ELSEVIER

Neuropsychologia 42 (2004) 1703–1708

NEUROPSYCHOLOGIA

www.elsevier.com/locate/neuropsychologia

Spatial-temporal anisometries following right parietal damage

Janice J. Snyder[a,*], Anjan Chatterjee[b]

[a] *Department of Psychology, Okanagan University College, 3333 University Way, Kelowna, BC, Canada V1V 1A7*
[b] *Department of Neurology, University of Pennsylvania, USA*

Received 16 June 2003; received in revised form 19 January 2004; accepted 8 April 2004

Abstract

Patients with right parietal damage often have a lateralized deficit of spatial attention. In addition to a spatial deficit, such patients have also been reported to have a non-spatial deficit in temporal processing. Here, we tested the hypothesis that these spatial and temporal deficits might be linked if the right temporal-parietal cortex is important in integrating spatial and temporal attention. In AF, a patient with an acute right temporal-parietal stroke, we replicated previous observations showing that he was biased to judge ipsilesional stimuli as occurring before contralesional stimuli. More importantly, for vertically aligned stimuli, AF more accurately judged the temporal order of successive ipsilesional than contralesional stimuli. Furthermore, his contralesional performance improved with stimuli with larger vertical separations. Taken together, these findings provide additional evidence that right temporal-parietal damage produces a processing refractory period for stimuli in contralesional space that extends in both space and time. These findings are in agreement with other studies that suggest that the right temporal-parietal cortex is important in integrating the where and when of stimuli.

Keywords: Extinction; Neglect; Spatial bias; Temporal order judgment; Time; Attention

1. Introduction

Right parietal damage frequently produces lateralized deficits of spatial attention. Paradigmatic of such deficits is the phenomenon of visual extinction. Patients with extinction show little difficulty in detecting a stimulus in their contralesional visual field if it occurs in isolation. However, they often fail to detect a similar contralesional stimulus if it occurs simultaneously with an ipsilesional one (Baylis, Simon, Baylis, & Rorden, 2002; Bender, 1952; di Pellegrino, Basso, & Frassinetti, 1998; di Pellegrino & De Renzi, 1995; Vaishnavi, Calhoun, & Chatterjee, 2001). The traditional view of extinction is that it reflects a pathologic reduction in attentional capacity (Chatterjee, 2002; Heilman, Watson, & Valenstein, 2003). Simultaneous stimuli compete for limited resources, and patients are biased to process ipsilesional rather than contralesional stimuli.

A variant of this traditional view of extinction (reflecting a biased competition in space) takes time into consideration. This "prior-entry hypothesis" postulates that attended stimuli require less time to reach conscious awareness than do unattended stimuli (Birch, Belmont, & Karp, 1967; Titchener, 1908), a claim borne out by research in healthy participants (e.g., Maylor, 1985; Stelmach & Herdman, 1991). In extinction, if attention is directed ipsilesionally then stimuli that are located in ipsilesional space reach conscious awareness earlier than stimuli in the contralesional space. Classic studies by Bender (1952) and Birch et al. (1967), showed that patients were aware of contralesional stimuli only if they preceded ipsilesional stimuli by some significant temporal increment. Recently, Rorden, Mattingley, Karnath, and Driver (1997; see also Robertson, Mattingley, Rorden, and Driver 1998) returned to these ideas. They used a temporal order judgment paradigm in which two visual events occur on either side of fixation at various temporal asynchronies. The task was to judge which of two events (left or right) occurred first while maintaining fixation. Typically, healthy participants correctly judge the temporal order of the events at asynchronies greater than 40 ms. In contrast, Rorden et al.'s two patients with right temporal-parietal damage correctly judged the contralesional event as occurring first *only* when it led the ipsilesional event by 200 ms. This asymmetry presumably reflects slower contralesional entry giving a temporal lead to the ipsilesional event. Thus, the asymmetry in spatial attention is thought to produce an asymmetry of temporal processing.

Distinct from this ipsilesional spatial bias, right frontal-parietal damage may also produce a non-spatial disrup-

* Corresponding author. Tel.: +1-250-545-7291 (local 2241); fax: +1-250-545-3277.
E-mail address: jsnyder@ouc.bc.ca (J.J. Snyder).

0028-3932/$ – see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.neuropsychologia.2004.04.003

tion in temporal processing (Husain, Shapiro, Martin, & Kennard, 1997). In the attentional blink paradigm, participants are presented with a series of rapidly occurring visual events (e.g., letters or digits) at a central location. Embedded within the stream of events is a target requiring identification, followed by a variable number of intervening events. On half the trials, a second target requiring detection or identification is presented. The attentional blink refers to the finding that identification of the first target impairs the identification of a second target when it is presented within 400 ms of the first target (Broadbent & Broadbent, 1987; Raymond, Shapiro, & Arnell, 1992; Shapiro, Raymond, & Arnell, 1994). Husain et al. (1997) found the attentional blink to be nearly four times longer in patients with right frontal-parietal damage than in healthy participants.

The finding that right parietal damage can produce a limited capacity to process stimuli in space and in time does not address the question of whether these two attentional resources are linked. Addressing this question would require an assessment of temporal processing both across and within visual hemifields. The prior entry hypothesis by itself does not require that temporal order judgments *within* visual field vary by hemifield. The delayed entry of the first contralesional stimulus could be followed by a delayed entry of the second stimulus, while maintaining the same just noticeable difference between the two events. Similarly, a prolonged attentional blink for events presented in a central location does not require that temporal order judgments *within* visual field vary by hemifield. The temporal increment required to detect the second stimulus could be equally prolonged in both locations.

Thus, while the right temporal-parietal cortex is clearly involved in spatial and likely involved in temporal processing, it is not clear that it integrates both spatial and temporal information. This spatial-temporal integration hypothesis would predict that the ability to distinguish between two successive events would be worse in contralesional space than in ipsilesional space. On this view the refractory period following the first event would be longer in contralesional than in ipsilesional space.

In the present experiment, we tested our hypothesis that temporal-parietal damage produces a processing refractory period in contralesional space involving both space and time in the following manner. First, we established that our patient had extinction. Second, we replicated Rorden et al.'s (1997) finding of asymmetrical temporal order judgment between visual fields. And most importantly, we critically tested our hypothesis by examining temporal order judgment within each visual field using two different vertical separations.

2. Patient and methods

2.1. Patient AF

This study has been approved by the ethics committee of the University of Pennsylvania and has been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. The patient gave his informed consent prior to his inclusion in the study.

AF, a 41-year-old right-handed man with some post-secondary education, was admitted to the hospital with an infarct in the posterior division of the right middle cerebral artery. A cranial CT scan performed 1 week after the onset of his symptoms revealed a temporal-parietal stroke, involving Brodmann's areas 21, 22, 37, 40 (see Fig. 1). AF had mild symptoms of unilateral spatial neglect on the Behavioral Inattention Test (total score 119/146). In addition, a computerized task revealed extinction of contralesional visual stimuli to double simultaneous stimulation. Equal numbers of contralesional, ipsilesional and bilateral trials were presented across the 3 days of testing (80 trials/condition: 60–100 and 20–200 ms durations). AF was correct on 96% of unilateral right, 85% of unilateral left, and 48% of bilateral trials.

2.2. Apparatus and materials

The experiments were conducted at the patient's bedside on a laptop computer with a 40 cm monitor (diagonal measurement) positioned at a distance of approximately 57 cm. The stimulus display consisted of a black background with a light-gray central fixation dot subtending 0.3° visual angle. The light-gray target letters "T" and "L" measured 1.0° in height and 0.6° in width.

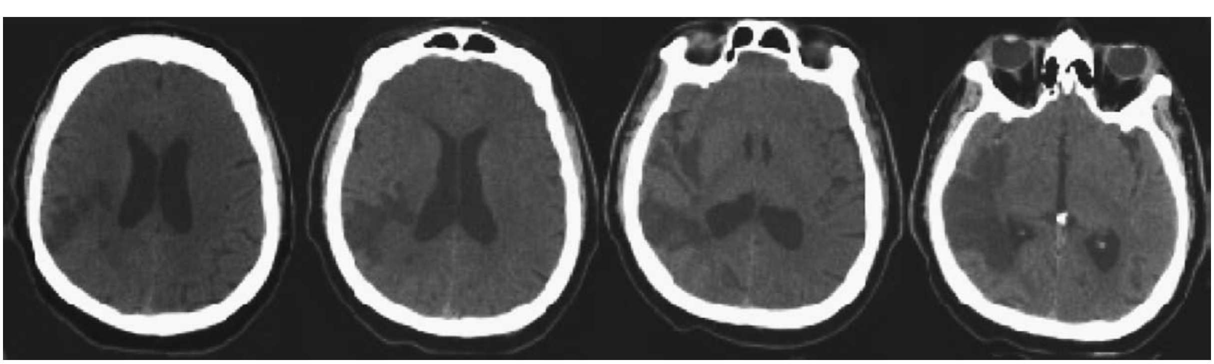

Fig. 1. Cranial CT scan of patient AF revealing right temporal-parietal damage involving Brodmann's areas 21, 22, 37, and 40.

2.3. Procedure

At the start of each trial, the fixation stimulus appeared and 1000 ms later, either a "T" or an "L" (stimulus 1, S1) appeared in the left or right visual field with equal probability. S1 was followed at various stimulus onset asynchronies (SOAs) by the second letter (stimulus 2, S2). Thus, if a "T" appeared first, then an "L" followed and vice versa. Both letters remained on the screen until a response was entered on the keyboard. At this time, the screen was cleared and the next trial was initiated. In all conditions, both letters appeared at a distance of 7.5° from the fixation stimulus. In condition 1 (between-field), S1 appeared in either the contralesional field or ipsilesional field followed by S2 in the opposite visual field. In conditions 2 and 3, S1 appeared in either the contralesional field or ipsilesional field and S2 appeared in same visual field. In condition 2, S1 appeared with equal probability either 1° above or 1° below the horizontal axis so that a vertical distance of 2° separated S1 and S2. In condition 3, S1 appeared with equal probability either 3.5° above or 3.5° below the horizontal axis so that a vertical distance of 7° separated S1 and S2. AF was instructed: to maintain fixation; that on every trial two letters, a "T" and an "L" would appear in succession; and that he had to identify which letter appeared first. He was told that on some trials it might be difficult to determine which letter appeared first and that on these occasions he must guess. His response was entered into the computer by the experimenter. In Fig. 2, panel A depicts a trial in which S1 and S2 occurred in the different visual fields (condition 1) and panel B depicts a trial in which S1 and S2 occurred in the same visual field at 7° of vertical separation (condition 3).

Testing was conducted on 3 days over a 5-day period. Prior to each testing, AF performed several practice trials in the appropriate condition. Condition 1 was conducted on day 1 and consisted of a total of 160 experimental trials at SOAs of: 870, 350, 290, 230, 175, 120, and 15 ms (12, 12, 12, 12, 12, 12, and 8 trials/visual field/SOA, respectively). Condition 2 was conducted on days 2 and 5 and consisted of a total of 288 experimental trials at SOAs of: 1400, 1050, 870, 350, 290, 230, 175, 120, and 15 ms (16, 16, 12, 16, 28, 12, 12, 12, 12, and 8 trials/visual field/SOA, respectively). Condition 3 was conducted on day 5 and consisted of a total of 64 experimental trials at SOAs of: 1400, 1050, 870, and 350 ms (8 trials/visual field/SOA).

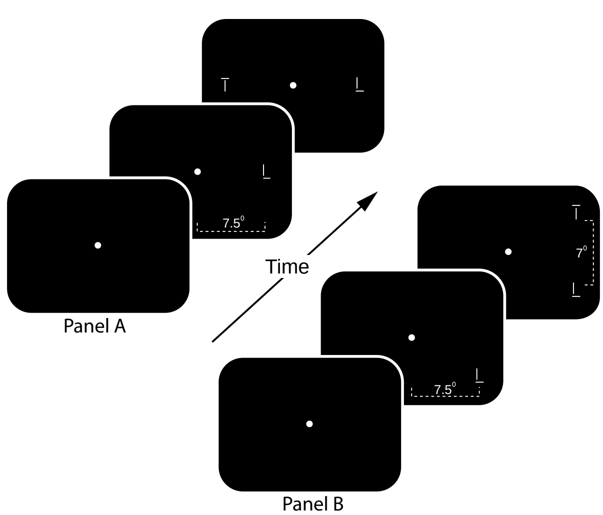

Fig. 2. Panel A illustrates a condition 1 (between-field) trial (in which the stimuli occurred in both ipsilesional and contralesional visual fields. Panel B illustrates a condition 3 (within-field) trial in which the stimuli occurred in the ipsilesional visual field at 7° of vertical separation.

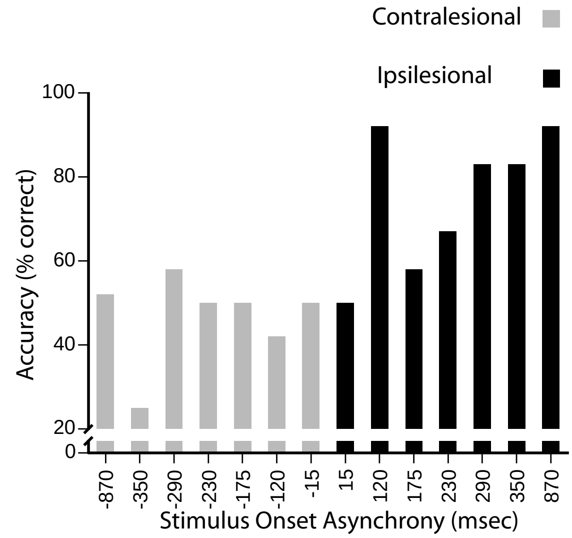

Fig. 3. Accuracy in condition 1 (between-field) trials as a function of stimulus onset asynchrony when the leading stimulus occurred in the contralesional field (gray bars) and ipsilesional field (black bars).

3. Results

Accuracy data for conditions 1–3 are presented in Figs. 3–5. For each condition, the data were analyzed as follows. A test for significance of difference between two proportions (Bruning & Kintz, 1977) was conducted to determine whether performance differed between the ipsilesional and contralesional fields. A test for significance of a proportion (Bruning & Kintz, 1977) was conducted to determine whether performance was above the level of chance in each hemifield.

3.1. Between hemifields analysis (condition 1)

AF correctly identified S1 as occurring first when it was presented in the ipsilesional field (76%) more often when it was presented in the contralesional field (45%), z-score $= 4.04$ (see Fig. 3).[1] Performance in the ipsilesional field was significantly different from the level of chance, z-score

[1] All significance tests are one-tailed, therefore, a significant z-score $= 1.645$.

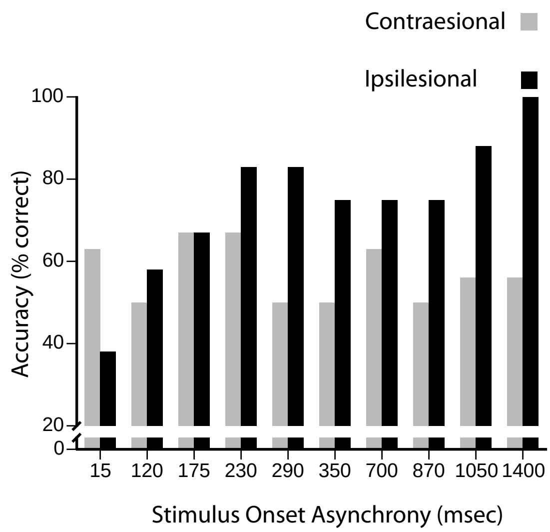

Fig. 4. Accuracy in condition 2 (within-field; 2° vertical separation) trials as a function of stimulus onset asynchrony when the leading stimulus occurred in the contralesional field (gray bars) and ipsilesional field (black bars).

= 4.69, whereas in the contralesional field it was not, z-score < 1. Furthermore, ipsilesional performance improved as SOA increased with accuracy greater than 80% at SOAs greater than 230 ms. This was not the case for his contralesional performance.

3.2. *Within hemifield analysis (2° separation; condition 2)*

AF correctly identified S1 as the first target when S1 and S2 were presented in the ipsilesional field (76%) more often than when S1 and S2 were presented in the contralesional field (56%), z-score = 3.64 (see Fig. 4). Performance in the ipsilesional field was significantly different from the level of chance, z-score = 6.29, whereas in the contralesional field it was not, z-score = 1.48. Ipsilesional performance in the temporal order judgment task improved to 75% or better at SOAs greater than 175 ms. Again, this was not so for contralesional performance. It is possible that the severity of AF's contralesional deficits may be reflective of the fact that he was tested in a subacute rather than chronic state, as is the case in most studies.

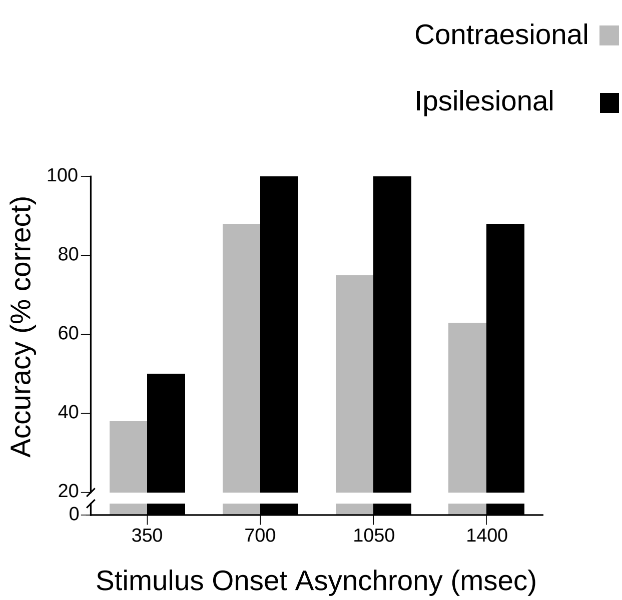

Fig. 5. Accuracy in condition 3 (within-field; 7° vertical separation) trials as a function of stimulus onset asynchrony when the leading stimulus occurred in the contralesional field (gray bars) and ipsilesional field (black bars).

3.3. *Within hemifield analysis (7° separation; condition 3)*

Again, AF correctly identified S1 as the first target when S1 and S2 were presented in the ipsilesional field (84%) more often that when S1 and S2 were presented in the contralesional field (66%), z-score = 1.66 (see Fig. 5). Importantly, performance across both hemifields was statistically significantly different from the level of chance, z-score = 3.91 and 1.77, for ipsilesional and contralesional fields, respectively.

Thus, it appears that increasing spatial separation reduced the temporal processing deficit observed with 2° of separations. As in the previous conditions, an improvement in ipsilesional performance was again observed with increasing SOA with accuracy better than 80% at SOAs greater than 350 ms. In addition, performance also improved with increasing SOA in the contralesional field with accuracy better than 60% at SOAs greater than 350 ms.

It has been previously reported (e.g., see Mark & Heilman, 1998) that some neglect patients have a combination of vertical and horizontal deficits. Thus, it was necessary to determine if AF's performance differed depending on whether S1 appeared in the upper or lower visual field. Importantly, AF's improved contralesional performance did not differ in the upper (69%) versus the lower (63%) visual field, z-score < 1.

3.4. *Within hemifield analysis at long SOAs (2° separation; condition 2)*

It is possible that in condition 2, AF's chance performance level for contralesional stimuli was the result of assessing performance across short and long SOAs (15–1400 ms). To ensure that performance with 2° vertical separations was in fact different than performance with 7° vertical separations, a test for significance of a proportion was conducted using only the SOAs tested in condition 3 (i.e., 350, 700, 1050, 1400 ms). However, even with this exclusion, AF's within-field contralesional performance remained at the level of chance, z-score < 1.

4. Discussion

The aim of our study was to explore the effects of right temporal-parietal damage on the ability to process stimuli in space and in time. The effects of such damage on spatial processing are well recognized. In addition to these spatial deficits, recent evidence suggests that right brain damage can also produce temporal processing deficits. The question we addressed was are these spatial and temporal deficits independent of each other, or are they linked?

We first established that our patient with right temporal-parietal damage, AF, had extinction. He had a lateralized deficit of spatial attention and was biased to be aware of ipsilesional rather than contralesional stimuli. Next, we showed that this lateralized deficit of spatial attention was also associated with a deficit in making temporal order judgments for stimuli that were presented bilaterally. He was more likely to report ipsilesional stimuli as occurring before contralesional ones. This bias to be aware of ipsilesional stimuli before contralesional ones replicates the classic observations by Bender (1952) and Birch et al. (1967) and more recent ones by Rorden et al. (1997). To test the hypothesis that the right temporal-parietal junction integrates spatial and temporal information we also assessed his ability to make judgments of temporal order within hemifields.

Our main finding is that AF was poorer at judging the order of events in contralesional space than in ipsilesional space. To be sure, a part of AF's contralesional deficit may be accounted for by a simple orienting or disengagement deficit towards contralesional space. However, such a deficit does not provide a complete explanation of the data. First, if slower orienting to the contralesional field was solely responsible for decreased accuracy, increasing the vertical separation of the stimuli in contralesional space should not have improved performance. Given that long SOAs were used, AF should have correctly identified the first contralesional target just as he did for a first ipsilesional target at the longest SOAs. Although, this was not the case for the 2° vertical separation between S1 and S2, critically, it was the case for the 7° separation. This difference demonstrates that the deficit is not purely one of contralesional space. Importantly, AF's improved contralesional performance was not restricted to either the upper or the lower visual field. This finding rules out the possibility that a vertical gradient of attention was also operating in our patient. Furthermore, if such a gradient of attention were operating, the predicted result would be that accuracy would be worse with greater spatial separation (i.e., at a 7° separation) because in this condition one of the stimuli would be well within the suspect quadrant. However, the opposite pattern of results was observed.

Second, given that the first letter remained visible until the end of the trial, it is unlikely that a single, non-competing, and enduring abrupt onset in the contralesional field would fail to elicit an orienting response—albeit a delayed one.

In our experiments, the successive stimuli did not appear in the same location, as happens in attentional blink experiments. Therefore, the possibility that perceptual masking effects may be prolonged in contralesional space and that this sensory effect might account for our data does not arise. Furthermore, we found that AF was better able to judge the order of stimuli in contralesional space if they were separated further in space (2° versus 7°). These findings, taken together with Rao, Mayer, and Harrington's (2001) demonstration of the role of the right parietal cortex in timing and Walsh's (2003) recent argument for the role of the right parietal cortex in sensory motor transformations with regard to both space and time, suggest that the right temporal-parietal junction plays a role in integrating spatial and temporal information. Damage to this area in our patient meant that he needed greater separation in space and time to be able to judge the order of successive events in contralesional than in ipsilesional space.

Our findings are also similar to observations made by di Pellegrino et al. (1998) in a patient with right temporal-parietal damage. Using a modification of the attentional blink paradigm, they found a longer blink for stimuli presented in contralesional space than in ipsilesional space. They suggested that it took their patient longer to process the first stimuli when it needed to be identified, resulting in a longer refractory period after its onset. Such a mechanism may be contributing to our finding. However, it would not explain why AF was better able to judge the order of stimuli that were separated by 7° than by 2°. From our data, it appears that a stimulus in contralesional space has a refractory wake that extends in both space and time. This refractory extension in space and time is interactive, such that limitations in awareness of successive events closer in time can be compensated to some extent by greater distance in space.

Most psychological models of time postulate an internal timekeeper composed of a pacemaker and an accumulator that tracks pulses (Block, 1990). Presumably, one would have difficulty distinguishing between two events that fall within a single pulse width. Our data suggests that the pulse width, which might be considered the resolving power of temporal attention, is itself modifiable by spatial attention. Perhaps it is not surprising that attention to space and time should be closely linked. Coherent goal-directed action depends on attention to both space and time. For instance, to bat a ball, one must attend to the location and to the speed of the approaching ball in order to calculate where and when to swing. It is interesting that most right-handed people prefer to bat with the ball coming in from their left hemispace, given our hypothesis that the right temporal-parietal cortex may be critical in directing attention to the where and when of stimuli.

Acknowledgements

This research was supported by National Institutes of Health Grant No. 037539 to A.C., and Natural Sciences and Engineering (NSERC) postdoctoral fellowship, NSERC grant, and University College of the Cariboo Scholarly Activity Grant to J.J.S.

References

Baylis, G. C., Simon, S. L., Baylis, L. L., & Rorden, C. (2002). Visual extinction with double simultaneous stimulation: What is simultaneous? *Neuropsychologia*, *40*, 1027–1034.

Bender, M. B. (1952). *Disorders in perception*. Springfield, IL: Thomas.

Block, R. A. (1990). Models of psychological time. In R. A. Block (Ed.), *Cognitive models of psychological time* (pp. 1–35). Hillsdale, NJ: LEA.

Birch, H. G., Belmont, I., & Karp, E. (1967). Delayed information processing and extinction following cerebral damage. *Brain*, *90*, 113–130.

Broadbent, D. E., & Broadbent, M. H. (1987). From detection to identification: Response to multiple targets in rapid serial visual presentation. *Perception* & *Psychophysics*, *42*, 105–113.

Bruning, J. L., & Kintz, B.L., (1977). *Computational handbook of statistics* (2nd ed., pp. 218–224). Glenview, IL: Scott, Foresman and Company.

Chatterjee, A. (2002). Neglect: A disorder of spatial attention. In M. D'Esposito (Ed.), *Neurological foundations of cognitive science* (pp. 1–26). Cambridge, MA: MIT Press.

di Pellegrino, G., Basso, G., & Frassinetti, F. (1998). Visual extinction as a spatio-temporal disorder of selective attention. *NeuroReport*, *9*, 835–839.

di Pellegrino, G., & De Renzi, E. (1995). An experimental investigation on the nature of extinction. *Neuropsychologia*, *33*, 153–170.

Heilman, K. M., Watson, R. T., & Valenstein, E. (2003). Neglect and related disorders. In K. M. Heilman & E. Valenstein (Eds.), *Clinical neuropsychology* (4th ed., pp. 296–346). London: Oxford University Press.

Husain, M., Shapiro, K., Martin, J., & Kennard, C. (1997). Abnormal temporal dynamics of visual attention in spatial neglect patients. *Nature*, *385*, 154–156.

Mark, V. W., & Heilman, K. M. (1998). Diagonal spatial neglect. *Journal of Neurology and Neurosurgery and Psychiatry*, *65*, 348–352.

Maylor, E. A., (1985). Facilitatory and inhibitory components of orienting in visual space. In M. I. Posner & O. S. Marin (Eds.), *Attention and performance XI* (pp. 189–207). Hillsdale, NJ: LEA.

Rao, S. M., Mayer, A. R., & Harrington, D. L. (2001). The evolution of brain activation during temporal processing. *Nature Neuroscience*, *4*, 317–323.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 849–860.

Robertson, I. H., Mattingley, J. B., Rorden, C., & Driver, J. (1998). Phasic alerting of neglect patients overcomes their spatial deficit of awareness. *Nature*, *395*, 169–172.

Rorden, C., Mattingley, J. B., Karnath, H.-O., & Driver, J. (1997). Visual extinction and prior entry: Impaired perception of temporal order with intact motion perception after unilateral parietal damage. *Neuropsychologia*, *35*, 421–433.

Shapiro, K. L., Raymond, J. E., & Arnell, K. M. (1994). Attention to visual pattern information produces the attentional blink in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 357–371.

Stelmach, L. B., & Herdman, C. M. (1991). Directed attention and perception of temporal order. *Journal of Experimental Psychology: Human Perception and Performance*, *17*, 539–550.

Titchener, E. B. (1908). *Lectures on the elementary psychology of feeling and attention*. New York: MacMillan.

Vaishnavi, S., Calhoun, J., & Chatterjee, A. (2001). Binding personal and peripersonal space: Evidence from tactile extinction. *Journal of Cognitive Neuroscience*, *134*, 181–189.

Walsh, V. (2003). A theory of magnitude: Common cortical metrics of time, space, and quantity. *Trends in Cognitive Sciences*, *7*, 438–488.