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Vowel Processing in the Left and Right Visual Fields

D. SALMASO AND C. UMILTÀ

Istituto di Psicologia, C. N. R., Roma and Istituto di Fisiologia Umana, Parma, Italy

Two laterality experiments were conducted to assess the performance of the left and right hemispheres in a letter classification task using only vowel pairs. In Experiment I stimuli were presented in a print-like form and neither physical nor name matches yielded hemispheric asymmetries. Experiment II, by using script-like vowels, showed an overall advantage of the right hemisphere for both kinds of match. These findings suggest that physical matches and name matches for print-like vowels are performed by both hemispheres. The right-hemisphere advantage for script-like letters is attributable to the higher-order level of spatial processing required by this material.

INTRODUCTION

Several studies (see reviews in Posner, 1978; Posner & Rogers, 1978) have established that when subjects are presented with linguistic stimuli, two different internal codes are formed. One is modality-dependent, that is, it is visual when the stimuli are visually presented, it is acoustic for auditory presentations, and possibly somesthesic for tactile presentations. On the contrary, the other type of code is modality-independent, that is, it represents the phonetic encoding of the stimuli irrespective of the modality in which they are shown. These two codes yield two different and isolable processing systems which can be independently utilized in a *same–different* classification task. This has been convincingly demonstrated in both the visual (see e.g. Posner & Mitchell, 1967) and the auditory (see, e.g., Pisoni & Tash, 1974) modalities. In fact, two visually identical letters (like AA or aa) or two acoustically identical speech sounds (like two /ba/'s with the same voice onset time) take less time to be classified as same than letters that share only the same name (like Aa) or speech sounds that share only the same phonetic category (like two /ba/'s with different voice onset times). Such a difference in response latency is usually attributed to the fact that when the two stimuli are physically identical they can be correctly classified on the basis of

Address reprint requests to: Dr. Dario Salmaso, Via dei Monti Tiburtini 509, 00157 Roma, Italy.

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the physical (i.e., visual or acoustic) code, whereas when they are physically different they must be classified on the basis of the modality-independent phonetic code. It is also assumed that the process of phonetic encoding of visually or auditorily presented linguistic stimuli takes a measureable amount of time which is reflected in longer response latencies for matches based on the phonetic code than for matches based on the physical codes.

In addition, it has been proposed that the two systems, besides being isolable, might also be located in different parts of the brain. That is, the left hemisphere (LH) of right-handers should be specialized for phonetic processing, whereas the right-hemisphere (RH) should be specialized for physical processing. In the case of visually presented stimuli, this notion has gained empirical support through the results of those studies (Cohen, 1972; Geffen, Bradshaw, & Nettleton, 1972) which showed shorter reaction times (RTs) in the right visual field–left hemisphere (RVF–LF) for phonetic matches (also referred to as name matches) and shorter RTs in the left visual field–right hemisphere (LVF–RH) for physical matches. More recent studies (Ledlow, Swanson & Kinsbourne, 1978; Simion, Bagnara, Bisiacchi, Roncato, & Umiltà, 1980; Umiltà, Sava, & Salmaso, 1980), while casting some doubt on the prevailing role of the RH as a physical processor, have confirmed the LH specialization for phonetic encoding and processing.

Taking for granted that name match of visually presented letter pairs is based on the modality-independent phonetic code, the degree of RVF–LH advantage for this type of match should be dependent on those same phonetic characteristics which have been shown to affect the degree of LH specialization in the case of auditorily presented speech stimuli. Dichotic listening experiments (see reviews in Darwin, 1974; Liberman, 1974) have shown that the LH plays a primary role mainly in the processing of phonetic parameters of rapidly changing acoustic information. Correspondingly, a LH superiority is not found for all classes of phonemes. As shown by Shankweiler and Studdert-Kennedy (1967), Darwin (1971), Cutting (1974), and Blumstein, Tartter, Michel, Hirsch, and Leiter (1977) only stop-consonants yield a very clear-cut right-ear (i.e., LH) advantage (see also reviews in Krashen, 1976; Springer, 1977). Vowels and fricatives, which have steady-state acoustic features, show no lateral asymmetry (vowels) or a less clear-cut LH advantage (fricatives). In other studies (Darwin, 1971; Godfrey, 1974; Haggard, 1971; Weiss & House, 1973) also vowel processing was found to yield a LH advantage comparable to that of stops, but only when the task was rendered more difficult by shortening the duration of the stimuli or by decreasing the signal-to-noise ratio.

If, as suggested by Liberman (1974) and Posner (1978), both visually and auditorily presented linguistic stimuli give rise to a common modality-independent phonetic code, it seems reasonable to predict that name matches for visually presented pairs of vowels should show no RVF–LH advantage, in agreement with the findings of the above-mentioned dichotic listening experiments. It is worth noting that in those previous studies which demonstrated a RVF–LH advantage for name matches, only stop-consonants (Umiltà et al., 1980), only consonants (Simion et al., 1980; Wilkins & Stewart, 1974), or both consonants and vowels (Cohen, 1972; Geffen et al., 1972; Davis & Schmidt, 1973; Ledlow et al., 1978) were used as stimuli. Experiment I aimed at investigating whether such a RVF–LH advantage would disappear when only vowels are employed as stimuli in a *same–different* letter classification task.

EXPERIMENT I

Method

Subjects. Eight female students of the University of Rome participated in the experiment. All were right-handed as determined by the Edinburgh Handedness Inventory (Oldfield, 1971) with right-eye preference for sighting. None had previous experience with the task. They were paid for their participation.

Stimuli. Experimental material consisted of pairs of letters printed on plain white cards (see Fig. 1A). The style chosen was Gill extra bold (RP series of R41). Photographic negatives of each pattern were mounted in slide holders for tachistoscopic projection on a back-projection screen. The two letters were placed one above the other to eliminate or reduce horizontal scanning effects (Bryden, 1966). Two-thirds of the stimuli consisted of same letter pairs, half of which were physical identity (PI) pairs (like AA, aa) and the other half were name identity (NI) pairs (like Aa or aA). Different pairs were both uppercase (AE), both lowercase (ae), or mixed (Ae), so that case could not be used as a classification cue. The letters chosen as stimuli were the five Italian vowels, that is A, E, I, O, U, and they appeared equally often in all types of pairs.

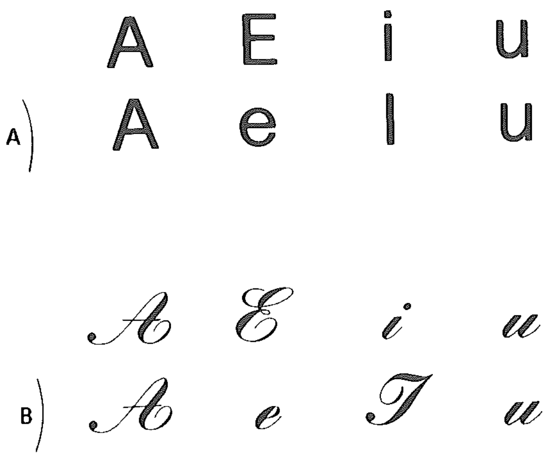

FIG. 1. Examples of vowel pairs both for *print-like* (a) and *script-like* (b) material. The first and the fourth pairs are examples of physical matches, while the second and the third are examples of name matches.

Procedure. Subjects seated in front of a translucent screen at a distance of 60 cm. A head- and chin-rest assured a constant head position. An acoustic signal (800 Hz for 1 sec) prompted the subjects to fixate a clearly marked central point of the screen. One half second after the warning signal, a slide was back-projected for 116 msec on the screen on a level with, and either to the left or right of, the central fixation point. Interstimulus interval was kept constant at 5 sec. The stimuli extended from approximately 5.8 to 7.2° of visual angle from fixation and the angular separation between fixation and the center point of the pairs was about 6.6°. Stimulus intensity and the luminance of environmental light were kept constant at 22.3 and 6.1 ftl respectively. The subject's task was to decide whether the letters in a pair were the same or different by pressing one of two keys using the index and middle fingers. Pressing a key stopped an electronic timer started at the beginning of the slide exposure. By written instructions subjects were told to respond "same" if the two letters had the same name and to respond "different" when the two letters had different names. They were also instructed to press the exact key as rapidly as possible while trying to avoid errors. Half of the subjects used their right hand, the other half their left hand. Four subjects used the forefinger for same responses and the middle finger for different responses, and four used the reverse arrangement. When projected, stimuli were white on a dark background. Each pair was not higher than 4° and not larger than 1.4°. The space between the two letters was about 0.7°. Eye movements were controlled by a TV camera which allowed detection of movements of about 0.8° of visual angle. Reaction times (RTs) that were coincidental with a detectable eye movement were discarded. Prior to starting, informal practice trials acquainted the subject with fixation of the central point and with pressing the correct key in response to same or different pairs. Each subject was tested during one session which lasted about 40 min. Each session consisted of 244 trials, divided into four blocks of 61 presentations. The four blocks of trials were presented to the LVF and to the RVF according to ABBA and BAAB sequences counterbalanced across subjects.

RESULTS AND DISCUSSION

All RTs corresponding to eye movement trials (less than 0.5%) and all RTs beyond 3.0 *SD* of the mean for each subject and for each condition were excluded from statistical analysis. A three-way within-subjects analysis of variance was carried out on mean correct RTs for *same* responses only. The three factors were: visual field (left and right), type of match (PI and NI), and type of letter (A, E, I, O, and U).

Type of letter and type of match main effects were significant: $F(4, 28) = 9.21$; $p < .001$ and $F(1, 7) = 31.65$; $p < .001$, respectively. Mean RTs differed according to what letter was presented: 708.6 msec for A, 725.9 msec for E, 616.4 msec for I, 672.1 msec for O and 681.7 msec for U. Physical identity matches were 85.0 msec faster than NI matches (638.4 vs. 723.4 msec). The interaction between type of letter and type of match was also significant: $F(4, 28) = 11.90$; $p < .001$. As shown in Table 1, the advantage of PI matches over NI was dependent on the type of letter. Neither the visual field main effect nor the interaction between visual field and type of match proved significant. Table 2A shows the relevant data for this nonsignificant two-way interaction, along with the results for *different* responses in the two visual fields. It is also worth noting that the type of letter did not affect the symmetry between

TABLE 1
MEAN RTs AS A FUNCTION OF TYPE OF LETTER AND TYPE OF MATCH FOR *PRINT-LIKE* STIMULI

	A	E	I	O	U
PI	611.3	646.8	599.9	662.0	672.2
NI	805.8	805.0	632.9	682.2	691.1
Mean	708.6	725.9	616.4	672.1	681.7
Difference	194.5	158.2	33.0	20.2	18.9
Percentage of errors	2.5	2.8	1.0	2.6	2.2

Note. PI: physical identity, NI: name identity.

the two fields (see nonsignificant interactions type of letter × visual field and type of letter × type of match × visual field). A second analysis of variance was executed on mean RTs for *same* and *different* responses. Only two factors were tested: visual field and type of response (same and different). Again RTs for the two visual fields were not different (see Table 2A), whereas the type of response main effect was significant: $F(1, 7) = 21.55$; $p < .005$. *Same* responses were faster than *different* (680.9 vs. 746.9 msec).

Two other analyses of variance were carried out to test the same factors for errors. Single letters yielded significantly different numbers of errors: $F(4, 28) = 3.93$; $p < .025$ (see Table 1). No other main effect or interaction reached statistical significance in these analyses.

Experiment I showed no significant effect attributable to hemispheric specialization. In the case of PI matches this finding can be viewed as confirmatory of those previous studies (Ledlow et al., 1978; Simion et al., 1980; Umiltà et al., 1980) which have failed to observe a RH specialization for matches based on the visual code and agrees with Mos-

TABLE 2
MEAN RTs AS A FUNCTION OF VISUAL FIELD, TYPE OF MATCH AND TYPE OF RESPONSE FOR *PRINT-LIKE* AND *SCRIPT-LIKE* STIMULI

		Same		
		PI	NI	Different
(A) Printlike letters	LVF	634.9	728.7	744.4
	RVF	642.0	718.1	749.3
	Mean	638.4	723.4	746.9
(B) Scriptlike letters	LVF	648.9	733.7	807.6
	RVF	674.4	783.6	847.3
	Mean	661.6	758.6	827.4

Note. PI: physical identity, NI: name identity, LVF: left visual field, RVF: right visual field.

covitch's (1979) notion of an equal ability of both hemispheres to conduct simple visuospatial processing. On the contrary, the lack of a LH specialization for NI matches is in disagreement with all previous studies (see Introduction above) which have shown a clear-cut RVF–LH advantage for matches based on the phonetic code. The only apparent difference between the present study and the previous ones is to be found in the use of vowels instead of consonants or a mixed set of both consonants and vowels. Thus, since NI matches should require also in the present study a comparison based on the phonetic code, the lack of lateral asymmetries can be attributed to the fact that the phonetic characteristics of vowels are processed equally easily by both hemispheres, as suggested by the results of dichotic listening studies.

However, this conclusion has a critical flaw, that is, the use of a null result prediction to test an experimental hypothesis. In the present case this problem is exacerbated further by the significant interaction between type of letter and type of match. Posner (1978) has shown that a pair of same letters differing in size but not in shape can be correctly classified on the basis of the visual code after an operation of normalization (analog matches according to Posner's terminology) which requires a certain amount of time. Now, the upper- and lowercase representations of I, O, and U were similar enough to allow analog matches. These letters did in fact yield comparatively small NI–PI differences (see Table 1) as should be expected when analog matches occur. Thus the notion of a lack of hemispheric specialization for the processing of vowel phonetic codes, besides resting on the null hypothesis logic, is also weakened by the possibility of an involvement of the visual code even in the case of the so-called name matches.

In order to avoid the defects of Experiment I, in Experiment II the same vowel stimuli were presented by employing a script-like typeface which has been shown to be more demanding from the point of view of visuospatial processing (see Bryden & Allard, 1976). In conformity with the results of a previous study (Umiltà et al., 1980) a LVF–RH advantage for PI matches was predicted, while two predictions were proposed for NI matches. The complexity of visuospatial processing along with the lack of any hemispheric specialization for the phonetic encoding of vowels, could yield a LVF–RH advantage even in the case of NI matches. On the other hand, the use of script-like letters could bring about a RVF–LH advantage attributable to the greater difficulty of phonetically encoding visually complex stimuli, in accordance with those dichotic studies (Darwin, 1971; Godfrey, 1974; Haggard, 1971; Weiss & House, 1973) which showed a LH advantage for vowels by increasing the complexity of the physical parameters of the acoustic signal. Experiment II aimed at investigating which of those two hypotheses was more tenable. Furthermore, with the kind of typeface chosen upper- and lowercase representations of each letter were so dissimilar to render analog matches extremely unlikely.

EXPERIMENT II

Method

Stimuli. Stimuli were again photographic negatives of pairs of letters printed on plain white cards (see Fig. 1B). The style chosen was Palace Script (SK series of R41). Letter stimuli were the five Italian vowels A, E, I, O, and U. Each pair, when presented, was no higher than 4° and not wider than 2°. The space between the two letters was about 0.7°. The stimuli extended from 5.2 to 7.2°, and the angular separation between the fixation mark and the center point of each pair was 6.2°.

Subjects. Eight new female subjects took part in this experiment. They were selected in the same way as before and were paid for the experiment.

Procedure. The experimental procedure exactly replicated that of Experiment I. Due to the complexity of the stimuli, subjects were given a longer informal practice session. However, accuracy proved lower than that in the previous experiment. The experimental session was conducted according to the same design as before.

RESULTS AND DISCUSSION

All correct RTs that did not exceed by more than 3.0 *SD* the general mean for each subject and for each condition and that did not correspond to eye movement trials (about 0.6%) were submitted to two analyses of variance, one for *same* responses only and the other for both *same* and *different* responses. The factors were the same as in Experiment I.

The analysis for *same* responses showed that the type of match main effect was significant: $F(1, 7) = 23.99$; $p < .005$. Physical identity matches were 97.0 msec faster than NI matches (661.6 vs. 758.6 msec). In this case also the visual field main effect reached statistical significance: $F(1, 7) = 6.90$; $p < .05$. Left visual field was 37.7 msec faster than RVF (691.3 vs. 729.0 msec). Seven subjects out of eight showed this trend. No other source of variability reached statistical significance. Table 2B shows the RT data for *same* responses as a function of visual field and the type of match, along with RTs obtained for *different* responses. The analysis conducted on both types of responses confirmed the difference between the two visual fields: $F(1, 7) = 7.57$; $p < .05$. Left visual field was 38.8 msec faster than RVF (749.4 vs. 788.2 msec). Seven subjects out of eight behaved in this way. *Same* responses (710.1 msec) were 117.3 msec faster than *different* responses (827.4 msec): $F(1, 7) = 36.85$; $p < .001$. Accuracy depended on the type of vowel: $F(4, 28) = 6.27$; $p < .001$. The errors were 3.3% for A, 2.7% for E, 0.8% for I, 3.6% for O, and 2.6% for U. Type of match was also significant: $F(1, 7) = 12.31$; $p < .01$, showing that fewer errors were made with PI matches (5.3 vs. 7.7%). No other source reached statistical significance in the analyses for errors.

The results of Experiment II were fairly straightforward, namely, there was a LVF–RH advantage under both match conditions. This finding for PI matches complements previous observations which had shown that a RH specialization emerged only when stimuli requiring a high-order level of visuospatial processing were employed (Bryden & Allard, 1976; Umiltà et al., 1980). A RH specialization for NI matches, which doubtless required phonetic encoding and processing also in the case of script-like vowels, is less obvious. However, as already suggested, such an outcome can be predicted if one accepts Moscovitch's (1979) notion of transmitted lateralization. This notion implies that when hemispheric specialization emerges at a given stage of information processing, it is then transmitted to the successive stages unless they require the specialized processing capabilities of the other hemisphere. In the present case, an RH specialization emerged at the level of visuospatial processing due to the visual complexity of the typeface employed. This RH specialization was then transmitted to level of phonetic processing since the phonetic characteristics of vowels did not call for the mechanisms specific of the LH. Alternatively, it may be proposed that the RH terminated earlier the stage of visuospatial processing for which it is specialized and thus it initiated earlier the stage of phonetic processing even if, in the case of vowels, this type of processing does not call for the specialized capabilities of any hemisphere. This can also explain why a RH advantage was found for different responses that should be emitted at the same stage of information processing at which NI matches take place (see Posner, 1978).

It is interesting to note that in Experiment II type of letter did not interact with type of match, confirming that in the case of script-like letters analog matches did not take place. In both experiments *same* responses were faster than *different*. This is a typical finding of *same–different* classification tasks (see e.g., Nickerson, 1972). However, in the present case the difference could also be attributed to the fact that most trials (two thirds) required a *same* response (see e.g., Hyman, 1953).

GENERAL DISCUSSION

The main findings of the present study can be better understood if discussed with reference to those of a previous work (Umiltà et al., 1980), in which the same experiments were conducted using only pairs of stop-consonants. This comparison requires a preliminary note of caution. In the present study only female subjects were used, whereas in the previous one there were subjects of both sexes. Even if there are not many convincing data for sex-related differences in cerebral lateralization (see Fairweather, 1976), the hypothesis that males are more lateralized than females is at least tenable (see review in Bryden, 1979). However, it must be stressed that in the two experiments with stops, 10 females out of 10 showed a LH superiority for NI matches and no source of variability involving sex approached statistical significance.

In the case of print-like stops utilized in the first experiment of our previous work (Umiltà et al., 1980) a LH advantage was found for NI matches, whereas no hemispheric asymmetry emerged for PI matches. It was suggested that visuospatial processing of print-like letters could be performed by both hemispheres. To the contrary, the phonetic processing required by name matches for stops could be performed only by the LH. In the present study, when pairs of print-like vowels were used, neither PI nor NI matches yielded hemispheric asymmetries. In the case of PI matches this finding can be viewed as confirmatory of the ability of both hemispheres to conduct simple visuospatial processing (Moscovitch, 1979). The lack of lateral asymmetry for NI matches can be attributed to the fact that phonetic characteristics of vowel sounds are processed by the two hemispheres, as shown by the results of dichotic listening studies (see Introduction above).

In the experiment with script-like stops (Umiltà et al., 1980), a significant interaction was observed between visual field and type of match, with PI matches yielding a RH advantage and NI matches yielding a LH advantage. We proposed that, while the phonetic encoding of stops was again performed in the linguistic hemisphere, the much more complex visuospatial processing of script-like letters was preferentially performed in the RH. In the case of script-like vowels, an overall RH advantage was found, regardless of the type of match. This result for PI matches can be easily explained as before by assuming that a RH advantage emerges when the requirement for visuospatial processing exceed the capabilities of the LH. The RH advantage for NI matches to script-like vowel pairs can be explained by considering: (1) that the phonetic characteristics of vowel sounds are amenable both to RH and LH encoding; and (2) that the better ability of the RH to process complex visuospatial material, apparent at the stage of visuospatial processing, is transmitted to the stage of phonetic processing that per se should not yield any hemispheric asymmetry (for a discussion of the hypothesis of transmitted asymmetry, see Moscovitch, 1979).

In conclusion, the present study seems to confirm previous findings of dichotic listening studies which found no hemispheric asymmetries with normally presented vowels, suggesting that name matches for vowel pairs do not require the phonetic mechanism specific of the linguistic hemisphere. This seems to give empirical support to the notion according to which visually and auditorily presented linguistic stimuli give rise to a common modality-independent phonetic code, that can be utilized for matching stimuli irrespective of the modality in which they are shown.

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