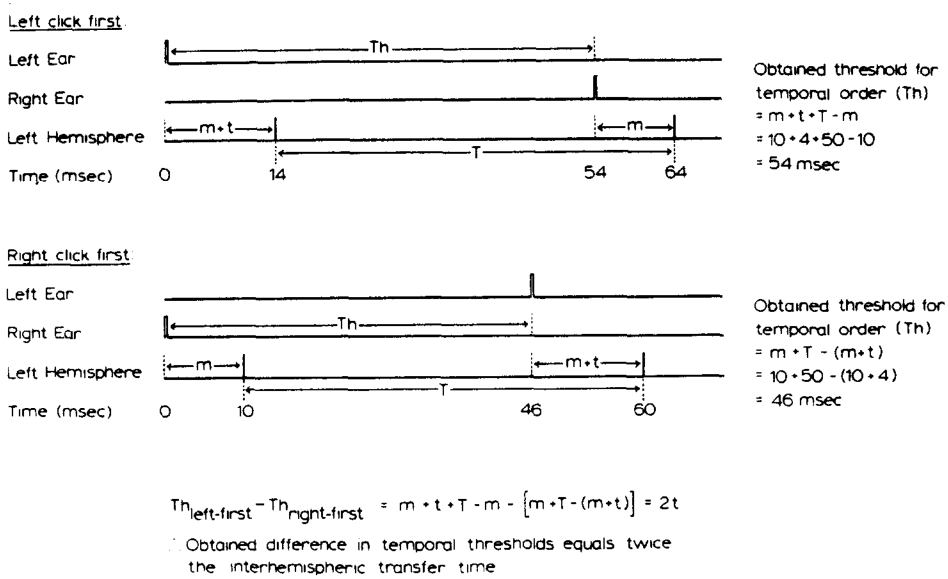

FIG. 1. Schematic representation of the rationale for the experimental hypothesis. If determination of successive order is based upon processes within the left hemisphere, it will take m msec for a right-ear input to be transmitted to that hemisphere, but it will take m plus an additional t msec (interhemispheric transfer time) for a left-ear input to reach there. An internal timing process begins upon arrival of the first click at the left hemisphere, where neural events must be separated by T msec in order to discriminate temporal order. The psychophysical threshold for temporal order (Th) reflects both the central threshold (T) and the transmission times (m and t). In order to illustrate the derivation of thresholds, the above example assumes that $m = 10$ msec, $t = 4$ msec, and $T = 50$ msec.

In the present study, 18 of the 20 subjects tested showed a lower threshold when the right-ear stimulus was delivered first. This is in accord with the assumption that the information was carried on the contralateral pathways and that the locus of processing was in the left hemisphere. For them, the transfer of left-ear information needed for the temporal discrimination is hypothesized as occurring from the right hemisphere to the site of temporal analysis in the left hemisphere. However, for the two subjects who obtained a lower threshhold for the left-first condition, the determination of temporal order may have occurred in the right hemisphere and for these individuals the transfer may have occurred from the left hemisphere to the right hemisphere. Therefore, to consider one-half of the difference in thresholds as an estimate of transfer time, it would be appropriate to base the estimate on the absolute value of the threshold difference. When this transformation is made, the value of the mean threshold difference from the method of constant stimuli is 4.4 msec and the estimate of transfer time is 2.2 msec. The estimate of transfer time from the method of limits is 2.8 msec. Both these values are consistent with previous estimates of interhemispheric transfer time reported for auditory, visual and cutaneous stimulation [1, 14, 17].

An alternative interpretation of the effect described here could be considered. When the left ear received the first click, the right hemisphere may have performed the task, but less efficiently (i.e. less accurately or more slowly) than the left hemisphere. If this were the case, then the ear effect might be based upon two kinds of temporal processes, differing in accuracy or latency, rather than providing the basis for an estimate of interhemispheric transfer time. A discussion of some clinical data may aid in evaluating this notion.

Previous studies [1, 5, 7, 17, 18] of right and left brain-damaged subjects, employing a task similar to that used in the present experiment, found hemispheric differences in successive-order thresholds ranging from 10 msec to 354 msec, with damage to the left hemisphere producing higher thresholds. Clearly, such differences are in excesss of the 5.7 and 3.2 msec mean threshold differences here reported. These clinical results suggest that right hemisphere processes for this task are much slower than would be required to yield the effect described here. While conceivable that such a very small hemispheric difference in timing processes could exist in normal subjects, it seems more reasonable to consider the figures obtained in the present experiments as values from which an estimate of callosal transfer time may be derived.

The present results suggest that the left hemisphere is specialized for judgments of temporal order, a finding which supports the more general notion of left hemisphere superiority for temporal processing. Although there are reports in the literature which identify the right hemisphere as having a role in some kinds of temporal discriminations, the left hemisphere seems to be prepotent in fine temporal analysis. MILLS and ROLLMAN [6] showed left-hemisphere superiority for processing information relating to stimulus duration when the durations were less than a critical value. Above that value, the right hemisphere's participation appeared to be equivalent to that of the left.

MURPHY and VENABLES [19, 20], however, reported a left-ear advantage (sampling right-hemisphere function) for discrimination of one versus two clicks when they presented subjects with paired clicks, separated by 0–100 msec, to the right or left ear. Although their findings could appear to suggest right-hemispheric specialization in processing temporal intervals as small as 2 msec, data on temporal acuity from both normal and clinical samples [21–24] provide a more probable interpretation. These studies have demonstrated that while the temporal order of stimuli separated by intervals of 10 msec or less may be discriminated, the basis for the discrimination appears to be loudness or pitch cues rather than temporal cues *per se*. In fact, MURPHY and VENABLES' [19, 20] subjects reported using pitch cues to facilitate their performance. Accordingly, their results might, in fact, represent right-hemisphere involvement in tasks which were not essentially temporal.

The recognition of melodic line is another task for which right hemisphere specialization has been proposed, since dichotic listening techniques with normal and brain-damaged subjects have yielded left-ear advantages [25, 26]. Although one component of melodic line is the temporal patterning, subjects could employ non-temporal strategies in the recognition task. For example, requiring a listener to adopt an experimentally induced strategy (analytic vs nonanalytic) when making his identification may result in either left or right ear advantages [27].

The extent of right-hemisphere participation in temporal tasks remains ambiguous, in part, because definitions of temporal tasks have often been unclear. A variety of "temporal discriminations" may be identified [23, 28], but the perceptual cues underlying them are not well known. Melodic recognition and MURPHY and VENABLES' [19, 20] data reflect performance on *nominal* temporal tasks in which the discrimination of a stimulus varying in time is, in fact, based upon non-temporal cues. To consider such tasks as representing temporal analysis lends confusion to the hemispheric delineation of temporal function.

A meaningful description of the hemispheres' respective roles should be based on the comparison of performance in *functional* tasks alone, that is, tasks in which temporal information *per se* provides perceptual cues for the discrimination. It is suggested that the present experiment is an example of such a functional task. The temporal separation at which a correct order judgment was made was beyond the range associated with peripheral interaction of the stimuli, so that qualitative differences in the composite sound could not have been the perceptual cues. Instead, the decision of temporal order had to be based upon an actual temporal cue: the arrival times of the representations of the two stimuli at some central location in the brain. Empirical analysis which distinguishes *functional* from *nominal* temporal tasks is of first importance in beginning to understand hemispheric specialization for temporal processing.

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Résumé :

On a utilisé 2 méthodes psychophysiques pour examiner le rôle de l'hémisphère gauche dans la discrimination auditive de l'ordre temporel. On demandait aux sujets de rapporter soit l'ordre soit la simultanéité de 2 clicks quand chacun était présenté à une oreille différente. Les résultats montrent que le seuil d'ordre temporel est plus petit lorsque le click de l'oreille droite précède celui de l'oreille gauche que lorsque les clicks sont présentés dans l'ordre inverse. On discute ces résultats selon une hypothèse suggérant que l'hémisphère gauche est le lieu du traitement temporel dans cette épreuve.