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Temporal order judgements as a sensitive measure of the spatial bias in patients with visuospatial neglect

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Visuospatial neglect is not a unitary phenomenon, but can be better considered a syndrome, consisting of a multitude of different spatial and non-spatial components. In this study, we used a temporal order judgement (TOJ) test in a large sample of stroke patients (n = 73) to scrutinize the contribution of a spatial bias to the performance on shape cancellation and line bisection tests. In the TOJ test, patients were presented with two elements, one in each visual field, after which the one needed to indicate which of the two elements was presented earlier. For each visual field, the presentation of the stimuli was determined by a staircase procedure where the interval between the two stimuli was determined by the performance of the patient. Results indicated that the strength of the spatial bias was strongly correlated with an object cancellation test, but not with a line bisection test. We argue that these findings are explained by differences in the extent to which a spatial bias determines performance on both tasks: In contrast to shape cancellation tests, successful performance on line bisection tests depends primarily on an object-based, allocentric representation of space, unrelated to any spatial bias in the detection of elements in the contralesional visual field.

Visuospatial neglect has generally been associated with an attentional imbalance between the two visual fields (Kinsbourne, 1987; Posner *et al.*, 1984). In recent years, however, it has become evident that visuospatial neglect is not a unitary phenomenon, but can be better defined in terms of a syndrome, consisting of a multitude of different spatial and non-spatial components (e.g., Malhotra *et al.*, 2004; Vallar, 1998; Van der Stigchel & Nijboer, 2014; Wansard *et al.*, 2016). In a recent factorial analysis, the total variance across various neglect screening tests was for 82% explained by three main factors related to perceptive/visuospatial, exploratory/visuomotor, and allocentric/object-centred aspects of spatial neglect (Verdon *et al.*, 2010). The concept of neglect being a multifaceted disorder is in contrast to the clinical practice in which deficits on neglect screening tests are commonly interpreted as reflecting a common attentional deficit. These neglect tests might not measure the same components of the neglect syndrome, however. Because of this, a given patient might show an impairment on one test (e.g., cancellation test), but not on the other (e.g., line bisection test), depending on which components are impaired in that particular

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patient. Indeed, previous studies have observed double dissociations between different neglect tests (Binder *et al.*, 1992; Ferber & Karnath, 2001; Halligan & Marshall, 1992; Schubert & Spatt, 2001; Sperber & Karnath, 2016; Van der Stoep *et al.*, 2013).

Additionally, there is now evidence that performance on both line bisection and cancellation tests can be confounded by other factors than a lateralized imbalance in attention. Typically, with line bisection tests, the patient has to bisect a number of lines on a sheet of paper (Axenfeld, 1894). Line bisection, however, requires the correct perception of the size of a single stimulus and successful performance therefore depends primarily on an object-based, allocentric representation of space (Rorden *et al.*, 2006). In contrast, on cancellation tests, patients have to cross the different targets interspersed among various non-target elements (Weintraub & Mesulam, 1985). Cancellation tests were developed to allow for assessing other aspects of the neglect syndrome, the idea being that the competition between different elements would make such a test more difficult and therefore more sensitive than line bisection tests which only require the correct perception of a single stimulus without any competition evoked by the presence of other elements (Ferber & Karnath, 2001; Vanier *et al.*, 1990). There is, however, ample evidence that performance on cancellation tests is mediated by deficits in spatial working memory. These problems might lead to deficits on cancellation tests which are unrelated to any spatial bias. Due to problems in spatial working memory, patients with neglect frequently revisit targets (Mannan *et al.*, 2005; Nys *et al.*, 2010; Rusconi *et al.*, 2002; Wojciulik *et al.*, 2001) and have problems reporting whether a certain object is novel which could result in inefficient search (De Wit *et al.*, 2017; Husain *et al.*, 2001). Both line bisection and cancellation tests are therefore likely to measure different aspects of the neglect syndrome.

So, although both tests have been used to asses neglect, none of these tests seems to be appropriate to exclusively measure the core component of the neglect syndrome: the spatial bias, favouring detection of elements in the ipsilesional visual field over the contralesional visual field. One test, which seems highly suitable to assess this spatial bias, is a temporal order judgement (TOJ) test. In such a test, patients are presented with two elements, one in each visual field, after which the patient has to indicate which of the two elements was presented earlier. For each visual field, the presentation of the stimuli is determined by a staircase procedure in that the interval between the two stimuli is determined by the performance of the patient. Any spatial bias is then revealed by a difference between these two staircases, as a lack of attention for a part of the visual field is associated with a delay in the perception of an object presented in the neglected part. This association can be explained by the law of prior entry discovered in healthy subjects (Shore *et al.*, 2001): A stimulus presented at an attended location will be perceived sooner than a comparable stimulus at an unattended location. This effect has been explained by differences in the rate of transfer of inputs from the early stages of sensory analysis to later decision processes, which is claimed to be more efficient for attended than for unattended locations (Shore *et al.*, 2001).

Previous studies using the TOJ test in neglect patients have shown that this test indeed captures the differences in spatial bias between the two visual fields. Patients with neglect tend to judge the right stimulus as having appeared prior to the left stimulus, unless the left stimulus leads substantially in time (Rorden *et al.*, 1997; Sinnett *et al.*, 2007). Furthermore, this imbalance has been shown to be reduced after prism adaptation, known to ameliorate neglect symptoms in a subset of neglect patients (Berberovic *et al.*, 2004) and when neglect patient's alertness is phasically increased during the assessment of the TOJ test (Robertson *et al.*, 1998).

In order to investigate to what extent performance on standard neglect tests is dependent on the spatial bias, the aim of this study was to relate performance on the TOJ test to performance on line bisection and cancellation tests. To this end, a large sample of stroke patients performed all three tests in the same session, allowing for a direct correlation between performances between the different tests. The TOJ test is appealing as it is a computerized test, which enables the modification of the thresholds based on the patient's performance. Therefore, this test will automatically be more difficult with accurate performance, which eliminates any ceiling effect, and easier if a patient has a very strong spatial bias, eliminating any floor effect. Instead of testing only neglect patients, we tested a large group of stroke patients, because we were also interested in patients who show no deficits on the standard neglect tests, but do show deficits on the TOJ test. Testing only diagnosed neglect patients might have obscured finding these patients.

Methods

Participants

We included stroke patients who were admitted for inpatient rehabilitation in rehabilitation centre 'De Hoogstraat' from November 2012 to August 2013.

Within the first 2 weeks of admission to the rehabilitation centre, a neuropsychological neglect screening took place as standard care. Patients were screened when they met the following criteria: (1) stroke (confirmed with a CT or MRI scan) as a diagnosis; (2) aged between 18 and 85 years; (3) no severe deficits in communication and/or understanding; and (4) normal or corrected-to-normal visual acuity. The TOJ test was measured as part of this screening.

The included patient's medical record was reviewed, and the following admission-to-rehabilitation data were captured: gender, age, lesion side, time post-stroke onset in days, indication of cognitive functioning as measured with the Mini-Mental State Examination (MMSE), motor strength of upper and lower extremities as measured with the Motricity Index (MI arm and leg), presence of language communication deficits as measured with the SAN ('Stichting Afasie Nederland'), and independence in (basic) activities of daily living as measured with the Barthel Index (BI).

The MMSE (Folstein *et al.*, 1975) is a screening instrument to globally assess cognitive functioning, including memory, orientation, attention, language, and visuoconstruction. Scores range from 0 (no items right) up to 30 (all items right).

The MI (Collin & Wade, 1990) is a short three-item test to administer loss of strength in the arm and leg. Scores range from 0 (no activity, paralysis) up to 33 (maximum normal muscle force) for each dimension, +1 gives a total score of 100.

The SAN is a short task of language communication. Scores range from 1 (no communication through language possible) to 7 (speech and understanding of language are unimpaired).

The BI (Collin *et al.*, 1988) measures the extent to which stroke patients can function independently in their activities of daily living. Scores range from 0 (completely dependent) up to 20 (completely independent).

Procedure

All patients performed a shape cancellation test, a line bisection test, and a TOJ test in the same session. The order of the tests was randomized across patients. The patients used their non-paretic arm to respond during the computerized tests, except for the TOJ test in which the patient responded verbally.

Shape cancellation test

The shape cancellation test consisted of 54 small targets (0.6° × 0.6°), 52 large distractors, and 23 words and letters (widths ranging from 0.95° to 2.1° and heights ranging from 0.45° to 0.95°). The stimulus presentation was approximately 18.5° wide and 11° high. Participants were instructed to click all targets using the computer mouse and tell the examiner when they had completed the test. No time limit was given. After each mouse click, a small circle appeared at the clicked location and remained on screen, regardless whether a target, distractor or a location in between was clicked. Participants viewed the display monitor from a distance of 120 cm.

Line bisection test

Three horizontal lines (22° long and 0.2° thick; 43.5 × 0.05 cm on the screen) were presented simultaneously at different positions. Similar to the Behavioral Inattention Test (Wilson *et al.*, 1987) and other line bisection tests (e.g., Axenfeld, 1894), we presented the lines at different locations. The first line was presented upper right, the third line upper left, and the middle line in the horizontal and vertical centre of the screen. The amount of horizontal shift between lines was 15% of the line length. Participants were asked to indicate the centre of each line by moving the cursor with the mouse and clicking on the subjective mid-point, where after a vertical line appeared at the clicked location. Participants had to start with the upper line and work their way down. The three lines were presented four times in a row, after which the average deviation from the mid-point was calculated for each line separately. Participants viewed the display monitor from a distance of 120 cm.

Temporal judgements test

A red and a green equiluminant square (0.26° × 0.26°) were presented 3.16° to the right or left of fixation. One of these two squares was presented earlier. Participants had to indicate verbally whether the green or red square was presented earlier. The experimentor subsequently pressed either the 'r' of the 'g' key to indicate a red or green response, respectively. We used a staircase procedure to investigate possible temporal differences between the right and left visual field. To this end, we determined the threshold for both visual fields by multiplying the current threshold for a particular visual field with 0.5 when three correct answers were given in a row and by multiplying it by 0.5 when one incorrect answer was given. The total experiment consisted of 100 trials. The sequence of trials was randomized. Participants viewed the display monitor from a distance of 90 cm.

Analyses

Shape cancellation test

Patients with a difference score of two or more omissions between the two sides of the screen were defined as patients with visuospatial neglect (see e.g., Van der Stoep *et al.*, 2013). We also computed the horizontal and vertical Centre of Cancellation (CoC), a indicative measure of severity of neglect. The CoC combines information of both the number of omissions and the location of the cancelled items, with a CoC-score towards zero indicating a symmetrical distribution of omissions (Rorden & Karnath, 2010).

We specifically focused on the difference score in the number of omissions and not the total cancellation score, because the total cancellation score only reveals non-spatial deficits. As our aim was to scrutinize the contribution of a spatial bias to the performance on shape cancellation and line bisection tests, we adopted the measure that best reflected this spatial bias.

Line bisection test

We calculated the deviation between the actual centre and the subjective mid-point for each line in degrees of visual angle. Deviation scores were transformed such that negative deviation values indicated a shift of the subjective mid-point to the contralesional side of the actual centre. Because of the low number of trials in the line bisection test, scores for the three lines were averaged. The cut-off score was defined as the mean deviation plus three standard deviations of performance of 28 healthy participants (Van der Stoep *et al.*, 2013). The cut-off scores for the deviation score were 0.47 and −0.74. Patients who showed an average deviation that was larger than the cut-off score were defined as having spatial neglect.

Temporal judgements test

For each participant and for each visual field, the temporal offsets of the last eight turning points were examined. Temporal offsets for which the contralesional target appeared first were expressed as negative numbers. The turning point data were averaged to determine the point of subjective simultaneity (PSS). Because the absolute thresholds for both visual fields differed greatly in magnitude between patients, the PSS was normalized with respect to the mean absolute thresholds for both visual fields. In this way, the PSS was expressed relative to the magnitude of the thresholds for both visual fields, revealing a clear indication of the strength of any lateralized bias, irrespective of any non-lateralized deficit. For example, a difference of 50 ms between the thresholds of both visual fields is more informative when both thresholds are below the 100 ms than when both thresholds are around the 300 ms.

The cut-off score was determined by including 20 age-matched control participants on the same task (mean age = 58 years, st. dev. = 16; $p = .59$). This cut-off score was defined as the mean PSS (i.e., normalized) of the control group plus two and a half standard deviations (mean = 0.36; st. dev. = 0.19). Patients who showed a PSS that was larger than the cut-off score (0.85) were defined as showing a lateralized deficit on the TOJ test. PSS values were transformed such that a negative PSS referred to a higher contralesional threshold, whereas a positive PSS indicated a higher ipsilesional threshold.

To validate the cut-off score, we used Crawford and Howell's significance test on differences between individual's score and control sample to investigate whether the adopted cut-off value of the TOJ test is indeed different from the control group (Crawford & Howell, 1998). By inserting our cut-off score and comparing it to the control sample, we could confirm that this cut-off score is indeed significantly different from the control sample ($t = 2.52$; $p = .02$; estimated percentage of normal population falling below individual's score: 98.95%). This comparison is not significant for a cut-off score of 1.6 times the standard deviation above the mean (p = .14).

Correlations between tests

To determine whether TOJ performance correlated with performance on the shape cancellation and line bisection test, we performed Pearson correlations between the PSS and both the omission difference score of the shape cancellation test and the deviation score of the line bisection test.

Results

Demographic and stroke characteristics

A group of 73 patients was included in the study. An overview of demographic and stroke characteristics is given in Table 1.

Shape cancellation test

Overall, the average total number of omissions was 2.07 (st. dev. = 4.95). The average difference score of omissions was 0.97 (st. dev. = 2.74). 21.9% of the patients had visuospatial neglect (*contralesional* neglect: 19.2%, mean difference score = 4.6 [st. dev. = 4.7]; *ipsilesional* neglect: 2.7%, mean difference score = 2.0 [st. dev. = 0]). For the non-neglect patients, the mean difference score was <0.01.

The absolute horizontal CoC of the neglect patients was 0.06 (st. dev. = 0.13), and the absolute vertical CoC was 0.02 (st. dev. = 0.02). For the non-neglect patients, both CoCs were lower than 0.01. The absolute horizontal CoC for the patients with contralesional neglect was 0.13 (st. dev. = 0.08), whereas this was only 0.06 (st. dev. = 0.005) for the patients with ipsilesional neglect.

Table 1. Mean scores and standard deviations at demographic and stroke characteristics of the whole group

	Patients (N = 73)
Gender (% male)	60.72
Age (years)	60.33 (11.28)
Time post-stroke (days)	30.23 (18.39)
Hemisphere of stroke (% right)	50.7% right
Aetiology (%)	
Ischaemic	85.7
Haemorrhage	27.0
SAH	1.6
Mini-Mental State Examination	26.59 (3.83)
Barthel Index	12.74 (5.61)
MI Arm	61.64 (36.59)
MI Leg	67.03 (34.07)
Stichting Afasie Nederland	5.57 (1.70)

Note. MI = Motricity Index.

Line bisection test

Overall, the mean deviation was 0.15 (st. dev = 0.52). 24.7% of the patients had visuospatial neglect (contralesional neglect: 21.9%, mean deviation = 0.80 [st. dev. = 0.41]; *ipsilesional* neglect: 2.7%, mean deviation = 1.22 [st. dev. = 0.44]). For the patients with deficits on this test, the mean deviation was approximately 2 cm on the screen (i.e., 4.5% of the total line). For the non-neglect patients, the mean deviation score was <0.01.

Temporal judgements test

Note that the PSS was normalized with respect to the mean absolute thresholds for both visual fields. The average normalized PSS was −0.12 (st. dev. = 0.52). The different PSSs for the patient group are represented in Figure 1, in which it can be seen that seven patients had a contralesional deficit (9.6%), as their score fall outside of a PSS of 0.85, which is the cut-off score as obtained in the control group. Using these same criteria, one patient had an ipsilesional deficit (1.4%). As the PSS is expressed relative to the magnitude of the thresholds for both visual fields, these values do not represent the actual difference between the thresholds for both visual fields. For the patients showing a deficit, their actual difference varied between 127 and 1,896 ms (mean = 737 ms, st.dev. = 637 ms). An example of the results of one of these patients (actual difference of 626 ms, PSS = −0.98) can be seen in Figure 2.

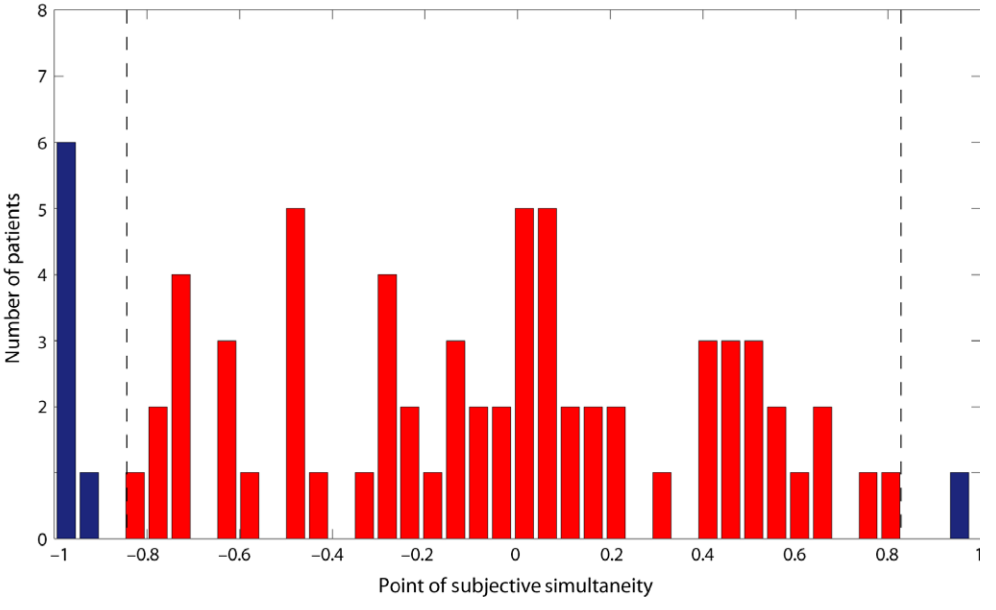

Figure 1. Overview of the different point of subjective simultaneity (PSS) scores for all the included patients. Negative values refer to a PSS in which the contralesional threshold is higher than the ipsilesional threshold. Patients scoring outside of the cut-off score (seven contralesional deficits; one ipsilesional deficit) are indicated in blue, whereas the patients scoring within the normal range are indicated in red. The cut-off scores are indicated by the vertical dashed lines. [Colour figure can be viewed at wileyonlinelibrary.com]

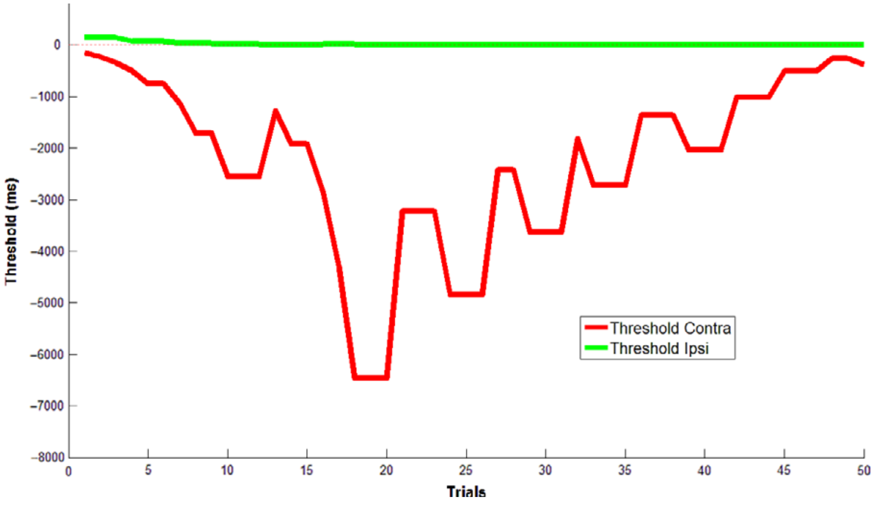

Figure 2. The progression of point of subjective simultaneity (PSS) across the 100 trials for one patient showing a deficit on the temporal order judgement (TOJ) test. Although the ipsilesional threshold stays constant and very low (green line), the contralesional threshold fluctuates and levels out at around 250 ms (red line). [Colour figure can be viewed at wileyonlinelibrary.com]

Shape cancellation test versus temporal judgements test

A Pearson correlation between the omission difference score on the shape cancellation test and the PSS for all patients revealed a significant correlation ($r = -.39$; $p < .001$). This indicates that the larger the asymmetry between the omissions in both visual fields, the larger the PSS was with a higher staircase for the contralesional hemifield. Indeed, the patients that were impaired on the shape cancellation test had a larger absolute PSS than the patients showing no deficits on the shape cancellation test, $t(71) = 3.87$; $p = .0002$.

In Figure 3, it can be observed that there are a few cases for which the attentional imbalance as indicated by the temporal judgements test was not reflected in the omission difference score. Three patients (4.1% of the total patient group) had an imbalance on the temporal judgement test, but no imbalance of two or more in omissions on the shape cancellation test. Along similar lines, 11 patients (15.1% of the total patient group) showed an imbalance on the shape cancellation test, whereas no clear attentional imbalance was observed on the temporal judgements test.

Line bisection test versus temporal judgements test

A Pearson correlation between the average deviation score on the line bisection test and the PSS revealed a non-significant correlation ($r = -.21$; $p = .08$).

In Figure 4, it can be observed that there were a few cases for which the attentional imbalance as indicated by the temporal judgements test was not reflected in the average deviation score. Three patients (4.1% of the total patient group) had an imbalance on the temporal judgement test, but fell within the cut-off scores on the line bisection test (i.e., −0.74 and 0.47). Along similar lines, 13 patients (17.8% of the total patient group) showed a deficit on the line bisection test, whereas no clear attentional imbalance was observed on the temporal judgements test. Furthermore, although the patients that were impaired on the line bisection test had a larger absolute PSS than the patients showing no deficits on the

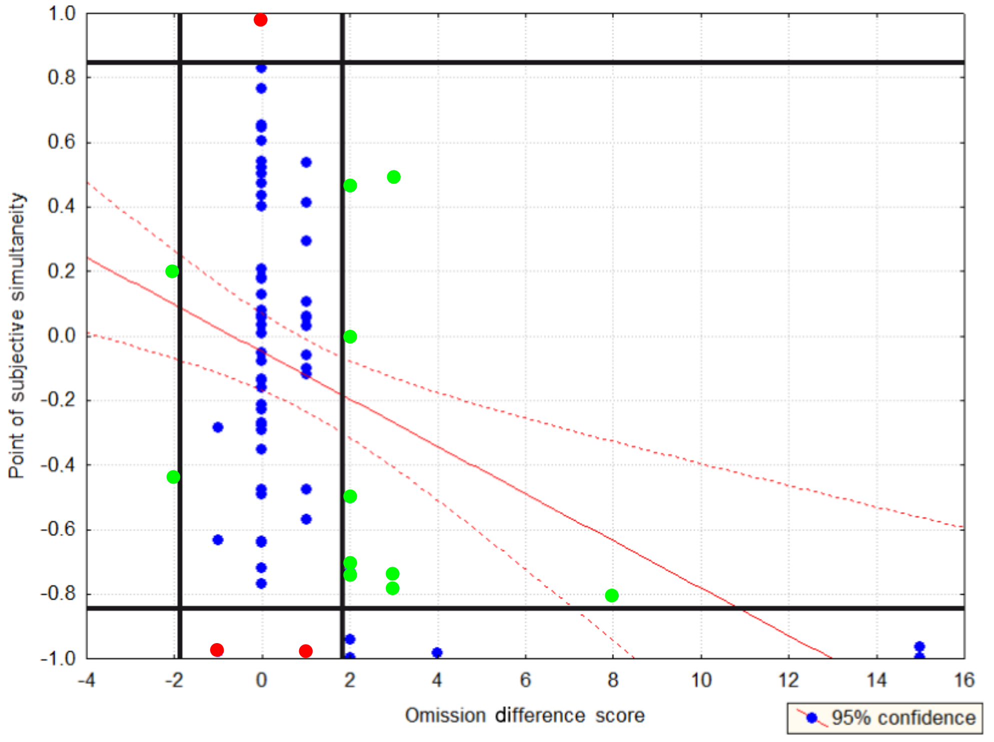

Figure 3. Correlation between the omission difference score and the point of subjective simultaneity (PSS). The red line indicates the line of best fit. The cut-off scores for the omission difference score (displayed on the *x*-axis) were 2 and −2. The cut-off scores for the PSS (displayed on the *y*-axis) were 0.85 and −0.85. The three patients who had an imbalance on the temporal order judgement (TOJ) test without any deficit on the shape cancellation test are indicated in red. The eleven patients who scored beyond the cut-off score on the shape cancellation test but showed no imbalance on the TOJ test are indicated in green. [Colour figure can be viewed at wileyonlinelibrary.com]

line bisection test, $t(71) = 2.12$; $p = .03$, the significance level of this effect was smaller than the same analyses for the shape cancellation test ($p = .03$ vs. $p = .0002$).

Influence of lesioned hemisphere

As it is known that visuospatial neglect is most dominantly associated with right hemisphere damage (e.g., Heilman & Van Den Abell, 1980), we compared performance on the different tests for patients with a right and a left hemisphere lesion. The groups were comparable in size (36 left hemisphere lesions vs. 37 right hemisphere lesions). Interestingly, the vast majority of the patients that were impaired at the TOJ test had a right hemisphere lesion (87.5%). Although less pronounced, a similar dominance was observed for the shape cancellation test (75%). Such an imbalance between the two hemispheres was not observed for the line bisection test, where 50% of the patients who were impaired on this test had a lesion to the left hemisphere. The other half of the patients had a lesion to the right hemisphere. We will further elaborate on these results in the General Discussion.

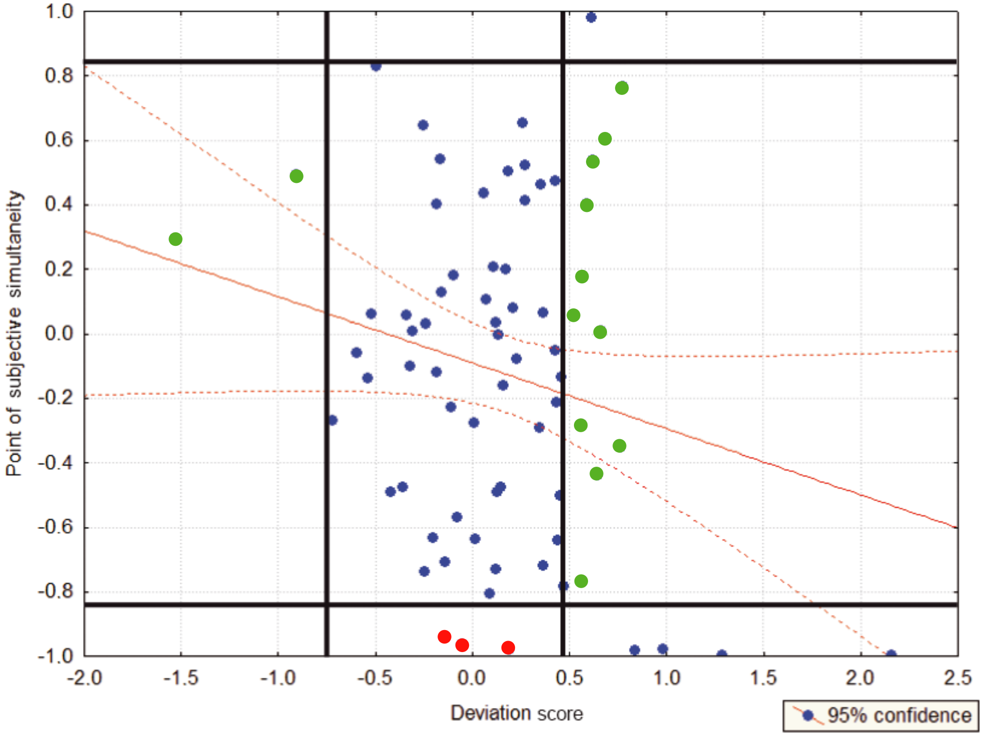

Figure 4. Correlation between the deviation score and the point of subjective simultaneity (PSS). The red line indicates the line of best fit. The cut-off scores for the deviation score (displayed on the *x*-axis) were 0.47 and −0.74. The cut-off scores for the PSS (displayed on the *y*-axis) were 0.85 and −0.85. The three patients who had an imbalance on the temporal order judgement (TOJ) test without any deficit on the line bisection test are indicated in red. The thirteen patients who scored beyond the cut-off score on the line bisection test but showed no imbalance on the TOJ test are indicated in green. [Colour figure can be viewed at wileyonlinelibrary.com]

GENERAL DISCUSSION

The aim of the present study was to scrutinize the contribution of a spatial bias to the performance on neuropsychological tests typically used to assess visuospatial neglect. Because neglect is not a unitary phenomenon, different neuropsychological tests are likely to measure different aspects of the neglect syndrome. We used the difference in judgements of temporal order between the contra- and ipsilesional visual field to measure the spatial bias in a given patient. The strength of this imbalance was correlated with performance on both a shape cancellation test and a line bisection test to unravel to what extent performance on these tests are associated with a spatial bias.

Results showed approximately 10% of a large sample of stroke patients had a spatial bias on the TOJ test which was abnormal compared to the results of a healthy control group. The vast majority of these patients had a contralesional deficit in that the threshold for the contralesional field (i.e., how much earlier a stimulus had to be presented in order to be reported as being presented earlier) was higher than for the ipsilesional visual field. This indicates that, for these patients, the rate of transfer of inputs from the early stages of sensory analysis to later decision processes was less efficient for the contralesional visual field compared to the ipsilesional field (Shore *et al.*, 2001).

When relating the performance on the TOJ test to the performance on the line bisection and the shape cancellation test, we observed a strong correlation with the shape, but not with the line bisection, test. This finding is consistent with earlier reports on dissociations between these two tests (Binder *et al.*, 1992; Ferber & Karnath, 2001; Halligan & Marshall, 1992; McGlinchey-Berroth *et al.*, 1996; Schubert & Spatt, 2001; Van der Stoep *et al.*, 2013). For both tests, around 20% of patients performed worse than the cut-off score, indicating that they showed deficits on that particular test. Interestingly, this percentage was twice as high compared to the TOJ test, in line with the idea that cancellation and line bisection tests also assess additional aspects of the neglect syndrome besides a spatial bias. These traditional tests might therefore be more sensitive in assessing a more broad range of the neglect syndrome compared to the TOJ test, which might only be sensitive to deficits in the spatial bias. Indeed, we identified patients with deficits on these tests who exhibited normal performance on the TOJ test. This dissociation was most apparent for the line bisection test, which also explains the lack of a correlation for the line bisection test with the TOJ test. There were only very few patients who showed the opposite pattern in that they performed abnormal on the TOJ test, while showing normal behaviour on the cancellation and line bisection test. The observed pattern of results is in line with the idea that the TOJ assesses only one component of the neglect syndrome, whereas performance on the other tests is subserved by multiple components.

It should be noted that the present cut-off scores were based on a relatively small control group. Although we think that these values are helpful in roughly distinguishing between patients with and without deficits, more research is need to establish definitive cut-off scores for the various tests used in our study. The choice of specific cut-off scores might also explain why results of all three tests revealed one case with ipsilesional deficits, although not the same case across tests. Although ipsilesional deficits are known to occur after frontal-subcortical lesions (Kim *et al.*, 1999), its presence in the current results could also be due to the specific cut-off scores used here. Therefore, the correlations presented here might be more informative regarding the underlying mechanisms of the line bisection and shape cancellation tests than the number of patients showing dissociations in performance between the different tests.

Performance on the line bisection test was not related to performance on the TOJ test, in contrast to the cancellation test. As mentioned in the Introduction, the line bisection test requires the correct perception of the size of a single stimulus, and successful performance depends primarily on an object-based, allocentric representation of space (Rorden *et al.*, 2006). Our results therefore indicate that object-based problems can be independent of such a bias. In contrast, these representations seem to be less required for successful performance on the shape cancellation test. This test requires other cognitive components, like a complete spatial representation of the visual field. Such a spatial representation might indeed be linked to an imbalance in the spread of attentional resources across the visual field. If there is an imbalance in the spread of attentional resources due to a spatial bias, a neglect patient will miss items outside of the attentional focus, resulting in omissions in the contralesional visual field. Although performance on cancellation tests is related to spatial biases, there are clearly also other components which contribute to deficits on the shape cancellation test, like spatial working memory (Mannan *et al.*, 2005; Wojciulik *et al.*, 2001). The current results, however, indicate that cancellation tests are more sensitive to a spatial bias than line bisection tests which measures other, perhaps more perceptual, aspects of the neglect syndrome.

Interestingly, deficits on the TOJ test were more frequently observed in patients with damage to the right hemisphere, comparable to deficits on the shape cancellation test.

Deficits on the line bisection test, however, were not associated with damage to a specific hemisphere. Given the hypothesized role of the right hemisphere in establishing an attentional balance between the two visual fields (e.g., Heilman & Van Den Abell, 1980), these results are in line with the idea that cancellation tests are more sensitive to a spatial bias compared to line bisection tests.

One limitation of the study is the possibility that the results could be influenced by the presence of patients with visual field defects, especially because neglect and hemianopia might be difficult to disentangle (Walker *et al.*, 1991). A patient with a visual field defect will perform poorly on the TOJ test whether the patient is fixating at the centre of the screen at the moment the two elements are presented. Although this is a limitation of the current study, we do like to argue that two findings might argue against such an influence. First, it is known that patients with hemianopia bisect the line with a bias to the contralateral visual field (Barton & Black, 1998). All patients in the current study who performed poorly on the TOJ test did not show such a bias on the line bisection test. Secondly, although we did not have the neurological scans for all patients in the current study, we did have access to the scans of the patients with deficits on the TOJ test. Inspection of these scans by a radiologist revealed that these patients did not have a lesion to the visual cortex, making visual field defects in these patients unlikely. However, to avoid this possible influence, future studies should control for visual field defects.

One additional possibility is that the current results are influenced by the presence of visual extinction, a disorder in which patients have difficulty detecting contralesional stimuli when presented simultaneously with an ipsilesional stimulus, but the ability to correctly identify them when not presented simultaneously (Vuilleumier & Rafal, 2000). Although the TOJ test indeed involves bilateral presentation, this presentation is not simultaneous, especially if patients perform poorly on this test. In this case, the timing between the presentation of the two stimuli is increased. We examined the neuropsychological reports to determine whether the patients who show deficits on the TOJ also show signs of extinction. Extinction was assessed using a standard visual extinction test in which patients were classified as having extinction when they failed to report at least two contralesional stimuli during bilateral simultaneous presentation, while accurately detecting unilateral stimuli (Beis *et al.*, 2004). Based on these criteria, only one patient who showed an attentional imbalance on the TOJ test was diagnosed with extinction, ruling out that our results are predominantly explained by the presence of visual extinction.

Neuropsychological tests are currently generally implemented as paper-and-pencil tests. Because of the rise of affordable and portable devices, an increase in computerized tests might be expected (De Wit *et al.*, 2017; Kane & Kay, 1992; Smit *et al.*, 2013). The TOJ test might be considered a suitable candidate for a novel neuropsychological test, which complements the line bisection and shape cancellation tests. Performance on the TOJ test does not depend on the reaction time of the patient, but requires a simple non-speeded response which of the two stimuli arrived earlier. Performance is therefore independent of any response bias, which can occur when patients respond in the preferred attentional direction in case of any uncertainty about the correct response. Because it is a computerized test, the thresholds can be modified based on patient's performance during the assessment using a staircase procedure. This results in a sensitive measure in which the chances of a ceiling or floor effects are minimized. Such tests might help in further unravelling the individual spatial and non-spatial components of the neglect syndrome.

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