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The attentional blink within and across the hemispheres: Evidence from a patient with a complete section of the corpus callosum

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ABSTRACT

The attentional blink (AB) refers to an impairment in the report of a second target (T2) if it closely follows the presentation of a first target (T1) in a rapid serial visual presentation (RSVP), when both targets must be reported. In the present study, a modified AB paradigm was used in which targets could appear in any of four simultaneous RSVP streams, one in each quadrant of the visual field. In half of the trials, T1 and T2 were displayed in the same visual hemifield (either left or right) and, in the other half, T1 and T2 were displayed in different visual hemifields. Using this paradigm with both neurologically intact individuals and a split-brain patient, we sought to investigate (1) possible hemispheric asymmetries in attentional processes, and (2) whether the AB would be reduced when targets are displayed in different visual hemifields. A comparable AB was found for both neurologically intact individuals and the split-brain patient, with no significant variations due to whether targets were displayed in the same or in different hemifields. A left hemisphere advantage in the processing of same and different hemifield targets was observed only in the split-brain patient.

1. Introduction

Attention enables us to select relevant information to be processed at the cost of a decreased awareness of unattended stimuli. Of interest in this study are the issues of hemispheric specialization in the processing of sequential visual targets and the effects of separating the processing of sequential targets between cerebral hemispheres by using a modified version of the attentional blink (AB) paradigm. In the most common AB paradigm, two targets are embedded in a rapid serial visual presentation (RSVP) stream of distractors presented at fixation (e.g., Raymond et al., 1992). Accurate report of a second target (T2) is typically impaired when presented within a stimulus onset asynchrony (SOA) between 200 ms and 500 ms of a first target (T1). Although there is still an ongoing debate about the level of processing at which the AB occurs and the exact causes of the AB, most models suggest that the AB occurs either as a result of an overload of post-perceptual mechanisms that consolidate targets in visual short-term memory, for problems in target selection at a post-perceptual processing level, or for distractor-induced suppression of trailing targets processing (Chun and Potter, 1995; Dell'Acqua et al., 2009; Di Lollo et al., 2005; Jolicœur, 1998, 1999; Jolicœur and Dell'Acqua, 1998; Nieuwenstein, 2006; Olivers and Meeter, 2008).

AB paradigms have been used with both neurologically intact individuals and patients to investigate whether well-known functional inter-hemispheric differences (e.g., spatial, configural, stimulus category processing) could also extend to a different ability of the two hemispheres to process sequential targets. The picture emerging from these studies is somewhat mixed. Several studies provided evidence suggesting a selective advantage of the right hemisphere over the left hemisphere in processing sequential stimuli (Holländer et al., 2005; Kessler et al., 2005). However, using a lateralized version of the AB paradigm similar to the one used in Holländer et al. (2005), in which T1 and T2 were displayed left or right of fixation, Giesbrecht and Kingstone (2004) found that the AB in a split-brain patient was more pronounced when T2 was displayed to the right hemisphere relative to when T2 was displayed to the left hemisphere, suggesting a selective advantage of the left hemisphere over the right hemisphere in processing sequential stimuli. Given that this is the only study reporting a left hemisphere superiority, one interesting question is that pertaining to the validity of those findings. Would a different split-brain patient, tested under similar conditions, behave like that described

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by Giesbrecht and Kingstone (2004), thereby replicating some form of selective disadvantage of the right hemisphere (or, viceversa, a left hemisphere advantage) in the processing of sequential targets? To answer this question, we examined a different split-brain patient using an AB paradigm with targets displayed in either the same or opposite hemifields.

In split-brain patients, the callosal fibers connecting the hemispheres are surgically sectioned to relieve intractable epilepsy, in essence eliminating virtually all cortical transfer of information from one hemisphere to the other. Earlier studies suggested that even in the absence of a corpus callosum, attentional resources were shared between hemispheres (i.e., the harder a hemisphere works on a task, the worse the other hemisphere will do on a task of constant complexity; Holtzman and Gazzaniga, 1982). However, there is still some controversy pertaining to this issue as more recent work has found that visual-spatial attention systems are in fact divided, and there is no inter-hemispheric interference in the absence of the corpus callosum in divided-attention tasks (e.g., Arguin et al., 1999). Thus, if in fact the corpus callosum plays a role in mediating attentional processing of the hemispheres, bilateral presentation of targets should abolish the AB in the split-brain patient, but not in healthy participants. Moreover, any hemispheric asymmetries in the processing of rapid temporal information should be more pronounced in the split-brain, because no attentional resources could be recruited from a specialized hemisphere to aid task performance in the opposing hemisphere via callosal connections.

A second motivation underlying the present study is related to a methodological issue that arises in the presentation of lateralized stimuli in the AB paradigm. In the Holländer et al. (2005) study, only one RSVP stream was presented on each side of fixation. Consequently, T1 and T2 were always presented in the same RSVP stream in intra-hemispheric trials, whereas, T1 and T2 were always presented in different RSVP streams in inter-hemispheric trials. This complicates the comparison between intra- and inter-hemispheric processing of T1 and T2 because visual-spatial attention need not be shifted from one RSVP stream to the other RSVP stream in intra-hemispheric trials, whereas this is likely to occur in inter-hemispheric trials. In the Giesbrecht and Kingstone (2004) study, the confound between same-stream/different-stream presentation and within-hemisphere/between-hemisphere presentation compromises the interpretation of results in terms of hemispheric differences, particularly because of documented differences in the AB when T1 and T2 are presented in the same stream versus in different streams (see Dell'Acqua et al., 2003). To overcome these methodological problems, we used four simultaneous RSVP streams, one in each quadrant of the visual field. Targets were displayed in any of the streams with equal probability. In this way, two targets could appear either in the same visual field (intra-hemispheric condition, in the same or in different streams) or in opposite visual fields (inter-hemispheric condition, necessarily in different streams). This experimental design enabled us to compare within-hemisphere and between-hemisphere AB effects under equivalent T1–T2 between-stream presentation conditions.

2. Experiment

2.1. Method

2.1.1. Neurologically intact participants

Twenty-two participants (14 women; 13 right handed), aged from 19 to 39 years (mean of 22 years), participated in the experiment for financial compensation. Given that two previous studies have reported no correlation between general intelligence and the magnitude of the AB (Colzato et al., 2007; Martens and Johnson, 2009), we did not match the neurologically intact group to the split-brain patient in terms of IQ.

2.1.2. Split-brain participant (M.L.)

M.L. is a 28 years old, left-handed man who underwent complete callosotomy for alleviation of intractable epilepsy at the age of 22. At the time of surgery, he had on average one generalized seizure and numerous absences per week. His seizures were characterized by a sudden fall followed by post-ictal confusion. At present, he has one or two absences per week. M.L. has retained complete independence of the responses signaled by his left and right hands. On standard cognitive assessments, M.L. has always functioned in the borderline range without a discernible discrepancy between his verbal and nonverbal skills. On the Wechsler Adult Intelligence Scale-Revised (WAIS-R), M.L. obtains a global IQ of 76. Presently, he lives with his father and is unemployed. His medication includes Dilantin, Lamictal, and Epival. A more detailed case history for M.L. can be found in Keenan et al. (2003).

2.1.3. Stimuli

Stimuli comprised four simultaneous RSVP streams of 14 randomly generated uppercase letter distractors (excluding B, I, and O) in which two digit targets were embedded. The RSVP streams were 2.2° (center to center) from fixation and equidistant from each other, one in each quadrant, as shown in Fig. 1. All characters were white on a black background and subtended an angle of $2^\circ \times 2^\circ$. Stimuli were presented using a 15-in. cathode-ray tube driven by a Pentium IV computer running MEL 2.0 software.

2.1.4. Design

Given that T1 and T2 could be presented unpredictably in any of the four RSVP streams, T1 and T2 sometimes appeared in the same RSVP stream (1/4 of the trials), and sometimes appeared in different RSVP streams (3/4 of the trials). When targets were presented in different streams, they could be presented in the same left–right visual hemifield (intra-hemispheric presentation) or in different hemifields (inter-hemispheric presentation). We anticipated that results from the same-stream trials would be different from the remainder of the trials because of previous work showing that these trials sometimes produce no AB effect, or even a reversed AB effect (Dell'Acqua et al., 2003). For present purposes, we focused mainly on two subconditions: (a) an intra-hemispheric condition in which T1 and T2 appeared in different streams, and (b) an inter-hemispheric condition in which T1 and T2 appeared in different hemifields.

A robust AB effect is observed whether subjects are required to count or identify the targets embedded in a central RSVP stream (Dell'Acqua et al., 2007). Therefore, to accommodate both M.L.'s limited manual dexterity with either hand (rendering typing responses on a numeric keypad difficult) and the fact that verbal responses could only be given for stimuli presented in the right visual field, we asked M.L., and control participants, to report how many digits they had seen (zero, one, or two digits) instead of the identity of the digits presented.

M.L. responded by lifting zero, one, or two fingers with the hand ipsilateral to the hemifield in which target(s) were seen (for example, M.L. would lift zero right hand fingers and one left hand finger to report having seen zero digits in the right hemifield and one digit in the left hemifield), and the experimenter recorded M.L.'s responses into the computer at the end of each trial. Control participants reported how many digits they saw on the left side of the visual display by pressing the "Z," "X," or "C" keys with fingers of the left hand for 0, 1, or 2 digits, respectively, and how many digits they saw on the right side of the visual display by pressing the "N," "M," or "," keys with fingers of the right hand for 0, 1, or 2 digits, respectively.

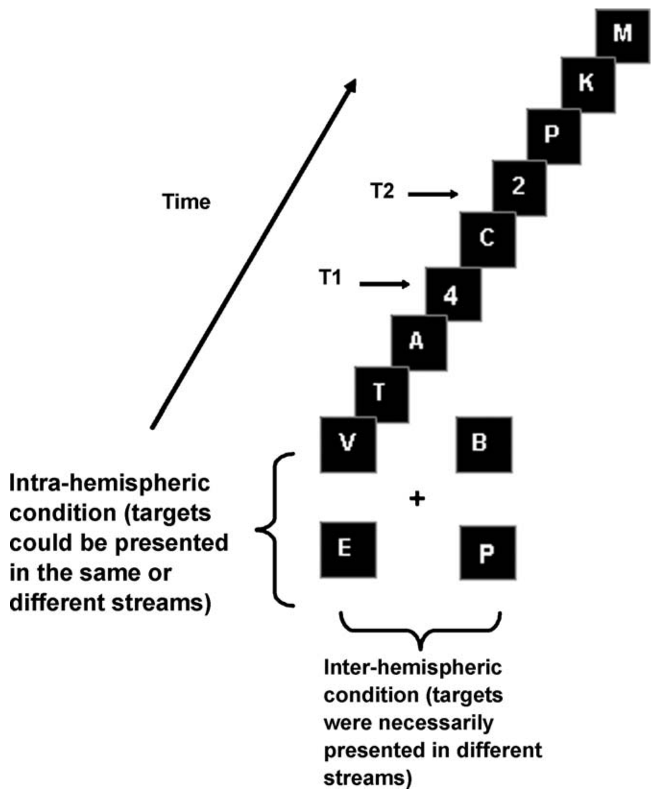

Fig. 1. Illustration of the timecourse and spatial layout of the stimuli in each trial. Four simultaneous RSVP streams, arrayed around fixation, were used in all trials (only one is shown over time in the illustration to avoid clutter). Shown here is an example in which both targets were presented in the same RSVP stream, at lag 2. In general, T1 and T2 could occur in any of the four RSVP streams, at random, without any spatial constraint, to avoid expectations that could bias the results (see text for further details).

Although two targets were always presented on every trial, this was never mentioned explicitly to the participants, ensuring that a priori odds did not influence subjects' guesses, and thus subjective chance level was about 11% (1/9: three possible responses with the right hand and three with the left hand). In addition to varying the spatial position of T1 and T2, the time interval between T1 and T2 was also varied in order to measure an AB. Two T1–T2 lags were used: a short lag, lag 2, in which there was one intervening frame between T1 and T2, and a long lag, lag 8. Each participant performed one practice block of 36 trials followed by four experimental blocks of 96 trials. Each condition was presented equally often in each block.

2.1.5. Procedure: neurologically intact participants

Participants were seated comfortably in a darkened room, 57 cm from the screen, with eyes level with the fixation point. Participants were instructed to maintain their eyes on the fixation point throughout each trial, and report whether they had seen zero, one, or two digits on either side of fixation. The SOA between RSVP items was 150 ms, with no inter-stimulus interval (ISI). Responses were entered using the keyboard without speed pressure, as described in Section 2.1.4. Eye movements were recorded from a sample of five different participants in a pilot experiment. Results from these pilot participants did not differ from the results reported below.

2.1.6. Procedure: M.L.

The procedure was the same as with neurologically intact participants, except for the following details. The experimenter was seated beside the participant. M.L.'s eye movements were monitored using a digital camera focused on one of his eyes. Trials in which eye movements were detected by the experimenter were rejected (less than 2%). M.L. was instructed to report whether he had seen zero, one or two numbers on either side of fixation, without speeded pressure, as described in Section 2.1.4. The experimenter entered M.L.'s responses using the keyboard of the computer at the end of each trial, and initiated the next trial. In order to bring M.L.'s performance to a level comparable with neurologically intact participants, the practice phase included 10 blocks of 36 trials each, and the SOA between RSVP items was extended to 233 ms.

2.2. Results: neurologically intact participants

A first series of analyses yielded no significant effects of handedness, so data was collapsed across left-handed and right-handed participants. Accuracy was calculated as a function of correct report of both targets, as our paradigm did not allow us to differentiate between report of T1 and T2 in intra-hemispheric trials. To avoid possible confounds, that is, a reversed AB effect for same-stream trials, analyses in intra-hemispheric conditions were conducted separately for trials in which targets were presented in different streams and those where targets were presented in the same stream.

2.2.1. AB effect

A summary of the results is illustrated in Fig. 2A. In the inter-hemispheric condition, mean accuracy was 42% at lag 2 condition and 57% at lag 8. In the intra-hemispheric condition, mean overall accuracy was 33% at lag 2 condition and 42% at lag 8. As expected, accuracy was generally higher at lag 8 than at lag 2, $F(1, 21) = 28.37$, $p < .001$. Mean accuracy was also higher in the inter-hemispheric condition than in the intra-hemispheric condition, $F(1, 21) = 35.00$, $p < .001$. The interaction between lag and the inter-/intra-hemispheric condition was not significant, $F(1, 21) = 2.34$, $p > 0.14$. Hence, although performance in general was higher in the inter-hemispheric condition, there was no reduction in the magnitude of the AB effect in the inter-hemisphere condition relative to the intra-hemisphere conditions.

Interestingly, on intra-hemispheric trials in which both targets appeared in the same RSVP stream, we found a tendency towards a reversed AB (Dell'Acqua et al., 2003). Mean accuracy in reporting the number of perceived targets was slightly higher at lag 2 (51%) than at lag 8 (47%), although this difference did not reach significance, $F(1, 21) = 1.97$, $p > 0.18$ (see Fig. 2A). Nonetheless, when same-stream and intra-hemispheric different-stream data were compared within the same ANOVA, a significant interaction between same-/different-stream and lag was observed, $F(1, 21) = 14.08$, $p < 0.001$.

2.2.2. Comparison of AB in the different hemispheres

Our experimental design limited the type of analyses that could be performed in intra-hemispheric conditions. Indeed, as participants were asked only to report the number of digits they had seen on each side of fixation, disentangling single target accuracy was impossible. For example, when both targets were presented to the right hemisphere and only one was reported, it was impossible to tell if T1 or T2 was the detected target in the trial. However, analyses of T2|T1 accuracy were performed in inter-hemispheric trials to evaluate whether the AB differed when T2 was presented to the left or to the right hemisphere. These analyses revealed no significant difference in the magnitude of the AB, $F(1, 21) = 0.015$, $p > 0.9$, or the reverse AB, $F(1, 21) = 0.011$, $p > 0.9$, between

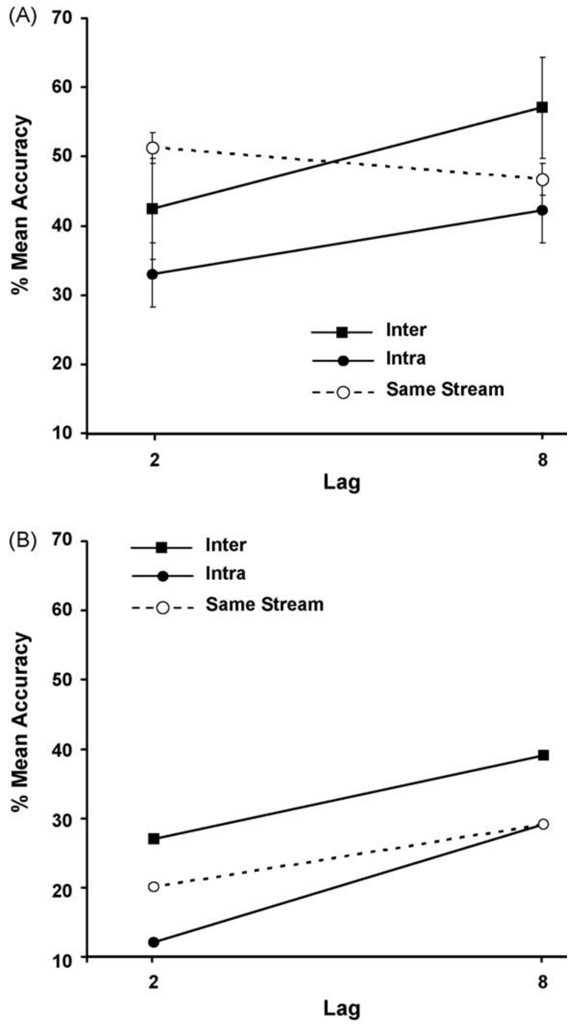

Fig. 2. (A) Neurologically intact participants. The full lines indicate the proportion of correct target report at lag 2 and lag 8 in inter- and intra-hemispheric conditions. The dotted line indicates the proportion of correct target reports at lag 2 and lag 8 in same-stream trials. Error bars represent the standard error of the means. (B) M.L. The full lines indicate the proportion of correct target report at lag 2 and lag 8 in inter- and intra-hemispheric conditions. The dotted line indicates the proportion of correct target reports at lag 2 and lag 8 in same-stream trials.

hemisphere. Furthermore, contrary to the findings of Holländer et al. (2005), we found no differences in T1 accuracy when T1 was displayed to either hemisphere, $F(1, 21) = 1.7$, $p > 0.2$, or T2 accuracy, $F(1, 21) = 2.5$, $p > 0.13$.

2.3. Results: M.L.

2.3.1. AB effect

A summary of the results is shown in Fig. 2B. On trials in which T1 and T2 were displayed in different RSVP streams, in the intra-hemispheric condition, mean accuracy was 12% at lag 2 condition and 29% at lag 8. In the inter-hemispheric condition, mean accuracy was 27% at lag 2 condition and 39% at lag 8. Although overall accuracy was lower for M.L. than for neurologically intact participants, mean difference across lags was similar to that observed in neurologically intact participants, suggesting that M.L. exhibited a typical AB effect.

As is evident in Fig. 2B, on trials in which T1 and T2 were displayed in the same RSVP stream, no evidence of a reversed AB effect was observed. Mean accuracy was 20% at lag 2, and 29% at lag 8.

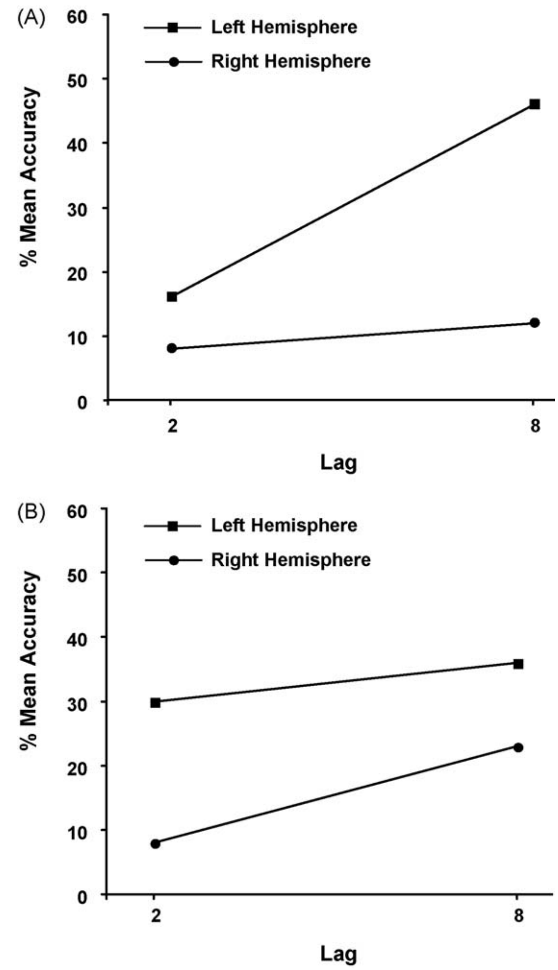

Fig. 3. Proportion of correct target report at lag 2 and lag 8 for M.L. in intra-hemispheric trials. (A) Different-stream trials. (B) Same-stream trials.

2.3.2. Comparison of AB in the different hemispheres

On intra-hemispheric trials where T1 and T2 appeared in different RSVP streams, M.L.'s mean performance was basically at chance with targets displayed to the right hemisphere (8% and 12%, at lag 2 and lag 8, respectively). With targets displayed to the left hemisphere, mean accuracy was just above chance at lag 2 (16%), and substantially higher at lag 8 (46%; see Fig. 3A). On intra-hemispheric trials where T1 and T2 appeared in the same RSVP stream (see Fig. 3B), we found no evidence of an AB for targets displayed to the left hemisphere, mean accuracy was 30% at lag 2 and 36% at lag 8. For targets displayed to the right hemisphere, mean performance was at chance at lag 2 (8%) and still very low at lag 8 (23%). On inter-hemispheric trials, mean T1 accuracy was higher when T1 was displayed to the left hemisphere (61% and 69%, at lag 2 and lag 8, respectively) than to the right hemisphere (46% and 58%, at lag 2 and lag 8, respectively). Mean T2 accuracy was also better when T2 was displayed to the left hemisphere (20% and 38%, at lag 2 and lag 8, respectively) than to the right hemisphere (14% and 37%, at lag 2 and lag 8, respectively). These results suggest a left hemisphere superiority in processing rapidly presented sequential stimulation.

3. Discussion

Our results indicate that dividing processing across the hemispheres does not abolish or even diminish the AB effect, neither in neurologically intact participants nor in a split-brain patient. Although report accuracy was lower for intra-hemispheric targets than for inter-hemispheric targets, the magnitude of the AB was of comparable magnitude within and across the hemispheres. This result was expected for neurologically intact participants, given their intact corpus callosum and the consequent efficient transfer of information across the hemispheres. More surprisingly was the absence of any reduction in the magnitude of the AB effect for M.L. in the inter-hemispheric condition relative to the intra-hemispheric condition, a result that bears a close resemblance to that observed by Giesbrecht and Kingstone (2004) with their split-brain patient. These authors interpreted their findings as evidence that the sub-cortical connections that are preserved in split-brain patients may be sufficient to transfer rapidly presented visual items from one hemisphere to the other (see also Dell'Acqua et al., 2005 for a similar interpretation with callosal agenesis patients). This possibility seems somewhat remote for M.L., however, given the clear inter-hemispheric dissociations found during his neurological testing. It is very unlikely that detailed visual form information capable of enabling accurate letter-digit discriminations could be transferred via sub-cortical pathways. On the other hand, it is possible that, once a digit was identified as a target by one hemisphere, information about the successful detection of a target could be transferred to the other hemisphere.

One viable account for the AB effect observed in inter- and intra-hemispheric conditions in M.L. derives from the recent AB model of Nieuwenhuis et al. (2005). The AB in this model takes place during the refractory period in locus coeruleus activity that occurs following an initial phasic response (i.e., norepinephrine discharge) elicited by a target stimulus detection. According to this model, because of the temporary unavailability of norepinephrine potentiation following detection of the first target, trailing targets presented during the refractory period do not receive the purported benefit of facilitation associated with the norepinephrine discharge triggered by the locus coeruleus, and therefore suffer the deficit in T2 processing observed as the AB. Our results could be explained in the context of this model if we suppose that each hemisphere can separately identify targets and trigger a burst of activity in the locus coeruleus independently of each other. The refractory period in the locus coeruleus, where the retinotopic organization of the visual field is not retained, would then impact the processing of subsequently-presented targets appearing in either hemisphere.

Another interesting result concerns the higher overall accuracy in the inter-hemispheric condition than in the intra-hemispheric condition, both for control subjects and for M.L. These results suggest that each hemisphere possesses its own capacity-limited attentional resources, and that these resources cannot be shared rapidly across hemispheres. The overall superior performance in the inter-hemispheric condition over the intra-hemispheric condition suggests that it is more taxing to process two targets in a given hemisphere than a single target. Crucially for the present argument is that this difference in hemispheric processing efficiency does not seem to exert any modulatory role on AB magnitude (which is indexed by the lag effect).

As expected, we found that, at the shorter lag, when T2 and T1 were presented at the same location, performance on T2 was better than when T2 and T1 were presented in a different location, without any sign of a trade-off between T1 and T2 (see Dell'Acqua et al., 2003). Dell'Acqua et al. (2003) raised several possibilities as to the cause of this reduced or reversed AB effect for same-stream trials, including T1 induced spatial cueing. Interestingly, although a tendency towards a reversed AB effect (i.e., higher accuracy of report of T2 at lag 2 than at lag 8) was found for our neurologically intact individuals, this pattern was not observed in our split-brain patient. This difference between the patient results and the control results suggests that T1 may have been an effective spatial cue for neurologically intact participants and a much less effective spatial cue for our split-brain patient. Furthermore, contrary to controls, M.L.'s performance in the RSVP task was characterized by a trade-off between T1 and T2, suggesting strongly that M.L. may have been slower than normals in moving attention from one position to another in absolute terms, or generally slower than controls in processing target information.

Although there were no hemispheric asymmetries in the magnitude of the AB observed in the left and right hemisphere in intra-hemispheric conditions, in inter-hemispheric conditions there seems to be evidence of left hemisphere superiority in T2 processing in our split-brain patient. These results are consistent with previous findings by Giesbrecht and Kingstone (2004), who observed a similar pattern in their split-brain patient, but not in neurologically intact controls. The most direct interpretation of our results lies in the often proposed theories that the right hemisphere is more involved in global aspects of visual form and spatial processing, whereas the left hemisphere is better able to attend to local aspects and is more specialized in temporal processing (Gazzaniga et al., 2001; Nicholls, 1996). Given the strong spatial component inherent to our design, however, it could be argued that the results observed in our split-brain participant may partially reflect more efficient guided search (the ability to locate targets by narrowing search only to items containing relevant target features: Wolfe et al., 1989). Indeed, Kingstone et al. (1995) found, in a study of split-brain patients, that it is in fact the left hemisphere that seems superior in guided search. Furthermore, the possibility remains that, as the left hemisphere is more specialized for language and reading, the use of alpha-numeric stimuli in both the present and the Giesbrecht and Kingstone (2004) studies may have given this hemisphere an advantage in target processing that was independent of the AB per se. This interpretation is also in line with the findings of an absolute left hemisphere language lateralization in our split-brain patient.

Despite our efforts to bring M.L.'s performance level up to a level equivalent with that of neurologically intact subjects (i.e., several pilot studies, adjustment of presentation duration of the stimuli, and a greater number of practice blocks), M.L.'s performance remained quite low. Nonetheless, M.L.'s results were similar in many ways to that of the neurologically intact participants, in that his accuracy showed a clear-cut lag effect and an overall advantage for inter-hemispheric target presentations over intra-hemispheric presentations, both of which were about of the same magnitude as that found with neurologically intact participants (see Fig. 4). The fact that M.L. shows patterns of

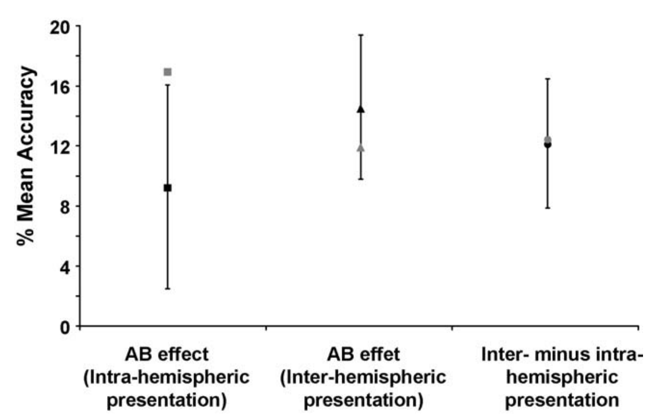

Fig. 4. Magnitude of AB effect (lag 8–lag 2) in intra- and inter-hemispheric conditions, and difference between inter-hemispheric target presentations and intra-hemispheric presentations for both neurologically intact participants (black symbols) and M.L. (grey symbols). Error bars represent the within-subjects 95% confidence interval of the means for the neurologically intact participants.

results that are similar to those observed for the controls, and most particularly, that M.L. had a robust AB effect in the inter-hemispheric condition shows, surprisingly perhaps, that the corpus callosum plays only a minimal role in the AB phenomenon.

M.L. has a lower IQ than our control participants. However, previous work has not found a strong relationship between the AB and IQ (Colzato et al., 2007). The absence of a strong relationship between the magnitude of the AB and IQ found in previous work suggests that M.L.'s low IQ is not a reason to doubt the validity of inferences based on his results. Indeed, the fact that M.L. had an average AB effect that was numerically very similar to the mean of the control participants provides further evidence that the AB is not strongly related to IQ (Colzato et al., 2007).

Nonetheless, interpretations for normal brain function and for split-brain function based on M.L.'s performance must be made with caution for other reasons. The first is that M.L. has suffered from years of severe epilepsy, which may have altered his brain in ways that could make his results non-representative of normal function. The second is that M.L. represents a single case, which makes it difficult to determine how representative he is relative to other callosotomized individuals and limits statistical evaluation of some results.

Importantly, our paradigm enabled a comparison across within-hemisphere and between-hemisphere AB effects in which the requirement for a shift of spatial attention from the location of T1 to the location of T2 was equated. It was critical to do so because there are several studies that show that the AB interacts with visual-spatial attention. For example, it has been shown that a correct representation of the spatial position of visual marking elements is difficult to attain during the AB (Olivers, 2004). Furthermore, horizontal shifts of attention are impaired by the AB effect (Dell'Acqua et al., 2006; Jolicœur et al., 2006a, 2006b; Robitaille et al., 2007). And it has also been shown that visual search is impaired if a search array is displayed during the AB interval (Ghorashi et al., 2007). When this critical factor was controlled, we found no evidence for a reduced AB when T1 and T2 were presented to different hemispheres compared to the AB observed when T1 and T2 were presented to the same hemisphere, both in neurologically intact individuals and in a split-brain individual.

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