

WE have studied the distortion of perceived time in a patient with left neglect. This patient consistently overestimated the duration of stimuli in the neglected space. Overestimation was observed both with an interval comparison (300/700 ms) and with a time production (1 s) paradigm. We suggest that encoding duration in the hundreds of milliseconds range is a process based on an internal clock mechanism. The functioning of that clock varies as a function of the processing load.

**Key Words:** Time perception; Time production; Spatial attention; Visuo-spatial neglect

## Time perception in a neglected space

Gianpaolo Basso, Paolo Nichelli,<sup>CA</sup>  
Francesca Frassinetti and  
Giuseppe di Pellegrino

Dipartimento di Patologia  
Neuropsicosensoriale, Sezione di Neurologia,  
Università di Modena, Via del Pozzo, 71, 41100  
Modena, Italy

<sup>CA</sup>Corresponding Author

### Introduction

Space and time are two fundamental matrices of human behaviour. Studying patients with cerebral lesions can help us to understand the physiological basis of processing these two dimensions. Challenging observations that constrain our views of spatial attention have been derived from patients affected by visuo-spatial neglect, a disorder of orienting attention to stimuli contralateral to a cerebral lesion. Patients with left-sided neglect may fail to orient attention to the left side of a display even when stimuli are presented in the right (intact) visual field.<sup>1-3</sup> These patients show reduced left side processing despite normal visual function and constitute a unique opportunity to test whether memory-based models or internal clock models can account for subjective duration. According to memory-based models, the duration of an interval is extracted either from the amount of information<sup>4</sup> or from the number of changes (cognitive, environmental, emotional, etc.) occurring during the interval.<sup>5</sup> Clock models maintain that subjective durations are a function of the amount of attention allocated to the passage of time. Decreased processing from the neglected side would decrease the amount of information and the number of changes extracted from that side but would make more resources available to the internal clock. As a consequence, memory-based and clock models would respectively predict under- and over-estimation of stimuli presented at a neglected location.

We have challenged these two classes of time perception models by studying the distortion of perceived time in a patient with left neglect. His performance at different spatial locations was com-

pared with that of six matched normal controls (NC) and one hemianopic patient without neglect (HP).

### Materials, Methods and Results

A.M. is a 59-year-old right-handed man who was examined 2 months after an ischaemic stroke, which caused a left hemianopia and a moderate motor impairment to the left limbs. A CT scan showed a large lesion involving the right temporal-occipital region, part of the thalamus, and the posterior arm of the internal capsule. A.M. was alert and cooperative, with no general intellectual deficit. However, he showed a severe left-sided visuo-spatial neglect. On cancellation tasks (Bells' Test<sup>6</sup> and Mesulam Cancellation Test<sup>7</sup>) he consistently omitted crossing out several items on the left side of the display. When we asked him to bisect lines of different length, he displaced the midline to the right of the true centre. When asked to describe a room, both by direct inspection or from memory, he omitted several items on the left side.

In three experimental sessions we presented A.M. and six normal controls with a visual display constituted by a matrix of 5 × 6 red circles (Fig. 1). Circles were enclosed in a grey rectangle that appeared always to the right of a fixation cross, in A.M.'s sound hemifield. A black dot displayed inside a red circle was the target stimulus. Subjects were sitting in front of the computer screen. The grey rectangle of the stimulus pattern subtended 8° × 9.5° and was placed 1° to the right of the fixation cross. The target stimulus was a 0.2° black dot appearing in the centre of a red circle. Fixation was monitored by an experimenter sitting at the rear of the computer screen.

**Experiment 1:** Experiment 1 aimed to assess whether A.M.'s visuo-spatial neglect was also present within his right visual field. We asked A.M. and NC subjects to verbally report dots appearing at random for 200 ms, either on the right (first and second column of the matrix) or on the left side (fourth or fifth column) of the display. A total of 96 stimuli were displayed, one at a time.

A.M. omitted 50% stimuli in the two leftmost columns and 18.7% in the two rightmost columns ( $\chi^2 = 10.39$ , d.f. 1,  $p = 0.001$ ), while no NC subjects failed to report any stimulus at any location. Based on the presence of neglect in the right visual field, we decided to compare A.M.'s subjective duration of stimuli appearing in neglected and non-neglected parts of the display, while still presenting stimuli in the intact visual field.

**Experiment 2:** Subjects were examined in two separate sessions, each constituted by a training and a testing phase. During training, 10 long (700 ms) and 10 brief (300 ms) stimuli were presented in one of the two circles marked with an asterisk in Figure 1. In each testing phase 160 stimuli (40 long and 40 brief for each location) were presented in a pseudorandom order in either the left or the right circle and subjects were asked to discriminate between them.

No NC made any discrimination error in any condition. In the training session, when stimuli were repeatedly presented in the same location, A.M. made no error. In the experimental session, when stimulus position was randomly varied, A.M. misjudged 59.2% and 13.4% respectively of brief and long stimuli presented at the left location ( $\chi^2 = 23.09$ , d.f. 1,  $p < 0.0001$ ). Conversely, he misidentified 8.6% of brief and 45.2% of long stimuli appearing at the right location ( $\chi^2 = 23.57$ , d.f. 1,  $p < 0.0001$ ). In conclusion, his temporal perception was affected by spatial position. He tended to judge left and right stimuli respectively longer and shorter than they were. A.M.'s pattern of responses can be interpreted either as overestimation of stimuli on the left side of the display or as underestimation of those on the right side. Alternatively, his time perception could be distorted in both fields. To distinguish between these alternatives, we devised a procedure (Experiment 3) that allowed us to compare A.M.'s subjective durations of left and right-sided stimuli with those of control subjects. Moreover, to exclude that any distortion of subjective duration was a consequence of left hemianopia rather than of unilateral neglect, we added an hemianopic patient (HP) as a further control subject. HP is a 56-year-old male who had undergone a right occipital infarction 2 years before his testing. Computerized visual field examination demonstrated left homonymous hemianopia without

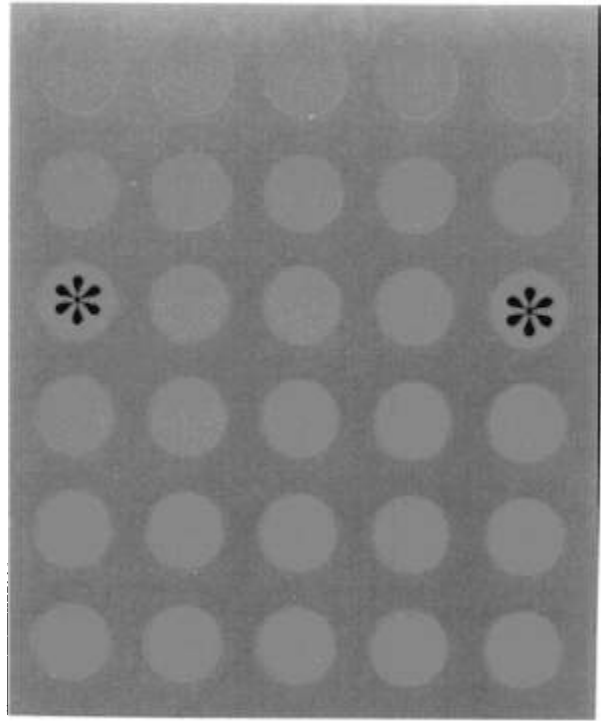


FIG. 1. Example of the stimulus pattern.

macular sparing. No other neurological deficits were detected. Furthermore, at the task described in Experiment 1, HP did not omit any stimulus at any location.

**Experiment 3:** In the third experiment, trials consisted of a variable wait (800–1200 ms) followed by the target stimulus. The subject were required to press a key to let the stimulus stay on the screen for 1 s. During training phase, 96 stimuli were displayed in a position  $1^\circ$  over the fixation cross and feedback on timing accuracy was provided with a  $\pm 150$  ms tolerance interval (correct, too short, too long). In two separate experimental sessions, a total of 480 stimuli (40 stimuli for each possible location) appeared in a pseudorandom order in any circle of the the first and fifth column. No feedback was given at this time. Note that, since we define overestimation as a ratio of  $> 1$  between estimated (predefined) and true (produced) duration, producing intervals shorter than expected is indicative of temporal overestimation.

As shown in Figure 2, A.M. produced an interval of 928 ms when the stimulus was displayed in the leftmost column. This interval was significantly shorter than the duration he was trained to produce at the fixation center ( $t_{233} = 3.369$ ,  $p = 0.0009$ ). This finding indicates that he was overestimating stimuli appearing on the left side of the display. Stimuli appearing in the rightmost column remained on the

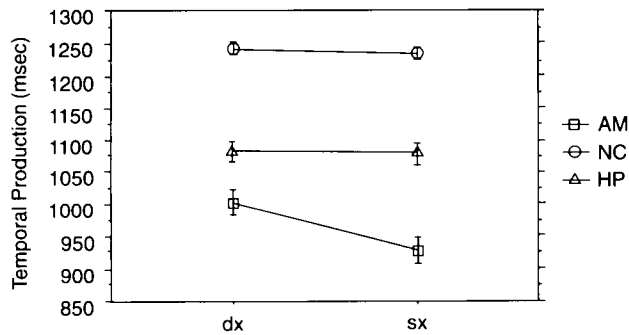


FIG. 2. Mean and standard error of the intervals produced by A.M., normal controls (NC) and an hemianopic patient (HP) in the left and in the right part of the display.

screen for an average of 1003 ms, not significantly longer than the trained duration ( $t_{236} < 1$ , n.s.). On average, A.M. produced intervals 75 ms shorter in the left than in the right side of the display ( $t_{469} = 2.493$ ,  $p = 0.01$ ), while neither HP nor any NC subject produced significant duration differences in relation to stimulus position (time differences ranged in NC subjects between +35 and -10 ms). NC subjects produced intervals of 1233 ms and 1242 ms, respectively in the leftmost and in the rightmost columns. HP produced 1078 ms at the left and 1081 at the right location. In conclusion, A.M. overestimated stimuli on the left side. NC subjects and HP showed a consistent trend toward underestimating both left and right-sided stimuli. However, no control subject showed any estimation difference according to the stimulus side.

## Discussion

Taken together, the data from our three experiments demonstrate a somewhat counterintuitive spatial distortion of temporal perception. A.M. perceived durations to be longer in that part of a display where he neglected 200 ms stimuli. Since it is conceivable that less information is available from neglected locations, our data challenge the hypothesis that duration is derived from the information stored in memory during the interval.

To account for the pattern of temporal order and simultaneous judgments in normal subjects, Stelmach and Herdman<sup>8</sup> proposed a model in which the temporal response of the visual system to a pulse of light is a skewed bell curve. According to this model, responses to impulses at unattended location would produce a broader function, i.e. the visual response would take more time to reach a maximum and more time to subside. On the contrary, responses to stimuli at attended location would be more brisk, with the response function reaching a maximum more quickly

and subsiding earlier. This theory anticipated that durations of unattended stimuli, due to their broader temporal profile, would appear to be longer, whereas duration of stimuli appearing at attended locations would appear to be shorter. Our results support this prediction.

As HP performed like NC subjects in the temporal production task, A.M.'s distorted subjective duration cannot be attributed to the presence of hemianopia but rather to left-sided visuo-spatial neglect. i.e. to defective allocation of attentional resources over the visual display. We hypothesize that attentional allocation affects the temporal profile of visual responses via an internal clock mechanism.<sup>9</sup> An internal clock consists of an accumulator that sequentially summates quantal time units produced by a pacemaker. The result obtained by the accumulator must then be compared to values in a reference memory system. In this framework, there are two possible explanations for the local temporal overestimation we have observed in A.M. According to one account, the pacemaker rate is constant and independent from the processing load, which only competes with the accumulator's reading of the pacemaker. Reduced visuo-spatial processing from the neglected side may increase resources available to the accumulator and result in a greater number of pulses in the time unit when stimuli are presented in the neglected field. Alternatively, the pacemaker rate might be affected. We may view pacemakers as reverberatory circuits containing several neurons with an oscillating activity.<sup>10</sup> Some of these neurons have input and/or output connections. We hypothesize that, under resting conditions, the oscillation stabilizes at a certain rate. Incoming information, by requiring extra computation, could slow it down. As a consequence of either mechanism, normal subjects after training with repeated presentation at the same visual location (i.e. with minimal visuo-spatial processing requirement), underestimated produced intervals when, during testing, they were required to distribute their attention over a larger visual display. Visuo-spatial neglect, by decreasing processing load, could either increase the number of pulses counted by the accumulator or accelerate the oscillation rate, which would ultimately cause temporal overestimation of stimuli appearing at the neglected location.

## Conclusion

This is the first report to show a link between a reduction in cognitive resources (caused by visuo-spatial neglect) and distortion of subjective stimulus duration. We have demonstrated that visuo-spatial neglect can cause overestimating stimulus duration at a neglected location. This finding supports models

maintaining that short durations are computed via internal clock mechanisms. We argue that the speed of the clock is affected by concomitant processing. Neglect, by reducing visuo-spatial processing, could speed up the rate of the internal clock. This would ultimately cause intervals to be judged longer than when they are measured with a slower clock.

**ACKNOWLEDGEMENTS.** This research was supported by a grant from the Italian National Research Council to P.N. We would like to thank Jordan Grafman for his helpful suggestions and for his support.

**Received 14 May 1996;**  
**accepted 4 June 1996**

## References

1. Driver J and Halligan PW. *Cognit Neuropsychol* **8**, 475-496 (1991).
2. Driver J, Baylis GC and Rafal R. *Nature* **360**, 73-75 (1992).
3. Behrmann M and Moscovitch M. *J Cogn Neurosci* **6**, 1-16 (1994).
4. Ornstein RE. *On the Experience of Time*. Middlesex, UK: Penguin, 1969.
5. Block RA. Contextual coding in memory. Studies of remembered duration. In: Michon JA and Jackson JL, eds. *Time, Mind, and Behavior*. Berlin: Springer-Verlag, 1985.
6. Gauthier L, Dehaut F and Joannette Y. *J Clin Exp Neuropsychol* **11**, 49-54 (1989).
7. Mesulam MM. Attention, confusional states and neglect. In: Mesulam MM, eds. *Principles of Behavioral Neurology*. Philadelphia, PA: Davis, 1985.
8. Stelmach LB and Herdman CM. *J Exp Psych: Human Perc and Perform* **17**, 539-550 (1991).
9. Gibbon J, Church RM and Meck WH. *Ann NY Acad Sci* **423**, 52-77 (1984).
10. Miall RC. *Neural Computation* **11**, 359-371 (1989).

### General Summary

We have examined subjective stimulus duration in a patient (A.M.) affected by left visuo-spatial neglect, a disorder that impairs the ability to orient attention contralateral to a cerebral lesion. We have demonstrated that A.M. neglected left sided visual stimuli even when they appeared in the right hemifield. At an interval comparison task, he judged stimuli on the left to be longer than those on the right side of the display. Temporal overestimation in the neglected field was confirmed with an interval production paradigm. These findings support the view that stimulus duration in the hundreds of milliseconds range is computed via an internal clock mechanism. The speed of the clock could be affected by concomitant processing. Reduced processing following visuo-spatial neglect could speed up the clock rate and cause temporal overestimation.