

# **Hemispheric Differences in Global/Local Processing Revealed by *Same–Different* Judgements**

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This paper investigates the hypothesis that the left and right hemispheres of the human brain are specialized for processing local and global stimulus information, respectively. Also, functional hemispheric differences with respect to “same–different” judgements are considered. The hypothesis was tested that the right hemisphere produces faster “same” judgements than the left hemisphere, whereas the opposite holds for “different” judgements. Two matching experiments are reported, in which compound test stimuli were presented either in the left or right visual field. The results of both experiments support the hypothesis that hemispheres are differently specialized for global/local processing. However, there was no indication that the hemispheres differ with respect to “same–different” judgements.

## INTRODUCTION

It is generally acknowledged that the hemispheres of the human brain are functionally different in several respects (e.g. Bradshaw & Nettleton, 1981; Sperry, 1974). However, some of the proposed asymmetries are still controversial (see Davidson & Hugdahl, 1995). Among these are hemispheric differences with respect to global/local processing. It has often been stated that the left hemisphere (LH) processes local stimulus information preferentially, while the right hemisphere (RH) is specialized for processing the global aspects of sensory input (for an overview see Robertson & Lamb, 1991). Unfortunately, the empirical evidence for this hypothesis is equivocal.

Studies into general aspects of local/global processing have frequently used *compound letters*. The global letter form of these stimuli is constructed out of smaller local letters (see Figure 1), and the task of the subjects usually is to

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		"Same" Responses								Global Response Level
		Comparison Stimulus		Test Stimulus						
Congruent Condition		A		A	A	A		A		
		A		A	A	A		A		
		A	A	A	A	A	A	A	A	A
		A		A	A	A		A		
		A		A	A	A		A		
Incongruent Condition		A	A	A	A	A	E	E	E	E
		A					E			
		A	A	A	A	A	E	E	E	E
					A					E
		A	A	A	A	A	E	E	E	E
		"Different" Responses								
		Comparison Stimulus		Test Stimulus						
Congruent Condition		A		A	S	S	S	S	S	
		A		A	S					
		A	A	A	A	A	S	S	S	S
		A		A	S					
		A		A	S	S	S	S	S	
Incongruent Condition		E		E	E	E	E	E	E	
		E		E	E				E	
		E	E	E	E	E	E	E	E	E
		E		E	E				E	
		E		E	E				E	

FIG. 1. Example stimuli used in Experiment 1, with the different conditions for the global response level.

identify either the local or the global letter. Navon (1977) found with such stimuli that the global letter is processed faster than the local ones. Moreover, if the global and local letters were response incompatible, i.e. if each letter was mapped onto a different response, then there was a global-on-local but no local-on-global interference. For explaining these results, Navon (1977) proposed that the information at the global and local level is processed sequentially, and that the global level is processed first. However, it has meanwhile been demonstrated that this hypothesis does not hold, and that the information at the global and local level is processed in parallel (e.g. Hoffman, 1980; Kinchla, Solis-Macias, & Hoffman, 1983; Miller, 1981; Navon, 1991).

Since compound letters are well suited for investigating global/local processing, they were also employed for examining corresponding hemispheric differences. One method is to present such stimuli to neuropsychological patients (for an overview see Robertson & Lamb, 1991). For instance, Lamb, Robertson, and Knight (1990) compared the performance of patients with lesions in either the left or right posterior superior temporal gyrus (LSTG versus RSTG group). They presented compound letters in the centre of the visual field, and found that LSTG patients had an advantage for processing the global information, whereas the RSTG patients showed an advantage with respect to the local information. Moreover, in contrast to a neurological intact control group, the patients showed no interference between the levels (see also Humphreys, Riddoch, & Quinlan, 1985; Robertson, Lamb, & Zaidel, 1993). Lamb et al. (1990) argued that the lesions prevented the integration of information from both the levels into a coherent whole. They concluded that the processing of global information is favoured by mechanisms associated with the right posterior superior temporal lobe, whereas mechanisms associated with the left posterior superior temporal lobe favour the processing of local information.

Also the results of a PET (positron emission tomography) study (Fink, Halligan, Marshall, Frith, Frackowiak, & Dolan, 1996) support the hypothesis that the hemispheres are differentially specialized for global/local processing. When subjects named the global letter of a compound stimulus, then their cerebral blood flow was increased in the right lingual gyrus, whereas naming the local letters led to an increased blood flow in the left inferior occipital cortex.

However, the results of visual-field studies in normal subjects are less conclusive. If the RH and LH are specialized for processing global and local information, respectively, then global letters should be identified faster for stimuli presented in the left visual field (LVF) than for those presented in the right visual field (RVF). The opposite result is predicted for the identification of local letters. Although some experiments found the expected differences (Hübner, 1997; Martin, 1979; Robertson et al., 1993; Sergent, 1982), others failed (Alivisatos & Wilding, 1982; Boles, 1984; Boles & Karner, 1996; van Kleeck, 1989).

While most visual-field studies into hemispheric differences with respect to global/local processing have used identification tasks, Alivisatos and Wilding (1982) used “same–different” judgements. Since the present paper is also concerned with “same–different” judgements, the method of Alivisatos and Wilding is considered in detail. After displaying a compound letter as a comparison stimulus in the central visual field (CVF), they presented a compound test stimulus either in the RVF or in the LVF. Although the local letters of the comparison stimulus were always identical to the letter at the global level, there were congruent, incongruent, and neutral matching conditions. Consider, for example, the congruent and incongruent conditions for the global target level. In the congruent “same” condition the letters of the test stimulus matched with those of the comparison stimulus at both levels, whereas in the incongruent condition, only the global letters were identical. For “different” responses a condition was congruent, if the letters at both levels did not match, whereas in the incongruent condition the letters matched at the local level but were different at the global level. An analogous pattern held for the local target level.

Alivisatos and Wilding (1982) found with this method that responses to the global target level in the incongruent conditions were slowed, but only for stimuli presented in the RVF. Comparisons at the local level generally led to increased response times on incongruent trials. However, there were no visual-field effects.

### Hemispheric differences with respect to “same–different” judgements

Interestingly, “same–different” judgements *per se* have also been investigated with respect to hemispheric differences. One line of research has contrasted performance in shape tasks with that in name tasks. While in shape tasks the subjects have to compare two letters (e.g. AA) for shape identity, they must compare letter pairs (e.g. Aa) for name identity in name tasks. Usually, judgements in name tasks take longer than those in shape tasks, an effect that has been called the *nominal–physical disparity* (Proctor, 1981). With respect to hemispheric differences it has been speculated that the RH is specialized for shape tasks, whereas the LH performs name tasks more efficiently. However, a review of the literature revealed that there is only little support for this hypothesis (Boles, 1981). In a recent paper, Eviatar, Zaidel, and Wickens (1994) again compared name and shape tasks for both hemispheres, and found merely small error differences for the name task under a deadline condition. They concluded that the hemispheres performed name and shape tasks in the same manner.

In shape tasks “same” judgements are often faster than “different” judgements. Also, there are more false–different errors than false–same errors (for an overview see Eviatar et al., 1994). This result is incompatible with the idea

that the matching process proceeds by serially scanning each stimulus dimension of the test stimulus until a difference is found. In this case “different” judgements would be faster, since for “same” responses all dimensions must be checked. To account for these results, Bamber (1969) proposed a two-process model, in which, additional to a serial processor, there is a *fast identity reporter* emitting a signal only when the stimuli are “same”. Although meanwhile some alternative models have been proposed, which will be considered later, it is important to note that the performance of the fast identity reporter was thought to rely on global stimulus processing, while “different” responses were assumed to depend on the processing of local information (Taylor, 1976). Thus, if the hypothesis that the hemispheres differ with respect to global/local processing is correct, then one should expect corresponding differences also for “same” and “different” judgements.

Several experiments, which were carried out to test this hypothesis, found no evidence for its correctness (Bagnara, Boles, & Simion, 1983; Bagnara, Boles, Simion, & Umilta, 1982). However, in a study of Patterson and Bradshaw (1975), where nonverbal visual stimuli (schematic faces) were employed, “same” responses were faster for LVF than for RVF presentations. Moreover, there was an opposite but nonsignificant effect for the “different” responses for certain conditions. Unfortunately, Hillger and Koenig (1991), in a similar experiment for “different” judgements, observed faster responses for LVF than for RVF presentations. These results demonstrate that it is still open as to whether the hemispheres differ with respect to “same–different” judgements.

The experiments reported here were conducted to answer the question of whether the laterality effects for global/local processing also occur under appropriate conditions in experiments with a matching task, and whether there are visual-field effects with respect to “same–different” judgements. The first experiment is similar to that of Alivisatos and Wilding (1982). However, to improve the quality of the data, more trials per condition were used, and a within-subjects design for the target-level factor was applied (Alivisatos and Wilding used different subjects for global and for local matching). Also, the comparison stimuli could have different letters at both levels.

In Experiment 1 several specific hypotheses were tested. First, global judgements should generally be faster than local judgements. Second, while global judgements should be faster for LVF stimuli than for RVF stimuli, local judgements should be faster for RVF stimuli than for LVF stimuli. Further, it was predicted that incongruent conditions should affect local judgements more than global judgements. For comparison at the global target level it was expected that “same” responses should be faster than “different” responses, since they are similar to those in shape tasks. No latency difference between “same” and “different” responses should occur with respect to the local target level. Finally, while “same” responses were expected to be faster for LVF than for RVF stimuli, the opposite should hold for “different” responses.

## EXPERIMENT 1

## Method

*Subjects.* Eight subjects (four male and four female), who ranged in age between 20 and 28 years, participated in the experiment. All were right-handed (by self-report), and had normal or corrected-to-normal vision.

*Apparatus.* The stimuli were presented on a 19"-colour monitor (Miro, type GDM-1965) with a resolution of  $1280 \times 1024$  pixels, which was connected to a graphics-board (Miro-Tiger) with 256 grey levels and a refresh rate of 75Hz (non-interlaced). A personal computer (PC) served for controlling stimuli presentation and response registration.

*Stimuli.* The stimuli consisted of black ( $0.314\text{cd/m}^2$ ) compound letters on a white ( $80\text{cd/m}^2$ ) background. The size of the local letters was  $0.29^\circ \times 0.38^\circ$  of visual angle. The vertical distance between the local letters was  $0.57^\circ$ , and the horizontal distance  $0.43^\circ$ . The global letter forms were constructed from local letters within a  $5 \times 5$  grid extending  $4.23^\circ \times 3.14^\circ$  of visual angle. The capital letters A, E, H, and S served as stimuli. Since the comparison stimuli could consist of different local and global letters, there were 256 possible pairs of comparison and test stimuli. Example stimuli are given in Figure 1.

Letter pairs could be either congruent or incongruent. For the condition of "same" responses, congruency means that at each level the letters of the comparison and test stimuli are identical (e.g. Ha-Ha, where "Ha" stands for a compound letter with "H" at the global, and "A" at the local level, and the first and second letter pair represents the comparison and the test stimulus, respectively). With four letters there are 16 different combinations of this type. Incongruency means that the letters at the target level are identical but different at the nontarget level (e.g. for local: Ha-Ea; for global: Ha-He). There are 48 different stimulus pairs of this type for each target level.

For "different" responses, congruency means that the letters at the target level as well as those at the nontarget level are different between comparison and test stimuli (e.g. Ha-Es). Only those stimuli were chosen whose letters also differed *within* each compound letter. There were 24 different stimulus pairs of this type. Incongruency means for the "different" responses that the letters at the target level are different while those at the non-target level are identical (e.g. for local: Ha-Hs; for global: Ha-Ea). For this case there were 48 different stimulus pairs.

To define an identical number of trials for each condition in each experiment block, the stimuli for conditions with less than 48 different stimulus pairs were included more often, such that for all global conditions (same, different, congruent, incongruent) there were 48 pairs.

Since this reasoning holds for the global as well as for the local target level, there were 192 constructed trials for each target level.

*Procedure.* The task for the subjects was to make “same–different” judgments by pressing one out of two response buttons with their index or middle finger, respectively, of the same hand. Gender, response-key mapping, and responding hand were counterbalanced across subjects. For instance, some of the subjects who responded with their right hand had to indicate “same” with their index finger and “different” with their middle finger. For other subjects the finger mapping was reversed. To keep the viewing distance constant at 127cm, the subjects were positioned in a head and chin rest.

Each trial started with the appearance of a comparison stimulus at the centre of the screen. After the subjects had pressed a key with the hand that was not used for responding to the stimuli, a blank screen appeared for a duration of 600msec followed by the test stimulus which was exposed for 67msec in either the left visual field (LVF) or the right visual field (RVF). The RVF or LVF stimuli were presented in such a way that their centre was 3.6° (visual angle) to the right or left of the screen centre, respectively. The subjects were told to keep their fixation at the centre of the screen during each trial. Response errors were signalled by a tone.

Altogether, there were four factors: Response (same, different), target level (global, local), congruency (congruent, incongruent), and visual field (LVF, RVF).

The 192 predefined trials for the global conditions were randomly separated into two blocks of 96 trials. At the beginning of each block five warm-up trials were presented. The same procedure was applied to the 192 different trials for the local conditions. In two sessions the subjects took part in 16 blocks. In half of the blocks they responded to the local level and in the other half to the global level. Together there were 1536 trials per subject, 96 trials for each of the 16 conditions. Local and global blocks alternated. Half of the subjects started with a global block and the other half with a local block.

## Results

*Response Times.* Only the latencies of correct responses were entered into the data analysis. To reduce the effect of extreme values, the data were trimmed by eliminating the three slowest and two fastest responses of each condition (cf. Rosenberger & Gasko, 1983). The trimming procedure was asymmetric to compensate the positively skewed latency distributions. Finally, the trimmed means were subjected to a four-factor analysis of variance (ANOVA) for repeated measurements on all four factors: Visual field (LVF, RVF), response (same, different), target level (global, local), and congruency (congruent, incongruent).

The target-level factor turned out to be significant,  $F(1, 7) = 14.9, p < .01$ . Comparisons at the global level were faster (563msec) than those at the local level (649msec). Also the response factor was significant,  $F(1, 7) = 24.9, p < .01$ . “Same” responses were faster (592msec) than “different” responses (621msec). Further, the congruency factor was significant,  $F(1, 7) = 11.2, p < .05$ . Responses to congruent stimuli were faster (601msec) than those to incongruent (611msec) stimuli.

The visual-field factor was not significant. However, there was a significant interaction between visual field and target level,  $F(1, 7) = 13.8, p < .01$ . Comparisons revealed that, while the responses to the global level were faster for LVF-stimuli (558msec) than for RVF-stimuli (569msec),  $F(1, 7) = 7.31, p < .05$ , those to the local level were faster for RVF-stimuli (631msec) than for LVF-stimuli (667msec),  $F(1, 7) = 7.27, p < .05$ . The corresponding mean times are depicted in Figure 2.

There was also a target level by response interaction,  $F(1, 7) = 19.7, p < .01$ . For the global level, “same” responses were significantly faster than “different” responses (539msec versus 587msec),  $F(1, 7) = 26.0, p < .01$ , while the difference was not reliable for the local level (644msec versus 654msec). Finally, there was a significant response by congruency interaction,  $F(1, 7) = 14.8, p < .01$ . “Same” judgements were significantly faster for congruent than for incon-

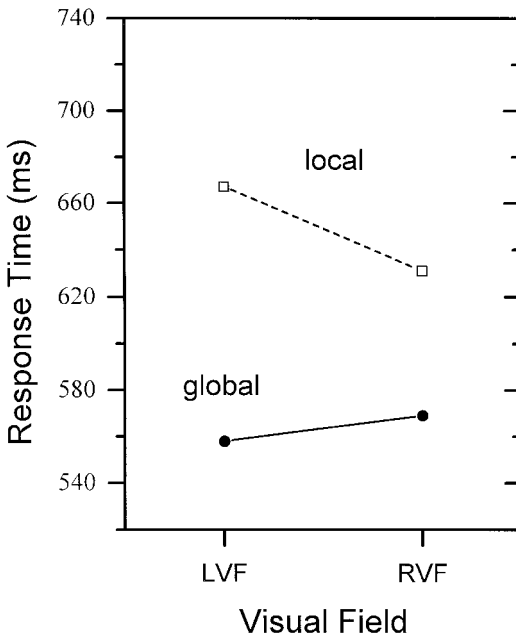


FIG. 2. Mean response times reflecting the two-way interaction between visual field and target level in Experiment 1.



gruent stimuli (577msec versus 606msec),  $F(1, 7) = 22.1, p < .01$ . For “different” judgements there was no reliable difference (615msec versus 626msec).

The data for all conditions are depicted in Figure 3. Although they seem to indicate that the “different” judgements for the local level are rather different from those for the global level with respect to congruency, the level by response by congruency interaction failed to reach significance,  $F(1, 7) = 3.81, p = .092$ .

**Error Rates.** The error rates are given in Figure 3. Errors occurred, on average, in 7.3% of the trials. After an arcsin transformation the error rates were subjected to a four-factor ANOVA analogous to that for the latency data. The target-level factor turned out to be significant,  $F(1, 7) = 14.7, p < .01$ . There were 9.5% errors for the global and 5% errors for the local target level. This indicates some speed-accuracy trade-off. Also the congruency factor turned

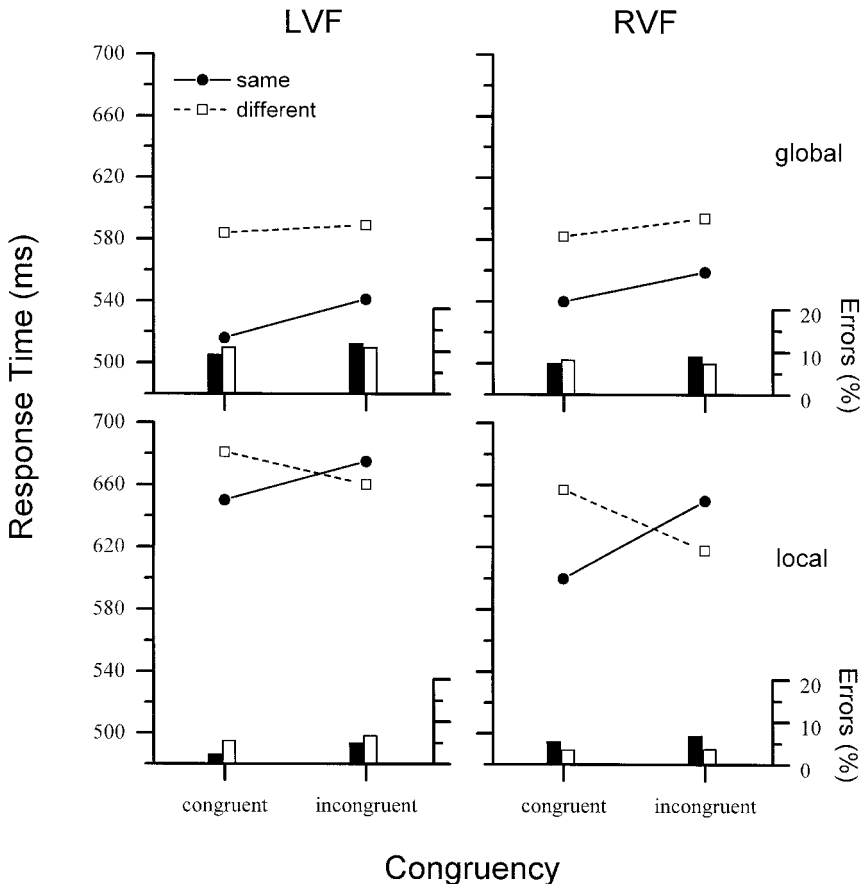


FIG. 3. Mean response times and error rates for the different conditions in Experiment 1.

out to be significant,  $F(1, 7) = 12.5$ ,  $p < .01$ . There were 6.7% errors for congruent and 7.9% for incongruent stimuli.

## Discussion

Judgements were faster for targets at the global level than for targets at the local level, and responses to congruent stimuli were faster than those to incongruent stimuli, yet there was no target-level by congruency interaction. This means that, despite the faster responses to global targets, the global-on-local interference was similar in effect to the local-on-global interference. However, the error rates indicate that the response-time difference between the global and local judgements could be due, at least partly, to a speed-accuracy trade-off.

As expected, "same" judgements were faster than "different" judgements for the global target level, while no difference was observed for the local level. The faster "same" judgements are in line with results of other shape-task studies.

Contrary to our hypothesis, there was neither a visual-field effect with respect to "same" nor with respect to "different" responses. Also, there occurred no congruency-effect difference between the visual-field conditions. This result is different from that in the Alivisatos and Wilding (1982) study, where for the global target level responses in congruent conditions were faster for RVF-stimuli relative to LVF-stimuli. In the present experiment, however, not only more trials were used than by Alivisatos and Wilding (1982), but also comparison stimuli with different letters at both levels were included. So, their result might be valid only for a specific condition, if at all.

As predicted, the hemispheres differed with respect to global/local processing. The global target level was processed more effectively for LVF-stimuli, while responses to local targets were faster for RVF-stimuli. This shows that under appropriate conditions the expected visual-field effects with respect to global/local processing occur also with a matching task. However, although the effects were significant, they were rather small, and one has to take a speed-accuracy trade-off into account.

The question arises, whether the employed method was optimal for producing large effects. It is important to note that in the present experiment congruency depended on whether the "same-different" relation between the letters at the nontarget level was identical to that at the target level or not. This definition did not take the relations between the *letters* at the different target levels into account, which, however, might have played an important role, as global/local studies with an identification paradigm have shown. There, congruency was usually defined in terms of the relation between target and nontarget letters. Analogously to these studies, one could consider such relations also in a matching paradigm. To get a first impression of how the letter relations affect performance, the data of Experiment 1 were reanalysed. Only "same" trials

were included in the reanalysis, because there were too few appropriate “different” trials. Since there was still a different number of trials available for each of the considered conditions, no statistical tests were conducted, and merely descriptive results are provided.

First, the local target level will be considered. For this level, two different trial types within the congruent condition can be distinguished. Remember that congruency for “same” trials means that the letters of the comparison and the test stimulus match at the target level as well as at the nontarget level. Let us first separate the trials where the letter at the target level was identical to that of the nontarget level (e.g. Hh-Hh). In this case we have a mean response time of 557msec. Now, if we consider the trials within the congruent condition where the letters between the levels were different (e.g. Eh-Eh), then the response times increased to 621msec. The analogous trials for the global target level led to mean response times of 499msec and 534msec, respectively.

In a similar manner one can define trial types within the incongruent conditions. Again, we will consider the local level first. If the target letter was also present at the global (nontarget) level (e.g. Eh-Hh), one finds a mean response time of 570msec. On the other hand, if the target letter was absent at the nontarget level (e.g. Ah-Eh) the mean response time increased to 624msec. The data for the global level point in the same direction although the difference is smaller (513msec versus 544msec).

We can also investigate whether the relations between the nontarget letter of the comparison stimulus and the letters of the test stimulus affected performance. For instance, if we analyse the incongruent trials, in which a response to the local target level was required, and where the letter at the nontarget level of the comparison was identical to the target letter (e.g. Hh-Eh), we obtain a mean response time of 645msec. On the other hand, if the letter was different (e.g. Ah-Eh) we find a latency of 624msec). The analogous mean response times for the global target level are 546msec and 544msec.

As this reanalysis reveals, while the identity of the letter at the nontarget level of the comparison stimulus had only a small effect, a large amount of variance is accountable to the relation between the target letter and the letter at the nontarget level of the test stimulus. Thus, what seems to be important is the relation between the letter at the target level of the comparison stimulus and the letters of the test stimulus. To distinguish this from the congruency relation, it will be called the *consistency* relation. “Same” trials are consistent if the target letter is also present at the nontarget level of the test stimulus. “Different” trials are consistent if the target letter is not present at the nontarget level of the test stimulus.

If interference between the levels is necessary for producing laterality effects, then the consistency relation should be more effective for attaining this objective than the congruency relation. That interference seems indeed to be essential for visual-field effects has been shown by Hübner (1997). In one of

his experiments the target level changed randomly from trial to trial. It turned out that the interference and the laterality effects were increased relative to an experiment, where the target level remained constant across trials. The result was interpreted in the way that the frequent attention switching between the levels prevented the subjects from focusing their attention optimally. This increased the interference between the global/local processes, and, in turn, enhanced the visual-field effects.

To investigate the hypothesis that interference is important for substantial visual-field effects, a second experiment was conducted, where consistency instead of congruency was varied systematically. Since the nontarget letter of the comparison stimulus had only a small effect with respect to the present aim, a single letter in the size of the local letters served as comparison stimulus in Experiment 2.

The specific hypotheses were similar to those of Experiment 1. Here, however, the consistency relation instead of the congruency relation was expected to produce reliable effects. Also, a reliable interaction between target level and consistency was expected. Since consistency was assumed to produce larger effects than congruency, appreciable visual-field effects with respect to global/local processing were expected in Experiment 2. The hypotheses concerning the “same–different” judgements were analogous to those of Experiment 1.

## EXPERIMENT 2

### Method

*Subjects.* Eight subjects (four male and four female), who ranged in age between 22 and 28 years, participated in the experiment. All were right-handed (by self-report) and had normal or corrected-to-normal vision.

*Apparatus.* The apparatus was identical to that in Experiment 1.

*Stimuli.* The same four letters as in Experiment 1 were employed. Here, however, the comparison stimuli were always a single letter in the size of one of the local letters. Thus there were only four comparison stimuli. Since again there are 16 different test stimuli, we have 64 ( $4 \times 16$ ) different combinations. The letter sizes were identical to those in Experiment 1.

The procedure for choosing the stimuli will be explained for the global response level: There are 12 different inconsistent “same” trials (e.g. e-Es, where “e” stands for the small comparison stimulus “E”, and “Es” for the compound test stimulus with “E” at the global, and “S” at the local level). Since only four different consistent “same” trials (e-Ee, s-Ss, a-Aa, h-Hh) are possible, they were repeated three times to also get 12 trials. Again, there are 12

different inconsistent “different” trials (e.g. e-Se). However, six different consistent “different” trials (e.g. e-Sa) are possible for *each* comparison stimulus. Thus, three trials were randomly selected from each set to obtain twelve trials ( $3 \times 4$ ). Together, 48 trials were defined with this procedure.

An analogous procedure was applied for the local target level.

*Procedure.* The comparison stimuli were presented at the centre of the screen, and consisted of a single local letter. The experimental factors were: Target level (global, local), consistency (consistent, inconsistent), visual field (LVF, RVF), and response (same, different). Each block consisted of 96 experimental trials (two times the 48 trials defined above) plus 5 warm-up trials. For the local as well as for the global target level six blocks were run. Altogether there were 2304 trials per person, i.e. 144 trials for each condition and each person.

The other details of the procedure were the same as in Experiment 1.

## Results

*Latencies.* The means were trimmed as in Experiment 1 and then subjected to a four factor ANOVA with repeated measures on all factors. The factors were target level (local, global), visual field (RVF, LVF), response (same, different), and consistency (consistent, inconsistent).

There was a significant visual-field effect,  $F(1, 7) = 8.71, p < .05$ . Responses to RVF-stimuli were faster (607msec) than those to the LVF stimuli (620msec). Also the response factor was significant,  $F(1, 7) = 26.4, p < .01$ . “Same” responses were considerably faster (584msec) than “different” responses (644msec). Finally, consistency produced reliable effects,  $F(1, 7) = 68.5, p < .001$ . Responses to consistent stimuli were faster (597msec) than those to inconsistent stimuli (630msec).

Surprisingly, the target-level effect was not significant. However, there was a significant target-level by visual-field interaction,  $F(1, 7) = 48.3, p < .001$ . While responses to the global level were faster for LVF-stimuli (593msec) than for RVF-stimuli (606msec),  $F(1, 7) = 15.9, p < .01$ , the opposite holds for responses to the local level (648msec versus 609msec),  $F(1, 7) = 26.6, p < .01$ .

There was also a significant interaction between response and target-level,  $F(1, 7) = 8.19, p < .05$ . The latency difference between “same” and “different” responses was larger for the global (77msec) than for the local target level (55msec), although the latter difference was still significant,  $F(1, 7) = 20.0, p < .01$ .

The response factor also interacted with consistency,  $F(1, 7) = 41.2, p < .001$ . For “same” trials consistency produced faster responses (552msec) than inconsistency (615msec),  $F(1, 7) = 41.2, p < .001$ , while there was no reliable difference for the “different” trials (642msec versus 646msec).

Of the three-way interactions the one between target level, visual field, and consistency turned out to be significant,  $F(1, 7) = 15.0, p < .01$ . The corresponding data are shown in Figure 4. This interaction was decomposed by analysing the data separately for both visual field conditions. For the RVF condition only consistency was significant,  $F(1, 7) = 71.8, p < .001$ . On the other hand, for the LVF condition consistency again had a reliable effect,  $F(1, 7) = 41.5, p < .001$ , as well as the response-level factor,  $F(1, 7) = 10.9, p < .05$ . Moreover, the interaction between response level and consistency was significant,  $F(1, 7) = 11.3, p < .05$ . The consistency effect was larger for the local level.

Finally, the four-way interaction between all factors was significant,  $F(1, 7) = 7.50, p < .05$ . The mean response times for the different conditions are shown in Figure 5. As can be seen, the data for the global LVF conditions are rather similar to those of the local RVF conditions, whereas the data of the global RVF conditions resemble those of the local RVF conditions. This seems to be at least the case for the "same" responses. To decompose the four-way interaction, the data for "different" and "same" trials were analysed separately.

For the "different" conditions no main effect was significant. However, there was a reliable target level by visual field interaction,  $F(1, 7) = 25.9, p < .01$ . Responses to the global level were faster for LVF-stimuli (626msec) than for RVF-stimuli (639msec), while those to the local level were faster for the RVF-stimuli (640msec) than for LVF-stimuli (671msec). Also the target level by consistency interaction was significant,  $F(1, 7) = 6.01, p < .05$ . For the global level consistent stimuli led to increased response times (636msec) relative to inconsistent stimuli (629msec), whereas for the local level consis-

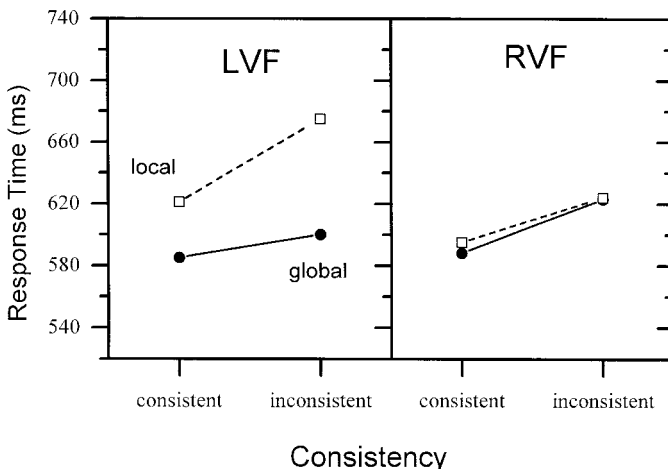


FIG. 4. Mean response times reflecting the three-way interaction between visual field, target level, and consistency in Experiment 2.

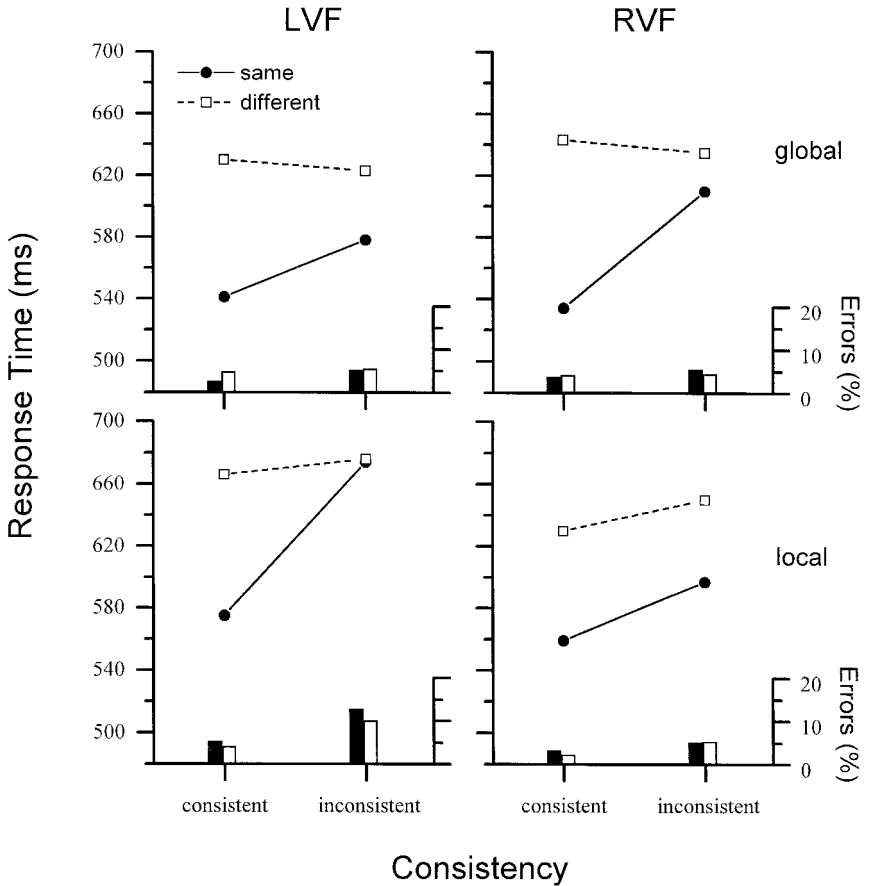


FIG. 5. Mean response times and error rates for the different conditions in Experiment 2.

tency reduced the response times (648msec versus 663msec). However, only the latter difference was significant,  $F(1, 7) = 6.92, p < .05$ .

For “same” responses the pattern of results is more complicated. First, the consistency factor was significant,  $F(1, 7) = 76.4, p < .001$ . Further, there was a target level by visual field interaction,  $F(1, 7) = 38.1, p < .001$ , which is similar to that for the “different” trials (global: RVF: 572msec, LVF: 559msec; local: RVF: 578msec, LVF: 625msec). Finally, the three-way interaction between target level, visual field, and consistency was significant,  $F(1, 7) = 33.6, p < .001$ . For a deeper analysis, the data for both target levels will be considered separately.

The responses to the global level show a significant consistency effect,  $F(1, 7) = 47.7, p < .001$ , and a significant consistency by visual-field interaction,  $F(1, 7) = 8.44, p < .05$ . There was a larger consistency effect for the RVF

condition (consistent: 534msec, inconsistent: 610msec) than for the LVF condition (consistent: 541msec; inconsistent: 578msec).

On the other hand, responses to the local target level were different for both visual fields,  $F(1, 7) = 19.1, p < .01$ . Those to RVF-stimuli were faster (578msec) than those to LVF-stimuli (625msec). Also the consistency effect was reliable,  $F(1, 7) = 35.1, p < .001$ , as was the visual field by consistency interaction,  $F(1, 7) = 71.5, p < .001$ . Different from the data for the global response level, a larger consistency effect occurred for the LVF condition (consistent: 575msec, inconsistent: 674msec) than for the RVF condition (consistent: 559msec, inconsistent: 597msec).

*Error Rates.* There were 5.3% errors on average. In Figure 5 the error rates for the individual conditions are shown. The arcsin transformed error rates were subjected to a four-factor ANOVA analogous to the latency data.

The target-level factor was significant,  $F(1, 7) = 7.00, p < .05$ . There were fewer errors for the global (4.5%) than for the local target level (6.1%). Also the effect of visual field was significant,  $F(1, 7) = 18.5, p < .01$ . Fewer errors were made for RVF-stimuli (4.3%) than for LVF-stimuli (6.4%). Finally, the consistency factor was significant,  $F(1, 7) = 25.2, p < .01$ . Consistent trials produced viewer errors (3.8%) than inconsistent trials (6.8%).

Of the two-way interactions the one between target level and visual field was significant,  $F(1, 7) = 14.5, p < .01$ . While for the global target level there was no difference between the visual fields (RVF: 4.5%; LVF: 4.6%), there was one for the local target level (RVF: 4.1%; LVF: 8.2%). Also, the two-way interaction between target level and consistency was significant,  $F(1, 7) = 8.44, p < .05$ . Consistency affected responses to the global target level to a smaller extent (consistent: 3.9%; inconsistent: 5.2%) than those to the local target level (consistent: 3.8%; inconsistent: 8.4%).

Further the three-way interaction between target level, visual field, and response was significant,  $F(1, 7) = 11.9, p < .05$ . To decompose this interaction, the data were analysed separately for “same” and “different” responses. For same responses there was a significant two-way interaction between target level and visual field,  $F(1, 7) = 17.9, p < .01$ . More errors were made at the global response level for stimuli presented in the RVF (4.68%) than for those presented in the LVF (3.19%), but the opposite held at the local response level (4.25% versus 9.11%). For “different” responses there was a significant visual-field main effect,  $F(1, 7) = 20.01, p < .01$ . Fewer errors were made for RVF stimuli (4.12%) than for LVF stimuli (6.21%). Moreover, there was also a significant target level by visual-field interaction,  $F(1, 7) = 7.47, p < .05$ . Although the error differences between the visual field conditions point in the same direction for both target levels, those for the local target level (LVF: 7.21%; RVF: 3.91%) were larger than those for the global target level (LVF: 5.21%; RVF: 4.34%).



Finally, the three-way interaction between target level, response, and consistency was significant,  $F(1, 7) = 6.94, p < .05$ . This interaction was also decomposed by analysing “same” and “different” responses separately. For “same” responses the consistency factor was significant,  $F(1, 7) = 16.2, p < .01$ . Fewer errors were made on consistent trials (3.7%) than on inconsistent trials (7.23%). Consistency had also a significant effect on “different” responses (3.9% versus 6.4%),  $F(1, 7) = 18.8, p < .01$ . Additionally, there was a significant target level by consistency interaction,  $F(1, 7) = 19.7, p < .01$ . For the global target level the difference between errors on consistent and inconsistent trials was smaller (4.51% versus 5.03%) than those for the local target level (3.29% versus 7.81%).

Altogether, the error data are compatible with the latency data, so that speed–accuracy trade-off effects can be excluded.

## Discussion

Unexpectedly, there was no main effect of target level. However, a significant visual-field by target-level interaction occurred. Information at the global level was processed faster for LVF-stimuli than for RVF-stimuli, whereas information at the local target level was processed faster for RVF-stimuli than for LVF-stimuli. The visual-field effect for global targets, averaged across the other conditions, was again rather small. Fortunately, in this experiment there was no indication of a speed–accuracy trade-off. On the other hand, the visual-field effect for local targets was appreciable. Figure 4 depicts the data averaged across response type. As can be seen, for LVF-stimuli there was a substantial target-level effect. The data indicate that the RH has difficulties with the processing of local information.

Visual-field effects were also observed with respect to “same–different” judgements. However, they occurred merely in connection with the four-way interaction and, therefore, are more difficult to interpret. Generally, “same” responses were faster than “different” responses. Further, while consistency had only small effects on “different” judgements, it severely affected “same” responses. The consistency effects also varied with visual field and target level. While the effect was larger for responses to the global level of RVF-stimuli than for those to the global level of LVF-stimuli, the opposite held for responses to the local level (see Figure 5). An explanation of this interesting pattern is provided in the next section.

## GENERAL DISCUSSION

Both experiments reported here demonstrate that the matching paradigm can be useful for investigating hemispheric differences with respect to global/local processing. The hypothesis that global information is processed more effec-

tively in the RH than in the LH, while the opposite holds for local information, is supported by the results of both experiments. On the other hand, no evidence was found for the hypothesis that the hemispheres differ with respect to “same–different” judgements. Although some effects for “same” responses were observed in Experiment 2, they are the consequence of the hemispheric preferences for processing global or local information, as will be shown later.

The results of the two experiments demonstrate further that interference between the target levels might be essential for the occurrence of visual-field effects (see also Hübner, 1997). If one considers merely the target-level by visual-field interaction, then the effect sizes are rather similar in both experiments. However, there are larger laterality effects for individual conditions in the second experiment. For instance, the largest visual-field difference between corresponding conditions was 49msec in Experiment 1, but 77msec in Experiment 2. As hypothesized, this difference corresponds to the difference between the consistency and congruency effects, respectively. The largest consistency effect (99msec) in Experiment 2 was about twice as large as the largest congruency effect (50msec) in Experiment 1.

This shows that it is important to know which stimulus relations are optimal for defining compatibility. In Experiment 1, where the comparison as well as the test stimuli were compound letters, response compatibility was defined by means of a *congruency* relation. A stimulus pair was considered as congruent, if the letters either matched or mismatched at both target levels. If the letters matched at one level but mismatched at the other level, the respective stimulus pair was regarded as incongruent. Presumably, Alivisatos and Wilding (1982) defined their congruency relation in the same way as the congruency relation in the present paper. They state that in their incongruent condition “the global level was different from the local level”. However, in their example of incongruent stimuli for “different” responses, the local level of the test stimulus happens to be identical to that of the global letter of the comparison stimulus. Thus, one is left to speculate that they also employed combinations where these letters were not identical.

The congruency relation does not take into account whether or not the letters matched *between* the levels of a single stimulus. However, as a reanalysis of the data revealed, the matching relation between the target letter of the comparison stimulus and the letter at the nontarget level of the test stimulus produced a large effect, which was not captured by the congruency relation. On the other hand, the relation between the nontarget letter of the comparison stimulus and the letters of the test stimulus was negligible.

To investigate whether an appropriately defined compatibility relation leads to appreciable visual-field effects, a second experiment was conducted, where only a single letter served as comparison stimulus, and a *consistency* relation was introduced. A stimulus pair was defined to be consistent, if the comparison letter matched or mismatched the letters at *both* levels of the test stimulus. In

inconsistent “same” or “different” trials, the target letter mismatched or matched the letter at the nontarget level of the test stimulus, respectively.

Since the congruency relation was not realized optimally in the first experiment, the results are difficult to interpret. A better method would have been to use different letters for each target level. In this case, consistency effects, in the sense of the relation defined for Experiment 2, would not have been intermixed with pure congruency effects. Because of the interpretation difficulties, at least with respect to the congruency issue, only the results of the second experiment will be discussed in detail.

How can the pattern of results in Experiment 2 be explained? It is surprising that inconsistency had so small effects on the “different” responses. A fast identity reporter (Bamber, 1969) which also processes the letter at the nontarget level, would falsely signal “same” on inconsistent “different” trials, since on these trials the target letter always occurs at the nontarget level (e.g. for the local target level: h-Ha). Because the identity is signalled quite fast, it should produce large interference effects with the “different” response. On the other hand, a mismatch at the nontarget level on “same” trials (e.g. for the global target level: h-Ha) should hardly interfere with the fast and, this time, correct signal of the identity reporter. Consequently, one would expect more interference on “different” than on “same” trials.

The *response competition model* proposed by Eriksen and his colleagues (Eriksen, O’Hara, & Eriksen, 1982; St James & Eriksen, 1991) also has difficulties in explaining the present data. They assume that coarse features, which many letters share, are encoded first. To detect a difference, the encoding process must proceed until a discriminating detail is found. Consequently, even different letters prime “same” responses in the beginning of the encoding process, so that “different” responses always have competition, and, therefore, are slower. On the other hand, “same” stimulus pairs do not prime “different” responses, so that there is no response competition, and, consequently, they are executed faster. For the present Experiment 2, if one assumes that the coarse features of the letter at the nontarget level also prime the “same” response, the response competition model would predict a larger interference for “different” than for the “same” responses, which was not the case.

Fortunately, there is a model of performance in “same–different” tasks that can explain the present data: the *noisy-operator theory* proposed by Krueger (1978). Krueger assumes that encoding processes are inherently noisy, and that “same–different” judgements are based on the output of a difference counter operating on the resulting noisy representations. The noise has the effect that it sometimes produces positive difference counts even on “same” trials. Consequently, a positive count does not always indicate “different”. Only very low and very high counts lead to immediate “same” and “different” responses, respectively. If the count is intermediate, then it does not provide sufficient evidence to trigger an immediate response. Rather, it invokes further processing

or *rechecking*. The important point is that noise is more likely to increase than decrease the difference count, so that rechecking occurs more often on “different” trials than on “same” trials. This asymmetry nicely explains why “same” responses are faster than “different” responses.

The noisy-operator theory can easily account for the results of Experiment 2. One simply has to assume that to some extent a comparison also takes place at the nontarget level, and that the output of this process contributes to the difference count. Let us first consider “same” trials. Inconsistent stimuli produce a mismatch of the target letter with the letter at the nontarget level. This increases the difference count, and, consequently, also the probability of an additional rechecking cycle, which would slow the response. The extent of the additional count depends on the level, and on the hemisphere to which the test stimulus is presented. If it is presented to the RH, and a response to the local level is required, then the encoding of the global letter is relatively fast and effective, and the mismatch at that level contributes considerably to the difference count. On the other hand, if this stimulus is presented to the LH, then the encoding of the global letter would be slower and less effective, so that the mismatch would contribute only little to the difference count. “Different” responses are less affected by inconsistency, because matches at the nontarget level cannot decrease the difference counter. Thus, the noisy-operator theory has no difficulties at explaining the present results.

To sum up, the present results demonstrate that the matching task is useful for investigating hemispheric differences with respect to global/local processing. The observed visual-field effects indicate that the LH is specialized for processing local information, whereas the RH is better at processing global information. The size of these effects seems to depend on the amount of interference between the target levels. On the other hand, no evidence was found for the hypothesis that the hemispheres differ with respect to “same-different” judgements.

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