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ORIGINAL ARTICLE

The Visual Scanning Test: a newly developed neuropsychological tool to assess and target rehabilitation of extrapersonal visual unilateral spatial neglect

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Abstract

Purpose Visual unilateral spatial neglect (VUSN) is a neuropsychological condition commonly experienced after stroke whereby patients are unable to attend to stimuli on the controlesional side of their space. VUSN can occur in the personal, peripersonal, and/or extrapersonal portion of patient's space. Traditional paper-and-pencil neuropsychological tests are widely used to evaluate VUSN, but they assess peripersonal VUSN. Instead, personal and extrapersonal neglect are less easily evaluated. The aim of this study was to present normative values for the Visual Scanning Test (VST), a new neuropsychological tool to quantitatively assess the extrapersonal VUSN.

Methods Eighty-six healthy subjects took part in the study (61 female), with a mean age of 52.8 years (SD = 17.0) and a mean of 14.0 years of education (SD = 5.2). The VST involved a visual search for a target between similar visual distractors, projected in the far space. The test was administered twice to each participant, with an interval of 2 weeks. From the recorded data, it was possible to obtain indexes related to the reaction times and to the accuracy of the performance on the VST.

Results Multiple linear regression analysis revealed that age and education significantly influenced VST-derived indexes. From the regression analysis, a correction grid for raw scores was built. Adjusted scores were then ranked, and by means of a non-parametric procedure, tolerance limits (both outer and inner one-sided) were defined.

Conclusions The present study provided normative data for the VST in an Italian population useful for both clinical and research purposes.

Trial registration ClinicalTrials.gov ID: NCT03931798

Keywords Unilateral spatial neglect · Neuropsychological assessment · Visual Scanning Test · Extrapersonal space · Normative data

Introduction

Unilateral spatial neglect (USN) represents one of the most frequent and disabling neuropsychological consequences of acute brain damage [1]. Its core feature is represented by patients' impairment to perceive sensory events and to perform actions in the controlesional side of the space [2] in absence of a lower-level sensory or motor deficit (e.g., hemianopsia, hemiplegia, and hemianesthesia) [3, 4].

The negative consequences on the activities of daily living are largely comparable between left and right-sided neglect [5, 6], although several studies found that controlesional USN is more frequent and more severe in right than left parietal damage [5–7]. Indeed, USN represents one of the major predictors for poor functional outcome following stroke [8, 9].

Due to its prominent impairment, USN has broadly been studied in the visual modality [10], even if the varied patterns of impairment suggest that USN can be conceived as a complex syndrome [2]. Patients with visual USN (VUSN) fail to react to visual events that occur in the controlesional side, as well as to orient and move toward them [2]. Furthermore,

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patients' affected limb could be less used [3]. VUSN can affect patient's own controlesional body (personal neglect), into the near space within reaching distance (peripersonal) or space beyond reaching distance (far extrapersonal space) [11, 12]. For example, patients with personal USN may fail to dress the controlesional side of their body, whereas patients with peripersonal USN may eat only half of the food in their plate [13]. Finally, patients with extrapersonal USN might collide with obstacles on the left side of the space [13] or fail to reach for far objects while they are walking [14]. Those portions of space may dissociate, and patient may show extrapersonal VUSN without alterations on the other portions of space (i.e., personal and peripersonal) [7, 15].

Traditional paper-and-pencil neuropsychological tests are useful and widely used to evaluate spatial neglect, and the type of task used can reveal selective patterns of impairment [16, 17]. Several instruments can provide an assessment of peripersonal VUSN [7, 18]. In fact, this portion of space can be assessed through line bisection, cancelation, or copy tasks which are normally completed within reaching distance [18–20]. Instead, personal and extrapersonal neglect are less easily evaluated. To the best of the authors' knowledge, both personal and extrapersonal VUSN deficits can be assessed through, respectively, the Fluff Test [21] and the Catherine Bergego Scale (CBD) [22]. Particularly for the latter, even if its psychometric strength is widely acknowledged, the time involved in observing a patient while he is completing 10 activities of daily living (such as grooming, dressing, or wheelchair driving), remains a major limitation to the use of the test. In fact, CBD may represent a useful indicator about the effectiveness of a therapeutic intervention, but it may result inappropriate as a neuropsychological assessment [23]. Recently, normative data for a distal version of a line bisection test have been proposed by Facchin and colleagues (2016), in which the patient was required to bisect distal lines in the extrapersonal portion of space [24]. This test is widely used in clinical setting, although its validation in extrapersonal space showed a lower reliability with the increase of the length of the lines, according to other bisection task studies [24]. The need for a valid and rigorous assessment procedure designed to detect extrapersonal neglect is broadly recognized [25]. In addition, the lack of specific tools may lead to lower detection rates for USN in patients in clinical setting and to miss potential dissociation in patient's portion of space [23–25]. Furthermore, the misdiagnosis of the whole spectrum of VUSN disorders raises relevant clinical implications because after being discharged, patients may return to the pre-morbid activities, such as driving or walking on the street, without being completely aware of the related risks [26]. Finally, paper-and-pencil tests can detect only a moderate or even severe deficit due to VUSN but not a mild impairment [26, 27] and they are not informative about patients' disability in natural setting [28]. According to these limitations of traditional paper-and-pencil tests, several studies have shown that computerized reaction time tasks are more sensitive in the detection of lateralized spatial attention deficits in patients with mild or remitted VUSN [23, 26, 29]. The aim of this study was to present and standardize a new neuropsychological tool that quantitatively assesses VUSN in the extrapersonal portion of space, analyzing the reaction times and the accuracy of patient's performance.

Methods

Test construction

According to the attentional theory originally proposed by Posner [30], USN is caused by a defective disengaging in spatial attention from ipsilesional stimuli [31]. Posner (1984, [30]) observed that patients with parietal-lobe damage were slowed down in the detection of a spatial pre-cued target occurred in the controlesional visual field that directed attention to the ipsilesional hemifield. Those observations led Posner to hypothesize that parietal damages could produce a "hyper"-attentional bias toward the ipsilesional hemispace that contrasts with the detection of controlesional stimuli [30].

According to this "hyper" attentional disengaging, a more recent theory supports that patient with VUSN may show an altered visual exploration due to an abnormal inhibition of return (IOR) [31, 32]. The IOR phenomenon states that in healthy subjects, the information processing of stimuli that occurs in an already inspected spatial location requires a wider response time [32], in order to promote the exploration of the visual scene through the inhibition of repeated orientation toward the same locations [33]. Therefore, due to an altered reallocation of spatial attention, patients with VUSN may have an impaired IOR and, consequently, a reduced visual exploration [34].

Several approaches aimed to increase the efficiency of the attentional distribution in the space [35]. To note, those works were mainly focused on the neuropsychological rehabilitation and to the best of the authors' knowledge, there are no specific assessments to detect visual searching disturbances in the far space. In fact, as described above, different neuropsychological instruments can assess this "hyper"-attentional bias [7, 8, 30], even if the major part of paper-and-pencil tests widely used are sensitive in the detection of VUSN in the peripersonal spatial dimension [7].

Test description

The Visual Scanning Test involved a visual search for a target (S) between similar visual distractors ($), projected in the far space. The VST required the presence of a blank wall and a projector, and to be carried out, participants must be positioned in a manner to reproduce a visual field of 52° × 45° [36].

The VST is composed by four trials, respectively named A1, B1, C1, and D1, each of them consisting of 20 visual search tasks. The overall VST is presented in sequence to the participant: that is, across the same session, all four trials A1, B1, C1, and D1 are entirely and subsequently administered to the participant. On about the 80% of cases, the test provided the presence of the target on the left, center, or on the right hemispace (see Table 1 for the frequency of the target on the left hemispace). In the remaining 20% of cases, the test provided the presence of a catch trial defined "False alarm," that is absence of the target, to assess the presence of frontal disturbances or malingering. The response to the "False Alarm" condition may be correct, if the patient correctly identifies the absence of the target, or wrong, if the patient reports a detection of the absent target. Across the four trials, the test is constructed according to an increasing attentive load for the target on the left-hemispace.

Firstly, patients were required to look at a fixation point (a colored star in the middle of the visual field) to always ensure the same starting position. After the start provided by the experimenter, participants were required to actively and freely explore the visual field to search for the visual target. During the visual search, patients were shown a screen containing dollar symbols ($), they were instructed to detect the presence of a letter (S), and naming its identification (saying YES or NO). Two types of errors could be made:

- Saying "NO" during the visual search in cases where the target was present ("Miss");
- Saying "YES" during the visual search in cases where the target was not present ("False alarm").

Each participant started the chronometer with a button when he/she moved from the fixation point to the visual search and stops it when he has completed the visual search. Then, the experimenter recorded the following: the reaction times (RTs) from the beginning of the visual search until participant's answer across each trial and the correct detection of the target (HITs), through a dedicated response form. Specifically, the experimenter was required to draw a sign (/) in case of error.

As VUSN is a syndrome characterized by a deficit in perception on the side of space opposite the lesion, it may determine both difficulties and slowness in orienting toward, responding to, and reporting stimuli that occur at the controlesional side of space [37]. For this reason, four indexes suggestive of possible asymmetries between hemispaces were analyzed in this work, with a specific focus on the speed and accuracy in the detection of the stimuli presented on the left extrapersonal portion of space:

Table 1 Frequency of the targets in each trial

Space/CT	Target presence (%)			
	Trial A	Trial B	Trial C	Trial D
Left side	20%	30%	40%	50%

– Space Asymmetry index due to time (SAI Time), where RTs mean represents the RTs average value over the four trials

$$SAI_{Time} = \frac{\text{RT mean left} - \text{RT mean right}}{\text{RT mean left} + \text{RT mean right}}$$

– Space Asymmetry index due to accuracy (SAI HITs), where HITs mean represents the accuracy average value over the four trials

$$SAI_{HITs} = \frac{\text{HITs mean left} - \text{HITs mean right}}{\text{HITs mean left} + \text{HITs mean right}}$$

– False Alarm RTs, consisting in the time over the four trials of the visual search in the "False alarm" conditions (answer "YES," where the target does not exist, False Alarm-RTs);
– The number of non-existing targets identified in the "False alarm" conditions (answer "YES," where the target does not exist, False Alarm).

Both SAI *time* and SAI *HITS* formulas give a representative value of the participant's performance, weighed on the patient's global capacity. For both indexes, values tending to 1 presuppose a predilection for the space on the left (e.g., longer reaction times and/or greater accuracy), and values tending to − 1 are indicative of a preponderance for the right space. To provide further measures of False Alarm, the number of non-existing targets identified and the relative RTs were measured.

Sample

Eighty-six healthy subjects took part in the study (61 females), with a mean age of 52.8 (SD = 17.0, range 25–85) and a mean of 14.0 years of education (SD = 5.2, range 3–31). The sample size was defined according to Capitani, E., & Laiacona, M. (2017, [38]) which identified in 75 subjects the smallest size required to define an outer and inner limit. In this study the sample was increased by 15% to account for possible drop-outs or missing data. The distribution of demographic data is shown in Table 2. Participants were naïve as to the purpose of the VST; none of them reported past or present neurological or psychiatric diseases, as well as visual disturbances. The presence of myopia or astigmatism did not represent an exclusion criterion if they were corrected by the use of glasses. Each VST was administered twice to each participant, with an interval of

Table 2 Demographic distribution

Age	n	Mean age (SD)	Mean School attendance (SD)	Gender (F/M)
25–45	29	32.4 (4.9)	16.2 (3.0)	19/10
46–65	35	57.1 (7.0)	13.9 (4.7)	25/10
66–85	22	72.8 (5.5)	11.0 (6.8)	17/5
Total	86	52.8 (17.0)	14.0 (5.2)	61/25

2 weeks, and the average value of the two tests was retained for further analysis, after having verified the reliability of data obtained through a test-retest assessment. Pearson r or Spearman rho coefficients were used for this purpose, according to data normal or not-normal distribution. Coefficient > 0.7 was deemed as acceptable.

All participants took part in the study on a voluntary basis after having provided their written informed consent and without receiving any reward. The research protocol was agreed according to the local regulations and complied with APA ethical standards.

Statistical analysis

Given our sample size, outer and inner tolerance limits were fixed, respectively, based on the values of the first and ninth ranked scores, after demographic adjustments. Participants' ability to detect the target during the administration of VST (discriminability: D') or the participants' response bias (response criterion: C), the signal detection theory was applied [39]. Signal detection measures allow for the separation of sensitivity level and decision level, with the d' parameter reflecting the subject's accuracy to discern an event (here, the presence of the target) from its background (distractors), and the C parameter reflecting the subject's decision criterion of response. D' and C values were calculated using mean raw accuracy data through the software Statilite (version 1.05, http://www.cabiatl.com/mricro/stats/index.html). Accuracy data were represented by the hits rates relative to total performance and isolated performance in the right and left space. We estimated a mean d' for each group of age from data. According to Macmillan and Creelman, a larger d' was associated to a higher sensitivity of the group in discriminating the presence of the target among distractors [39]. In the following analyses, data were examined using SPSS version 25 (SPSS Inc., Chicago, IL, USA). A multiple linear regression model was first applied to test the independent effects of age, sex, and education on the above mentioned indexes. The best fitting linear model for each index was sought to adjust original scores according to the demographic variables found to be associated with each index ($p < 0.05$). The effect of education level was explored after logarithmic, quadratic, and reciprocal transformation, while age was included in the models after logarithmic transformation: "log(100-age)," as suggested by Capitani et al. (1997, [40]). Corrected scores were calculated by adding (or subtracting) the contribution of each variable for each age group (25–45, 46–65, 66–85) and/or education level (≤ 5 years, 6–13 years, ≥ 14 years) [41]. Based on the obtained results, correction grids were created. No adjustment was made to the top end of the scale, to avoid errors due to the fixed upper limit of the test scores. Adjusted scores were then ranked, and tolerance limits (both outer and inner one-sided) were defined. Due to the non-normal distribution of some of the adjusted indexes, a non-parametric procedure [42] was adopted. Above the outer tolerance limit, it is expected to find at least 95% of the normal population (with 95% confidence), while above the inner tolerance limit, it is expected to find at most 95% of the population (with 95% confidence). The scores falling between the outer and inner tolerance limits are defined "borderline scores" because a controlled judgment cannot be expressed.

Results

Table 3 contains the descriptive statistics of the variables included in the analysis. From the results shown in Table 3, participants' performance appeared to be tendentially more rapid and accurate on the left side during the entire administration of the VST (respectively, SAI-RTs and SAI-HITS). Moreover, an increased latency in reaction times under the conditions of "False Alarm" and a very high average level of accuracy were found.

Figures 1 and 2 reported d' and c values among groups of different age. Participants showed a high sensitivity in detecting the target among distractors and their performances appeared to be an effective ceiling. Furthermore, participants demonstrated an overall response tendency to say "yes" (i.e., presence of the target).

Table 3 Descriptive statistics of the variables included in the analysis

Index	Mean ± SD Median (IQR)
SAI Time (in s)	− 0.9 ± 0.1
SAI HITS (number of correct answer)	− 0.003 ± 0.048
False Alarm-RTs (in s)	4.1 ± 1.5
False Alarm (% of correct rejection)	100.0 (0.0)

The table contains the descriptive statistics of sample performances and their unit. SAI TIME (in s) represents RTs average value over the four trials; SAI HITS (accuracy) represents the average value over the four trials of correct responses; False Alarm RTS (in s) represents the time over the four trials of the visual search in the "False alarm" conditions; False Alarm represents the number of non-existing targets identified in the "False alarm" conditions

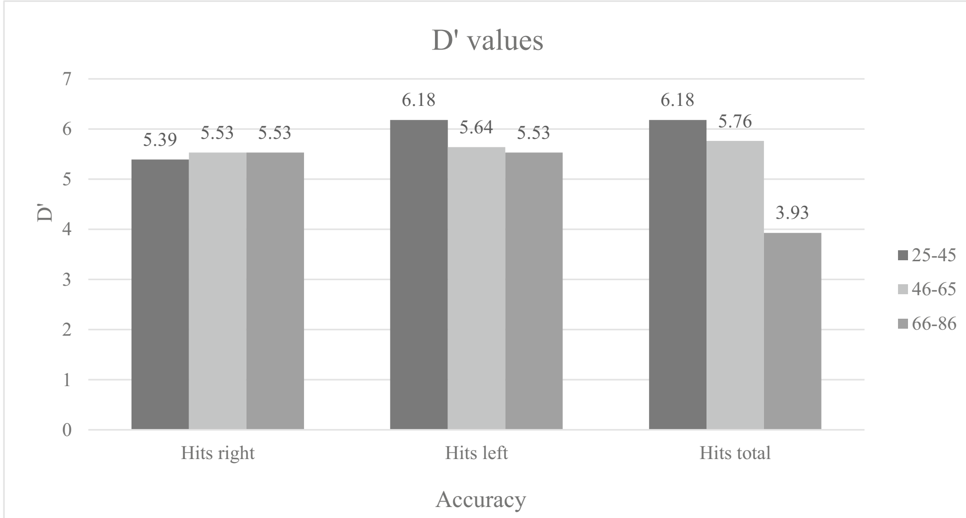

Fig. 1 D' values among group of age

The regression analyses showed that the logarithmic transformation of age [log10(100-age)] and the education or the reciprocal transformation of education (in years) were the most effective in reducing residual variance. SAI RTs was not influenced by age nor education. On these bases, we calculated the best linear models relating the dependent variable with the most suitable transformations of independent variables (Table 4 contains the age and education best transformations and models used).

To adjust the performance of each newly tested individual, correction factors were then derived (see Table 5), except when no external factors influenced the performance (e.g., age for *SAI RTs*). It was not possible to define the correction for people with equal or less than 5 years of schooling because, according to the Italian legislative system (law 1859/62), it is compulsory to attend school at least up to 16 years of age.

Finally, Table 6 reports the outer, the border, and the inner limits. These limits could not be defined for *SAI HITs* as, in accordance with the procedure proposed by Capitani and Laiacona (2017, [38]), the number of observations for the event analyzed was less than 75.

Discussion

The Visual Scanning Test is a new neuropsychological instrument based on a perceptual tasks that investigate extrapersonal space. Due to the lack of neuropsychological instruments to assess visual searching in the far space, the VST may be used to detect visual searching alterations and the availability of normative data allows its utilization in clinical practice.

From a theoretical point of view, this test may represent a suitable tool to detect an abnormal visual exploration due to an “hyper attentional bias” toward stimuli localized in a specific hemifield [30] and reduced IOR [32], analyzing both the RTs and the accuracy. Particularly, being patients with VUSN less accurate or slower in orient toward, respond to and report

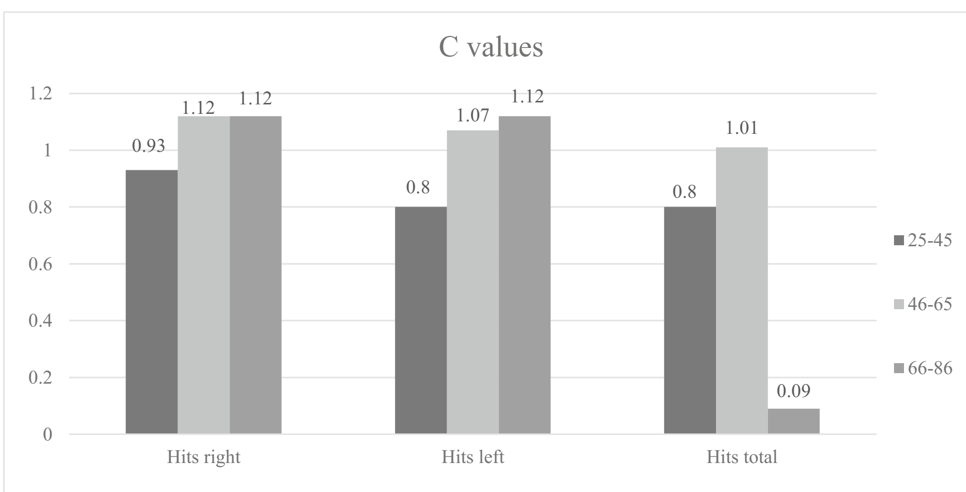

Fig. 2 C values among group of age

Table 4 Age and education best linear models

Index	Best linear model	R	R^2	p
False Alarm-RTs	Raw score+4.341 [$\log_{10}$(100-age)-1.643]	0.254	0.245	< 0.001
SAI RTs	–	–	–	–
SAI HITS	–	–	–	–
False Alarm-HITs	Raw score-3.897 [$\log_{10}$(100-age)-1.643]	0.100	0.089	0.003

Table 6 Non parametric tolerance limits of the adjusted scores

	Outer limits	Borderline scores	Inner limits
False Alarm-RTs	≥ 7.83	7.82–6.29	≤ 6.28
SAI RTs	≥ 0.16	0.15–0.03	≤ 0.02
SAI HITS	–	–	–
False Alarm-HITs	≤ 88.85	88.86–99.99	= 100

stimuli that occur in the controlesional side of space [37], VST may be used in patients to detect symptoms of extrapersonal VUSN. Together with the accuracy and the RTs, the increasing attentional load for the target on the left-hemispace may represent an index of VUSN. Similarly, the indexes of spatial asymmetry due to the time and to the performance may be informative regarding the presence of a decreased or slowed down performance over the four trials in a particular hemispace. Finally, RTs of CT may contribute to provide an articulated and quantitative evaluation of a slowed performance.

The assessment of visual search speed and accuracy in extrapersonal VUSN may have ecological implication. Patient with extrapersonal VUSN might collide with obstacles on the left side of the space [13] or fail to reach for far objects while they are walking [14], so a rigorous assessment of these difficulties can provide information relevant to the rehabilitation project. The VST provides several advantages: firstly, its ease and quick administration. In fact, the entirely VST requires on about 20 min, according to patient's performance rapidity. Furthermore, this test gives the possibility to define four indexes based on patient's performance. As described above, these indexes are informative the presence of asymmetry in the visual exploration in the far space both regarding the speed and the accuracy. However, this study presents some limitations: the first limitation is represented by a reduced normative sample. As described in the statistical analyses, in accordance with the procedure proposed by Capitani and Laiacona (2017, [38]), the number of participants is tending low, sometimes so that it is not sufficient for the calculation of some indexes (e.g., *SAI HITs* and False Alarm *RTs*). Further study may implement the normative sample, in order to increment the statistical power of the VST. Therefore, the obtained results should then be considered in the context of the patient's overall neuropsychological performance. The focus on the above mentioned indexes derived from participants' performances through the VST administration represents a methodological choice. In fact, in future works, it would be interesting to assess VST outcomes sensitivity to discriminate between healthy participants and patients (by using ROC curve analysis), and to identify which indexes are more sensitive in the detection of VUSN symptoms in clinical setting, to support the neuropsychological rehabilitation project. According to the statistic, the evaluation of both convergent and divergent validity compared with other validated and widely used in clinical practice neuropsychological instruments is needed in order to increase the psychometric validity of VST. Finally, other limitations are represented both by the apparatus required to carry out the VST, because it needs an adequate room with a blank wall and also a projector, and by the manual scoring system to obtain all the above mentioned indexes that might be too much time-demanding. To overcome this latter limitation, an automatic scoring system should be implemented in further studies.

Table 5 Correction grid for indexes

	Age (years)		
	25–45	46–65	66–85
False Alarm-RTs	0.81	− 0.07	− 0.95
SAI RTs	–	–	–
SAI HITS	–	–	–
False Alarm-HITs	− 0.72	0.06	0.85

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Compliance with ethical standards

All participants took part in the study on a voluntary basis after having provided their written informed consent and without receiving any reward. The research protocol was agreed according to the local regulations and complied with APA ethical standards.

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Priftis K, Passarini L, Pilosio C, Meneghello F, Pitteri M (2013) Visual scanning training, limb activation treatment, and prism adaptation for rehabilitating left neglect: who is the winner? Front Hum Neurosci 7:360. https://doi.org/10.3389/fnhum.2013.00360
2. Vallar G &Calzolari E. (2018) Unilateral spatial neglect after posterior parietal damage. Handb Clin Neurol 151:287–312. https://doi.org/10.1016/B978-0-444-63622-5.00014-0
3. Vallar G, Bolognini N (2014) Unilateral spatial neglect. In: Nobre AC, Kastner S (eds) Oxford library of psychology. The Oxford handbook of attention. Oxford University Press, New York, pp 972–1027. https://doi.org/10.1093/oxfordhb/9780199675111.013.012
4. Bisiach E, Vallar G, Perani D, Papagno C, Berti A (1986) Unawareness of disease following lesions of the right hemisphere: anosognosia for hemiplegia and anosognosia for hemianopia. Neuropsychologia 24(4):471–482. https://doi.org/10.1016/0028-3932(86)90092-8
5. Ten Brink AF, Verwer JH, Biesbroek JM, Visser-Meily JM, Nijboer TC (2017) Differences between left-and right-sided neglect revisited: a large cohort study across multiple domains. J Clin Exp Neuropsychol 39(7):707–723. https://doi.org/10.1080/13803395.2016.1262333
6. Ten Brink AF, Biesbroek JM, Oort Q, Visser-Meily JM, Nijboer TC (2019) Peripersonal and extrapersonal visuospatial neglect in different frames of reference: a brain lesion-symptom mapping study. Behav Brain Res 356:504–515. https://doi.org/10.1016/j.bbr.2018.06.010
7. Bowen A, McKenna K, Tallis RC (1999) Reasons for variability in the reported rate of occurrence of unilateral spatial neglect after stroke. Stroke 30(6):1196–1202. https://doi.org/10.1161/01.STR.30.6.1196
8. Denes G, Semenza C, Stoppa E, Lis A (1982) Unilateral spatial neglect and recovery from hemiplegia: a follow-up study. Brain 105(3):543–552. https://doi.org/10.1093/brain/105.3.543
9. Machner B, Könemund I, von der Gablentz J, Bays PM, Sprenger A (2018) The ipsilesional attention bias in right-hemisphere stroke patients as revealed by a realistic visual search task: neuroanatomical correlates and functional relevance. Neuropsychology 32(7):850–865. https://doi.org/10.1037/neu0000493
10. Gainotti G (2010) The role of automatic orienting of attention towards ipsilesional stimuli in non-visual (tactile and auditory) neglect: a critical review. Cortex 46(2):150–160. https://doi.org/10.1016/j.cortex.2009.04.006
11. Appelros P, Nydevik I, Karlsson G, Thorwalls AM, Seiger A (2003) Assessing unilateral neglect: shortcomings of standard test methods. Disabil Rehabil 25(9):473–479. https://doi.org/10.1080/0963828031000071714
12. Buxbaum LJ, Ferraro MK, Veramonti T, Farne A, Whyte JMDP, Ladavas E, Frassinetti F, Coslett HB, Coslett HB (2004) Hemispatial neglect: subtypes, neuroanatomy, and disability. Neurology 62(5):749–756. https://doi.org/10.1212/01.WNL.0000113730.73031.F4
13. Danckert J, Ferber S (2006) Revisiting unilateral neglect. Neuropsychologia 44(6):987–1006. https://doi.org/10.1016/j.neuropsychologia.2005.09.004
14. Berti A, Smania N, Rabuffetti M, Ferrarin M, Spinazzola L, D'amico A, .., & Allport A, (2002), Coding of far and near space during walking in neglect patients, Neuropsychology 16(3) 390, DOI: https://doi.org/10.1037/0894-4105.16.3.390, 399
15. Lindell AB, Jalas MJ, Tenovuo O, Brunila T, Voeten MJ, Hämäläinen H (2007) Clinical assessment of hemispatial neglect: evaluation of different measures and dimensions. Clin Neuropsychol 21(3):479–497. https://doi.org/10.1080/13854040600630061
16. Pedroli E, Serino S, Cipresso P, Pallavicini F, Riva G (2015) Assessment and rehabilitation of neglect using virtual reality: a systematic review. Front Behav Neurosci 9:226. https://doi.org/10.3389/fnbeh.2015.00226
17. Parton A, Malhotra P, Husain M (2004) Hemispatial neglect. J Neurol Neurosurg Psychiatry 75(1):13–21
18. Coslett HB (2018) Apraxia, neglect, and agnosia. Continuum: lifelong learning in Neurology, 24(3, BEHAVIORAL NEUROLOGY AND PSYCHIATRY) 768–782. https://doi.org/10.1212/CON.0000000000000606
19. Butler BC, Eskes GA &Vandorpe RA. (2004) Gradients of detection in neglect: comparison of peripersonal and extrapersonal space. Neuropsychologia 42(3):346–358. https://doi.org/10.1016/j.neuropsychologia.2003.08.008
20. Cipresso P, Pedroli E, Serino S, Semonella M, Tuena C, Colombo D et al (2018) Assessment of unilateral spatial neglect using a free mobile application for Italian clinicians. Front Psychol 9. https://doi.org/10.3389/fpsyg.2018.02241
21. Cocchini G, Beschin N, Jehkonen M (2001) The Fluff test: a simple task to assess body representation neglect. Neuropsychol Rehab 11(1):17–31. https://doi.org/10.1080/09602010042000132
22. Azouvi P, Olivier S, De Montety G, Samuel C, Louis-Dreyfus A, Tesio L (2003) Behavioral assessment of unilateral neglect: study of the psychometric properties of the Catherine Bergego Scale. Arch Phys Med Rehabil 84(1):51–57. https://doi.org/10.1053/apmr.2003.50062
23. Cunningham LJ, O'Rourke K, Finlay C, Gallagher M (2017) A preliminary investigation into the psychometric properties of the Dublin Extrapersonal Neglect Assessment (DENA): a novel screening tool for extrapersonal neglect. Neuropsychol Rehab 27(3):349–368. https://doi.org/10.1080/09602011.2015.1084334
24. Facchin A, Beschin N, Pisano A, Reverberi C (2016) Normative data for distal line bisection and baking tray task. Neurol Sci 37(9):1531–1536
25. Rengachary J, d'Avossa G, Sapir A, Shulman GL, Corbetta M (2009) Is the Posner reaction time test more accurate than clinical tests in detecting left neglect in acute and chronic stroke? Arch Phys Med Rehabil 90(12):2081–2088. https://doi.org/10.1016/j.apmr.2009.07.014
26. Bonato M (2012) Neglect and extinction depend greatly on task demands: a review. Front Human Neurosci 6:195. https://doi.org/10.3389/fnhum.2012.00195
27. Barrett AM, Buxbaum LJ, Coslett HB, Edwards E, Heilman KM, Hillis AE, … Robertson IH (2006) Cognitive rehabilitation interventions for neglect and related disorders: moving from bench to bedside in stroke patients. J Cogn Neurosci 18(7)1223–1236. https://doi.org/10.1162/jocn.2006.18.7.1223
28. Hasegawa C, Hirono N, Yamadori A (2011) Discrepancy in unilateral spatial neglect between daily living and neuropsychological test situations: a single case study. Neurocase 17(6):518–526. https://doi.org/10.1080/13554794.2010.547506
29. Bonato M, Deouell LY (2013) Hemispatial neglect: computer-based testing allows more sensitive quantification of attentional disorders and recovery and might lead to better evaluation of rehabilitation. Front Human Neurosci 7:162. https://doi.org/10.3389/fnhum.2013.00162
30. Posner MI, Walker JA, Friedrich FJ, Rafal RD (1984) Effects of parietal injury on covert orienting of attention. J Neurosci 4:1863–1874. https://doi.org/10.1523/JNEUROSCI.04-07-01863
31. Priftis K, Umiltà C, Zorzi M, Bonato M (eds) (2015) Spatial and non-spatial aspects of neglect. Frontiers Media SA. https://doi.org/10.3389/978-2-88919-584-8

32. Lupiáñez J, Klein RM, Bartolomeo P (2006) Inhibition of return: twenty years after. Cogn Neuropsychol 23(7):1003–1014. https://doi.org/10.1080/02643290600588095
33. Bartolomeo P (2014) The attention systems of the human brain. In: Attention Disorders After Right Brain Damage. Springer London. https://doi.org/10.1007/978-1-4471-5649-9_1
34. Bourgeois A, Chica AB, Migliaccio R, de Schotten MT, Bartolomeo P (2012) Cortical control of inhibition of return: evidence from patients with inferior parietal damage and visual neglect. Neuropsychologia 50(5):800–809. https://doi.org/10.1016/j.neuropsychologia.2012.01.014
35. Kerkhoff G, Schenk T (2012) Rehabilitation of neglect: an update. Neuropsychologia 50(6):1072–1079. https://doi.org/10.1016/j.neuropsychologia.2012.01.024
36. Bolognini N, Rasi F, Coccia M, Ladavas E (2005) Visual search improvement in hemianopic patients after audio-visual stimulation. Brain 128(12):2830–2842
37. Ten Brink AF, Visser-Meily JM, Nijboer TC (2018) Dynamic assessment of visual neglect: the mobility assessment course as a diagnostic tool. J Clin Exp Neuropsychol 40(2):161–172
38. Capitani E, Laiacona M (2017) Outer and inner tolerance limits: their usefulness for the construction of norms and the standardization of neuropsychological tests. Clin Neuropsychol 31(6–7):1219–1230. https://doi.org/10.1080/13854046.2017.1334830
39. Macmillan NA, Creelman CD (2004) Detection theory: A user's guide. Psychology press
40. Capitani E (1997) Normative data and neuropsychological assessment. Common problems in clinical practice and research. Neuropsychol Rehab 7.4:295–310. https://doi.org/10.1080/713755543
41. Capitani E, Laiacona M (1997) Composite neuropsychological batteries and demographic correction: standardization based on equivalent scores, with a review of published data. The Italian Group for the Neuropsychological Study of Ageing. J Clin Exp Neuropsychol 19:795–809. https://doi.org/10.1080/01688639708403761
42. Wilks KK (1941) Determination of sample size for setting tolerance limits. Ann Math Stat 12:91–96

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