

Do the Hemispheres Watch Each Other? Evidence for a Between-Hemispheres Performance Monitoring

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This study tested the hypothesis that when tasks are complex, response selection and performance monitoring are divided across the hemispheres, and when tasks are simple, response selection and error monitoring are done in the same hemisphere. Using a divided visual field paradigm, the authors presented a target and an interference stimulus, either to the same visual field or to different visual fields, and encouraged error correction. The interference stimulus was timed to interfere with posited error processing. Four tasks were used: bar graph identification, lexical decision, and complex and simple versions of the flankers task. The first three tasks revealed a pattern of contralateral interference, suggesting that error processing occurred in the hemisphere that did not process the initial target. The fourth task showed ipsilateral interference, suggesting that the same hemisphere processed the target and monitored itself. The authors conclude that the pattern of hemispheric cooperation in error processing is affected by task complexity.

Keywords: hemispheric integration, error processing, task complexity

A large amount of research in the last 50 years has shown performance asymmetries in lateralized tasks. Converging data from functional imaging studies in the last 15 years have shown cortical asymmetries in activation patterns when stimuli are presented centrally, supporting models of hemispheric specialization for the tasks being performed. However, relatively little is known about how the two hemispheres of the brain differ in their ability to detect and respond to errors in these same tasks. If participants are urged to correct erroneous responses, the latency of these corrections can give a global index of error processing.

Using correction response times (RTs), we have demonstrated a phenomenon we termed the *reverse laterality effect for corrections* (Hochman & Eviatar, 2004). In that study, we examined hemispheric division of labor in initial processing and error processing in tasks for which hemispheric specialization exists. We used lexical decision as a left hemisphere task and bar graph judgment as a right hemisphere task. Participants had to respond to one of two stimuli presented to both visual fields (VFs) and were instructed to correct their errors. The results showed the classic asymmetry for initial responses in both tasks: a right VF (RVF) advantage for the lexical decision task, and a left VF (LVF) advantage for the bar graphs task. However, for corrections, the results reversed. In both tasks, corrections of erroneous responses to a stimulus presented to the VF of the inferior hemisphere were faster and more accurate than corrections of erroneous responses to a stimulus presented to the VF of the superior hemisphere. We interpreted our findings as support for Zaidel's (1987) suggestion of a division of labor between the hemispheres in error processing. More specifically, we concluded that when a stimulus is presented to the inferior hemisphere, the superior one does the error processing, and vice versa. Thus an advantage of presentation to the VF of the inferior hemisphere is always expected for corrections.

However, an alternative account of our results may be that the superiority of the inferior hemisphere for corrections is a result of stronger activation of its own monitor, as it is more prone than the superior hemisphere to produce erroneous responses. According to this explanation, our results are still congruent with the situation in which both initial processing and subsequent error processing are done in the same hemisphere. In the experiments reported below, we used a lateralized dual task paradigm to examine the lateralization patterns of error processing unequivocally.

The question of whether error monitoring in complex tasks is more demanding than error monitoring in simple tasks has never been examined directly. However, Scheffers, Humphrey, Stanny, Kramer, and Coles (1999) showed that the more resource demanding the task at hand is, the more resource demanding is the error monitoring in that task. Studies exploring interhemispheric interactions have shown that performance improves when operations are divided across the hemispheres (Hellige, Jonsson, & Michimata, 1988; Liederman, 1986a; Luh & Levy, 1995). Thus, even though one hemisphere may do a particular task less capably or efficiently than the other, it nonetheless has the capacity to contribute (Beeman & Chiarello, 1998; Chabris & Kosslyn, 1998). Banich and her colleagues (Banich & Belger, 1990; Banich & Karol, 1992; Weissman & Banich, 2000) have suggested that the degree to which interhemispheric cooperation underlies performance changes with the complexity of the task being performed. Hence, it is plausible to assume that in certain tasks, both performance and performance monitoring (specifically, error processing) improve as a result of between-hemispheres cooperation.

Hochman and Meiran (2005) showed that error processing is capacity limited. That is, it is prone to interference by the requirement to perform another task simultaneously. The paradigm used in that study allowed them to interfere with error processing. In the present study we modified their dual task paradigm to interfere with the error correction process in the context of hemispheric interaction. Two visual stimuli were presented in rapid succession. The participants were requested to respond to both stimuli as quickly as possible. Henceforth, the first presented stimuli will be called the *target*, and the second presented stimuli will be called the *interference stimulus*. Participants were told that while performing the dual task, if after

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responding to the target they happened to think that they erred, they should replace the executed response to the target as quickly as possible, but still respond to the interference stimulus.

Both the target stimuli and the interfering stimuli were lateralized, appearing in one VF at a time. Target stimuli and interfering stimuli were introduced either to the same VF (ipsilateral condition) or to opposite VFs (contralateral condition). If errors are processed in the same hemisphere that received the stimulus, then an interference stimulus presented to the same VF as the target would result in longer correction responses than an interference stimulus presented to the other VF (i.e., ipsilateral interference). If, however, error processing occurs in the other hemisphere, the one that did not receive the target, then we would see longer correction responses when the interference stimulus is presented to the other VF (i.e., contralateral interference). If each hemisphere contributes to error processing regardless of the side that received the target stimulus, then error processing would be disturbed to the same extent regardless of the side that received the interference stimulus.

The rationale of our paradigm is based upon the assumption that dual-task performance depends heavily on whether the same or different hemispheres are used by the two tasks, with less interference arising in the latter case (e.g., Kinsbourne, 1981). More specifically, we assumed that presenting an interference stimulus to one VF would mostly overload the VF that received that stimulus, so that if error processing is made in one hemisphere, presenting interference to that hemisphere would hinder error correction more than presenting interference to the other hemisphere. This assumption is supported by a large number of studies that examined hemispheric functions in dual tasks paradigms (e.g., Hellige, Cox, & Litvac, 1979; Liederman, 1986b; Scalf, Banich, Narechania, & Liebler, 2001). Although contradictory results were reported by Pashler and O'Brien (1993), the extent to which the stimuli in Pashler and O'Brien's experiments were actually lateralized is rather questionable,¹ and the results from their experiments may not be relevant to hemispheric division of labor in dual tasks.

It is crucial to note that the dual task paradigm here is not used to create competition between the initial task (the response to the target) and the interference task. Rather, the interference task is timed to interfere with error processing, not initial processing. To do this, following Hochman and Meiran (2005), we timed the interfering stimuli to appear almost simultaneously with the production of the initial response to ensure that we did not interfere with the selection of the initial response to the target.² In addition, we used a different modality for the response to the interference task. Thus, we attempted to maximize the probability that we interfered with error processing that occurs after initial response selection but not with initial response selection.

Interpretations of responses in the divided VF paradigm assume that responses to stimuli in one VF reflect processing in the contralateral hemisphere. However, when normal participants respond to a lateralized stimulus, callosal transfer occurs quite early in the process (Coulson, Federmeier, Van Petten, & Kutas, 2005). Thus, although according to the rationale of the divided VF paradigm, the hemisphere that receives the stimulus (the target, the interference, or both) is expected to process it, we must take callosal transfer into account in our explanations. We assumed, as others have done (e.g., Allain, Carbonnell, Burle, Hasbroucq, & Vidal, 2004), that error processing begins slightly before the execution of the initial response. We attempted to interfere with this process specifically by presenting an interfering stimulus

approximately 250 ms before the initial response. The timing of events may have been crucial, and callosal transfer of both the target and the interference stimulus from one hemisphere to the other may hinder our ability to interpret our findings. For example, even if contralateral presentation of the interference stimulus interfered with error processing more than ipsilateral presentation of

¹ Pashler and O'Brien (1993) presented a series of five experiments in which pairs of tasks were examined, and various manipulations were used to promote hemispheric task separation. The first three experiments combined a verbal (presumably left hemisphere) choice task with another task that would be assumed to rely on either the left or the right hemisphere: a compatible spatial choice task with lateralized visual input and manual output. Experiments 4 and 5 examined pairs of tasks with both input and output lateralized to opposite hemispheres. In Experiment 4, both tasks required a compatible response to spatial position (above vs. below the horizontal midline). Experiment 5 included the spatial task as Task 1 (with LVF presentation and left-hand response) and a rhyme judgment as Task 2. Results in all five experiments revealed that dual-task interference was not modulated by these manipulations. Pashler and O'Brien claimed that their results implicate a bottleneck in action selection which is in some ways anatomically as well as functionally central. That is, there is no indication that the standard hemispheric manipulation of stimulus, response, and form of coding can moderate this bottleneck by permitting resources or mechanisms in different hemispheres to function independently. However, the extent to which the stimuli in Pashler and O'Brien's experiments were actually lateralized is rather questionable. In Experiments 1, 2, 3, and 5, one of the stimuli was always presented to both VFs, and hence, it was not possible to produce input lateralized to one hemisphere exclusively. As to the output, as far as we know, although it has been shown by many studies that the production of a vocal response is heavily lateralized to the left hemisphere, there is no direct empirical evidence for the laterality of vocal response selection. In Experiment 4, the first stimulus was always presented to the LVF and the second stimulus was always presented to the RVF. Hence, participants could anticipate the direction of the stimulus and direct both of their eyes toward the stimulus, preventing lateralization of the stimulus. Moreover, within each trial, between presentation of the first stimulus to the presentation of the second stimulus, participants' visual attention was not redirected toward the center, preventing control over the visual hemifield that received the stimulus. Thus, the results from this series of experiments may not be relevant to hemispheric division of labor in dual tasks.

² To hinder the error process, Hochman and Meiran (2005) had to assume a time frame for the occurrence of that process. They did so on the basis of findings from the evoked potential literature, showing that an error process is activated shortly before the overt response (e.g., Allain, Carbonnell, Burle, Hasbroucq, & Vidal, 2004), and is vulnerable to interference up to 150 ms after the overt response (Rabbitt, 2002). Hochman and Meiran set the interference timing in their study to appear within this time frame. However, because it is not possible to foresee how long it will take to respond in any given trial, the computer program predicted the initial RT on the basis of performance in the preceding block of trials; the timing of the interference was programmed so that it would appear at three predicted time frames: before, during, and after the initial response. In the statistical analysis, interfering stimuli actually appearing between 200 ms before the initial response and 50 ms before the initial response were sorted into the before category. Interfering stimuli actually appearing between 50 ms before the initial response and 100 ms after it were sorted into the during category, and interfering stimuli actually appearing between 100 ms after the initial response and 250 ms after it were sorted into the after category. Results revealed that only an interference presented before the overt response was found to interfere with error correction. On the basis of Hochman and Meiran's findings we timed the lateralized interference stimulus in the present study so it would engage a participant's given hemifield about 150 ms before the overt response, as presented in the Method section.

the interference stimulus as we expect, one could still argue that it is not the error processing of the contralateral side that coincided with the contralateral interference stimulus. Rather, the error processing could still have been done ipsilaterally (in the same hemisphere that saw the target), but when the interference stimulus was presented to the ipsilateral side, it appeared too early to coincide with the error processing, and hence, error correction was not affected. However, when the interference stimulus appeared in the contralateral side immediately after it was processed, it was callosally transferred to the ipsilateral side, just in time to coincide and interfere with the error process.

The design of the study allows us to test for this scenario, as it allows us to use the logic of dual task models. Usually in dual task paradigms when participants are asked to make responses to both stimuli as quickly as possible, both responses are hindered (Pashler, 1990, Exp. 3; Pashler, 1991, Exp. 3). In the present study, we asked the participants to both correct themselves and respond to the interference as quickly as possible. Therefore, if processing of the interference stimulus is competing with the error process in the same hemisphere to which the interference stimulus was presented, the response to the interference stimulus should also suffer from dual task constraints. Thus, RT asymmetry patterns to the interference stimuli should pattern with the RT patterns of corrected responses.

Four experimental tasks are presented. In the first experiment, we used a task for which there is right hemisphere superiority (bar graph judgment). In the second experiment, we used a task for which there is left hemisphere superiority (lexical decision). In the third experiment, we used a task for which there is no hemispheric superiority based on the original flankers task (Eriksen & Eriksen, 1974) that is often used in the error detection literature, with several modifications (Kaplan & Zaidel, 2002). In the fourth experiment, we used a simpler version of the flankers task.

We examined two major hypotheses. The first hypothesis has to do with the lateralization of error processing: Does it occur in the same hemisphere as did the initial processing, or in the other hemisphere? The second hypothesis has to do with the interaction of this phenomenon with the complexity of the task.³ We used a dual task paradigm timed in such a way so that the secondary task interfered with error processing, not initial processing of the main task. We reasoned that comparison of RTs of corrected responses (CRTs) with RTs of interference stimuli (IRTs) in the two VFs would indicate where error processing occurred. Therefore, we used these two dependent variables in a series of analyses of variance (ANOVAs) that used VF of the target (VFT) as an indication of the hemisphere that did the initial processing and VF of the interference stimulus (VFI) as an indication of the hemisphere that processed the interference stimuli. The predictions are straightforward:

1. If error processing occurs in the same hemisphere as did the initial target processing (i.e., ipsilateral error processing), then both CRT and IRT should be longer when the interference stimulus is presented to the same VF as the target. We call this outcome *ipsilateral interference*.
2. If error processing occurs in the opposite hemisphere from the one that did the initial target processing (i.e., contralateral error processing), then both CRT and IRT should be longer when the interference stimulus is presented to the opposite VF from the target. We call this outcome *contralateral interference*.

Method

Participants

The participants were 10 native Hebrew speakers (3 men, 7 women). All participated in all four experiments. All were students at the University of Haifa, were right handed, had no left-handed family members, and had no history of neurological illness.

Design

All four experiments had the same design: a main task followed by the same interference task. First we describe the main task for each experiment separately. Then we describe the general procedure (for order of events in each trial, see Figure 1) and the interference task.

Materials and Procedure

Bar graphs task. The stimuli were six bar graphs representing whole numbers from 1 to 6 (Boles, 1994). The bar graphs appeared as vertical rectangles against horizontal reference lines at the 0, 4, and 8 levels. Each bar graph appeared 72 times in each VF, resulting in 432 experimental trials. The bar graphs subtended $2.4^\circ \times 6.7^\circ$ off visual angle, with the inner edge 2° from fixation. The center of the bar graphs was level with the fixation point. Stimuli were presented for 90 ms.

The participants were asked to indicate whether the number represented by the target bar graph was odd or even by pressing one of two keys (ascending or descending arrow) with their index finger.

Lexical decision task. The stimuli were two lists of 216 four-letter Hebrew words and 216 four-letter Hebrew pronounceable orthographically regular nonwords. The lists were mixed and randomized to create 432 trials. Letter strings were presented in black letters on a gray background for 130 ms. Letter strings were presented randomly either to the left of fixation or to the right of fixation, with the more central edge of each stimulus at 1.5° of visual angle from fixation.

The participants were asked to indicate whether the letter string was a word or a nonword. Stimulus-response mapping was switched from block to block so that the key that was used for the word stimuli in the current block served as the nonword key in the following block and vice versa.

Complex flankers task. The task that was used to assess error-monitoring is based on the original flankers task (Eriksen & Eriksen, 1974) that is often used in the error detection literature, with several modifications (Kaplan & Zaidel, 2002). The stimuli were either black or red equilateral

³ Initial RTs of the simple flanker are expected to be much faster than initial RTs of the complex flanker. Hence, one might argue that the error process in each of the tasks occurs in different time frames relative to response onset (for instance, in the simple flanker because of the rapid response latency, the error process might occur after the production of the overt response whereas in the complex flanker, it might occur before the production of the response). In this case any differences in VF of the Target \times VF of the Interference Stimulus interaction between the two tasks may not be related to different pattern of hemispheric division of labor in error processing as we argue. Rather these differences may be related to a hindrance of the error process at different stages in each of the tasks. However, Pailing and Segalowitz (2004) compared a simple version of the flanker task with a complex version of the task, and although RTs of the simple version were indeed much faster than RTs of the complex version, the latencies (measured from response onset) of the evoked response potential component related with the error process (the error-related negativity; see General Discussion for a brief description) were almost the same for the two tasks, revealing independence of the error process from the latency of the error itself.

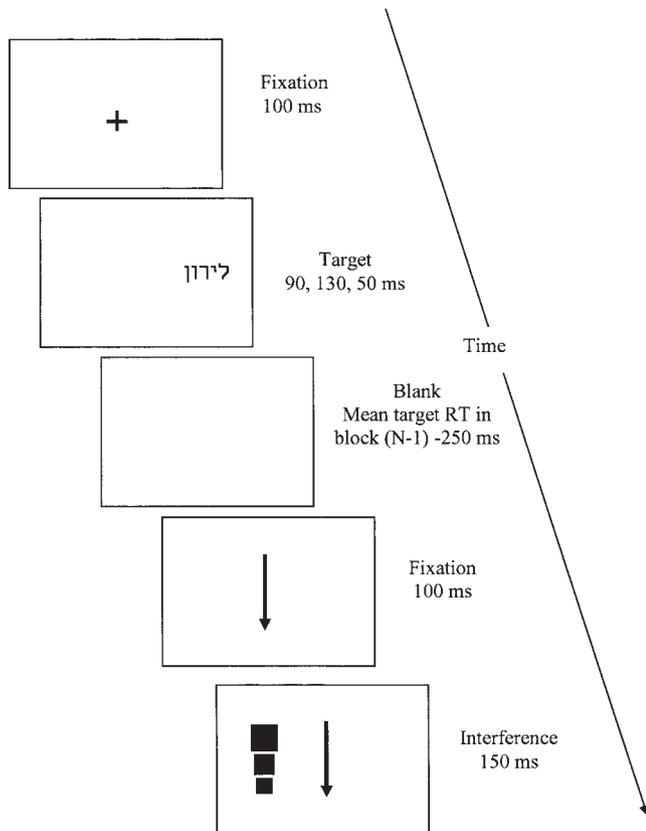


Figure 1. Order of events on each trial for Experiments 1-4. The sequence of events on each trial was as follows: A 1,000-Hz tone sounded for 100 ms to alert the participant that the trial was beginning, a fixation cross was presented alone for 100 ms, and immediately the stimuli were presented for 90, 130, or 50 ms (depending on the task). If no response was given within 700 ms after the target stimuli disappeared in the bar graphs and lexical decision tasks, or 300 ms in the flankers tasks, a short sound was presented, indicating delayed response. A fixation arrow appeared in the middle of the computer screen 250 ms before the anticipated response to the target stimuli (calculated according to the averaged RT in the previous block of trials). After the presentation of the fixation arrow for 100 ms, the interfering rectangles appeared for 100 ms. The fixation arrow remained on screen until the interfering rectangles disappeared. Note that only the main task was changed among the experiments. The stimuli in the figure are not drawn to scale. RT = response time.

triangles, each side measuring 0.75° of visual angle. Two types of triangles were used: "down" triangles had a flat edge on top, with a point at the bottom. "Up" triangles were flipped so that the pointed end faced upwards. Triangles were presented on a gray background, with their inner edge 1.5° of visual angle from the central fixation cross. Each trial began with two distractor triangles appearing either in the LVF or RVF. One triangle was above the midline, and the other was below, both in the same VF. The triangles were positioned so that their edges were 1.5° above or below the horizontal midline. After 100 ms, the target triangle appeared between these two, on the horizontal midline in the same VF as the distractors. All three triangles remained for another 50 ms, and then disappeared. On half the trials, the stimuli appeared in the LVF, and on half they appeared in the RVF. Half of the targets were pointing up, and half were pointing down. The flanking stimuli were either compatible, pointing in the same direction as the target, or incompatible, pointing in the opposite direction. The two

flanking stimuli always pointed in the same direction as each other. Half of the trials were compatible, and half were incompatible. The participants were instructed to respond only to the central triangle. When the triangles were colored black, responses were made by pressing spatially compatible arrow keys on the computer key board (target pointing up—arrow pointing up; target pointing down—arrow pointing down). However, when the triangles were colored red the stimulus-response mapping was switched so that responses were made by pressing spatially incompatible arrow keys. The sequence of events from the appearance of the central triangle was as in Experiment 1 except that in case no response was given 300 ms after the target stimuli disappeared, a short sound was presented, indicating delayed response.

Simple flankers task. Experiment 4 was identical to Experiment 3 except that all three triangles appeared only in black, such that updating of the response procedure was not necessary.

Interference task. An arrow appeared in the center of the computer screen, pointing either up or down. The arrow subtended 0.5° of visual angle. The interfering stimuli were three rectangles subtending 0.7×0.7 , 0.5×0.5 , and 0.3×0.3 degrees of visual angles appearing either in the RVF or in the LVF. The rectangles were presented in a vertical array so that they could be presented within one VF. One rectangle was positioned at the midline with its center leveled with the fixation point. The inner edge of the middle rectangle was positioned 2° of visual angle from the central fixation arrow. The two other rectangles were positioned above and below the midline so that their edges were 1.5° of visual angle above or below the horizontal midline. The rectangles were positioned according to their relative size. In half the trials the biggest rectangle was positioned above the midline, and in the other half it was positioned below the midline. The vertical order of the rectangles was randomly chosen. All stimuli were composed of black lines on a gray background.

Interference Timing

Because it is not possible to foresee how long it will take to respond in any given trial, the computer program predicted the initial RT for each VF separately on the basis of RT performance in the preceding block of trials. Thus, the first block was a training block with no interference, the second block was also without interference, and the mean RT for initial responses of the second block was used in the third block, which included interference. The timing of the interference was programmed so that it would appear 250 ms before the anticipated response.

General Procedure

The participants were seated with their chin in a chin rest that held their eyes 57 cm from the screen. The participants first performed a practice set of 40 trials, during which feedback was given about the correctness of the response (happy or sad face at the fixation). No feedback was given during the experimental trials. The participants were asked to consider the initial response to the target as the main task. The response to the interference and correction responses were to be treated equally. All responses were to be made as quickly and as accurately as possible. The participants were encouraged to spontaneously correct themselves if they thought they had made an error. To achieve enough correctable errors, we administered a bonus system giving full credit for quick correct responses and a quarter of a credit for delayed responses (indicated by a sound) or corrections. A quarter of a credit was also given for correct response to the interference. Figure 1 illustrates the timing and sequence of events on each trial. This sequence was the same in all of the experiments, with only the main task changing among them, as detailed below. The sequence of events on each trial was as follows: A 1,000-Hz tone sounded for 100 ms to alert the participant that the trial was beginning, the fixation cross was presented alone for 100 ms, immediately the stimuli were presented for 90 ms. In

case no response was given within 700 ms after the target stimuli disappeared, a short sound was presented, indicating delayed response. The fixation arrow appeared in the middle of the computer screen 250 ms before the anticipated response to the target stimulus. After 100 ms, the interfering rectangles appeared for 150 ms. The fixation arrow remained on screen until the interfering rectangles disappeared. The participants were requested to decide as quickly as possible whether the interfering rectangles were ordered from the bigger rectangle to the smaller one or from the smaller rectangle to the bigger one. Responses were vocal ("up" or "down") and were spoken to a microphone connected to the computer that stopped a voice-key counter that measured RT. The direction of the fixation arrow indicated to the participants whether they should begin the size estimation from the upper rectangle to the lower rectangle or vice versa. The 1,000-Hz tone sounded for 100 ms 1.5 s after a response to the interference to alert the participant that the next trial was beginning. Correction responses to the main task could be made until the appearance of the alerting tone.

The participants completed 24 blocks of 18 trials each. In half of the blocks, participants had to respond with their right hand and in the other half they had to respond with their left hand in a random order. At the end of each block feedback was given, indicating the number of credits earned for quick, delayed, and correction responses.

Results

This study examined two related issues. The main hypothesis was that error processing of a response to a lateralized stimulus takes place in the hemisphere that did not perform the initial processing. The second issue is a corollary to the main hypothesis: that the complexity of the original task is crucial to this division of labor, so that it does not occur when the task is simple.

The critical test of these hypotheses is a two-way interaction between the VF to which the target was presented (VFT) and to which the interference stimulus was presented (VFI). First, the existence of such an interaction indicates lateralization of the error process in general. Second, the specific shape of the interaction, whether we see ipsilateral or contralateral interference, indicates whether error processing occurs in the same or in the opposite hemisphere.

Table 1 lists the results of the separate two-way ANOVAs done in each of the four tasks. In all of the tasks, the two-way interaction of VFT \times VFI was significant. In all of the tasks, neither factor had a main effect.

These results support the hypothesis that error processing is lateralized. The leftmost and middle columns in Figure 2 illustrate the cell means for both CRT and IRT in all four tasks. It can be seen that there is contralateral interference in the bar graphs, lexical decision, and complex flankers tasks and ipsilateral interference in the simple flankers task for RTs of corrections and for

RTs to interference stimuli in corrected trials. This pattern supports the hypothesis that the interference stimuli interfered with, and were interfered with by, error processing occurring at the side that received the interference stimulus.

Analyses of Initial Responses

We analyzed the initial responses to see whether the interference task affected them. We used the same 2×2 ANOVA as before, using RT of initial correct responses for each of the tasks. The interaction between VFT and VFI was not significant in any of the tasks, nor was there a main effect of VF of the interference. A significant main effect of VF of the target was found only in the lexical decision task, revealing the classic RVF advantage, $F(1, 9) = 6.21, p = .05$. A similar series of analysis on incorrect corrected responses revealed no significant results. Table 2 lists the mean RTs and the mean frequencies of correct and of erroneous corrected responses.

Effect of Error Processing on the Interference Stimuli

An additional indication of the lateralization status of error processing is RT to the interference stimuli in the cases of correct and incorrect corrected responses. We assume that response monitoring occurs on all of the trials. However, on incorrect trials in which an error is detected, error processing proceeds until the correction response is made. On correct responses, this does not occur. Therefore, the prediction is that responses to the interference stimuli will be longer on corrected trials than on trials in which the initial response was correct. Table 3 lists the results of the ANOVA that was performed for each of the tasks and compared the IRT in trials that were corrected and trials that were correct. In the former, the processing of the interference stimulus competed with error processing, whereas in the latter, no error occurred, so that error processing was minimal. Comparison of the figures in the middle and rightmost columns of Figure 2 illustrates this interaction. When no error processing occurred (on correct trials), the processing of the interference stimuli was not affected by the VF of the target.

General Discussion

This study had two goals. The first was to further examine our claim that each hemisphere monitors the ongoing process in the contralateral hemisphere (Hochman & Eviatar, 2004). We had suggested that error processes and corrections of responses to lateralized stimuli originate at the hemisphere that did not see the

Table 1
Statistical Results for the Four Tasks: VFT \times VFI Interaction

Variable	Bar graphs			Lexical decision			Complex flankers			Simple flankers		
	<i>F</i>	<i>p</i>	η^2	<i>F</i>	<i>p</i>	η^2	<i>F</i>	<i>p</i>	η^2	<i>F</i>	<i>p</i>	η^2
CRT	54.30	<.0001	.36	50.34	<.0001	.13	118.27	<.0001	.23	8.46	<.01	.44
IRT	104.7	<.0001	.20	149.65	<.0001	.18	56.52	<.0001	.27	236.66	<.0001	.17

Note. *dfs* = 1, 19. VFT = visual field of the target; VFI = visual field of the interference stimulus; CRT = response time of correction responses; IRT = response time of interference stimuli.

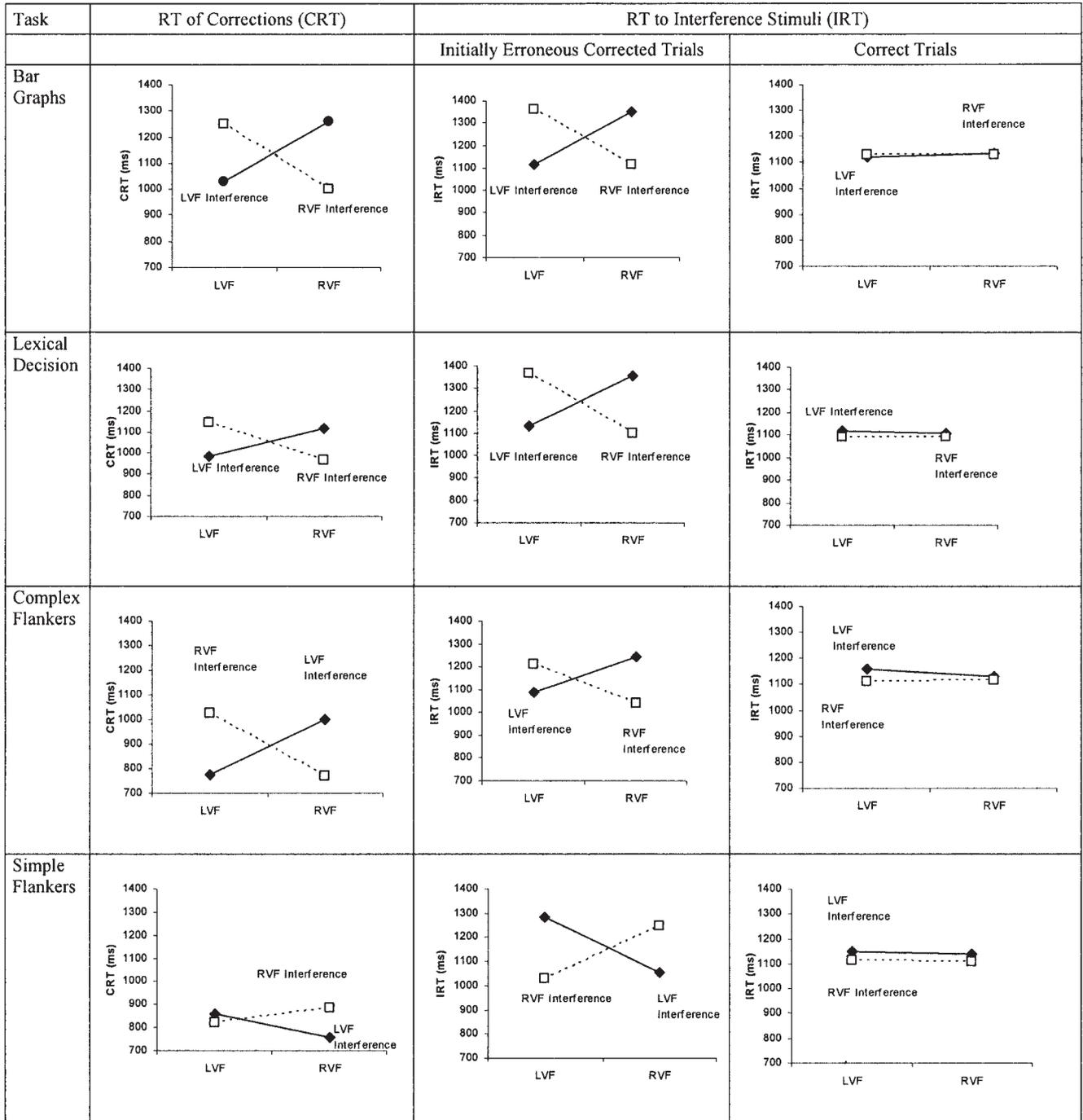


Figure 2. Response times (RTs) of correction responses (left column) and RTs of responses to the interference stimulus when the initial response was a corrected error (middle column) and when the initial response was correct (right column), as a function of visual fields of the interference (VFI) and of the target (VFT).

initial stimulus. This hypothesis predicts that interference presented to the hemisphere that received the target stimuli will disturb error correction less than interference presented to the hemisphere that did not receive the target stimuli. The patterns of results in the bar graphs, lexical decision, and complex flankers

tasks support our hypothesis. As seen in Figure 2, RTs to interference stimuli and corrected responses show the same pattern of lateralized patterns in the corrected responses and in the responses

A crucial element in our argument is that the similarity of lateralized patterns in the corrected responses and in the responses

Table 2
Mean Latencies (in Milliseconds) and Frequencies of Correct Responses and of Erroneous but Corrected Responses, as a Function of Task and Visual Field of Target

Task	Correct responses				Erroneous corrected responses			
	LVF		RVF		LVF		RVF	
	RT	Frequency	RT	Frequency	RT	Frequency	RT	Frequency
Bar graphs	620.6	151.3	589.6	138.7	613.1	38.6	564.8	49.7
Lexical decision	597.8	140.0	555.3	133.5	531.1	41.8	525.4	51.4
Complex flankers	588.8	152.9	568.5	146.3	435.0	37.6	425.7	43.9
Simple flankers	506.5	181.3	499.0	178.6	390.5	33.4	373.7	32.8

Note. LVF = left visual field; RVF = right visual field; RT = response time.

to the distractor task arises from a collision of the monitoring process responsible for error correction and the initial processing of the distractor stimuli. We believe that the specific patterns we found exclude alternative explanations. One possible alternative explanation is that the interfering task may not have disrupted monitoring, per se, but simply have distracted processing away from the hemisphere receiving the initial stimulus (at least in the case of the complex tasks). That is, monitoring may have been carried out entirely in the receiving hemisphere but may have been disrupted by distraction rather than by direct interference.⁴ We have several arguments against this interpretation. First, responses to the distractor were not affected by the VF of the initial stimuli that were responded to correctly (the rightmost column of Figure 2). Thus, it cannot be the case that simply having to transfer attention to the other VF affected performance to the distractor. In addition, as described in the introductory section, the principle of the dual task interference effect is that decrements occur in task performance as a result of collisions in the processes underlying that performance. As reviewed in the introductory section, a number of studies have shown that these decrements lessen when the two tasks are presented to different VFs, and this is interpreted as indicating hemispheric separation of the two processes. Thus, when error monitoring and distractor processing are occurring in the same hemisphere, we should see a decrement in performance for both of them, and if they are occurring in different hemispheres, we should see much less decrement in both of them. In the complex tasks, we found that both the latency of corrections and the latency to the distractor were decelerated in the opposite VF from the one that saw the initial stimulus. We interpret this as reflecting a collision between the processes underlying performance in both tasks—that is, they were occurring in the same hemisphere.

The second goal of the study, following work done by Banich and her colleagues (Banich & Belger, 1990; Banich & Karol, 1992; Weissman & Banich, 2000), was to examine the effects of task complexity on interhemispheric cooperation. It can be seen that the pattern on the simple flankers task is different from the other three tasks. Specifically, here we see ipsilateral interference, suggesting that error processing and corrections originate in the same hemisphere that performed the initial processing. Thus, it is not the case that error processing always occurs in the opposite hemisphere, as suggested by Zaidel (1987); rather, this occurs only when the initial task is above a certain level of complexity.

The design of our experiment is not informative about the types of processes that occurred in the different tasks. It is clear that the bar graphs, lexical decision, and flankers tasks require different cognitive processes to be solved. The similarity between the patterns of corrections and interference is therefore more notable: When a task is above a certain level of complexity, the cognitive architecture of the process is such that error monitoring and production of a corrected response are done in the hemisphere that did not do the initial processing. What seems to matter is the overall load, not the specific details of the cognitive processes involved in solving the task.

Our data dovetail with an important development in lateralization research: the emerging focus on interhemispheric integration during cognitive processing. Additional relevant evidence comes from electrophysiology. A large number of studies have examined a negative-going evoked response potential called the error-related negativity (ERN) that is found immediately following incorrect responses (e.g., Gehring, Goss, Coles, Meyer, and Donchin, 1993). Gehring and Knight (2000) reported that in patients with focal lesions to the lateral prefrontal cortex (PFC), ERN activity and corrective action were both influenced by damage. These authors argued that the usual pattern of ERN activity must depend upon the cooperation of the PFC in both cerebral hemispheres, because unilateral PFC lesions were sufficient to disrupt the pattern.

The task used by Gehring and Knight (2000) was a modified version of the classic flanker task in which participants had to recall a cue to know which letter in a pair of stimuli was the target. Pailing and Segalowitz (2004), commenting on this research, observed the following:

Although the findings for the PFC group suggest that this region contributes to error monitoring, it is important to consider whether the same results would have been observed if they had used a different task, one that does not place the same demands on working memory and attention. (Pailing and Segalowitz, 2004, p. 217)

As the complex flanker task used in the present study was designed to exert working memory and attentional resources just like the modified flanker used by Gehring and Knight, the results of the present study suggest that had they used a simple, less resource-demanding task, the results would have reflected the capability of

⁴ We are indebted to an anonymous reviewer for this point.

Table 3

Statistical Comparisons of Response Times to Interference Stimuli in Initially Erroneous but Corrected Trials, Versus Trials in Which the Initial Response Was Correct

Effect	Bar graphs			Lexical decision			Complex flankers			Simple flankers		
	<i>F</i>	<i>p</i>	η^2	<i>F</i>	<i>p</i>	η^2	<i>F</i>	<i>p</i>	η^2	<i>F</i>	<i>p</i>	η^2
VFT × VFI × Type	136.22	< .001	.18	110.04	< .0001	.19	89.89	< .0001	.14	136.54	< .0001	.15
VFT × VFI	69.05	< .0001	.21	144.46	< .0001	.22	27.00	< .001	.19	188.79	< .0001	.17
VFT × Type	< 1			1.77			< 1			< 1		
VFI × Type	< 1			< 1			< 1			< 1		
VFT	< 1			3.66	< .088	.003	1.76			< 1		
VFI	< 1			7.17	< .05	.003	37.44	< .0005	.18	< 1		
Type	6.85	< .05	.15	21.57	< .0001	.23	< 1			2.01		

Note. *dfs* = 1, 9. VFT = visual field of target; VFI = visual field of interference stimulus; Type = corrected or initially correct trials.

an intact left or right PFC to monitor performance, as we found initial processing and subsequent error processing to be made in a single hemisphere when the task was simple.

Our results show a dissociation between initial processing and the monitoring of this processing when the initial presentation of both the target and the interfering stimulus were lateralized. Thus, the relevance of our findings to more general models of monitoring may not seem straightforward. However, imaging studies have shown asymmetries in brain activation that are congruent with models of hemispheric specialization (e.g., see Bookheimer, 2002, for a review) when the stimuli are presented centrally. These studies also, very often, reveal bilateral patterns: Although activation may be more prominent in the left hemisphere during a linguistic task, we also see right hemisphere activation. Just, Carpenter, Keller, Eddy, and Thulborn (1996) proposed that functional networks of brain regions that function together to subserve a cognitive process are dynamic, such that added complexity in the cognitive process results in the conscription of additional brain areas to the networks. Thus, characteristics of the task can affect the architecture of the network of brain areas that function together to perform it.

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