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Protocol

The traffic light paradigm: a reaction time task to study laterally directed arm movements

Paolo Bartolomeo[a,b,*]

[a]INSERM Unit 324, Centre Paul Broca, 2ter Rue d'Alésia, F-75014 Paris, France
[b]Neuroscience Department, Hôpital Henri-Mondor, Créteil, France

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Abstract

Patients with unilateral brain damage may show slowed or hypometric arm movements toward the contralesional space, as compared to movements directed towards the side of the brain lesion. The present article describes a reaction time paradigm devised to study accuracy and latency of directional arm movements in normal human subjects and brain-damaged patients. Experimental paradigms hitherto used to explore directional motor disorders often do not reliably disentangle between perceptual and motor factors, because they employ lateralized perceptual stimuli. The traffic light paradigm, instead, consists of visual stimuli presented on the vertical midline (like a traffic light) and hand responses to be produced in either hemispace. Thus, participants have to produce lateralized arm responses to central visual stimuli. Performance on this 'motor' paradigm can be contrasted with performance on a 'perceptual' reaction time task, consisting of similar, but lateralized visual stimuli and central motor responses. Results obtained with these paradigms on normal participants and brain-damaged patients are presented and discussed. These results give empirical support to the claim that the traffic light paradigm is suitable to study directional motor disorders in relative isolation from perceptual biases.

Theme: Neural basis of behaviour

Topic: Cognition

Keywords: Unilateral neglect; Directional hypokinesia; Reaction time; Brain damage

1. Type of research

1. (1) Attentional processes [48–50]
2. (2) Movement programming [31,44]
3. (3) Mechanisms of unilateral neglect [23]
4. (4) Directional motor disorders [9–13,15,17,18,26, 27,29,30,32,34–37,39,40,43,45–47,53]
5. (5) Hemispheric specialization [52]

2. Time required

Total: max. 40 min.

- Equipment set-up, task instructions and practice trials — 10 min (Aphasic patients may require a longer time than other participants to understand the task instructions.)
- Two experimental conditions — 10 min each. (Because the traffic light paradigm is a reaction time (RT) task with fixed number of trials, the time required to perform the task depends on the overall RT performance of each participant. For normal individuals, each condition of the task (up/left, up/right, see below, Section 5) normally requires less than 7 min. For patients with unilateral neglect, who often show

Abbreviations: LBD, Left brain-damaged; RBD, Right brain-damaged; RT, Reaction time

*Tel.: +33-1-4078-9210; fax: +33-1-4589-6848/4580-7293.
E-mail addresses: paolo@broca.inserm.fr (P. Bartolomeo), http://paolo.broca.inserm.fr/ (P. Bartolomeo).

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abnormally slow RTs, in our experience [7] the time required may increase up to about 10 min per experimental condition.)

- Interval between conditions — 10 min. During this time, paper-and-pencil neglect tests (such as those described in Ref. [4]) and the 'perceptual' RT task (see below, Section 7.2.2) may be administered.

3. Participants

The traffic light paradigm has been administered to normal individuals and to patients with unilateral brain lesions [4,6,7,16]. These participants generally found the task easy. Some aphasic patients with severe impairment in comprehension could not perform the task because they were unable to understand the task instructions. Occasional patients with extensive frontal damage could not learn the perception–action coupling needed to perform the task. On the other hand, patients with severe forms of unilateral neglect were usually able to perform the task [4,7,16]. Individuals who do not have normal or corrected-to-normal visual acuity should be excluded from studies employing the traffic light paradigm. Participants with unilateral hemispheric damage should use the hand ipsilateral to their lesion.

4. Materials

Almost any personal computer can be used to run the traffic light paradigm. The paradigm is currently implemented on Macintosh® desktop computers using SuperLab pro® software (which samples the keyboard two to three times every millisecond), but any hardware/software which can deliver simple images and collect RTs to the nearest millisecond from the computer keyboard would be adequate. A laptop computer can be used, provided that the monitor can deliver images with reasonable timing (LCD monitors are not suitable), but a separate, full-sized keyboard must be used to collect RTs. There is no special need for a colour monitor.

5. Detailed procedure

Participants sit in front of a computer monitor at a distance of approximately 50 cm. A paper board is placed on the computer keyboard, leaving three windows open on three different positions: a left-sided area (keys *q*, *w*, *e*, *a*, *s*, *d* of the American keyboard), a middle area (keys *i*, *o*, *p*, *k*, *l*, *;*), and a right-sided area (keys *7*, *8*, *9*, *4*, *5*, *6* of the numeric keypad). Left- and right-sided areas are about 13 cm distant from the middle area. Three black disks, each 13 mm in diameter, are presented on a white background, arranged in a vertical array at the midsection of the screen, similar to a traffic light. The distance between disks is 23 mm. After an interval of 2000 ms, one of the disks becomes grey (target: Fig. 1).

Upon the appearance of an upper target, participants have to move their hand from the home position near the centre of the keyboard to whatever key is situated in a lateral (e.g., left-sided) area, at a distance of about 16 cm from home position. Depending on the task conditions, each participant may use either the right or the left hand to perform the task. When a middle target appears, response keys are in the middle area, about 10 cm from the home position; when a lower target occurs, participants have to press a key on the other lateral (e.g., right-sided) area, at about 16 cm from home position. The target disappears when a response is made or after 5000 ms. After every trial, participants have to again place their hand at the home position. Response time is measured to the nearest millisecond from target onset to key press. One block of 12 practice trials and 10 blocks of four upper-, four middle-, and four lower-target trials each is presented. The order of

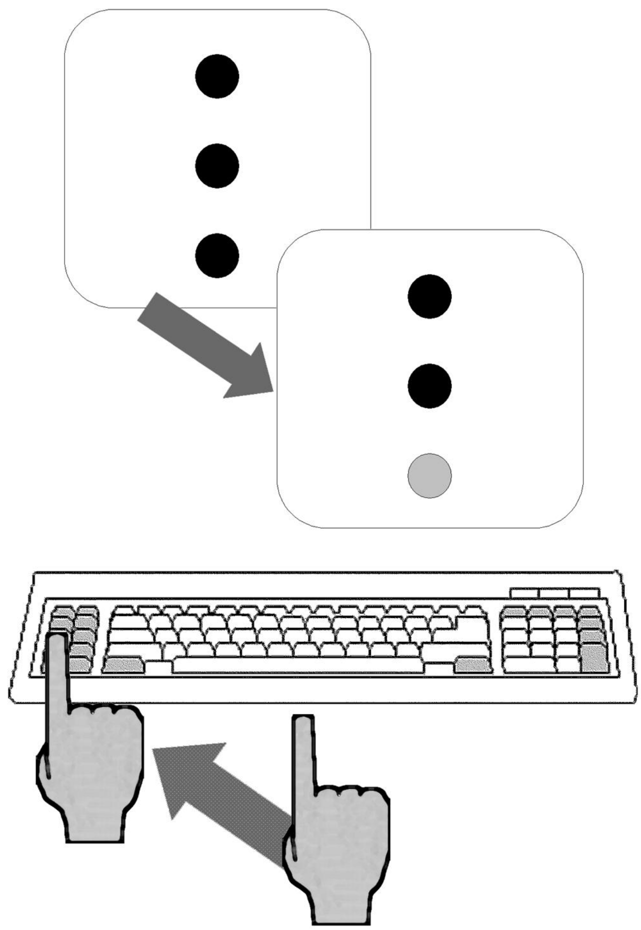

Fig. 1. The traffic light paradigm. A trial is shown in which the appearance of a lower target requires a left-sided response.

trials within a block is randomised. A typical experimental session begins with the RT task. Afterwards, other tests are administered (e.g., the paper-and-pencil visuospatial tests). At the end of the session, an inverted version of the RT task is performed (e.g., upper target→right-sided response, lower target→left-sided response). The order of performance of the two test conditions (upper/left, upper/right) is counterbalanced across participants.

Only correct lateralized responses, i.e., responses directed to the left- or the right-sided area, are taken into account in the RT analysis. All responses with RTs either less than 150 ms or more than 4500 ms are discarded from analysis. RTs and accuracy rates are entered in repeated-measures analyses of variance, with response site (left, right), task condition (up/left, up/right) and their order of performance as within-subject factors. The hand used and the presence or absence of unilateral neglect may constitute between-subject factors. To compare asymmetries of RTs or accuracy of response between patient groups with different overall RTs, laterality scores (e.g., (RT left − RT right)/(RT left + RT right)) can be obtained and used as dependent variable.

6. Results

We have employed the traffic light paradigm to study lateralized arm movements in patients with focal lesions in the right or in the left hemisphere. In a first study [7], 34 right brain-damaged (RBD) patients, of whom 14 showed signs of left neglect, and 15 normal controls took part in the experiment.

Results showed that neither the neglect nor the non-neglect group of patients had any evidence of directional slowing of performance with lateralized responses (Fig. 2). These results suggest that, when lateralized visual feedback is minimized, a slowing of leftward arm movements does not play a crucial role in left unilateral neglect, consistent with other abundant evidence [29,30,43]. It must be noted that left neglect patients did show an asymmetry of performance in the traffic light paradigm, because they were less accurate for left-directed than for right-directed responses; however, their speed in producing left-directed movements which correctly landed in the response area was comparable to that for rightward movements. Indeed, accuracy of performance, but not RTs, correlated with results on the neglect test battery and with performance on a ‘perceptual’ RT test with lateralized visual stimuli and central manual response (see below, Section 7.2.2). Inspection of individual performance revealed that only two RBD patients (showing no signs of severe neglect) were consistently slowed in producing leftward motor responses. We accounted for the observed dissociation between accuracy and speed by proposing that neglect patients were impaired in perceptually coding the left-sided response site; however, leftward movements per se were normal for most patients, as shown by RTs in those trials in which the left-sided landing area was correctly reached. While these

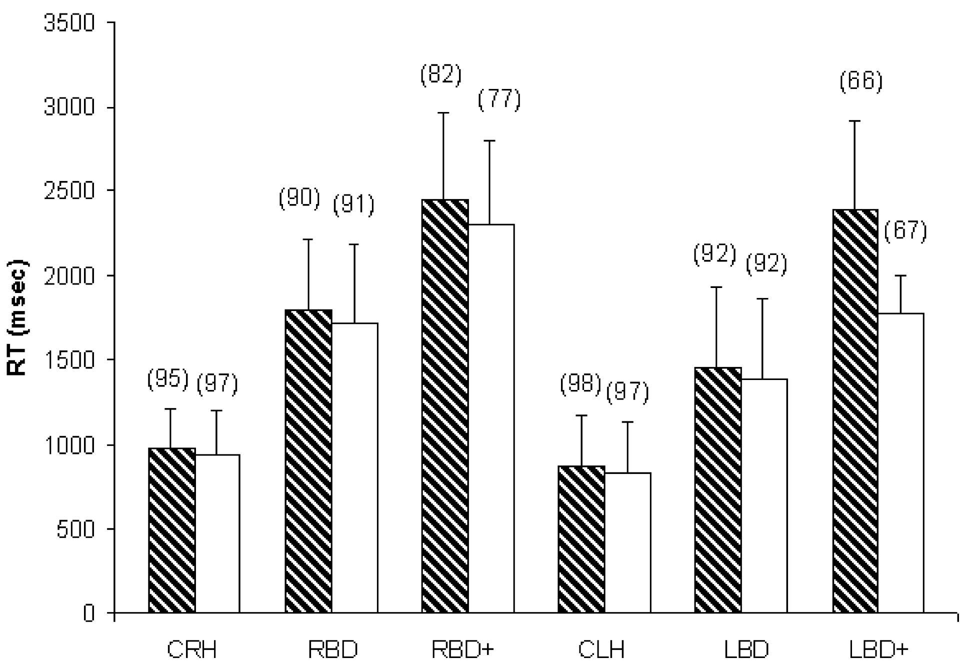

Fig. 2. Mean RTs and percentage of accuracy (in parentheses) on the traffic light paradigm of control subjects and RBD and LBD patients with or without contralesional neglect for response sites contralateral (hatched bars) and ipsilateral (white bars) to the hand used. Error bars represent 1 S.D. RBD patients used their right hand (data from Refs. [6,7]). CRH, controls using their right hand; RBD, right brain-damaged patients without signs of neglect; RBD+, right brain-damaged patients with left neglect; CLH, controls using their left hand; LBD, left brain-damaged patients without neglect; LBD+, left brain-damaged patients with right neglect.

results still leave open the possibility that a directional motor disorder may contribute to left neglect signs in some instances, they clearly also make the case for a double dissociation between left neglect and directional bias in executing arm movements.

In a subsequent study [6], 28 left-brain damaged (LBD) patients, of whom three had signs of right unilateral neglect, performed the traffic light paradigm with their left, unaffected hand. Ten age-matched, right-handed normal individuals also performed the task with their left hand. Results (see Fig. 2) revealed a very different picture from the study on RBD patients [7]. LBD patients with right neglect made a substantial amount of errors for both response sites (perhaps consistent with the notion of a left hemisphere dominance for action selection [52]), but were consistently slowed when producing arm movements toward the right (neglected) side, as compared to left-directed movements. As a matter of fact, when comparing the results of the two studies on RBD and LBD patients, LBD patients with neglect seems to be the group showing the most intense directional bias when producing laterally directed arm movements (Fig. 2). Taking into account patients with and without signs of neglect, the directional RT asymmetry shown by LBD patients in the traffic light paradigm positively correlated with performance on the perceptual RT task (which was generally less biased than in left neglect patients). This evidence needs confirmation, especially because of the low number of right neglect patients that could be recruited, due to the rarity of this disorder. Nevertheless, our results are in broad agreement with the hypothesis [23] that different mechanisms underlie left and right neglect. These results can be interpreted as reflecting a fundamental difference between laterally directing one's attention (as required by unilateral neglect tests) and the production of laterally directed hand movements without the need of a perceptual target selection. While ocular saccades, or covert shifts of attention, may be reflexively induced by the sudden onset of a target [48,54], the production of goal-directed hand movements typically require more controlled processes [31]. Thus, the frequent failure to find leftward hypokinesia for arm movements in RBD neglect patients might result from the fact that, in these patients, controlled processes are relatively preserved as compared with the heavily rightward-biased stimulus-dependent mechanisms [8,33]. On the other hand, right neglect might perhaps involve a bias affecting processing stages more closely related to endogenous orienting and action programming.

7. Discussion

The main advantage of the traffic light paradigm, as compared to most previous paradigms used to study directional motor disorders, is that no lateralized targets are presented in subjects' visual fields. This in order to minimize the influence of perceptual factors on the motor task. However, to detect a directional motor disorder the sites of response have to be lateralized. This could in principle render difficult the interpretation of a slowing of contralesionally directed responses. Would it arise from purely motor problems, or from a deficit in the perceptual encoding of the contralesional response area? Two arguments from the results of our study on RBD patients [7] contribute to settle this issue. First, most patients did not show this directional slowing, but a decreased accuracy for left-directed responses. This strongly suggests that the traffic light paradigm is indeed apt to dissociate perceptual from praxic factors in neglect, as the perceptual encoding of response location did not apparently influence RTs once the movement was started. Second, in the same study also a 'perceptual' RT paradigm was used (see below, Section 7.2.2), with lateralized targets and central responses. Results of this task showed a lateral asymmetry (RTs to right targets faster than RTs to left targets) in RBD patients, which correlated with the outcome of neglect tests and with accuracy, but not with RTs of the traffic light paradigm. Also this result suggests that RTs on the traffic light paradigm measure an ability different from perceptual space analysis.

7.1. Trouble-shooting

The traffic light paradigm involves a relatively easy task procedure, compared with other paradigms used to explore directional hypokinesia (e.g., tasks which require the patient to perform visually guided actions with a mirror providing 'inverted' visual feedback [53], or line bisection where the bisection point trajectory is 'inverted' by a pulley [10]). In our experience, the large majority of patients with focal brain lesions could satisfactorily perform the task. Some patients, however, could not understand the task instructions due to severe aphasia. Other (rare) patients, especially those with extensive frontal damage, had difficulty learning the stimulus–response coupling, or produced several perseverations or response. In some cases, these difficulties could be overcome by increasing the number of practice trials.

7.2. Alternative and support protocols

7.2.1. Alternative protocols

Several experimental paradigms have previously been proposed to study directional arm movements in brain-damaged patients, mostly in order to study their role in the determinism of left unilateral neglect. However, almost all these paradigms involved the presentation of lateralized visual stimuli, thus rendering difficult any conclusion about the role of a purely (pre)motor mechanism in subjects' performance. A notable exception is the task devised by Heilman et al. [27], and reported in their seminal article on directional hypokinesia. These authors asked six left neglect patients, seven LBD patients without neglect and 12 right-handed controls to move a handle as quickly as possible along a fixed horizontal pathway in the frontal plane, either rightward or leftward. Neglect patients were slower to initiate hand movements towards the left side of space than rightward-directed movements. Once the movement was initiated its speed did not vary, regardless of the direction. Normal controls and LBD patients without neglect did not show any asymmetry. Bisiach et al. [9] recorded the accuracy of 16 left neglect patients when pressing left- or right-sided buttons in response to lateralized visual stimuli. Crossed and uncrossed conditions were performed, in which the side of stimulation and the side of motor response were, respectively, the opposite or the same. Most errors concerned left-sided responses, irrespective of the side of stimulation, thus suggesting the presence of an ‘output neglect’. However, in the right stimulus/left response condition, crucial for demonstrating the output component, the ipsilesional stimulation could have captured patients’ attention [20,22], thus decreasing accuracy on contralesional responses. Other attempts to isolate the motor aspects of neglect include a line bisection test, in which a pointer could be moved by a pulley in the direction opposite to the hand movement [10], and a line cancellation test where left and right sides could be reversed using a mirror [13,53], an epidiascope [46], or a TV monitor [17,45]. These studies demonstrated instances of ‘motor’ and ‘perceptual’ forms of neglect. While perceptual factors prevailed in most neglect patients, motor factors seemed more pronounced in patients with lesions involving the frontal lobes, which appeared consistent with evidence coming from case reports [15,17,18,34]. However, Na et al. [45] found that ‘perceptual’ and ‘motor’ patterns of performance on line bisection and line cancellation were not always coherent in the same patients, thus casting doubts on the capacity of these paradigms to reliably distinguish between ‘motor’ and ‘perceptual’ forms of neglect. The particularly demanding situation faced by patients asked to perform a motor task with visual feedback being artificially reversed with respect to the proprioceptive feedback could render the task very difficult for patients with frontal lobe damage, thus explaining their impaired performance in the non-congruent condition [38].

More ‘ecological’ paradigms devised to study directional motor disorders have often failed to provide evidence for these disorders. Mijovic’ [43] asked 40 right brain-damaged patients to find a target among distractors by moving the stimulus display board under a panel until the target appeared in a window (e.g., to bring a right-sided target into view, the board was to be moved towards the left). Patients were fast and accurate in this task, thus not showing any evidence of directional hypokinesia. Ishiai et al. [29,30] asked neglect patients to extend a line leftwards to double its original length. The presence of a directional motor disorder should have shortened the left part of the line, but this was neither observed in patients with parietal lesions, nor in patients with frontal lesions. Patients as a group performed in the range of controls, with occasional patients showing a tendency to overextend lines. Bisiach et al. [12] examined 91 left neglect patients and 43 RBD patients without neglect on a similar line extension task, but additionally requiring patients to extend lines also rightward. Twenty-seven neglect patients showed a tendency to leftward overextension, but 14 other neglect patients showed an opposite rightward overextension. In a similar vein, Perri et al. [47] compared line bisection with paper-and-pencil extension either toward the left or toward the right side. They studied 25 right-brain damaged patients (of whom 16 had left neglect) and 11 controls. Neglect patients deviated rightward on line bisection, but they performed no differently from controls or patients without neglect when extending lines in either direction. It might thus be that line extension evokes different attentional mechanisms than the perceptual evaluation of a visual scene or of a to-be-bisected line. As Ishiai et al. [29,30] note, neglect patients rarely look at the left end of a line when bisecting it; on the other hand, when extending a line patients’ attention may follow the leftward movement of the pencil tip. Thus, line extension could be a spatial task which forces neglect patients to continuously monitor their spatially oriented activities, thereby reducing or eliminating signs of neglect. In the *landmark test* [26], subjects have to point to either of the ends of a mid-transected line which they judge closer to the transection, under the assumption that leftward hypokinesia would force patients to point predominantly to the right extremity, independent of their perceptual judgement. Of eight patients tested by Harvey et al. [26], seven pointed consistently leftward, thus showing perceptual forms of neglect. Only one patient pointed predominantly rightward, a pattern suggestive of directional motor deficit. Bisiach et al. [11] tested 121 neglect patients on a similar task. Patients had either to manually point to the shorter segment of a black pre-bisected line, or to name the colour of the shorter segment of lines composed of two segments, one black and the other red. Instances were found of ‘perceptual bias’ (i.e., patients pointing to or defining the left segment as shorter) and of ‘response bias’ (the opposite pattern of performance). Both forms of bias correlated with each other across the two task conditions (pointing versus verbal responses). However, perceptual bias was mainly associated with anterior brain lesions, whereas response bias was more frequently associated with subcortical damage, contrary to the prevalent theoretical framework [41]. In some cases, the authors found the two types of bias to be present in the same patient. Mattingley et al. [36] requested brain-damaged patients to press buttons which were horizontally arranged and illuminated in sequence from left to right or in the opposite direction. RBD neglect patients were slower when executing leftward movements than when moving rightward. In particular, patients with retro-rolandic lesions were slowed when initiating movements toward a button illuminated on the left side, whereas patients with anterior or subcortical lesions showed a decreased speed of leftward movements. However, in this paradigm patients had to detect the occurrence of a left-sided stimulus before moving to reach it, thus rendering difficult any interpretation of these results in terms of directional hypokinesia. Indeed, in another study employing the same paradigm, Mattingley et al. [37] found that leftward movements were slowed in neglect patients only when the movement path could not be predicted in advance, and a concurrent right distractor was presented. In a further study, Mattingley et al. [39] asked left neglect patients with right parietal or frontal lesions to reach for lights appearing right or left of fixation with their hand starting at the body midline (i.e., between the targets) or left or right of both targets. Parietal patients showed a deficit in initiating leftward reaches. However, when the hand started from the extreme right position, left targets evoked again slower responses than right targets (which also required a leftward movement in this condition), indicating that the impairment did not concern leftward movements per se, but only leftward movements directed to left-sided targets.

In the light of these considerations, the traffic light paradigm appears to provide a reasonably suitable task to study directional arm movements independently of lateralized perceptual deficits. In our experience, this paradigm was simple enough as to be performed by the vast majority of patients, with the exception of some aphasic patients with severe comprehension deficits. The addition of a 'perceptual' RT task (see Section 7.2.2. below), consisting of lateralized perceptual stimuli and central responses, allows a direct comparison in single subjects between the ability to process lateralized visual stimuli and the capacity to produce lateralized hand responses.

7.2.2. *Support protocols*

7.2.2.1. 'Perceptual' RT task. The principal aim of the traffic light paradigm is to isolate directional motor disorders from more perceptually related components of unilateral neglect. It is thus of interest to compare participants' performance on this task, characterized by central visual stimuli and lateralized responses, with performance on a similar RT task, in which stimuli are lateralized and responses centred. Here follows a description of the procedure of this 'perceptual' RT task, which has been shown to be sensitive to forms of spatial bias not evident on paper-and-pencil testing [2–4,7].

Subjects sit in front of a computer monitor at a distance of approximately 50 cm. Three horizontally arranged black disks are displayed, the central disk being located at the centre of the screen. Distance between disks is 23 mm. During the test, the disks are always present on the screen. After an interval of 2000 ms, one of the disks became grey (target: Fig. 3).

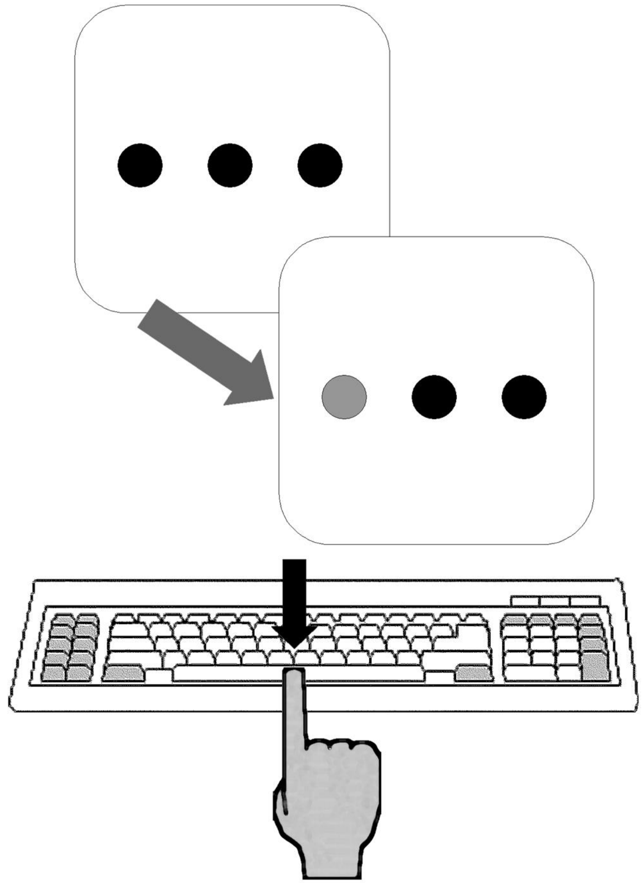

Fig. 3. The 'perceptual' RT paradigm. A trial is shown in which a left-sided target is presented.

When a right- or a left-side target appears, subjects have to respond by pressing the computer spacebar with the index finger as quickly as possible. Depending on the task conditions, each participant may use either the right or the left hand to perform the task. Subjects have to refrain from responding when the middle circle became grey (*catch trials*, a procedure devised to avoid the possibility of subjects responding to the fixed time interval[1]). Response time is measured from target onset to key press. The target disappears when a response is made or after 5000 ms. One block of six practice trials and 10 blocks of four right- and four left-sided trials each are presented. The order of trials within a block is randomised. In order to minimize the influence of possible oculomotor components, subjects are instructed to keep fixation on the central circle, and eye position is monitored.

7.2.2.2. Neglect battery. To explore the relationships between unilateral neglect and the performance on the traffic light paradigm, unilateral neglect has to be assessed by a

[1]Catch trials may be avoided if the intertrial interval is randomized. For example, it can be randomly chosen from the set 1000, 1300, 1700 or 2000 ms [2,3].

battery of paper-and pencil visuospatial tests. Here follows a short description of the component tasks of the battery we used [4,6,7,16]. Other standardized batteries for unilateral neglect are the Behavioural Inattention Test [25] and the French battery for neglect evaluation [51].

In the *overlapping figures task* [22], patients are requested to identify five patterns of overlapping linear drawings of common objects. Each pattern included a central object (e.g., a basket) with a pair of objects depicted over each of its sides (e.g., a lamp and a watch on the left side, a pipe and a key on the right side).

In the *cancellation tests*, an horizontal A4 sheet is presented to the patient, who is asked to cancel stimuli of various kind which are scattered on it: lines [1], As (among other letters [42]), or silhouettes of bells (among other objects [24]).

In *line bisection tests*, patients are asked to bisect horizontal lines. We used a version of this test originally described by D'Erme et al. [19]. It consists of three 62-mm, three 100-mm, and two 180-mm samples, horizontally disposed in a vertical A4 sheet, in a fixed random order, at different distances from the left margin of the sheet.

The *copy of a drawing* is another task which can be diagnostic of neglect. One can for example ask patients to reproduce a linear drawing representing a house and four trees [23], presented on a horizontal A4 sheet.

To obtain a quantitative measure of spatial bias in each component test of the visuospatial battery, one may compute laterality scores for each of the neglect tests using the following procedure [4]. For the line bisection test, one can calculate the cumulated percentage of deviation from the true centre for all the lines. Rightward deviation assumes a positive sign, whereas leftward deviations carry a negative sign. For the overlapping figures test and each of the cancellation tests, the bias toward the right side can be estimated by using a laterality score, defined as

$$(x_1 - x_2)/(x_1 + x_2).$$

Values for x_1 are given by the number of items identified on the right side for the overlapping figures test, or the number of items cancelled on the right half of the page for the cancellation tests. Values for x_2 are computed in an analogous fashion, i.e., by using the number of left-sided identified overlapping figures and the number of left-sided cancelled items. One advantage of this laterality score is that it provides a quantitative estimate of spatial bias which is independent of the overall level of performance (e.g., of the total number of cancelled lines). The score can range from -1 (all the items reported or cancelled on the left side, none on the right side) to $+1$ (the opposite situation). A correction is needed for cancellation tasks performed by patients with severe neglect, who cancel only the rightmost items, without crossing the midline. In order not to underestimate their neglect, the laterality score obtained by these patients is augmented by the proportion of the number of neglected items on the right side (max. $+1.48$ for line and letter cancellation, and $+1.47$ for bell cancellation, corresponding to a single item cancelled on the right). The landscape copy may be evaluated by assigning 2 points to each item completely omitted, 1 point to each item whose right half was copied, and 0 points to each item completely copied. The obtained scores can thus range from 0 (all the items completely copied) to 9 (only the right half of a single item copied).

8. Essential references

Original papers: [4,6,7,16,27]
Book chapters: [5,14,28,38]
Review papers: [21]

9. Quick procedure

1. Participants sit in front of a computer monitor at a distance of approximately 50 cm.
2. A paper board is placed on the computer keyboard, leaving three windows open on three different positions: a left-sided area (keys *q*, *w*, *e*, *a*, *s*, *d* of the American keyboard), a middle area (keys *i*, *o*, *p*, *k*, *l*, *;*), and a right-sided area (keys *7*, *8*, *9*, *4*, *5*, *6* of the numeric keypad).
3. Three black disks, each 13 mm in diameter, are presented on a white background, arranged in a vertical array at the midsection of the screen, similar to a traffic light. After an interval of 2000 ms, one of the disks becomes grey (target).
4. Upon the appearance of an upper target, participants have to move their hand from the home position at the centre of the keyboard to whatever key is situated in a lateral (e.g., left-sided) area. When a middle target appears, response keys are in the middle area. When a lower target occurs, participants have to press a key on the other lateral area. The target disappears when a response is made or after 5000 ms. After every trial, participants have to again place their hand at the home position. Response time is measured from target onset to key press.
5. One block of 12 practice trials and 10 blocks of four upper-, four middle-, and four lower-target trials each is presented. The order of trials within a block is randomised.
6. At the end of the session, an inverted version of the RT task is performed (e.g., upper target→right-sided response, lower target→left-sided response).
7. Only correct lateralized responses, i.e., responses directed to the left- or the right-sided area, are taken into account in the RT analysis. All responses with

RTs either less than 150 ms or more than 4500 ms are discarded from analysis.

8. RTs and accuracy rates are entered in repeated-measures analyses of variance, with response site (left, right), task condition (up/left, up/right) and their order of performance as within-subject factors. The hand used and the presence or absence of unilateral neglect may constitute between-subject factors. To compare asymmetries of RTs or accuracy of response between patient groups with different overall RTs, laterality scores (e.g. (RT left − RT right)/(RT left + RT right)) can be obtained and used as a dependent variable.

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