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Spatial constraints on focused attention: beyond the right-side advantage

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Abstract. The subjects listened to one of two simultaneous synthetic speech syllables delivered independently over two loudspeakers. When the loudspeakers were situated at 90° to the left and to the right, right-side advantage was found. When one loudspeaker was situated in front of the subject in the median plane, and the other at one of several azimuthal positions around him, an advantage of the frontal position was observed in all cases. On the other hand, performance on the nonfrontal message was affected significantly by its position. The pattern of performance which is observed can be described in terms of three component factors: a right-side advantage, related presumably to cerebral dominance, an advantage of sources situated in front of the subject over those at his back, and possibly an advantage of sources near the median plane over more remote ones.

1 Introduction

There is a large literature documenting the fact that when subjects listen to speech messages presented dichotically over earphones (i.e. one message delivered to each ear), the message delivered to the ear contralateral to the dominant cerebral hemisphere is identified better. This effect, generally called *right-ear advantage*, can be observed whether attention is divided between the ears (Kimura 1961) or focused through prior instructions on one of them (Kimura 1967). Thus it does not reflect the prevalent choice of a strategy favoring one side, but a real perceptual constraint which cannot be completely overcome through attention focusing.

In previous experiments we have shown that with two messages originating from apparent sources situated respectively to the left and to the right of the median plane one observes a *right-side advantage*: the message coming from the right is recognized better. The asymmetry can be obtained with the impression of localization produced through actual separation of two loudspeakers (Morais and Bertelson 1973; Morais 1975) and stereophonic techniques involving either intensity or time differences between presentation of each message in two earphones (Morais and Bertelson 1975). It can be abolished by misleading the subject about the actual position of the sources (Morais 1975). Because the right-side advantage obtained through time differences is smaller than the one observed with dichotic presentations, the possibility that intensity at the privileged ear plays some role, besides spatial position, in creating auditory asymmetries cannot be completely ruled out. The difference between the two conditions can, however, probably be attributed to differences in degree of apparent lateralization (Morais and Bertelson 1975). For the time being the most parsimonious position seems to be that right-side advantage in the dichotic situation is a special case of a more general relation of processing efficiency to felt spatial location: items presented to the right ear are processed better than items presented to the left ear because they appear to the subjects as coming from a region to their right, not because they reach an ear more directly connected to the processing centers, as is implied in the interpretation suggested by Kimura (1961) and adopted by the majority of subsequent authors. The substitution of a relation to space for a relation to ear of access does not imply, however, that the relationship between the direction of the effect and the side of cerebral dominance should be questioned. This relationship has in fact been firmly established by Kimura (1961).

Differences in performance related to location of the auditory source are probably not limited to left–right asymmetries. In fact, Morais and Bertelson (1973) also reported that, when their two loudspeakers were one in front of the subject and the other to one side, the message from the frontal source was always identified better.

The present experiment was designed to obtain a more comprehensive description of spatial constraints on the focusing of attention. Subjects were confronted with two simultaneous messages: one coming from the front and one from a different azimuthal position. The situation with one message coming from the left and the other from the right was included for comparison purposes. In our previous experiment (Morais and Bertelson 1973) three syllables were presented over each of the two loudspeakers on each trial and the subjects attempted total recall. The results could thus be due to memory limitations and attentional strategies in addition to perceptual effects. In the present experiment a single consonant–vowel syllable was presented through each loudspeaker, and the subjects' task was to identify one message only, as indicated by prior instructions: in this focused-attention situation any effect can be unequivocally considered to be perceptual.

2 Method

2.1 *Subjects*

Sixteen right-handed students who reported no hearing defect were tested. Nine were male and seven female. Their ages were in the range 16–22. Each took part in two 60 min sessions held on different days.

2.2 *Material and experimental situation*

The experimental tape employed in this study was provided by Dr C Darwin and prepared with a parallel formant speech synthesis program on the Elliott 4130 computer at the Department of Experimental Psychology of the University of Sussex. It contained 300 pairs of simultaneous consonant–vowel (CV) syllables, selected from the set: */ba/, /da/, /ga/, /pa/, /ta/, /ka/.* Each syllable lasted 300 ms. One pair occurred every 5 s. The two syllables of each pair were recorded on different tracks, at a pitch of 100 Hz on track 1 and 161 Hz on track 2; they were never tokens of the same syllable. Each of the fifteen different pairs of syllables occurred twenty times, ten times under each of the two possible distributions between the tracks. A short tape where each of the six syllables was recorded four times in random order simultaneously on both tracks, one syllable every 5 s, was prepared also for use in a preliminary screening test.

The material was played on a Revox A 77 tape recorder at an intensity level of about 65 dB (SPL). Each channel of the tape recorder was connected to one of two loudspeakers (Isophon HSB 15/8). These were positioned at head level and in the different experimental conditions occupied particular positions along a circle 110 cm from the center of the room. The room was quiet though not soundproof and measured 4·30 m x 3·20 m. The subject sat on a stool with a fixed backrest in such a way that his head was at the center of the room. He wore a headlight with a narrow beam which provided a control for the orientation of his head.

2.3 *Procedure*

There were eight conditions, depending on the location of the two loudspeakers. In seven of them one loudspeaker was in front of the subject (0°) and the other was at one of the following seven azimuths: 45°, 90°, and 135° to the left (respectively, conditions 45°L, 90°L, and 135°L), 45°, 90°, and 135° to the right (conditions 45°R, 90°R, and 135°R), and straight behind the subject (condition 180°). In the eighth condition one loudspeaker was situated at 90° to the left and the other at 90° to the right (condition L–R). The subjects were instructed during presentations always to keep the beams of their headlights on a small colored circle (diameter 0·8 cm) which was posted on the wall in front of them for condition L–R, and on the frontal loudspeaker for the other seven conditions.

Each of the two sessions consisted of 12 practice trials and 288 experimental trials. At the beginning of the first session, the subject was given a screening test, in which he had to identify twenty-four syllables delivered simultaneously through the loudspeakers at 90° to the left and to the right. The subjects who made more than five errors on this test were eliminated. The practice trials were presented under the experimental condition which was to be run first. They consisted of two groups of six trials defined by the position of the source the subject should listen to. The experimental trials were grouped in eight blocks of thirty-six trials corresponding to the eight conditions, and within each block in four runs of nine trials. The subject was told before each run of trials the position of the source he should listen to and was instructed to report only the syllable from that source. He was told to write down the syllable on a response sheet immediately after the trial; he was encouraged to guess when he was not sure. After the first practice group of trials, and after each group of trials within an experimental block, the report instructions were shifted and, at the same time, the loudspeakers were reversed; as a consequence the subjects were listening to the same loudspeaker and to the same track of the tape (track 2 where the pitch was 161 Hz) across the whole experiment.

Each of eight different orders of presentation of the eight conditions, determined by a Latin square balanced for sequential effects, was assigned to two subjects. Of the two subjects in the same line, one was run with his sagittal plane along the longest horizontal dimension of the room and the experimenter and tape recorder at his back, and the other subjects with his sagittal plane along the shortest horizontal dimension of the room and the experimenter and tape recorder on his left. The order of listening to one or to the other of the two positions in each condition was reversed in the second session for each subject and counterbalanced across the subjects.

3 Results and discussion

Let us first consider condition L–R. Fourteen out of the sixteen subjects recalled the right-side message better than the left-side message; the opposite-side advantage was observed for the other two subjects ($p < 0{\cdot}002$, by a one-tailed sign test). The percentage of correct responses averaged over the sixteen subjects was 55·0 for the left-side message and 61·6 for the right-side message. The mean percentage of responses which consisted of intrusions from the unattended message was 16·4 when trying to recall the left-side message and 12·2 when trying to recall the right-side message. As a measure of the laterality effect we used the percentage-of-errors (POE) scoring procedure (Krashen 1972) for two reasons: the first is that a comparison with previous results of the present authors would be immediately available; the second is that, according to Marshall et al (1975), this measure is unbiased by variations in level of performance for a range of performances above 50%. The POE score expresses the error score for a particular location as a percentage of the total number of errors, i.e. as a percentage of the number of errors for that location plus the number of errors for the other location employed in the same condition. The error score for one location is the number of syllables presented in that location which were not recalled correctly. In condition L–R the mean left-side POE score was 54·5, which was significantly different from 50 by a one-tailed t-test ($t = 3{\cdot}29$, d.f. $= 15$, $p < 0{\cdot}005$).

Thus, when listening to speech with sound sources at 90° to the left and to the right, right-side advantage was found. This finding is not new, but in the present experiment the side difference was obtained under conditions where no effect of memory factors can be suspected at all. Whereas in the previous experiments (Morais and Bertelson 1973, 1975; Morais 1975) three syllables were presented in each position or each side, here only one syllable was presented on each side. As in the two last studies mentioned above, the subject knew in advance the side from which the syllable that he had to identify would be coming. Right-side advantage was thus observed with a paradigm which directly reflects perceptual processing and, except for the substitution of loudspeakers for headphones, has been used quite often in recent years for studying speech perception through the measure of right-ear advantage.

The seven conditions in which a frontal source was put in competition with one in a different position provide us with a first general description of spatial constraints on focused attention. There are two ways to look at these data. First, we can for each condition compare performance on the frontal message and on the nonfrontal one. Table 1 gives the distribution of subjects according to the sign of the difference. Figure 1 gives the mean nonfrontal POE score, together with the corresponding t-tests. An advantage of the frontal position is apparent in every condition. The nonfrontal POE score is significantly superior to 50 in every condition except condition 45°R. It seems thus that focusing on a frontal source gives always a better performance than focusing on a nonfrontal position[1].

The other way of analysing the data consists of making comparison between the different conditions. The degree of frontal-position advantage changes with the nonfrontal position. A two-way analysis of variance (subjects and position) applied

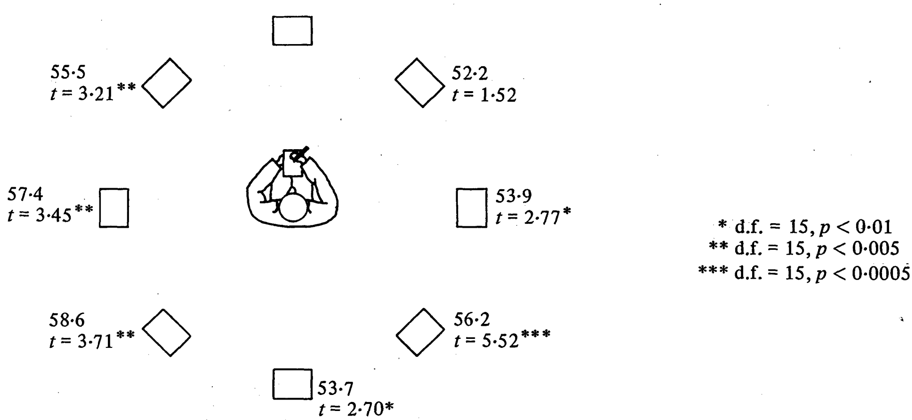

Figure 1. Mean nonfrontal percentage of errors scores for the seven 'frontal' conditions with the corresponding t values and levels of significance.

Table 1. Distribution of subjects according to spatial differences in the seven 'frontal' conditions.

Condition	Position giving better performance			
	frontal	nonfrontal	neither	p (one-tailed sign test)
45°L	12	2	2	0·006
90°L	12	3	1	0·018
135°L	12	2	2	0·006
180°	10	3	3	0·046
135°R	14	1	1	0·001
90°R	11	3	2	0·029
45°R	9	3	4	not significant

[1] One referee has raised the problem that this result may have been influenced by the fact that a message was present in the frontal position on almost all trials. This possibility will be investigated in an experiment where all positions are used equally often.

to the POE scores gave an effect of position significant at $p < 0{\cdot}05$ ($F = 2{\cdot}44$, d.f. = 6, 90). These changes in POE scores could result from changes in performance on both the frontal and the nonfrontal message with the location of the nonfrontal source. Figure 2 shows the percentage of correct responses and the percentage of intrusions separately for the two messages and for each condition. The effect of the azimuthal position of the nonfrontal message on performance on the frontal message is small, and is found non-significant by analysis of variance ($F = 0{\cdot}96$, d.f. = 6, 90 for correct responses, and $F = 0{\cdot}70$, d.f. = 6, 90 for intrusions). The effect on performance on the nonfrontal message is much larger. This effect is significant ($F = 2{\cdot}64$, d.f. = 6, 90, $p < 0{\cdot}025$ for correct responses, and $F = 3{\cdot}93$, d.f. = 6, 90, $p < 0{\cdot}005$ for intrusions). Duncan's multiple comparison test shows that for correct responses condition 135°L is significantly worse than 45°L, 45°R, and 90°R, and 135°R is worse than 45°R. Intrusions are significantly more numerous for 135°L than for 90°L, 45°L, and 90°R, and more numerous for 135°R than for 90°R and 45°R.

The pattern of performance on the nonfrontal messages could tentatively be analysed in terms of several components.

The first apparent component is a superiority of the right side of space. Each position to the right of the median plane gives a better performance than the corresponding position to the left. This is presumably another manifestation of the mechanism responsible for right-side advantage. It should be noted, however, that the degree of right-side superiority revealed by pairwise comparisons of symmetrical nonfrontal positions is smaller than the right-side advantage observed in condition L–R. A left-side POE score can be computed for each pair of nonfrontal positions. Its values are respectively 50·8 for 45°L and R, 51·0 for 90°L and R, and 51·5 for 135°L and R, to be compared to 54·5 for condition L–R. The case of conditions 90°L and R, where the positions compared in the POE score are the same as for condition L–R, is particularly striking. The observation adds to the growing body of evidence regarding which presentation conditions are more sensitive to laterality effects: it suggests that competition between opposite azimuthal positions provides a more sensitive situation than competition between closer positions.

A second component would be a superiority of sources in the anterior half of space over sources in the posterior half. Two aspects of the data support the assumption of this component: the existence of a frontal advantage in the 180°

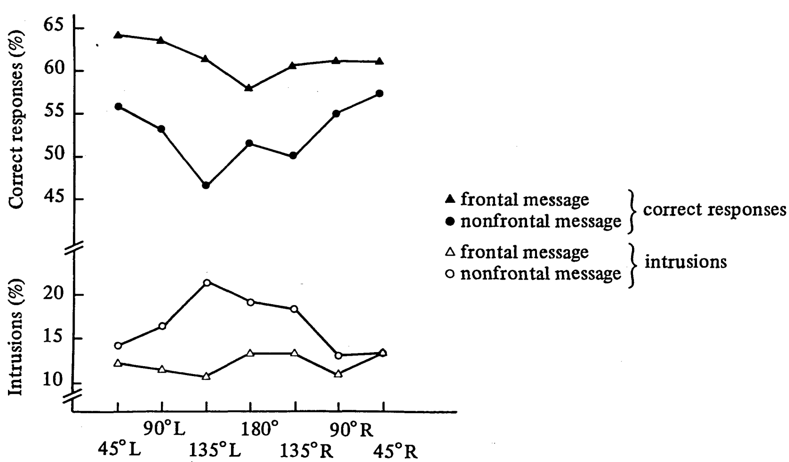

Figure 2. Mean percentage of correct responses and mean percentage of intrusions for the frontal and for the nonfrontal messages in each of the seven 'frontal' conditions.

condition and the fact that there are more correct responses and less intrusions for messages in each of the 45° positions than in the corresponding 135° position. It might be objected perhaps that the fall in performance between 45° and 135° can be due to the fact that the competing message occupied the frontal position. Attention could be attracted by this competing message, making focusing on the relevant message more and more difficult with increasing separation. But under this assumption the performance on frontal messages should show a similar decrease with increasing distance of the nonfrontal irrelevant message, and we have seen that there is only a negligible nonsignificant tendency in that direction. Only a very small part of the superiority observed for the anterior sources would thus possibly be attributable to competition from the frontal source and the rest would be due to genuine anterior–posterior asymmetry. This kind of asymmetry has obvious adaptive value, since it promotes perception of the sound coming from the direction one is facing.

A possible third component would be superiority of sources near the median plan over more distant ones. The only suggestion for this component comes, however, from the fact that performance appeared to be better on messages in position 180° than in either 135°L or 135°R, and that the nonfrontal POE score was significantly greater for the 135° condition than for the 180° one (by Duncan's test). The fact that performance is lower in the 90° positions than in the corresponding 45° conditions might be attributed to this component, but could equally be attributed to the better established anterior–posterior gradient. Confirmatory data are needed before this component can be discussed further.

The previous analysis[2] into components must now be validated by looking for possible experimental dissociations. For instance, while right-side superiority is known to be related to cerebral dominance and to hold in general only for material calling for phonetic or linguistic analysis, the other components might be not so specific to a particular type of material.

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[2] The generality of the present results has been questioned on the ground that only one level of recognition difficulty has been considered. The possibility that a different pattern would be obtained at another difficulty level cannot be formally excluded. In this respect it is worth mentioning the results of Cullen et al (1973) who found that right-ear advantage for CV syllables was invariant with variations both of SPL and of binaural masking.