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EVIDENCE FOR STIMULUS–RESPONSE COMPATIBILITY EFFECTS IN A DIVIDED VISUAL FIELD STUDY OF CEREBRAL LATERALIZATION *

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The question addressed here was whether lateral asymmetry of processing might be influenced by response position, a factor which is usually considered irrelevant in divided visual field studies of cerebral lateralization. For this purpose a lexical decision task, which had previously been investigated with lateral unimanual two-finger choice reactions (Heister et al. 1983), was carried out under different manual and vocal response conditions so as to uncover possible S–R compatibility effects. In the first study, thirty-two subjects responded unimanually, with their responding hand held in a medial position. In the second study, twenty-four subjects responded vocally, i.e., in both cases the spatial (right/left) cues of the response position were eliminated. The reaction time advantage for compatible S–R pairings obtained with lateral hand position disappeared in the experiment with medial hand position, and the right-field superiority for vocal reactions was much smaller than the right-field superiority for right-hand reactions in the earlier lateral experiment. This indicates that an S–R compatibility effect contributed to the results of the earlier experiment. Thus, S–R compatibility can affect even unimanual reactions in lateralization studies.

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At least two research areas use latencies of laterally given responses to laterally presented stimuli as their central dependent variable: (1) In human neuropsychological experiments, employing the divided visual field technique, the investigation of response times is considered a sensitive method for inferring the cerebral locus of processing and thus for detecting hemispheric capabilities ('splitting the normal human brain with reaction time', see Filby and Gazzaniga 1969; Beaumont 1982). (2) Studies of stimulus–response (S–R) compatibility regard reaction time differences between spatially compatible and spatially incompatible S–R pairings as indicating information processing aspects of response selection (see, e.g., Fitts and Seeger 1953; Sanders 1967, 1980; Nicoletti et al. 1982).

One of the conclusions of this paper is that both research areas should not be studied in isolation. We shall provide empirical evidence that S–R compatibility contributes as an interfering factor to the results of divided visual field studies. This means in particular that genuine neuropsychological concepts like 'hemispheric specialization' and 'interhemispheric connectivity' do not always suffice to account for data obtained in certain experimental designs; cognitive concepts like S–R compatibility must be considered as well. Conversely, certain designs, intended to study S–R compatibility require additional consideration of neuropsychological concepts.

This can be made plausible in the following way. In studies of S–R compatibility there is a common distinction between relevant and irrelevant stimulus location. In the first case subjects perform a spatial choice reaction task (see, e.g., Brebner et al. 1972), in the second case subjects respond to a non-spatial feature of the stimulus, but the data are also analyzed according to the irrelevant spatial relationship between stimuli and responses. The S–R compatibility effect obtained in studies with irrelevant stimulus location has also been called the 'Simon effect' (see Hedge and Marsh 1975). The non-spatial tasks used in such studies have always been fairly simple: common paradigms are color discrimination (see, e.g., Craft and Simon 1970; Umiltà and Nicoletti 1985), shape discrimination between squares and circles (see, e.g., Wallace 1971) or discrimination between the words 'right' and 'left' (see, e.g., Simon and Rudell 1967). One can well imagine designs using more difficult tasks with higher cognitive demands like lexical decision about strings of letters presented laterally in the visual fields. Lexical decision tasks with visual half-field stimulation are common in neuropsychological lateralization experiments. In other words, certain studies on hemispheric specialization might be viewed as studies on S–R compatibility with irrelevant stimulus location.

To study the validity of this argument, we investigated whether S–R compatibility may have affected the data of an earlier experiment (Heister et al. 1983), which studied lateralization of lexical processing in combination with sex differences. In this experiment high and low familiar words as well as high and low familiar meaningless syllables were presented in the right or left visual field. Subjects reacted unimanually with their index or middle finger to indicate the lexical category (word vs. non-word) of the string of letters presented as stimulus, while the responding hand (either the right or the left) was held in normal lateral position (i.e., the right hand on the right side of the body, and the left hand on the left side, see fig. 1, panels A and B). Response times for men showed a right-field superiority for right-hand reactions and a left-field superiority for left-hand reactions, i.e., a pattern that also corresponds to an S–R compatibility effect. Women did not show this pattern of results.

In order to isolate a possible effect of S–R compatibility, we repeated the experiment of Heister et al. (1983) with the same stimuli and the same task, but with different response modalities. In the first study responses were given with the response buttons turned 90° and mounted in a middle position (see fig. 1, panel C); in the second study responses were given vocally. In both cases the spatial right/left relationship on the response side was eliminated, so that eventual effects of S–R compatibility should disappear.

If S–R compatibility has added to the results of Heister et al. (1983), it would be due to the relationship between right and left fields and right and left positions of responding hands, although no choice between hands but between fingers of one hand was required. An effect of S–R compatibility due to the different hands could be additional to a compatibility effect between right and left field and spatially right and left finger. This was studied by Heister et al. (1986 (relevant

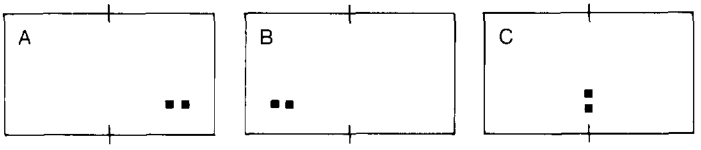

Fig. 1. Schematic diagram of locations of response buttons for the manual response conditions (A, B: lateral hand position of Heister et al. 1983; C: medial hand position).

stimulus location), 1987 (irrelevant stimulus location)). Although a strong finger compatibility effect was found in these last two studies (ca. 50 msec), an additional hand compatibility effect was not observed in a design in which the responding hands alternated several times between blocks of trials. Only in a design where hands were held constant throughout an experimental session, Heister et al. (1987) found a minor hand compatibility effect. The results of that study cannot be simply transferred to the present investigation. A more demanding cognitive task was used with much higher uncertainty and average response latencies which are three times as long as in the standard S–R design with red–green discrimination of Heister et al. (1987).

In most studies of S–R compatibility, male and/or female subjects are chosen arbitrarily. Yet, in the analysis of higher cognitive functions there are suggestions about sex differences in cerebral lateralization (see McGlone 1980). Especially in view of the sex differences found by Heister et al. (1983), it cannot be excluded that there are also sex differences in S–R compatibility under our experimental conditions. Therefore both males and females were chosen as subjects.

In the following, we first present the results of a reanalysis of the data of Heister et al. (1983), as far as they are relevant to the present study, and discuss them with respect to the problem of S–R compatibility (experiment 1); then we report the results of the replication with response buttons in the middle position (experiment 2) and, finally, we discuss a replication with vocal responses (experiment 3).

Experiments 1 to 3

Since the three experiments only differ with respect to the response modality (and, of course, with respect to subjects), we first describe the general aspects of the method.

Method

Subjects

Students and university employees served as paid subjects. All were right-handed according to a German adaptation of the Oldfield handedness questionnaire (Oldfield 1971) and had no close left-handed relatives. They were all native speakers of German and had normal or corrected-to-normal vision tested with a Bausch & Lomb 'Vision Tester' to ensure an adequate level of performance.

Stimuli and apparatus

Stimuli were 30 German three-letter words (15 high-familiar and 15 low-familiar nouns) and 30 regular but meaningless German three-letter syllables (15 high-familiar and 15 low-familiar). Since no standard word frequency count is available for German, the familiarity of the stimuli was determined in a previous study by C. Kolbert based on ratings of 50 students, who had to guess how often they had used, heard or read the trigrams (words and non-words). The non-words were meaningless syllables that can be part of regular German words. (The familiarity variable was specific for the study of Heister et al. (1983); it is not evaluated in this reanalysis.) Each stimulus was presented twice, once in the right and once in the left visual field. The stimuli were presented vertically to prevent the possible influence of left-to-right scanning tendencies and subtended a visual angle of 0.3° horizontally and 1.26° vertically. They were printed in uppercase Letraset script (Folio Medium Extended, No 454) white on dark ground. The second letter of each word or syllable was located on the horizontal midline and the distance to the fixation point (a small white x) was 2.5°.

The subjects received 120 experimental trials and 20 similar but not identical practice trials. The slides were presented in a fixed random order in two blocks; half of the male and half of the female subjects received them in one order and the other half in reversed order. The subjects sat with their heads in a head-and-chin rest and had to focus on the fixation point when the experimenter gave a signal. Immediately after the signal a stimulus flashed for 125 msec on a back-projection screen. The subject had to decide whether a regular word or a meaningless syllable was presented. Reaction times were recorded in msec, whereby errors as well as responses with reaction times over 3 sec were excluded from analysis.

Experiment 1 (Heister et al. 1983)

Method

Subjects

Subjects were 16 men and 16 women aged 19 to 35.

Response modality

Half of the men and half of the women used their right hands for response, the other half their left hands. They distinguished between words and meaningless syllables by pressing one of two buttons with the index or middle finger of the responding hand. The response keys were attached either to the left side (for left-hand reactions) or to the right side (for right-hand reactions) of the experimental desk (see fig. 1, panels A and B). The responding hand was held in natural palm-down position. Which key was used for responses to words and which one for responses to meaningless syllables was counterbalanced across right and left responding male and female subjects.

Results

For the purpose of the present study, we present a reanalysis of the reaction time data of Heister et al. (1983), disregarding effects of lexical category and stimulus

Table 1
Mean response times (in msec) and standard deviations (in parentheses).

	Experiment 1		Experiment 2			Experiment 3	
	Right field	Left field	Right field	Left field		Right field	Left field
Men							
Right hand	1200	1303	1109	1111	Vocal	1189	1242
	(358)	(442)	(321)	(347)	response	(251)	(329)
Left hand	1154	1087	1150	1213			
	(239)	(225)	(233)	(258)			
Women							
Right hand	1114	1119	1186	1200	Vocal	1159	1137
	(248)	(276)	(326)	(327)	response	(242)	(199)
Left hand	1019	1023	1246	1301			
	(147)	(173)	(284)	(347)			

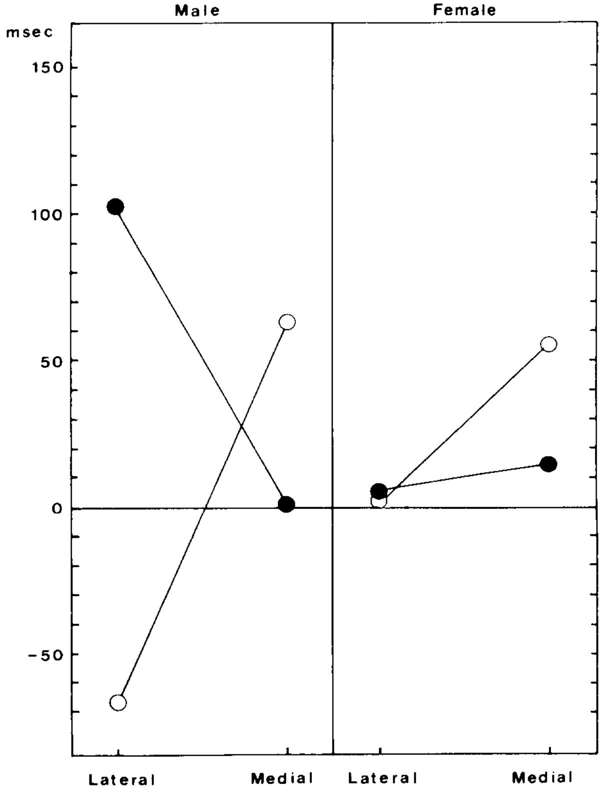

Fig. 2. Field differences (L–R) in msec for left (unfilled) and right (filled circles) reacting men and women in experiment 1 (lateral response) and experiment 2 (medial response). Positive values express a right-field superiority (faster reactions), negative ones a left-field superiority.

familiarity as well as an analysis of errors. An analysis of variance was performed on the mean reaction times of the correct responses faster than 3 sec with sex, hand and visual field as main factors. The corresponding cell means are shown in table 1. A graphical representation of the field differences is part of fig. 2.

A significant interaction between visual field and responding hand was obtained ($F(1, 28) = 7.42$, $p = 0.01$), which is due to the results of the male subjects. Men showed a right-field advantage for right-hand reactions of 103 msec (1200 vs. 1303 msec) and a left-field advantage for left-hand reactions of 67 msec (1087 vs. 1154 msec), whereas women showed practically no field difference. This sex difference is expressed in the significant interaction between sex, responding hand and visual field ($F(1, 28) = 7.27$, $p = 0.01$). It is confirmed by the results of separate analyses of variance for men (significant interaction between responding hand and visual field ($F(1, 14) = 9.20$, $p < 0.01$), no other effect significant) and women (no significant effect at all).

Discussion

Men showed a pattern of results that qualitatively corresponds to an S–R compatibility effect for field of stimulation and responding hand, spatially compatible reactions being faster than incompatible ones. Quantitatively such an S–R compatibility effect is surprisingly high in view of the very small hand compatibility effect found in a study with two-finger choice reactions (see Heister et al. 1987). A post hoc neuropsychological explanation would be that, for male subjects, the left as well as the right hemisphere are able of processing linguistic information (although, according to the literature, this might be expected for women rather than for men, see McGlone 1980). With bihemispheric language capability, stimuli from both the right and left visual field can be processed in the hemisphere where they directly arrive (i.e., in the right hemisphere for left-field stimulation and in the left hemisphere for right-field stimulation). Transfer of information to the other hemisphere, which would cause a delay of responses, would then only be necessary if the response is not initiated in the same hemisphere, i.e., if the response is not given by the hand opposite to the hemisphere in which information has been processed. This is precisely the case if the right hand responds to stimuli in the left field and the left hand to stimuli in the right field. However, this explanation would again only explain the qualitative pattern and not the size of the effect. According to this cerebral pathway hypothesis the effect should have merely amounted to the callosal crossing time for which estimates are in the range of a few milliseconds (see Bashore 1981; Kinsbourne and Hicks 1978).

The absence of a field superiority effect for women is also difficult to interpret, in particular in view of the fact that neuropsychological results in this field are often contradictory (see the discussion in Heister et al. (1983)). One possible background could be that intrahemispheric cognitive/motor interference takes place (see Heister 1984b). For the present purpose it is important that if an S–R compatibility effect was present in Heister et al. (1983), men and women do not appear to be equally susceptible. This might have to be attributed to the specific kind of task we are dealing with.

Experiment 2

Method

Subjects

Thirty-two new subjects (16 male, 16 female) aged 16 to 32 participated.

Response modality

The only difference with experiment 1 was that the response buttons were mounted in the middle position and turned by 90° as shown in fig. 1 (panel C) i.e., subjects held the forearm of their responding hand parallel to the body.

Results

As in experiment 1, an analysis of variance with the factors sex, hand and visual field was carried out. The cell means are given in table 1, the field differences are shown in fig. 2. The only significant source was a main effect for visual field ($F(1, 28) = 6.68$, $p < 0.05$), demonstrating an overall right-field superiority which is mainly due to left-hand reactions: the right-field superiority for left-hand reactions was 63 msec for men and 55 for women, for right-hand reactions 2 msec for men and 14 for women. This was confirmed by the interaction between field of stimulation and responding hand, which was marginally significant ($F(1, 28) = 3.84$, $p = 0.06$) and by a significant main effect for field in a subanalysis for left-hand responses ($F(1, 14) = 11.19$, $p < 0.01$). The main effect for sex and all interactions with the factor sex were far from significant ($F(1, 28) < 1$).

To compare experiments 1 and 2 (see fig. 2 for the changes in field difference), a common analysis of variance with the factors experiment, sex, hand, and visual field was carried out. It showed significant interactions between experiment, hand and visual field ($F(1, 56) = 11.21$, $p < 0.01$) and between experiment, sex, hand and visual field ($F(1, 56) = 5.34$, $p < 0.05$). This demonstrates that the reaction time preference for the visual field ipsilateral to the responding hand, which was present for men in the first experiment, disappeared and even shifted to the opposite for the left hand. In addition, a main effect of visual field was obtained ($F(1, 56) = 4.79$, $p < 0.05$), which is due to the general right-field superiority in the second experiment.

Discussion

The right-field superiority for experiment 2 as well as for experiments 1 and 2 taken together is not surprising and can be interpreted as expressing the superiority of the left hemisphere for the language task in these experiments. It corresponds to well-known findings in studies with lexical decisions (for review see Heister (1984a)). What is more interesting are the effects with the factor hand. The designs of experiment 1 and experiment 2 differ only in the placement of the response buttons. Whereas in experiment 1 the right or left *position* of the responding hand was still confounded with *anatomical* right or left, in experiment 2 the spatial right or left cue of the response position was eliminated. Therefore effects with the factor hand in experiment 2 are more easily related to neuroanatomical connectivity. Differences between experiments 1 and 2 can be ascribed to the specific way of processing spatial information in experiment 1, especially S–R compatibility.

The results show that the large reaction time advantage for compatible S–R pairings with males in experiment 1 disappeared in experiment 2. This suggests that this effect of experiment 1 is in fact due to S–R compatibility. Furthermore, since there is no difference in the results between males and females in the second experiment, we must adopt the hypothesis that in experiment 1 a sex difference in S–R compatibility is present, i.e., with this linguistic task men seem to be subject to the influence of S–R compatibility whereas women are not.

Although standard S–R effects may be quite large, our effect obtained for men (more than 80 msec) exceeds by far the marginal hand compatibility effect of the comparable study of Heister et al. (1987). In that study the task was red–green discrimination and only females served as subjects; hence one might hypothesize that male subjects would have shown a stronger compatibility effect. Yet, the only existing study on sex differences in S–R compatibility (Simon 1967) obtained a stronger S–R compatibility effect for females (with auditory stimulation). It might be more plausible therefore to attribute the larger size of the compatibility effect for men in experiment 1 to the higher cognitive demands (lexical decision, vertical stimulus presentation). These higher demands have the characteristic that subjects are less certain in their decision than they are in the case of color discrimination. Thus, many more errors are made than the small number in the usual studies of S–R compatibility. One may speculate that degrees of uncertainty and task difficulty determine the size of the S–R compatibility effect and can perhaps even cause sex differences like those observed here. It could be hypothesized that more uncertainty in decision leads to a larger compatibility effect; in addition, it might be assumed that uncertainty with lexical decisions is less for women than for men. This is supported by the fact that men were overall (although not significantly) slower than women and committed more errors (see Heister et al. (1983) for a detailed evaluation of the accuracy data of experiment 1).

Experiment 3

Method

Subjects

Twenty-four new subjects (12 male, 12 female), aged 19 to 40, participated.

Response modality

Responses were given vocally instead of manually. Subjects reacted by saying '*Ja*' ('Yes') to words and by '*Nein*' ('No') to syllables. Their voices stopped an electronic timer triggered by the onset of the stimulus.

Results

An analysis of variance with the factors sex and visual field was performed. The cell means and standard deviations are given in table 1. None of the main effects or interactions proved significant. The same holds for separate subanalyses for men and women. The mean reaction times showed a right-field superiority of 53 msec for men and a left-field superiority of 22 msec for women.

Discussion

Since with vocal reactions, the 'response organ' is in the body midline, there is neither spatial compatibility nor incompatibility of the response position with the positions of laterally presented stimuli. Since vocal responses are initiated in the left hemisphere, they correspond neuroanatomically to responses with the right hand. So we should expect that results with vocal reactions are similar to the results for right-hand reactions of experiment 2. In particular for men, there should be a less pronounced right-field superiority than for the right-hand reactions in experiment 1. The absence of any significant effects is in accordance with this hypothesis. Although the right-field superiority for vocal reactions is about 50 msec more than for the right-hand reactions of experiment 2, it is still 50 msec smaller than for the right-hand reactions of experiment 1.

However, comparison of vocal results with results of manual experiments is complicated by the fact that different response modalities interfere with cognitive information processing, and even this may be different for men and women (see Low and Rebert 1978; Green 1984; Heister 1984a, b). This may also explain the greater right-field superiority for men with vocal reactions as compared to the medial experiment and the left-field superiority for women pointing slightly into the 'wrong' direction. (Such 'paradoxical' field superiorities for vocal reactions have sometimes been reported, see Bashore 1981; Bashore et al. 1982.) In general, results of the vocal experiment, though difficult to interpret, do at least not repudiate the influence of S–R compatibility and sex difference on the results of experiment 1.

General discussion

The main question of this study was whether S–R compatibility effects might influence unimanual reaction times in a divided visual field study of language lateralization. For this purpose an earlier study of Heister et al. (1983) with responses given laterally was repeated with different response modalities (manual response in medial position, vocal response) which were seen as extinguishing right/left S–R compatibility effects. Especially the results of the study with medial response buttons in comparison to the results of Heister et al. (1983)

support the hypothesis that in this experiment a strong S–R compatibility effect – but only for men – was present. This result may be due to the higher demands of this experimental task (viz., lexical decision) as compared to standard S–R designs.

In conclusion, the findings strongly suggest that a systematic investigation of S–R compatibility in lateralization studies with higher cognitive demands provides a more detailed picture of this phenomenon with entirely new aspects (such as sex differences).

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