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## Assessment and Functional Impact of Allocentric Neglect: A Reminder from a Case Study

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### Abstract

SR suffered a right hemispheric stroke more than three years ago, and now lives with left-sided hemiparesis and chronic spatial neglect due to damaged white matter pathways connecting the frontal, temporal and parietal regions. We report here that SR suffers from both viewer-centered (i.e., egocentric) and object-centered (i.e., allocentric) spatial neglect. Notably, unlike most neuropsychological and functional assessments that focus on egocentric deficits, a specialized neuropsychological figurative discrimination test (the Apples test) revealed SR's allocentric neglect. Further, using assessments sensitive to detect functional deficits related to allocentric neglect, we observed SR's difficulty in reading and using clocks, reflecting his object-centered errors in these everyday activities. SR's case suggests that allocentric-specific assessments, both neuropsychological and functional, are valuable in standard neglect examinations, particularly to predict daily function after stroke. We recommend that neglect-related functional disability be distinguished further with respect to allocentric spatial deficits, and functional assessments for allocentric neglect should be validated in future large sample studies. Identifying allocentric neglect early, and learning about its influence on daily function, may enhance care quality and facilitate effective rehabilitation planning for stroke recovery.

### Keywords

Stroke; spatial neglect; egocentric neglect; allocentric neglect; figurative discrimination tasks

### INTRODUCTION

This case presentation describes an 84-year-old man – SR (false initials) – who survived a right hemispheric stroke more than three years ago, and lives with chronic spatial neglect and left-sided hemiparesis. Interestingly, his symptoms of spatial neglect include abnormal spatial bias toward the right side not only with respect to the viewer-centered reference frame (egocentric), but also the object-centered reference frame (allocentric). In this Grand

Round, we report an extensive evaluation of SR's neglect symptoms manifested on conventional paper-and-pencil tasks and in everyday functional activities.

Commonly occurring after right hemisphere damage (Fullerton, McSherry, & Stout, 1986; McGlone, Losier, & Black, 1997; Ringman, Saver, Woolson, Clarke, & Adams, 2004; Stone et al., 1991; Wee & Hopman, 2008), spatial neglect renders stroke survivors with an inability to attend to, perceive, and make responses to stimuli presented on the contralesional side of personal, peri-personal, or extra-personal space (Berti et al., 2002; Heilman, 2004; Heilman, Watson, & Valenstein, 2012; Mesulam, 1999) accompanied by functional disability (Barrett & Burkholder, 2006). In some cases, spatial neglect can manifest as a failure to generate or maintain a normal representation of the contralesional side of mental images (Berti, 2004; Bisiach & Luzzatti, 1978; Piccardi, Bianchini, Zompanti, & Guariglia, 2008). Importantly, sensory or motor defects post-stroke do not account for the disorder of spatial neglect; rather, spatial neglect is a neurocognitive disorder resulting from deficits in processing spatial information (Heilman, et al., 2012).

One way to describe neglect in persons with right-brain damage is simply stating that they are biased toward the right hemispace. However, spatial neglect may also be present in different reference frames (Driver & Halligan, 1991). Neglect patients with abnormal bias in spatial exploration typically manifest neglect on the reference frame centered at their body — egocentric or viewer-centered reference frame. When having a meal served on several plates, for example, these individuals may finish the food on plates that are on the right side of their body but may pay little attention to plates on the left side. Unlike those with egocentric neglect, patients with allocentric or object-centered neglect (Hillis, Newhart, Heidler, Marsh, et al., 2005; Ota, Fujii, Suzuki, Fukatsu, & Yamadori, 2001) may be able to attend to objects (e.g. plates) on both sides of the body but might only finish food on the right side of each plate. Because of the distinct behavioral manifestations of egocentric and allocentric neglect (Hillis, 2006), the neuroanatomical correlates (Golay, Schnider, & Ptak, 2008) and efficacy of interventions (Pachalska, Franczuk, MacQueen, & Talar, 2004) for allocentric neglect may differ from those for egocentric neglect.

Prior studies suggest that after right-brain damage, egocentric and allocentric neglect may occur either independently or in combination, and the relative occurrence of egocentric and allocentric neglect is highly variable (see Table 1 for a summary of selected studies). Pure or isolated allocentric neglect, i.e., without any manifestation of egocentric neglect, is considered rare. The debate on the existence of isolated allocentric neglect is an ongoing topic in the field of neglect research. On one extreme, some propose that allocentric deficits can only be found in conjunction with egocentric deficits (Rorden et al., 2012; Yue, Song, Huo, & Wang, 2012); at the other extreme, as Bickerton and colleagues (2011) suggest, when allocentric neglect is assessed with a sensitive test, it may not be uncommon. Pure allocentric neglect occurred in 44% of neglect patients reported in Chechlacz et al. (2010), 29.4% in Hillis et al. (2005), and 11.4% in Medina et al. (2009). This diversity may be attributed to differences in inclusion criteria across studies as well as methodological differences in detecting allocentric neglect (Molenberghs, Sale, & Mattingley, 2012; Yue, et al., 2012).

Given that most neuropsychological and functional assessments of neglect heavily focus on egocentric deficits, allocentric neglect is under-represented and may be detectable only with specialized assessments. Line bisection is a commonly used neglect assessment tool, along with visual search, target cancellation and drawing/copying tasks (Ting et al., 2011). When neglect patients with right-brain damage try to bisect a horizontal line, they usually make responses far right of the center. Such deviation may reflect neglect either of the left half of the body (egocentric), or the left half of the line or the page on which the line extends

(allocentric;(Chatterjee, 1994). Therefore, line bisection test alone may not distinguish between egocentric and allocentric neglect appropriately (Rorden, Berger, & Karnath, 2006). But when combined with visual search or cancellation tests such as the Bells test (Gauthier, Dehaut, & Joanette, 1989), deviation observed in line bisection may help distinguish the types of neglect (Golay, et al., 2008). For example, Golay and colleagues (2008) suggested that a patient has allocentric neglect if the line bisection performance is impaired with relatively normal cancellation performance, and that a patient has egocentric neglect if he or she demonstrates impairment in target cancellation with relatively normal line bisection performance. This dual-test method may be sensitive, however others recommend more specialized tests such as the figurative discrimination tasks like the Gap Detection test (Hillis, 2006; Ota, et al., 2001) and the Apples test (Bickerton, et al., 2011) to validly assess for both allocentric and egocentric neglect in one test. Compared to commonly used visual search task, such as the Bells test, which only assesses lateralized asymmetry in the body-centered reference frame, figurative discrimination tasks such as the Apples test assess neglect in both the reference frames based on the body as well as individual items (Bickerton, et al., 2011).

While there are a relatively small number of studies dedicated to allocentric neglect, there are even fewer studies assessing everyday activities related to allocentric neglect. One exception is Bickerton et al.'s study (2011), in which individuals with allocentric neglect were more impaired in everyday activities in comparison with those with pure egocentric neglect. It is well known that spatial neglect, or specifically, egocentric spatial bias leads to disability in daily living (Azouvi et al., 1996; Barrett & Burkholder, 2006) and predicts poor rehabilitation outcomes (Cherney, Halper, Kwasnica, Harvey, & Zhang, 2001; Katz, Hartman-Maeir, Ring, & Soroker, 1999; Paolucci, Antonucci, Grasso, & Pizzamiglio, 2001). Whether allocentric neglect predicts worse stroke recovery and outcome, needs investigation. Further, deficits on neuropsychological tests may not be sufficient to define spatial neglect, rather we suggest that this disorder is “[abnormal] spatial bias in a [person] with a brain lesion, associated with functional disability” (Barrett & Burkholder, p. 337). Therefore, individuals with allocentric neglect may demonstrate object-centered spatial bias and manifest object-centered functional disability.

SR, the case presented in this Grand Round, has chronic spatial neglect with a profile of distinct egocentric *and* allocentric neglect characteristics. We performed an extensive evaluation of SR's neglect symptoms and assessed his everyday activities. From his medical records and rehabilitation history, the disorder of spatial neglect was addressed by his outpatient occupational therapist about 2 years post stroke, but he was never treated with specific rehabilitation methods targeting spatial neglect. Additionally, the therapist reported unfamiliarity of the distinction between egocentric and allocentric neglect, and was unaware of any theory-driven and evidence-based intervention that may ameliorate SR's neglect symptoms. Through this report, we aim to promote the use of appropriate functional assessments and paper-and-pencil tests for distinguishing egocentric and allocentric neglect, and to understand the neurocognitive mechanism of neglect symptoms in SR's behavior, so that targeted treatments can be identified and tested.

## CASE REPORT

### Patient Characteristics

SR (false initials), an 84-year-old man with 12 years of formal education, suffered from an ischemic stroke in the right middle cerebral artery distribution involving the right temporal lobe. This cerebral vascular accident or stroke occurred more than 3 years ago. At that time, infarction involved the right watershed brain areas, particularly the temporal paraventricular white matter (WM) and frontal and subcortical WM, on apparent diffusion coefficient

(ADC) maps performed 17 days after stroke onset. Additionally, age-related bilateral microvascular disease, and diffused cerebral atrophy (volume loss) were also reported (Figure 1). Originally, SR was admitted to the hospital because of a complaint of left-sided weakness.

SR has a history of gout, coronary artery disease, hypertension, bladder carcinoma, myocardial infarction, hypercholesterolemia, glaucoma and type-II diabetes. At the time of inpatient admission to the rehabilitation facility (about 3 years before testing), he presented with left hemiparesis and needed assistance with ambulation and everyday activities. At this time, using the Medical Research Council (MRC) Scale for Muscle Strength, SR's left upper extremity was 1 of 5 proximally, i.e., only a trace of movement was observed, and 0 of 5 distally, i.e., no movement was observed; SR's left lower extremity was 2 of 5 proximally, i.e., he was able to move without resistance from gravity, and 1 of 5 distally, i.e., only a trace of movement was observed. A percutaneous endoscopic gastrostomy tube was placed secondary to dysphagia. He was discharged after 28 days of hospitalization. About 7 months later, he began outpatient therapy with a goal to increase the use of his left arm and to increase independence in activities of daily living. At that time, he needed maximum assistance with dressing and bathing. After 31 sessions of outpatient occupational therapy, he was discharged. Almost 2 years later, SR returned to outpatient occupational therapy. He demonstrated little to no subjective changes since the time of hospital discharge. He still required maximal assistance for all activities of daily living, especially, dressing and bathing, and had an aide for 3 to 4 hours a day. One of the authors, an occupational therapist (OT; author NS), recognized that he demonstrated disorganized search patterns for visual scanning, and showed impairment on neuropsychological paper-and-pencil test of spatial neglect. Additionally, she noted that SR would forget to dress the left side of his body, ignore people sitting on the left, let his left hand drag in the wheel of his wheelchair, and infrequently turned to the left. To address SR's functional difficulties, the OT used mirrors and adaptive devices to assist SR's practices in activities of daily living. However, SR continued to demonstrate significant left neglect, especially in dressing tasks, and required moderate to maximum verbal cuing to recognize that he had "forgotten" the left side of his shirt. At the time of outpatient therapy discharge (about 1 year ago), SR had no subjective improvement in his neglect symptoms and was greatly dependent for everyday activities at home, requiring caregiver supervision at all times. The OT documented that his prognosis was fair to poor subsequent to significant spatial neglect, requiring moderate to maximal verbal cuing to recognize his deficit.

Since his discharge from outpatient therapy, SR participated in the present study during which he underwent neglect examination by paper-and-pencil neuropsychological tests, including the Behavioral Inattention Test (BIT; (Wilson, Cockburn, & Halligan, 1987), the Bells test (Gauthier, et al., 1989), and the 'trees-&-house' figure copying test (Gainotti, Messlerli, & Tissot, 1972). He was also examined with a functional assessment, the Catherine Bergego Scale (Azouvi, et al., 1996), designed to detect neglect-related disabilities in everyday activities. In addition, he was tested for multi-domain cognitive functions (Florida Mental Status Exam; Doty, Bowers, & Heilman, 1990) and independence in self-care and mobility (Barthel Index; Mahoney & Barthel, 1965). During this first round of comprehensive evaluation, his neglect symptoms suggested presence of both egocentric and allocentric neglect. To learn further whether both neuropsychological and functional evaluation would reveal allocentric neglect, we invited him for a subsequent examination with figurative discrimination tasks (the Gap Detection and the Apples test) and specific functional tasks (reading articles and words, and setting and telling time) posited to be sensitive to detect allocentric neglect. The BIT, the Gap Detection test, the 'trees-&-house' figure copying test, and the functional tasks were repeated 3 times,  $9 \pm 2.8$  days apart, over a period of 30 days.

## Tests of General Cognitive Functions and Independence in Self-care

**Florida Mental State Examination (FMSE)**—Cognitive functioning in SR was assessed with the FMSE (Doty, et al., 1990), which examines six cognitive domains: attention, intention, verbal memory, language and related function, and visual-spatial ability. In particular, *attention* was assessed by examining distractibility in right or left visual fields, digit span (repeating a string of numbers after the examiner), visual search task, visual, auditory and tactile extinction measurements, and line bisections; *intention* was assessed by test of imperistence (holding eyes closed until prompted to open), ranking level of general activity or movement, contrasting movement programs from verbal instructions, and word fluency; *verbal memory* was assessed by a short-form Boston Naming Test (Kaplan, Goodglass, & Weintraub, 1983) and Form 1 of the Hopkins Verbal Learning Test - Revised (Benedict, Schretlen, Groninger, & Brandt, 1998); *language and related function* was assessed by monitoring spontaneous speech for fluency, paraphasia and circumlocution, simple naming and sentence repetition task, and by tests of comprehension, reading, writing, praxis, finger naming and right-left confusion; *visual-spatial ability* was evaluated by figure copying and recall and by locating states on a blank map of the US. In addition, the Mini Mental State Examination (Folstein, Folstein, & McHugh, 1975) was also performed. The normal range for each test was extracted from the original publications of each test included in the FMSE and MMSE, or from Strauss et al.(2006).

**Barthel Index**—The Barthel Index is a 10-item scale (Mahoney & Barthel, 1965) used to quantify SR's degree of independence in activities of daily living such as feeding, bathing, toileting, mobility, etc. Higher scores on the Barthel Index indicate greater independence (score ranges from 0 to 100).

## Tests of Personal Neglect and Visual Extinction

**Personal Neglect Test**—SR was instructed to use his right or intact hand to touch six left body parts including ear, shoulder, elbow, wrist, waist, and knee (Bisiach, Vallar, Perani, Papagno, & Berti, 1986). Hesitation in reaching and searching impact the total score negatively, the maximum of which is 18 with 3 points for immediate reaching to each body part.

**Visual Confrontation Test**—For the assessment of visual field defects or hemianopia, experimenter presented a single visual stimulus either on the ipsilesional side or on the contralesional side pseudorandomly in 20 trials. To detect visual extinction during double simultaneous stimulation, visual stimuli were presented simultaneously on both sides in 10 trials, along with unilateral stimulation either on the ipsilesional side in 5 trials or on the contralesional side in 5 trials (Bisiach & Faglioni, 1974); the order of presentation was pseudorandom. A visual stimulus was wiggling movements of experimenter's index finger in the peripheral visual field of the patient, who reported the side of the stimulus presentation.

## Paper-and Pencil Tests of Spatial Neglect

The BIT, the Bells test, the Gap Detection test, and the 'trees & house' copying task described in this section were repeated three times over a course of 30 days. Test materials were placed orthogonal to SR's mid-sagittal plane.

## Behavioral Inattention Test (BIT)

We administered the six conventional BIT subtests (Wilson, et al., 1987), including line crossing, letter cancellation, star cancellation, figure and shape copying, line bisection, and



representational drawing. The abnormal cut-off score was <129 out of 146 total (Halligan, Cockburn, & Wilson, 1991). Individual cut-offs for the six subtests are provided in Table 2.

### Bells Test

The Bells test is a visual search test similar to letter and star cancellation in the BIT, but it is more sensitive to detect moderate to mild neglect (Gauthier, et al., 1989). In the Bells test, SR marked bell-shaped targets amid distractors (tree, house, violin, apple, etc.), which are equally but randomly distributed in 7 columns on a letter-sized page (grid not visible). Search pattern was recorded. Six or more omissions out of 36 possible targets indicated abnormal behavior (Gauthier, et al., 1989). Specifically, more than 2 omissions on the left versus right on the page, and starting search from right-sided columns (5<sup>th</sup> column or beyond; leftmost column = 1 and rightmost column = 7) indicate presence of left egocentric neglect (Azouvi et al., 2006; Azouvi et al., 2002).

### 'Trees & House' Copying

SR was presented with a five-element figure consisting of two pine trees, a house and two trees arranged from left to right, located in the upper half on a horizontally oriented page (Gainotti, et al., 1972). He was instructed to copy all elements of the figure in the lower half of the page. A maximum of 10 can be scored on this test, and a score lower than 10 is indicative of impaired performance (Fortis et al., 2010).

### Gap Detection Test

This test consists of 10 fully-outlined circles, 10 circles with a gap or an opening on the left side and 10 circles with a gap on the right side, all of which are arranged evenly on a letter-sized page. SR was instructed to mark the fully-outlined circles. Allocentric errors referred to marking circles with gaps on the left side (contralesional) as if they were fully-drawn circles, and egocentric errors referred to target omissions on the left side of the page (Ota, et al., 2001).

### Apples Test

In this test, 150 apple-shaped stimuli are arranged pseudorandomly on a letter-sized page, in two rows and five columns, with 15 apples in each cell (note that there is no grid visible on the actual test sheet); 50 apples with an opening on the right-side, 50 with an opening on the left-side, and 50 fully-outlined complete apples form the test. SR was instructed to mark only the fully-outlined complete apples. Three scores were derived from this test using the equations below (Bickerton, et al., 2011):

$$\text{Accuracy score} = \text{Total targets (fully-outlined complete apples) marked} \quad (\text{Eq. 1})$$

Egocentric asymmetry score = Number of marked stimuli (complete apples) on the right side – number of those on the left side

Allocentric asymmetry score = Number of marked left side-open apples – number of marked right side-open apples

Accuracy score of less than 42 (of 50 fully-outlined apples) indicates an overall impaired performance. Positive values of asymmetry scores indicate spatial neglect of the left egocentric and/or allocentric space. An egocentric asymmetry score greater than 2 indicates left egocentric neglect; an allocentric asymmetry score greater than 1 indicates left allocentric neglect (Bickerton, et al., 2011).

## Functional Assessments of Spatial Neglect

### Catherine Bergego Scale (CBS)

The CBS is a 10-item observational scale that measures neglect-specific difficulties in everyday activities (Azouvi, et al., 1996). The CBS assesses for leftward or rightward spatial bias in conducting daily functions in personal, peri-personal and extrapersonal space (Chen, Hreha, Fortis, Goedert, & Barrett, 2012), and CBS subscores can detect deficits in perceptual and motor spatial domains (Goedert et al., 2012). Although total CBS scores have been used in prior studies as a single factor to detect neglect and to measure improvements after neglect interventions (Fortis, et al., 2010), recently Goedert et al. (2012) identified 2 underlying factors in the total CBS related to perceptual-attentional (PA) and motor-exploratory (ME) functional deficits associated with neglect. We report both CBS-PA and CBS-ME scores for SR. Further, we used the Kessler Foundation Neglect Assessment Process (Chen, Hreha, et al., 2012) to administer and score the CBS. Each item on the CBS is scored from 0 (indicating ‘no neglect’) to 3 (indicating ‘severe neglect’), with a total score of 30. Higher CBS scores indicate worse performance.

### One-word Reading Test

This test involves reading right side-up and upside-down words (Hillis, 2006; Hillis, Newhart, Heidler, Marsh, et al., 2005). After reading 6 words for practice (3 right side-up and 3 upside-down), SR read 20 words presented right side-up and 20 upside-down; each word was placed in the center of a page. Presentation order of right side-up and upside-down words was pseudorandom. If SR had difficulty with word recognition or pronunciations, he was instructed to spell out the word.

### Article and Menu Reading

Article and menu reading tests are part of the BIT behavioral subtests (Wilson, et al., 1987). In the article reading test, SR read out loud a short article arranged in columns on the left, center and right of the page. In the menu reading test, SR was presented with an unopened menu. He was instructed to open the menu, and read out names of food-items arranged in four columns, 2 columns on a page placed on the left-side and 2 columns on a page placed on the right side of SR’s mid-sagittal plane. Complete and partial word omissions, and/or partial or whole word substitutions in menu and article reading tests were scored negatively. The cutoff score for both these tests is 8 of a maximum score of 9 (Halligan, et al., 1991).

### Telling and Setting Time

SR was asked to set and tell time using his personal wrist watch (similar to the BIT subtest; Wilson et al., 1987). First, he was instructed to set three times that required clock hands to be present: 1) only in the right half, 2) only in the left half, and 3) in both halves of the watch face. Time was reset to 12 o’clock prior to beginning a new trial. Second, he was instructed to tell time with three placements of hands (same as the set time task), i.e., when both hands were in right or left half, or one hand in each halves of the watch face. The experimenter presented the watch directly in front and on SR’s mid-sagittal plane as he adjusted or told time.

## RESULTS

A detailed profile of SR’s performance on each test is provided in this section. He scored 10 of 42 on the NIH Stroke Scale, indicating moderate stroke severity (Briggs, Felberg et al., 2001).

## General Cognitive Functions and Independence in Self-care

Overall, we noted that SR was alert but mildly slow in his movements. We observed that he used short, simple sentences during conversations, and spoke more slowly than average (spontaneous speech score: 4 of 12; FMSE). He was agreeable, easy to work with, and followed instructions appropriately. The score was consistent with cognitive impairment (MMSE = 21 out of 30). The Barthel Index score (35 of 100) indicated his lack of independence in self-care and mobility.

The appendix provides FMSE scores. Key findings related to spatial neglect, memory, and language functions are described here. SR's line bisections revealed a rightward bias ( $10.3 \pm 4.6$  mm rightward of the true line center). He demonstrated auditory extinction (single stimulation: 100% accurate; double stimulations: 0% accurate, omitted left-sided stimuli) and tactile extinction (single stimulation: 90% accurate; double stimulations: 0% accurate, omitted left-sided stimuli). He did not demonstrate visual extinction (single and double stimulations: 100% accurate) in this battery. As to his visual-spatial ability, SR had no difficulty with simple figure copying and locating regions on a map, and although his immediate visual memory was impaired, errors in this test appeared unrelated to lateralized spatial deficits.

SR presented with moderate to severe difficulty in verbal episodic memory. Specifically, he scored zero on both immediate and delayed 3-word recall. SR's performance on the Hopkins Verbal Learning Test (a 12-word list) was also poor for immediate recall, delayed recall and recognition when compared to age- and education-adjusted normative data (Hester, Kinsella, Ong, & Turner, 2004). His semantic memory was intact for naming five prior presidents of the United States. He also had difficulty on working memory assessed with verbal calculations (0 out of 5, serial subtractions), which improved with the use of paper and pencil for computations (3 out of 5). Time orientation was normal.

SR's word retrieval and confrontational naming performance on the BNT was within the normal range (13 out of 15 correct, short-form). Fluency of spontaneous speech was mildly impaired with no paraphasic or circumlocution errors. Pace of his speech was slow with too few words in short and simple sentences, and his articulation was mildly impaired. Naming, reading, writing, comprehension, praxis, and finger naming were normal. He had no right-left confusion.

## Personal Neglect and Visual Extinction

SR immediately reached for 6 left body parts (ear, shoulder, elbow, wrist, waist, knee) using his right hand, indicating absence of personal neglect. SR performed at 85% accuracy for double simultaneous detection of visual stimuli when this was repeated with the visual confrontation test (17 of 20 correct), while he reported unilateral visual stimulus in the left or right visual field normally (100% accurate). SR's performance accuracy was inconsistent with more trials of double simultaneous stimulation in the visual confrontation task compared to the FMSE battery (10 versus 5 double stimulation trials). Although SR responded accurately with lesser trials (5 of 5 double trials) in the FMSE battery, mildly impaired performance (3 of 10 incorrect) in the visual confrontation task suggests presence of visual extinction which was observable when the number of double trials increased.

## Paper-and-Pencil Tests of Spatial Neglect

Table 2 presents SR's performance on all the paper-and-pencil tests. On average, SR's BIT score was below the cut-off ( $121.3 < 129$ ). Specifically, he demonstrated left-sided spatial neglect in line crossing ( $32 < 34$ ), star cancellation ( $47.3 < 51$ ), figure and shape copying ( $0.67 < 3$ ), line bisection ( $6 < 7$ ), and representational drawing ( $1 < 2$ ).



On the Bells test, SR omitted 9 targets mainly on the left side. Difference in omissions on the left and right side of the page was 7, more than the cutoff of 2 (Azouvi et al., 2006), consistent with left egocentric neglect. Additionally, he exhibited a right-to-left horizontal scanning pattern, starting his search from the rightmost column (7; Figure 2), again, consistent with left egocentric neglect.

Like his performance on the BIT subtests of figure and shape copying and representational drawing, SR's performance on the 'Trees & House' copying test revealed the tendency to omit drawing or copying the left side of objects (Figure 3), suggesting the presence of allocentric neglect.

The Gap Detection test, however, was not sensitive in distinguishing allocentric or egocentric neglect. On average, SR correctly identified 9.7 full circles and rarely mistook a gapped circle for a full circle (Table 2).

The Apples test, a visually more crowded test than the Gap Detection test, revealed that SR was impaired (accuracy: 38 of 50 full apples marked). He presented with both egocentric and allocentric neglect based on the cutoffs of asymmetry scores (egocentric asymmetry score =  $6 > 2$ ; allocentric asymmetry score =  $39 > 1$ ). Figure 4 presents the data in percentages from the left to right columns of the test sheet. Virtually, no right side-open apples were marked, which indicates that SR correctly identified them. However, the fully-outlined and left side-open apples were both marked more on the right than the left side, consistent with egocentric neglect. Further, a Fisher's exact test was performed on each column to compare these two stimuli. We found no significant difference between the number of marked fully-outlined apples versus left side-open apples in any column ( $p > .01$ ), suggesting that SR regarded apples with left-openings as fully-outlined or complete apples. These results revealed his spatial deficits in both egocentric as well as allocentric reference frames.

### Functional Assessments of Spatial Neglect

Table 3 summarizes SR's CBS total and subscores. Overall, during the 30 days of study participation, his neglect severity remained at about the same level with the CBS ranging from 13 to 15 out of the total score of 30. SR's CBS-PA and CBS-ME subscores also remained at the same level ranging from 6-10 of 18 and 5-7 of 12, respectively. SR was mostly aware of his limbs and body parts (CBS:  $M = 0.7$ ,  $SD = 0.58$ ; personal neglect score =  $18/18$ ). When he was asked to locate personal belongings in his living room (3 belongings on his right and 3 on his left), he presented with mild-to-moderate neglect ( $M = 1.7$ ,  $SD = 0.58$ ); he was able to locate all 6 objects, but consistently had trouble on his left side. For the most part, he began cleaning his mouth, or grooming (combing) hair or face on his right side first, and went slowly and hesitantly towards the left. SR was able to locate a short-sleeved t-shirt placed on his left side by crossing over the mid-line to the left, but had trouble finding the left sleeve and was unable to complete dressing ( $M = 1.7$ ,  $SD = 0.58$ ). Spontaneous leftward gaze orientation ( $M = 2$ ) was moderately impaired, while the auditory attention to a loud noise on his left, and navigation in his house to the left were mildly impaired. SR had difficulty in his wheelchair; he consistently collided with furniture and a door frame on the left side.

On a one-word reading test, SR erred only once (out of 20) on right side-up words, where he substituted the word 'moment' for 'momentum'. Of the 20 upside-down word readings, he made 7 word or letter substitution errors (Table 2); these errors are shown in Figure 5. Notice that he omitted 's' at the end of 2 words, which because of the upside-down presentation were on the left side. He had difficulty with upside-down 'p' and 'd'. While spelling, he substituted 'o' for an upside-down 'c' in the word 'dogmatic', and 'a' for an

upside-down 'e' in the word 'center'; because of the upside-down presentation, upside-down 'c' and 'e' appeared similar to a circle with a left-opening in the Gap Detection test. However, these substitutions were not consistent.

SR's performance on menu and article reading was noteworthy. He scored below the cutoffs for both menu and article readings (both scored on average  $6.3 < 8$ ; Table 2). Specifically, on the article reading task, although he began by approaching the leftmost column, he randomly omitted words on the left side in sentences within columns independent of column location with respect to the page, which is consistent with left allocentric neglect. For example, he omitted words on the left side of sentences in the right-most (ipsilesional side) column. Occasionally, he also substituted or omitted left-sided letters within a word independent of its position with respect to the page. For example, he substituted 'accept' for 'concept', 'would' for 'could', and omitted 2 left-sided letters in 'deserving', reading it as 'serving'.

In the time setting task, SR erred more often setting and adjusting time when the target time specified both hands were in the left-half of the watch (8:50, 10:45, and 6:50; he started trials at a neutral position – 12:00). SR erred 4 out of 9 times while setting, and 3 out of 9 times while telling time. These 7 errors were made when watch-hands were in the left and right halves, or when both hands were in the left half of the watch (errors when adjusting 8:50, 10:45, 6:50, 2:40, or telling 8:45, 10:45, 7:10); no errors were reported when the target time specified for the watch-hands to be positioned solely in the right half of the watch face (Figure 6). We are unable to provide support to this observation by formal statistics, and needs to be validated further in future, large sample studies.

## DISCUSSION

The present report describes a chronic spatial neglect patient, SR, who suffers from both egocentric and allocentric neglect since his stroke more than 3 years ago. After a comprehensive examination, we observed that SR made consistent left-sided object-centered errors in figurative discrimination tasks, which is indicative of allocentric neglect. He also demonstrated an egocentric spatial deficit, especially on paper-and-pencil tests such as the Bells test and the Apples test (Table 2), where we observed that he omitted targets on the left side of the page. SR's allocentric neglect was most evident on allocentric-specific paper-and-pencil tests, particularly the Apples test.

The Apples test was more sensitive and consistent in detecting SR's allocentric neglect, rather than the Gap Detection test. With a denser array of targets and distractors per space unit, both the visual search and figurative discrimination tasks are relatively more difficult in the Apples test (Bickerton et al., 2011). Consistent with SR's performance, the Apples test may be a more reliable neuropsychological assessment for allocentric neglect, especially in chronic neglect patients who may have learned to compensate for their spatial deficits. Nonetheless, without these specialized tasks, whether it is the Apples or the Gap Detection test, commonly used neuropsychological assessments, such as the Behavioral Inattention Test, would not have revealed evidence of allocentric neglect in SR.

Besides neuropsychological indications, we found that SR made both allocentric and egocentric errors on daily function tasks. On an article reading test, SR occasionally omitted words located on the left side of a sentence, substituted words within a sentence, and omitted left-sided letters within a word, independent of the location of sentences or words with respect to the page. Left-sided letter substitution and omission errors were also evident in one-word reading, but this task does not allow distinction of allocentric versus egocentric errors. Setting and telling time errors were made when one or both watch-hands were in the

left half of the watch. We interpret his performance on these tasks as evidence of the functional impact of SR's allocentric neglect.

Association between functional dependence and presence of specific neglect subtype is still debatable. SR was quite dependent on others for his daily needs (Barthel Index = 35). Physical disability, presence of spatial neglect, and impairment in global cognitive function are all significant predictors of poor everyday function after stroke. In SR's case, besides being chronically hemiplegic, his suboptimal cognitive status (MMSE = 21) and his chronic although mild neglect (CBS = 9.5; BIT = 121.3) may have impeded his efforts to regain functional independence. However, how the relative difference in the severity of egocentric versus allocentric neglect impacts daily functions is unclear. In Bickerton et al.'s study (2011), individuals with pure allocentric neglect or dual egocentric and allocentric neglect deficits had greater functional dependence than those with pure egocentric neglect. This finding suggests that allocentric neglect may be more disabling than egocentric neglect, which calls for better clinical tools to detect and treat allocentric neglect. We also posit that allocentric and egocentric neglect may differentially affect spatial-perceptual versus spatial-motor cognitive domains, especially in functional tasks, and future studies assessing effects of neglect subtypes will provide further insight.

Interestingly, although SR's occupational therapist reported his neglect symptoms, SR was never treated for neglect or more specifically, for allocentric deficits. Since spatial neglect in general is under-represented in research and under-recognized in clinical practice, it is possible that individuals with such disorder do not receive focused rehabilitation (Chen, McKenna, Kutlik, & Frisina, 2012; Edwards et al., 2006). Rehabilitation outcomes of a treatment program may differ depending on the survivor's spatial cognitive deficits (Pachalska, et al., 2004). In a treatment study with two neglect patients, one with egocentric neglect and the other with allocentric neglect, Pachalska et al. (2004) found that the two patients responded differently to specific treatments. Visual scanning therapy was more effective in treating allocentric neglect while the spatio-motor control training was more effective in treating egocentric neglect. The former required the patients to visually scan from non-neglected to neglected side; the latter trained the patients making complex but controlled bilateral motor movements (Pachalska, et al., 2004). Such findings are consistent with the view that spatial neglect is a complex, non-unified neurocognitive disorder, and that effective treatments must be tailored to target specific deficits in this broadly-defined population (Barrett et al., 2006; Fortis, Chen, Goedert, & Barrett, 2011). In the case of SR, a combination of visual scanning and spatio-motor-targeted treatment may address both his allocentric and egocentric deficits. However, research on allocentric neglect or even treating it is so scarce that currently no treatment recommendation is available.

Brain regions or networks critical for spatial neglect depends on specific spatial cognitive deficits (Verdon, Schwartz, Lovblad, Hauert, & Vuilleumier, 2010). Prior studies provide evidence of a wide range of brain regions involved in spatial neglect. However, only a few studies, summarized in Table 1, classified brain regions by egocentric versus allocentric neglect. Specifically, these studies suggest that lesions involving the inferior parietal regions, frontal cortex, frontoparietal areas and subcortical white matter are associated with egocentric neglect while lesions in temporal areas (i.e., superior, middle and inferior temporal gyri, and superior temporal sulcus) and the angular gyrus may be strongly associated with allocentric neglect; lesions in the medial temporal gyrus, temporoparietal junction and insula, and superior WM pathways are involved in both egocentric and allocentric neglect (Chechlacz, et al., 2010; Chechlacz et al., 2012; Grimsen, Hildebrandt, & Fahle, 2008; Hillis, Newhart, Heidler, Barker, et al., 2005; Verdon, et al., 2010; Yue, et al., 2012). In addition to cortical or gray matter lesions, damage to the WM, as observed in SR, is also associated with spatial neglect (Doricchi & Tomaiuolo, 2003; He et al., 2007;

Leibovitch et al., 1998; Urbanski et al., 2011). However, only a few WM studies separated egocentric and allocentric neglect before analyzing neuroanatomic-behavior associations.

SR's clinical radiology images indicated that he had suffered damage to WM pathways connecting the frontal lobe with the temporal and parietal brain areas. By evaluating a single case, it is difficult to identify WM pathways specifically related to his chronic neglect, versus other primary sensory and/or motor conditions (e.g., left hemiparesis), or WM pathways specific to egocentric versus allocentric neglect. Consistent with SR's profile of damage, Chechlacz et al. (2012) also found involvement of superior longitudinal fasciculus, a superior WM pathway, in persistent egocentric and allocentric neglect. Further, based on prior studies summarized in Table 1, Yue et al. (2012)'s in particular, we posit that restricted activity in paraventricular temporal WM, connecting the temporal lobe with the frontal and occipital regions, may be associated with SR's allocentric neglect, while the anatomical frontoparietal disconnectivity due to disrupted superior WM pathways may critically account for SR's egocentric neglect (Figure 1).

In conclusion, egocentric and allocentric neglect can co-exist and may complicate the manifestation of spatial neglect in conventional and functional assessments. SR provides an opportunity to emphasize that allocentric neglect and its impact on daily function is under-investigated and under-treated, and that future research should help improve understanding of how allocentric deficits induce functional impairments in relation to allocentric deficits, and what brain networks are commonly injured in association with allocentric neglect, and what treatments may best target allocentric and egocentric spatial dysfunctions. We recommend that assessments that allow separation of allocentric and egocentric deficits, both neuropsychological and functional, should be an essential part of standard neglect examinations and cognitive screening (Humphreys, Bickerton, Samson, & Riddoch, 2012). Functional assessments administered in this study such as the article, menu and one-word reading, and setting and telling time, and other sensitive tests should be validated in large sample size studies, not only as a tool to detect allocentric neglect, but also to monitor improvement after rehabilitation programs, focused on improving object-centered deficits. Identifying allocentric neglect after stroke and learning about its influence on daily function may enhance care quality and facilitate effective rehabilitation planning (Lincoln, Drummond, & Berman, 1997).

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## Appendix

### Florida Mental Status Examination

Cognitive domains	Assessments	Scores (SR's score / maximum score)
Domain I. Attention		
	Distractibility	6 / 6
	Digit span (forward)	3 / 5
	Letter Cancellation	10 / 10
	Double Simultaneous stimulation    Single	29 / 30

Cognitive domains	Assessments	Scores (SR's score / maximum score)
	Double	8 / 15
	Line bisection	32.3 / 35.4
	<b>Total</b>	<b>88.3 / 101.4</b>
<b>Domain II: Intention</b>		
	Impersistence	15 / 15
	General activity (movement)	0 / 5 - Normal
	Contrasting programs (1-2, 2-1)	10 / 10
	<b>Total</b>	<b>25 / 30</b>
<b>Domain III: Verbal Memory</b>		
	Hopkins verbal learning test - Recall	12 / 36
	Hopkins verbal learning test - Recognition	6 / 12
	Hopkins verbal learning test - Long term recall	2 / 12
	Orientation	8 / 10
	Registration	3 / 3
	Calculation task	3 / 5
	"Spell WORLD backwards"	5 / 5
	Short term recall	0 / 3
	Long term recall	0 / 3
	Remote memory	5 / 5
	<b>Total</b>	<b>44 / 94</b>
<b>Domain IV: Language and related functions</b>		
	Spontaneous speech	4 / 12
	Naming	2 / 2
	Repetition	3 / 3
	Comprehension	2 / 3
	Reading	3 / 3
	Writing	1 / 1
	Praxis	3 / 3
	Finger naming	3 / 3
	Right-left confusion	5 / 5
	<b>Total</b>	<b>26 / 35</b>
		13 / 15
	15-item BNT Short-form (Cut-off: <11)	
<b>Domain V: Visual spatial</b>		
	Copying	1 / 1
	Mapping	4 / 5
	Visual memory	0 / 1
	<b>Total</b>	<b>5 / 7</b>

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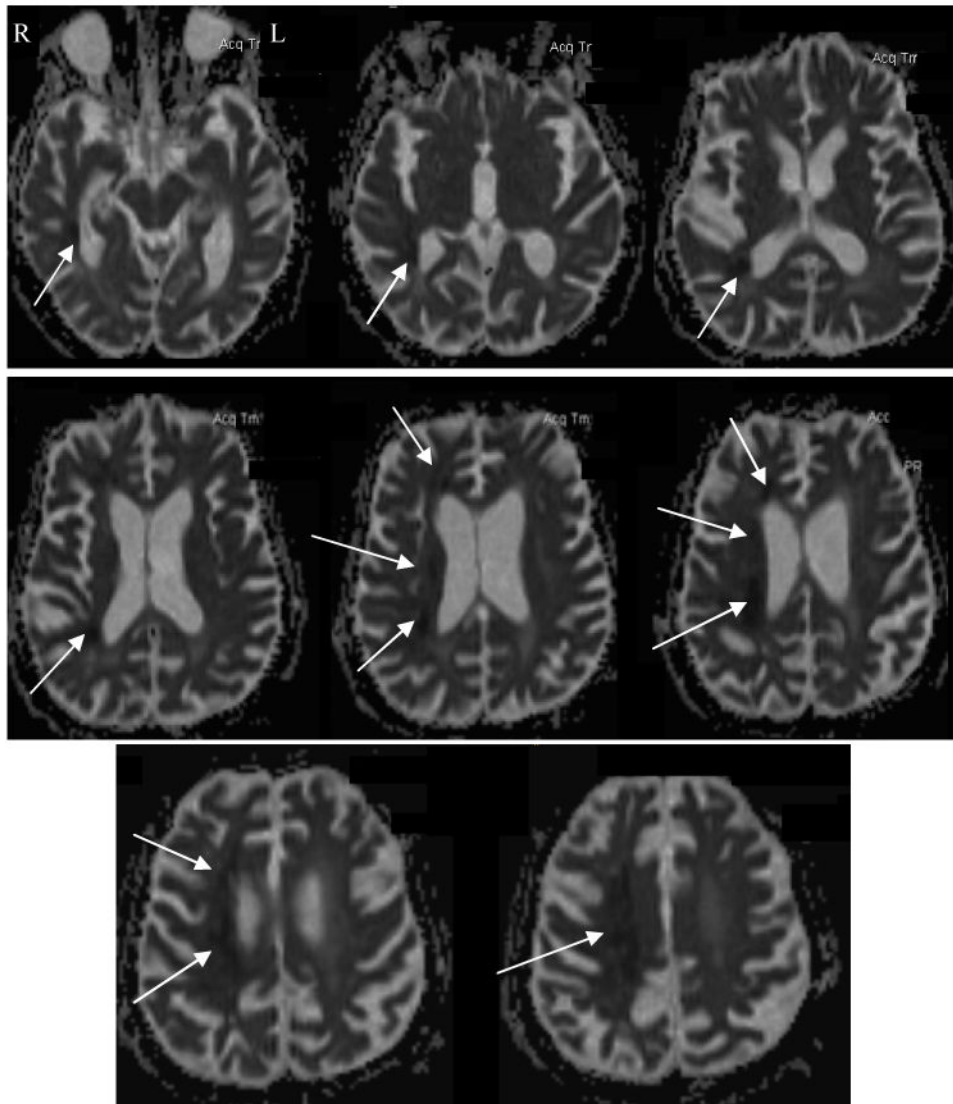
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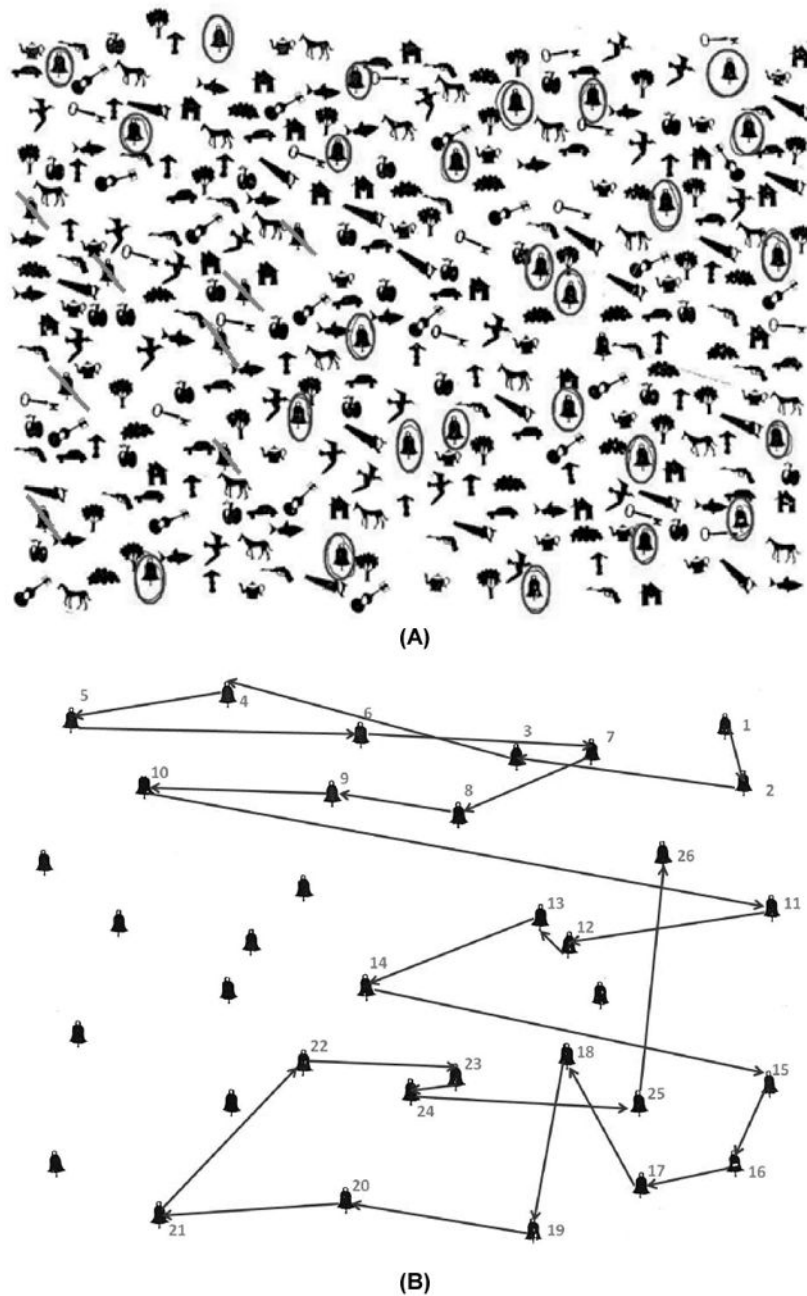
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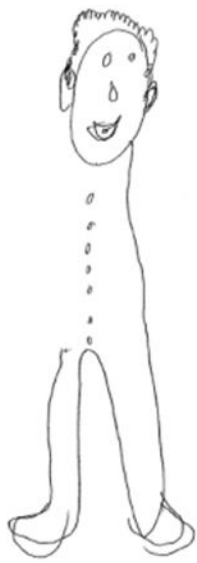


**Figure 1.** Apparent diffusion coefficient maps from magnetic resonance imaging performed 17 days after SR's ischemic stroke. White arrows point to areas of hypointensity, reflecting restricted water motion. Age-related bilateral microvascular disease and diffused volume loss were also observed. Areas of infarction in the right temporal lobe were identified on MRI 7 days after stroke according to SR's radiology report (not shown), but they are not well-demonstrated on sub-acute apparent diffusion coefficient maps presented here.

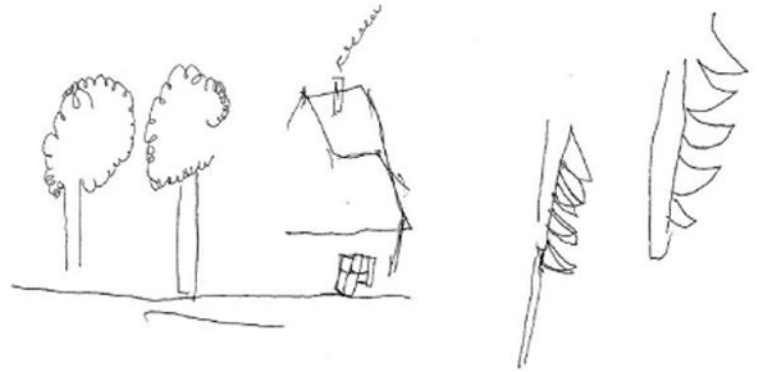


**Figure 2.**

A) SR's performance on the Bells Test reveals his egocentric neglect. Circles indicate targets (bells) correctly located by SR, and gray lines indicate SR's target omission errors. B) SR's search pattern is indicated by arrows and numbers.



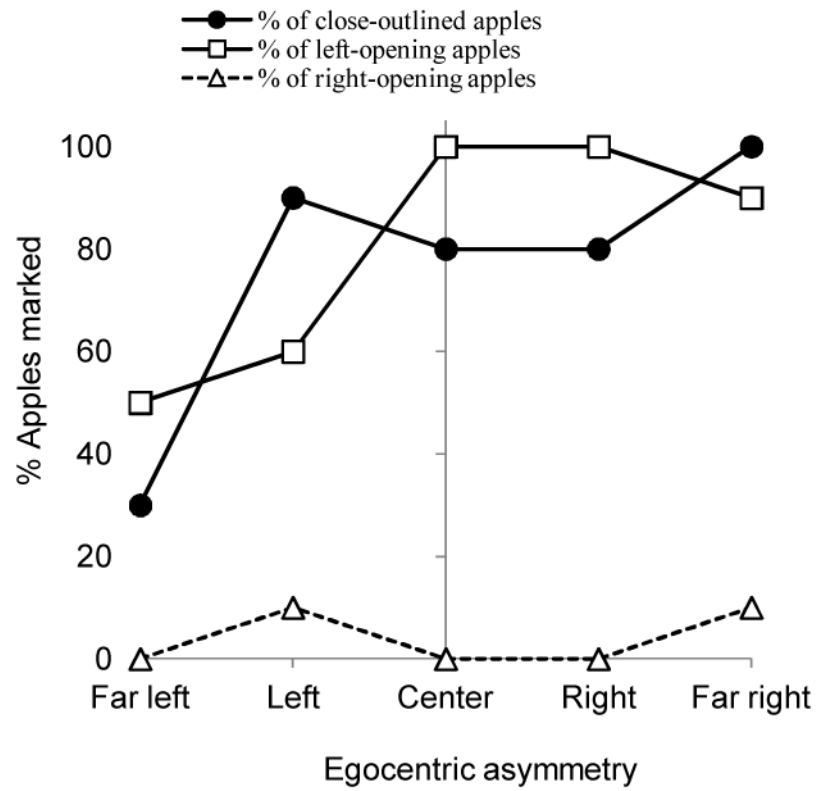
(A)



(B)

**Figure 3.**  
A) SR's free drawing of a person. B) His performance on the 'Trees & House' copying test.





**Figure 4.** Performance from left to right spatial grid on the Apples Test.

	<u>Stimulus</u>	<u>Response</u>
1.	<b>suoıııdo</b>	<b>opinion</b>
2.	<b>səsodııd</b>	<b>d-u-r-p-o-s-e-s</b>
3.	<b>dogmatic</b>	<b>p-o-g-m-a-t-i-o</b>
4.	<b>ııııht</b>	<b>pright</b>
5.	<b>ıeııeı</b>	<b>c-a-n-t-e-r</b>
6.	<b>səposıe</b>	<b>episode</b>
7.	<b>ııııı</b>	<b>n-u-i-t</b>

**Figure 5.** SR's performance on one-word reading test. Listed here are the errors he made out of the 20 upside-down word readings. SR spelled out unrecognized words; these words are represented by hyphens (-).



(a) Errors made when instructed to *tell* time



(b) Errors made when instructed to *set* or *adjust* time

**Figure 6.**  
Errors in telling (a) and setting (b) time using SR's personal watch.

Table 1

Summary of lesion locations involved in egocentric versus allocentric neglect

Article	Participants	Inclusion criteria	Lesion findings	
			Allocentric Neglect	Egocentric Neglect
Hillis et al., 2005		Acute ischemic infarct confined to right subcortical areas	Right STG	Right angular gyrus
Chechlacz et al., 2010		Included CO poisoning patients	Cortical: More posterior damage: posterior STS, & angular, MTG, ITG & middle occipital gyri WM: SLF, SFO, ILF, IFOF, TR, CR Both disorders independently associated with WM lesions	Cortical: Middle frontal, postcentral, SMG, and STG, and insula
Verdon et al., 2010	80 acute & subacute phases (16 severe neglect; 25 no neglect; 39 different degrees of neglect severity)	Also compared lesions in patients with and without hemianopia, & hemiplegia separately	Temporal areas near PHG, extending in WM towards the MTG on lateral surface. Involvement of WM extending towards both MTC and LTC	<i>Perceptual neglect:</i> Right IPL near SMG extending into adjacent WM <i>Exploratory neglect:</i> Right IFL, anterior DLPF, posterior MFG, subcortical WM
Grimsen et al., 2008		Focused on cortical lesions only	Ventromedial temporal cortical structures	Frontoparietal regions, especially premotor cortex
Medina et al., 2008		Right ischemic strokes only	Posterior MTC & ITC (BA 37), & posterior insula	Right SMG (BA 40) extending ventrally into STG and MTG
Golay et al., 2008		Post-hoc subgrouping; chronic at least 2 months post-stroke; right vascular damage	Insular cortex, comprising the WM beneath STG Paraventricular WM of the parietal lobe	Frontal structures or projections WM of frontal lobe, anterior to the caudate nucleus
Yue et al., 2012		Right hemisphere lesions	STG and MTG	--

Abbreviations: BA = Brodmann area; Ctrl = Controls; Ego = Egocentric; Allo = Allocentric; CO = Carbon monoxide; STG = Superior temporal gyrus; STS = Superior temporal sulci; MTG = Middle temporal gyrus; ITG = Inferior temporal gyrus; SMG = Supramarginal gyri; PHG = Parahippocampal gyrus; WM = White matter; MTC = Medial temporal cortex; LTC = Lateral temporal cortex; IPL = Inferior parietal lobe; IFL = Inferior frontal lobe; DLPF = Dorsolateral prefrontal cortex; MFG = Medial frontal gyri; ITC = Inferior temporal cortex; SLF = superior longitudinal fasciculus; SFO = superior fronto-occipital fasciculus; ILF = inferior longitudinal fasciculus; IFOF = Inferior fronto-occipital fasciculus; TR = Thalamic radiation; CR = Corona radiata

Table 2

Data Summary.

	Perfect score (max or min possible score)	Mean	SD	Cut-off for spatial neglect
<b>Tests of spatial neglect</b>				
Total BIT	146	121.3	4.51	<129
1. Line crossing *	36	32.0	6.93	<34
2. Letter cancellation	40	33.7	6.03	<32
3. Star cancellation *	54	47.3	2.89	<51
4. Figure & shape copying *	4	0.67	0.58	<3
5. Line bisection *	9	6.0	2.00	<7
6. Representational drawing *	3	1.0	1.00	<2
The Bells test (omissions) *	0	9.0	—	>6
1. Omissions (left minus right) *	0	7.0	—	>2
2. Starting point (Columns arranged from left=1 to right=7) *	1	7	—	>5
Trees & house drawing *	10	6.7	0.29	<10
Visual extinction: Unilateral	20	20	—	
Visual extinction: Double simultaneous	20	17.0	—	
Personal neglect	18	18	—	<18
<b>Allocentric neglect assessments</b>				
Gap detection test	10	9.7	0.58	
1. Marked complete circles	10	9.7	0.58	
2. Crossed circles with left-gap	5	0.7	1.15	
3. Crossed circles with right-gap	5	0.0	—	
<b>Apples test</b>				
1. Accuracy score *	50	38	—	<42
2. Egocentric asymmetry score *	0	+6	—	>+2
3. Allocentric asymmetry score *	0	+39	—	>+1
<b>Functional assessments</b>				
Barthel Index	100	35	—	
CBS *	30	9.3	0.31	>1
<b>Allocentric neglect assessments</b>				
BIT: Menu reading *	9	6.3	3.06	<8
BIT: Article reading *	9	6.3	1.15	<8
Telling time	3	2.2	1.04	<2
Setting time *	3	1.7	0.58	<2
<b>One-word reading test</b>				
1. Errors: Upside down reading	—	7	—	—
2. Errors: Right-side up reading	—	1	—	—

\* indicates abnormal rightward bias if a given test has a cut-off score.

SD = Standard deviation; max = Maximum; min = Minimum



**Table 3**

Catherine Bergego Scale (CBS) scores for 3 sessions (on average 9 days apart). Perceptual-attentional (CBS-PA) and motor-exploratory (CBS-ME) subscores are calculated based on the result of Goedert et al.'s factor analysis (2012).

	CBS Items	Session 1	Session 2	Session 3
1	Personal belongings	2	1	2
2	Grooming	1	1	1
3	Gaze orientation	2	2	2
4	Auditory attention	2	1	0
5	Eating	1	1	—
6	Cleaning after meal	2	0	1
	CBS-PA	10	6	7.2
7	Limb awareness	0	1	1
8	Dressing	1	2	2
9	Navigation	1	1	0
10	Collisions	3	3	3
	CBS-ME	5	7	6
	CBS Total	15	13	13.3
	Mean		13.8	
	SD		1.07	

0-no left neglect; 1-mild neglect; 2- moderate neglect; 3- severe neglect