Postprint of a Study on the Value of Eye Tracking-Based Dynamic Task Assessment for Post-Stroke Unilateral Spatial Neglect

Authors: Yang Yuxuan, Zhang Han, Du Juan, Wang Lingling, Xie Yulei, Yin Kaiming, Zhang Bo, Zhang Bo

Date: 2023-04-03T00:00:00+00:00

Abstract

Background: Unilateral spatial neglect (USN) is a common cognitive disorder following stroke that severely impacts patients' functional recovery and quality of life. Therefore, objective assessment is crucial for facilitating functional recovery in patients.

Objective: To investigate the feasibility of using eye-tracking-based dynamic tasks to assess USN in subacute stroke patients.

Methods: Thirty hospitalized patients in the subacute phase after stroke were recruited from the Department of Rehabilitation Medicine at Nanchong Central Hospital between September 2021 and July 2022. USN was assessed using the conventional subtests of the Behavioral Inattention Test (BIT-C), the Catherine Bergego Scale (CBS), and an eye-tracking-based dynamic task, all completed within one week of admission, with adverse reactions during assessment recorded. A CBS score > 0 was diagnosed as USN, and a BIT-C total score < 129 was diagnosed as USN. The eye-tracking-based dynamic task assessment lasted 2 minutes total. Based on the spatial distribution of patients' fixation points, patients were classified as: non-USN patients (fixation points distributed across four quadrants) and USN patients (fixation points not distributed across four quadrants). Two professional rehabilitation therapists performed the clinical scale assessments and eye-tracking-based dynamic task assessments. Correlation analysis and consistency analysis were conducted on the three assessment results.

Results: The eye-tracking-based dynamic task assessment identified 14 patients with left USN and 16 non-USN patients among the 30 patients. USN patients had a higher proportion of fixation points on the right screen compared to non-USN patients ($Z = -4.776$, $P < 0.001$); USN patients also showed a significant

difference in fixation point proportions between left and right screens (Z = -3.49, P < 0.001). BIT-C assessment identified 15 patients with a total score < 129, diagnosed as USN patients, with the remaining 15 as non-USN patients. CBS assessment identified 16 patients with varying degrees of USN, with the other 14 as non-USN patients. BIT-C and the eye-tracking-based dynamic task showed high consistency in detecting USN patients (Kappa = 0.933, P < 0.001). Spearman rank correlation analysis revealed a negative correlation between the proportion of right-side fixation points and BIT-C total score (rs = -0.776, P < 0.001). CBS and the eye-tracking-based dynamic task showed substantial consistency in detecting USN patients (Kappa = 0.867, P < 0.001).

Conclusion: Eye-tracking-based dynamic task assessment of USN is feasible, with assessment results showing substantial consistency with BIT-C and CBS results. The assessment is less time-consuming, with high patient engagement and motivation, and can serve as a supplement to standard USN assessments.

Full Text

Preamble

Value of a Dynamic Eye-tracking Task in Assessing Unilateral Spatial Neglect after Stroke

YANG Yuxuan[1], ZHANG Han[1], DU Juan[1], WANG Lingling[2], XIE Yulei[2], YIN Kaiming[1], ZHANG Bo[1]*

[1]Department of Rehabilitation Medicine, the Second Clinical Medical School of North Sichuan Medical College/Nanchong Central Hospital, Nanchong 637000, China
[2]Department of Rehabilitation Medicine, Affiliated Hospital of North Sichuan Medical College, Nanchong 637000, China

*Corresponding author: ZHANG Bo, Chief physician; E-mail: 79915726@qq.com

Abstract

Background
Unilateral spatial neglect (USN) is a common post-stroke cognitive impairment that severely affects functional recovery and quality of life. Objective assessment is therefore essential to facilitate patients' functional recovery.

Objective
To investigate the feasibility of using a dynamic eye-tracking task to assess USN in subacute stroke patients.

Methods
Thirty inpatients in the subacute phase after stroke were recruited from the Department of Rehabilitation Medicine at Nanchong Central Hospital between September 2021 and July 2022. USN was assessed using the Behavioral Inattention Test-Conventional subtest (BIT-C), Catherine Bergego Scale (CBS), and a

two-minute dynamic eye-tracking task, all completed within one week of admission. Adverse effects during assessment were recorded. USN was diagnosed by a CBS score >0, a BIT-C total score <129, or gaze points distributed outside the four screen zones (with gaze points distributed within all four zones defined as non-USN). Correlation and consistency analyses were used to evaluate the results of the three assessments.

Results

Based on the dynamic eye-tracking task performance, 14 patients exhibited left-sided neglect and 16 had no USN. USN patients showed a higher percentage of gaze points on the right side of the screen than non-USN patients (Z=-4.776, P<0.001), with a significant difference in gaze point percentages between left and right screen sides in USN patients (Z=-3.49, P<0.001). BIT-C assessment identified 15 patients with USN and 15 without. CBS assessment revealed that 16 patients had varying degrees of USN, while the remaining 14 were non-USN. The BIT-C and dynamic eye-tracking task showed high consistency in detecting USN (Kappa=0.933, P<0.001). Spearman' s rank correlation revealed a negative correlation between the percentage of right-side gaze points and BIT-C total score (rs=-0.776, P<0.001). The CBS and dynamic eye-tracking task also demonstrated good agreement (Kappa=0.867, P<0.001).

Conclusion

The dynamic eye-tracking task is feasible for assessing USN, showing good consistency with BIT-C and CBS results while requiring less time and eliciting high patient engagement and motivation. It can serve as a supplement to standard USN assessment.

[**Key words**]

Stroke; Unilateral spatial neglect; Eye-tracking; Dynamic task; Feasibility study; Kappa value

---

Introduction

Stroke is the second leading cause of death and a major cause of disability worldwide, representing a significant public health concern [1]. Approximately one in three stroke survivors is diagnosed with unilateral spatial neglect (USN) [2], which is more common in patients with right hemisphere damage. USN can also occur in other types of brain injury and primarily results from damage to neural networks involved in spatial information processing and attentional control [3]. USN is defined as a failure to respond to environmental stimuli on the side contralateral to brain injury in the absence of other sensory or motor deficits [4]. Research indicates that approximately 40% of USN patients continue to experience neglect symptoms [5-6], which disrupt basic self-care activities (such as dressing and grooming), impair postural balance [7-8], and interfere with reading ability [9-10]. USN also severely impacts the rehabilitation process for inpatients, leading to prolonged hospital stays [11-13] and increased family burden [14].

Most USN patients are unaware of their symptoms or potential consequences during the initial disease stage [15-17], preventing them from seeking timely treatment or learning compensatory strategies. USN imposes profound consequences on stroke survivors and their families, and objective assessment to determine the presence and severity of USN is crucial for guiding multidisciplinary rehabilitation to mitigate its adverse effects [18].

Currently, no consensus exists among clinicians regarding methods for identifying USN and monitoring post-treatment improvement, and accurate, comprehensive assessment of USN remains a major clinical challenge. Neuropsychological assessments such as paper-and-pencil cancellation tasks, line bisection tests, and reading tests [18], along with ecological assessments like the Catherine Bergego Scale (CBS) [19], are commonly used. Eye-tracking technology is emerging as a novel assessment tool. Research on early detection of mild cognitive impairment and Alzheimer' s disease has shown that eye-tracking tests can effectively differentiate cognitive function among normal subjects, Alzheimer' s patients, and those with mild cognitive impairment [20]. Additionally, eye-tracking has been applied to USN assessment. Baheux et al. [21] and Broeren et al. [22] used eye-tracking devices to monitor neglect symptoms during static tasks, where participants performed line bisection and cancellation tests (lines, letters, stars) in a virtual environment (computer). However, static task-based assessments lack dynamic information during evaluation and ecological validity. Gomes Paiva et al. [23] used wearable eye-tracking glasses to study patients' walking in real-world environments and assess USN by exploring the timing of left-right target stimuli, though most acute and subacute patients lack the capacity for real-world walking.

Therefore, our research team explored using eye-tracking technology during dynamic tasks to assist in screening and evaluating USN in subacute stroke patients. Dynamic tasks allow patients to freely explore dynamic space to search for target stimuli, offering greater real-world relevance than static tasks while increasing cognitive demands [24]. Additionally, this paradigm based on eye-movement interaction technology enables convenient patient assessment, with each dynamic task requiring only 2 minutes and being applicable to populations unable to complete scales due to hand dysfunction.

Methods

Participants

Thirty inpatients in the subacute phase after stroke were recruited from the Department of Rehabilitation Medicine at Nanchong Central Hospital between September 2021 and July 2022. Inclusion criteria were: (1) meeting diagnostic criteria for ischemic [25] or hemorrhagic stroke [26] with CT or MRI confirmation of cerebral hemorrhage or infarction; (2) age 18-80 years; (3) in the subacute phase of stroke (1-6 months post-onset); (4) Mini-Mental State Examination (MMSE) score $ $10 or ability to cooperate with testing; (5) intact visual fields or corrected to normal; and (6) stable condition able to complete testing in a seated position. Exclusion criteria were: (1) history of neurological or psychiatric disorders; (2) severe comprehensive aphasia making it difficult to follow therapist instructions; (3) severe hearing loss; or (4) failure to provide informed consent.

This study was approved by the Ethics Committee of Nanchong Central Hospital (approval number: 2021-007), and all patients provided informed consent. The study was registered with the Chinese Clinical Trial Registry (ChiCTR2100049482).

Assessment Procedures

Therapists conducted rough peripheral visual field measurements using confrontational visual field testing (dynamic method). Examiner and patient sat facing each other at eye level, half a meter apart. When examining the right eye, the patient' s right eye and examiner' s left eye fixated on each other while covering the opposite eye. The examiner moved a finger slowly from the periphery toward the center from various directions at equal distance between them; if both saw the finger simultaneously, the field was generally considered normal.

Cognitive level was assessed using the Chinese version of the Mini-Mental State Examination [27]. General data collected included age, sex, handedness, days post-stroke, brain lesion location, and cognitive level. Handedness was evaluated using the Edinburgh Handedness Inventory [28].

Paper-and-pencil tests are the most commonly used USN assessment methods in clinical practice. The Behavioral Inattention Test-Conventional subtest (BIT-C) contains multiple paper-and-pencil tests, and CBS is recommended as the most suitable USN assessment for inpatients [29]. Therefore, our team selected these two assessment methods as standards for comparison with eye-tracking dynamic task results. All patients completed BIT-C, CBS, and the eye-tracking dynamic task within one week, with researchers recording results and adverse effects during assessment.

Eye-tracking Dynamic Task Assessment The dynamic eye-tracking task used a high-performance eye-tracking device (Hangzhou Jizhi Medical Technology Co., Ltd., Model: JZ-RZ-20US, Figure 1) for analysis. Each subject sat 60 cm from the device, holding side handrails with both hands to maintain relatively fixed posture during task completion (if subjects could not grasp with one or both limbs, family members assisted in posture fixation), ensuring minimal upper body and head movement. Therapists adjusted subjects' positions until their eyes could be detected by the device (Figure 1). Before assessment, subjects completed device calibration by fixating on three calibration points on the display (twice). The eye-tracking device below the monitor, based on pupil-corneal reflection technology, offers high precision, non-contact, and non-invasive advantages.

Two regions of interest (ROI) were set on the left and right sides of the screen, with the device automatically providing percentage values for gaze points (eye search and fixation) on each side. Researchers manually divided the screen into four zones by connecting the upper and lower quarter points to create left-inner, left-outer, right-inner, and right-outer zones (Figure 2). Patients were classified based on gaze point spatial distribution: non-USN patients (gaze points distributed across all four zones) and USN patients (gaze points not distributed across all four zones).

The insect-shooting task from the cognitive rehabilitation training and assessment system (bilateral, simple level) served as the dynamic task. During assessment, insects moved randomly from bottom to top on the left and right sides of the monitor, and subjects were instructed to search for target stimuli (insects) on the display and shoot them down by gazing at them until the assessment ended. The assessment lasted 2 minutes. Before formal assessment, therapists explained requirements and methods, with patients receiving one practice opportunity that stopped once mastery was confirmed, followed by formal assessment.

All eye-tracking dynamic task assessments were completed by one rehabilitation therapist (DJ), who was blind to patients' clinical assessment results.

Clinical Scale Assessment CBS is an ecological USN assessment tool with good reliability and validity [30]. The scale comprises 10 items: grooming, dressing, eating, mouth cleaning, gaze direction, limb awareness, auditory attention, collisions, spatial orientation, and item searching. Each item scores 0 (normal) to 3 (severe neglect), with CBS score >0 diagnosing USN. Neglect severity is divided into three grades: 1-10 (mild), 11-20 (moderate), and 21-30 (severe). The total score is the average item score multiplied by 10 (excluding non-applicable items).

BIT-C includes widely used paper-and-pencil tests [31]: (1) line, letter, and star cancellation tests; (2) figure and shape copying; (3) line bisection; and (4) representational drawing. The sum of each test score yields the BIT-C total score (0-146), with scores <129 diagnosing USN; lower scores indicate more severe neglect.

In the cancellation tests, targets were presented on A4 paper (210 mm × 297 mm), and patients were to cross out all lines, letters "E" and "R," and small stars without time limits, with missed targets recorded. Maximum scores were 36, 40, and 54 points respectively, with cutoffs of 34, 32, and 51.

For figure and shape copying, subjects copied three figures (a four-pointed star, a cube, and a flower) and three line-composed figures onto A4 paper. Maximum score was 4, cutoff 3.

In line bisection, three 20 cm horizontal lines on A4 paper required patients to mark the midpoint as accurately as possible. Scoring (0-3) was based on distance from true center: <1 cm deviation = 3 points; 1-2 cm = 2 points; 2-3 cm = 1 point; >3 cm = 0 points. Maximum was 9, cutoff 7.

For representational drawing, patients drew a clock, a person, and a butterfly from memory on A4 paper. Each drawing was scored for symmetry (0 = asymmetric, 1 = symmetric), with maximum 3 and cutoff 2.

All clinical assessments were completed by one professional rehabilitation therapist (XYL), blind to eye-tracking dynamic assessment results.

Statistical Analysis

SPSS 25.0 software was used for data analysis. The Shapiro-Wilk test assessed normality. Normally distributed continuous data were expressed as mean ± standard deviation; otherwise, median (P25, P75) was used. For outcome measures, independent samples t-tests were used for normally distributed data, with paired t-tests analyzing left-right gaze point percentage differences in USN (and non-USN) patients. For non-normal distributions, Mann-Whitney U tests were used, with Wilcoxon signed-rank tests evaluating left-right gaze point percentage differences. Pearson correlation analyzed relationships between right gaze point percentage and BIT-C total score for normal distributions; otherwise, Spearman rank correlation was used. Paired chi-square tests and Cohen' s Kappa assessed consistency between BIT-C, CBS, and eye-tracking dynamic task results. P<0.05 indicated statistical significance.

Results

Participant Characteristics

Among the 30 subacute stroke patients, 19 were male and 11 female; age ranged 34-78 years (mean 60.3$±11.5).$Mostpatientswereright - handed(96.7±40.7.Lesionlocations : righthemispherein19, lefthemispherein5, andbilateralin6.Onesubjectco on MMSE.

Eye-tracking Dynamic Task Results

The eye-tracking dynamic task revealed that 14 of 30 patients had left USN: 3 with gaze points only in the right-outer zone, 8 in right-inner and right-outer zones, and 3 in left-inner and right-side zones. The remaining 16 patients were non-USN, with gaze points distributed across all four zones (Table 1).

USN patients showed significantly higher right-side screen gaze point percentages than non-USN patients (Z=-4.776, P<0.001). Comparison of left-right screen gaze point percentages in USN patients also revealed significant differences (Z=-3.49, P<0.001) (Table 2).

Clinical Scale Results

All patients completed BIT-C and CBS assessments. BIT-C identified 15 patients with USN (total score <129) and 15 without. CBS assessment revealed 16 patients with varying USN severity and 14 non-USN patients (Table 1).

Consistency and Correlation Analysis

BIT-C and the eye-tracking dynamic task showed high consistency in detecting USN (Kappa=0.933, P<0.001). Spearman rank correlation revealed a negative correlation between right-side gaze point percentage and BIT-C total score (rs=-0.776, P<0.001). CBS and the eye-tracking dynamic task also demonstrated high consistency (Kappa=0.867, P<0.001).

Patients found the eye-tracking dynamic task novel and interesting, with high acceptance.

Discussion

USN is a common disabling condition after stroke [32] and can also occur in other brain injury types [33-34]. In visual search tasks, USN patients exhibit not only omission of visual targets but also more general search performance deficits, such as unsystematic search patterns and irregular eye movement patterns [35-36]. Our findings indicate that the eye-tracking dynamic task holds considerable potential for monitoring and rehabilitation guidance of USN in subacute stroke patients.

Classic paper-and-pencil tests are commonly used clinically to assess neglect severity. These simple tests focus on evaluating patients' ability to search for/delete static stimuli, directly expressing reduced target search performance on one side but providing little information about how patients dynamically scan and explore. Eye-tracking devices can record dynamic task assessment processes in real-time and visually display eye movement trajectories (search and fixation). This enables clinicians to evaluate visual search patterns and analyze aspects such as time spent exploring left-right space or number of fixations on each side to identify significant spatial difficulties related to post-stroke USN. Moreover, dynamic tasks simulate active human perception of environmental dynamics, offering greater ecological validity than static tasks [37].

Research suggests USN patients retain ability to extract low-level feature information while complex search performance is impaired [38-39]. Dynamic tasks increase cognitive demands, potentially better detecting USN. Previous studies show USN patients tend toward repetitive behaviors in ipsilesional space

[40] and exhibit ipsilesional attentional bias. In typical visual behavior, eye movements and spatial attention are closely related [37]; spatial bias in eye movements (search and fixation) may be a hallmark of USN. In static stimulus visual search, left USN patients rarely find targets in left-outer regions [41]. We found this visual search bias also exists in dynamic tasks: left USN patients spent significantly less time (fixation percentage) in left visual space than right, differing markedly from non-USN patients' right-side fixation percentages (Z=-4.766, P<0.001). Furthermore, spatial distribution of fixations correlated with neglect severity (as indicated by BIT-C scores). Interestingly, one patient diagnosed with mild left USN by BIT-C (total score 113) showed normal gaze point spatial distribution in the eye-tracking dynamic task, suggesting that as BIT-C total scores increase, fixation distribution between left and right visual fields may gradually change. Gaze point spatial distribution alone may not accurately diagnose patients with mild neglect, but overall diagnostic results showed high consistency with BIT-C. Right-side fixation percentage also negatively correlated with BIT-C total score; more severely neglectful patients had more fixations in right visual field, even confined to right-outer regions.

Dynamic stimulation paradigms with free eye movement show greater ecological validity than static stimulation. Therefore, we also analyzed consistency between ecological assessment results and eye-tracking dynamic task results. We used CBS as the ecological assessment, which has high sensitivity and was recommended by Azouvi et al. [30] as the most appropriate USN assessment tool for inpatients. Our results showed high consistency between CBS and eye-tracking dynamic task in identifying USN (Kappa=0.867). One patient diagnosed with mild neglect by CBS (showing limb neglect) was not identified by eye-tracking dynamic task or BIT-C, suggesting dissociation may exist between visual-based and behavioral observation-based neglect assessments, confirming that USN is a complex neuropsychological syndrome for which no single test can completely and accurately identify the condition [42].

Specific directional eye movement characteristics may provide an effective way to quantify neglect symptoms. However, as a preliminary study, our sample size was small, requiring expansion in future research. Additionally, we primarily examined the assessment role of eye-tracking dynamic tasks in subacute stroke patients; sensitivity and reliability for acute or chronic stroke patients require further investigation. Diagnosing USN based solely on gaze point spatial distribution appears somewhat weak, resulting in missed diagnosis of mild neglect patients. However, given our small sample size and lack of stratified analysis by neglect severity, we cannot yet determine sensitivity of the eye-tracking dynamic task for mild neglect patients. We used a simple-level dynamic task; whether higher difficulty levels (faster target movement, more simultaneous targets) can more sensitively detect mild neglect requires further study. Future research should continue exploring eye movement characteristics in USN patients to propose more precise diagnostic criteria.

References

[1] GBD 2019 Stroke Collaborators. Global, regional, and national burden of stroke and its risk factors, 1990-2019: a systematic analysis for the Global Burden of Disease Study 2019[J]. Lancet Neurol, 2021, 20(10): 795-820. DOI: 10.1016/S1474-4422(21)

[2] ESPOSITO E, SHEKHTMAN G, CHEN P. Prevalence of spatial neglect post-stroke: a systematic review[J]. Ann Phys Rehabil Med, 2021, 64(5): 101459. DOI: 10.1016/j.rehab.2020.10.010.

[3] CORBETTA M, SHULMAN G L. Spatial neglect and attention networks[J]. Annu Rev Neurosci, 2011, 34: 569-599. DOI: 10.1146/annurev-neuro-061010-113731.

[4] HEILMAN K M, VALENSTEIN E, WATSON R T. Neglect and related disorders[J]. Semin Neurol, 2000, 20(4): 463-470. DOI: 10.1055/s-2000-13179.

[5] NIJBOER T C W, KOLLEN B J, KWAKKEL G. Time course of visuospatial neglect early after stroke: a longitudinal cohort study[J]. Cortex, 2013, 49(8): 2021-2027. DOI: 10.1016/j.cortex.2012.11.006.

[6] RENGACHARY J, HE B J, SHULMAN G L, et al. A behavioral analysis of spatial neglect and its recovery after stroke[J]. Front Hum Neurosci, 2011, 5: 29. DOI: 10.3389/fnhum.2011.00029.

[7] NIJBOER T C, TEN BRINK A F, VAN DER STOEP N, et al. Neglecting posture: differences in balance impairments between peripersonal and extrapersonal neglect[J]. Neuroreport, 2014, 25(17): 1381-1385. DOI: 10.1097/WNR.0000000000000277.

[8] VAN NES I J, VAN KESSEL M E, SCHILS F, et al. Is visuospatial hemineglect longitudinally associated with postural imbalance in the postacute phase of stroke?[J]. Neurorehabil Neural Repair, 2009, 23(8): 819-824. DOI: 10.1177/1545968309336148.

[9] BOUKRINA O, CHEN P, BUDINOSKA T, et al. Exploratory examination of lexical and neuroanatomic correlates of neglect dyslexia[J]. Neuropsychology, 2020, 34(4): 404-419. DOI: 10.1037/neu0000619.

[10] VALLAR G, BURANI C, ARDUINO L S. Neglect dyslexia: a review of the neuropsychological literature[J]. Exp Brain Res, 2010, 206(2): 219-235. DOI: 10.1007/s00221-010-2386-0.

[11] DI MONACO M, SCHINTU S, DOTTA M, et al. Severity of unilateral spatial neglect is an independent predictor of functional outcome after acute inpatient rehabilitation in individuals with right hemispheric stroke[J]. Arch Phys Med Rehabil, 2011, 92(8): 1250-1256. DOI: 10.1016/j.apmr.2011.03.018.

[12] CHEN P, HREHA K, KONG Y, et al. Impact of spatial neglect on stroke rehabilitation: evidence from the setting of an inpatient rehabili-

tation facility[J]. Arch Phys Med Rehabil, 2015, 96(8): 1458-1466. DOI: 10.1016/j.apmr.2015.03.019.

[13] TARVONEN-SCHRÖDER S, NIEMI T, KOIVISTO M. Comparison of functional recovery and outcome at discharge from subacute inpatient rehabilitation in patients with right or left stroke with and without contralateral spatial neglect[J]. J Rehabil Med, 2020, 52(6): jrm00071. DOI: 10.2340/16501977-2698.

[14] CHEN P, FYFFE D C, HREHA K. Informal caregivers' burden and stress in caring for stroke survivors with spatial neglect: an exploratory mixed-method study[J]. Top Stroke Rehabil, 2017, 24(1): 24-33. DOI: 10.1080/10749357.2016.1186373.

[15] CHEN P, TOGLIA J. Online and offline awareness deficits: Anosognosia for spatial neglect[J]. Rehabil Psychol, 2019, 64(1): 50-64. DOI: 10.1037/rep0000207.

[16] RONCHI R, BOLOGNINI N, GALLUCCI M, et al. (Un)awareness of unilateral spatial neglect: a quantitative evaluation of performance in visuo-spatial tasks[J]. Cortex, 2014, 61: 167-182. DOI: 10.1016/j.cortex.2014.10.004.

[17] VALLAR G, BOTTINI G, STERZI R. Anosognosia for left-sided motor and sensory deficits, motor neglect, and sensory hemiinattention: is there a relationship?[J]. Prog Brain Res, 2003, 142: 289-301. DOI: 10.1016/S0079-6123(03)42020-7.

[18] AZOUVI P, BARTOLOMEO P, BEIS J M, et al. A battery of tests for the quantitative assessment of unilateral neglect[J]. Restor Neurol Neurosci, 2006, 24(4/5/6): 273-285.

[19] AZOUVI P, OLIVIER S, DE MONTETY G, et al. Behavioral assessment of unilateral neglect: study of the psychometric properties of the Catherine Bergego Scale[J]. Arch Phys Med Rehabil, 2003, 84(1): 51-57. DOI: 10.1053/apmr.2003.50062.

[20] TADOKORO K, YAMASHITA T, FUKUI Y, et al. Early detection of cognitive decline in mild cognitive impairment and Alzheimer' s disease with a novel eye tracking test[J]. J Neurol Sci, 2021, 427: 117529. DOI: 10.1016/j.jns.2021.117529.

[21] BAHEUX K, YOSHIZAWA M, YOSHIDA Y. Simulating hemispatial neglect with virtual reality[J]. J Neuroeng Rehabil, 2007, 4: 27. DOI: 10.1186/1743-0003-4-27.

[22] BROEREN J, SAMUELSSON H, STIBRANT-SUNNERHAGEN K, et al. Neglect assessment as an application of virtual reality[J]. Acta Neurol Scand, 2007, 116(3): 157-163. DOI: 10.1111/j.1600-0404.2007.00821.x.

[23] GOMES PAIVA A F, SORRENTINO G, BIGNAMI B, et al. Feasibility of assessing post-stroke neglect with eye-tracking glasses during a

locomotion task[J]. Ann Phys Rehabil Med, 2021, 64(5): 101436. DOI: 10.1016/j.rehab.2020.09.004.

[24] SPREIJ L A, TEN BRINK A F, VISSER-MEILY J M A, et al. Increasing cognitive demand in assessments of visuo-spatial neglect: testing the concepts of static and dynamic tests[J]. J Clin Exp Neuropsychol, 2020, 42(7): 675-689. DOI: 10.1080/13803395.2020.1798881.

[25] Chinese Society of Neurology, Chinese Stroke Society, PENG Bin, et al. Chinese guidelines for diagnosis and treatment of acute ischemic stroke 2018[J]. Chinese Journal of Neurology, 2018, 51(9): 666-682.

[26] Chinese Society of Neurology, Chinese Society of Neurology Cerebrovascular Disease Group. Chinese guidelines for diagnosis and treatment of acute intracerebral hemorrhage (2019)[J]. Chinese Journal of Neurology, 2019, 52(12): 994-1005. DOI: 10.3760/cma.j.issn.1006-7876.2019.12.003.

[27] KATZMAN R, ZHANG M Y, OUANG-YA-QU, et al. A Chinese version of the Mini-Mental State Examination; impact of illiteracy in a Shanghai dementia survey[J]. J Clin Epidemiol, 1988, 41(10): 971-978. DOI: 10.1016/0895-4356(88)90034-0.

[28] The assessment and analysis of handedness: the Edinburgh inventory[J]. Neuropsychologia, 1971, 9(1): 97-113. DOI: 10.1016/0028-3932(71)90067-4.

[29] AZOUVI P. The ecological assessment of unilateral neglect[J]. Ann Phys Rehabil Med, 2017, 60(3): 186-190. DOI: 10.1016/j.rehab.2015.12.005.

[30] AZOUVI P, SAMUEL C, LOUIS-DREYFUS A, et al. Sensitivity of clinical and behavioural tests of spatial neglect after right hemisphere stroke[J]. J Neurol Neurosurg Psychiatry, 2002, 73(2): 160-166. DOI: 10.1136/jnnp.73.2.160.

[31] WILSON B, COCKBURN J, HALLIGAN P. Behavioural inattention test[Z]. 1987.

[32] OSAWA A, MAESHIMA S. Unilateral spatial neglect due to stroke[M]//Stroke. Brisbane (AU): Exon Publications, 2021: 121-132. DOI: 10.36255/exonpublications.stroke.spatialneglect.2021.

[33] CHEN P, WARD I, KHAN U, et al. Spatial neglect hinders success of inpatient rehabilitation in individuals with traumatic brain injury: a retrospective study[J]. Neurorehabil Neural Repair, 2016, 30(5): 451-460. DOI: 10.1177/1545968315604397.

[34] CHEN P, LANDER V, NOCE N, et al. Prism adaptation treatment for spatial neglect post brain tumour removal: a case report[J]. J Occup Ther, 2020, 33(1): 25-29. DOI: 10.1177/1569186120921472.

[35] BEHRMANN M, EBERT P, BLACK S E. Hemispatial neglect and visual search: a large scale analysis[J]. Cortex, 2004, 40(2): 247-263. DOI: 10.1016/s0010-9452(08)70120-5.

[36] SAMUELSSON H, HJELMQUIST E K, JENSEN C, et al. Search pattern in a verbally reported visual scanning test in patients showing spatial neglect[J]. J Int Neuropsychol Soc, 2002, 8(3): 382-394. DOI: 10.1017/s1355617702813194.

[37] WALLE K M, NORDVIK J E, BECKER F, et al. Unilateral neglect post stroke: eye movement frequencies indicate directional hypokinesia while fixation distributions suggest compensational mechanism[J]. Brain Behav, 2019, 9(1): e01170. DOI: 10.1002/brb3.1170.

[38] AGLIOTI S, SMANIA N, BARBIERI C, et al. Influence of stimulus salience and attentional demands on visual search patterns in hemispatial neglect[J]. Brain Cogn, 1997, 34(3): 388-403. DOI: 10.1006/brcg.1997.0915.

[39] ESTERMAN M, MCGLINCHEY-BERROTH R, MILBERG W. Preattentive and attentive visual search in individuals with hemispatial neglect[J]. Neuropsychology, 2000, 14(4): 599-611. DOI: 10.1037//0894-4105.14.4.599.

[40] KAUFMANN B C, FREY J, PFLUGSHAUPT T, et al. The spatial distribution of perseverations in neglect patients during a nonverbal fluency task depends on the integrity of the right putamen[J]. Neuropsychologia, 2018, 115: 42-50. DOI: 10.1016/j.neuropsychologia.2018.01.025.

[41] MACHNER B, KÖNEMUND I, VON DER GABLENTZ J, et al. The ipsilesional attention bias in right-hemisphere stroke patients as revealed by a realistic visual search task: Neuroanatomical correlates and functional relevance[J]. Neuropsychology, 2018, 32(7): 850-865. DOI: 10.1037/neu0000493.

[42] BUXBAUM L J, FERRARO M K, VERAMONTI T, et al. Hemispatial neglect: subtypes, neuroanatomy, and disability[J]. Neurology, 2004, 62(5): 749-756. DOI: 10.1212/01.wnl.0000113730.73031.f4.

Author Contributions: YANG Yuxuan conceived the research idea, designed the study, and wrote the manuscript; ZHANG Han refined the study design and guided manuscript writing; DU Juan implemented the study and assisted with manuscript writing; WANG Lingling collected, organized, entered, and statistically analyzed data; XIE Yulei implemented the study; YIN Kaiming recruited patients; ZHANG Bo supervised the study, was responsible for article quality and review, and takes overall responsibility for the article. All authors approved the final manuscript.

Conflict of Interest: The authors declare no conflict of interest.

Received Date: 2022-12-02; **Revised Date**: 2023-03-01

Editor: MAO Yamin

Note: Figure translations are in progress. See original paper for figures.