The Value of Eye-Tracking Dynamic Task Assessment for Post-Stroke Unilateral Spatial Neglect: A Postprint Study

Authors: Yang Yuxuan[1], Zhang Han[1], Du Juan[1], Wang Lingling[2], Xie Yulei[2], Yin Kaiming[1], Zhang Bo[1]*

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Abstract

Background Unilateral spatial neglect (USN) is one of the common cognitive impairments following stroke, which severely affects patients' functional recovery and quality of life. Therefore, objective assessment is crucial for facilitating patients' functional recovery.

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

Methods Thirty subacute inpatients post-stroke were recruited from the Department of Rehabilitation Medicine at Nanchong Central Hospital between September 2021 and July 2022. Patients' USN status was evaluated using the conventional subtests of the Behavioral Inattention Test (BIT-C), the Catherine Bergego Scale (CBS), and eye-tracking-based dynamic tasks within one week of admission, with adverse reactions during assessment recorded. A CBS score >0 was diagnostic of USN. A BIT-C total score <129 was diagnostic of USN. The eye-tracking-based dynamic task assessment lasted 2 minutes in total. Patients were classified based on the spatial distribution of their fixation points: non-USN patients (fixation points distributed across 4 regions) and USN patients (fixation points not distributed across 4 regions). Clinical scale assessments and eye-tracking-based dynamic task assessments were completed by two professional rehabilitation therapists. Correlation and consistency analyses were performed on the three assessment results.

Results The eye-tracking-based dynamic task assessment revealed that among the 30 patients, 14 were left USN patients and 16 were non-USN patients. The proportion of fixation points on the right screen was higher in USN patients than in non-USN patients (Z=-4.776, P<0.001); comparison of fixation point proportions between left and right screens in USN patients revealed significant

differences (Z=-3.49, P<0.001). The BIT-C assessment showed that 15 patients had a BIT-C total score <129 and were diagnosed as USN patients, while the remaining 15 were non-USN patients. The CBS assessment indicated that 16 patients had varying degrees of USN, while the other 14 were non-USN patients. BIT-C and eye-tracking-based dynamic tasks demonstrated high consistency in detecting USN patients (Kappa=0.933, P<0.001); Spearman rank correlation analysis revealed that the proportion of right fixation points was negatively correlated with the BIT-C total score (rs=-0.776, P<0.001). CBS and eye-tracking-based dynamic tasks showed high 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 high consistency with BIT-C and CBS results. Moreover, the assessment process is less time-consuming, with high patient engagement and motivation, and can serve as a supplement to standard USN assessments.

Full Text

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 cognitive impairment after stroke that severely affects patients' functional recovery and quality of life. Objective assessment is therefore essential to facilitate rehabilitation.

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 evaluated 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 CBS score >0, BIT-C total score <129, or gaze points distributed

outside the four screen zones (with distribution across all four zones defined as non-USN). Two professional rehabilitation therapists conducted all assessments. Correlation and consistency analyses were performed among the three evaluation methods.

Results: Based on the eye-tracking dynamic task, 14 patients exhibited left-sided USN and 16 were classified as non-USN. USN patients showed a significantly higher percentage of gaze points on the right side of the screen compared to non-USN patients (Z=-4.776, P<0.001), and a significant difference in gaze distribution between left and right screen sides (Z=-3.49, P<0.001). BIT-C assessment identified 15 USN patients and 15 non-USN patients. CBS assessment revealed 16 patients with varying degrees of USN and 14 non-USN patients. The BIT-C and dynamic eye-tracking task showed high consistency in detecting USN (Kappa=0.933, P<0.001). Spearman's rank correlation analysis revealed a negative correlation between right-side gaze percentage 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 a feasible method for assessing USN, showing good consistency with both BIT-C and CBS results. The assessment is time-efficient, promotes high patient engagement and motivation, and can serve as a valuable supplement to standard USN evaluation.

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

Introduction

Stroke is the second leading cause of death worldwide and a major cause of disability, 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 the brain lesion in the absence of other sensory or motor deficits [4]. Research indicates that approximately 40% of USN patients continue to experience neglect symptoms long-term [5-6], which disrupt basic self-care activities (such as dressing and grooming), impair postural balance [7-8], interfere with reading ability [9-10], prolong hospitalization [11-13], and increase family burden [14].

Most USN patients are initially unaware of their symptoms or their potential consequences [15-17], preventing them from seeking timely treatment or learning compensatory strategies. Objective assessment to determine the presence and severity of USN is crucial for guiding multidisciplinary rehabilitation and miti-

gating its adverse effects [18]. Currently, no consensus exists among clinicians regarding optimal methods for identifying USN and monitoring treatment improvements; accurate and comprehensive USN assessment remains a major clinical challenge. Conventional assessments include neuropsychological tests such as paper-and-pencil cancellation tasks, line bisection, and reading tests [18], as well as ecological evaluations like the Catherine Bergego Scale (CBS) [19]. Eye-tracking technology is emerging as a novel assessment modality—studies have shown its effectiveness in distinguishing cognitive function among normal subjects, Alzheimer's disease patients, and those with mild cognitive impairment [20]. Eye-tracking has also been applied to USN assessment, with researchers using eye-tracking devices to monitor neglect symptoms during static tasks such as line bisection and cancellation tests (lines, letters, stars) in virtual environments [21-22]. However, static task assessments lack dynamic information and ecological validity.

Gomes Paiva et al. [23] used wearable eye-tracking glasses to study patients' walking in real-world environments, assessing USN by exploring response times to left and right-sided target stimuli. However, most acute and subacute patients lack the capacity for real-world ambulation. Therefore, our research team explored the use of eye-tracking technology during dynamic tasks to screen and evaluate USN in subacute stroke patients. Dynamic tasks allow patients to freely explore dynamic space to locate target stimuli, offering greater ecological relevance than static tasks while imposing additional cognitive demands [24]. Furthermore, this paradigm based on eye-tracking interaction enables convenient patient assessment—a single dynamic task requires only two minutes and can be administered to patients with hand dysfunction who cannot complete traditional scales.

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) diagnosis of ischemic [25] or hemorrhagic [26] stroke confirmed by CT or MRI; (2) age 18-80 years; (3) subacute phase (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; (6) stable condition able to sit and complete testing. Exclusion criteria were: (1) history of neurological or psychiatric disorders; (2) severe comprehensive aphasia preventing following therapist instructions; (3) severe hearing loss; (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 preliminary peripheral visual field measurements using confrontation 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; if both saw the finger simultaneously, the field was 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, 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) includes multiple paper-and-pencil tests, and CBS is recommended as the most suitable USN assessment for inpatients [29]. Therefore, our team selected these two assessments as standards for comparison with the eye-tracking dynamic task. All patients completed BIT-C, CBS, and the eye-tracking dynamic task within one week, with researchers recording results and any adverse events during assessment.

Eye-Tracking Dynamic Task Assessment

The dynamic eye-tracking task was performed using a high-performance eye-tracking device (Figure 1, Hangzhou Jizhi Medical Technology Co., Ltd., Model: JZ-RZ-20US). Each subject sat 60 cm from the device, holding both side handrails to maintain relatively fixed posture during task completion (if the subject could not grasp due to unilateral or bilateral limb dysfunction, family members assisted with posture stabilization), ensuring minimal upper body and head movement. Therapists adjusted subject positioning until their eyes were 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 uses pupil-corneal reflection technology, offering 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 (search and fixation) on each side. Researchers manually divided the screen into four zones (divided by lines connecting the upper and lower quarter points into left-inner, left-outer, right-inner, and right-outer zones, Figure 2). Patients were

classified based on gaze distribution: non-USN (gaze points distributed across all four zones) and USN (gaze points not distributed across all four zones).

The "shooting insects" 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. Subjects were instructed to search for target stimuli (insects) on the display and "shoot" them by fixating on them until the assessment ended. The total assessment time was two minutes. Before formal assessment, therapists explained requirements and methods, and patients had one practice opportunity that stopped once mastery was confirmed, followed by formal assessment.

One rehabilitation therapist (DJ) conducted all eye-tracking dynamic task assessments, blinded to patients' clinical evaluation results.

Clinical Scale Assessments

Catherine Bergego Scale (CBS): This ecological USN assessment tool demonstrates 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 retrieval. Each item scores 0 (normal) to 3 (severe neglect). CBS score >0 indicates USN. Neglect severity is divided into three grades: 1-10 (mild), 11-20 (moderate), and 21-30 (severe). The total score is the average of all applicable items multiplied by 10.

Behavioral Inattention Test-Conventional subtest (BIT-C): This 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 all test scores yields the BIT-C total score (range 0-146), with <129 indicating USN. Lower scores indicate more severe neglect.

In the cancellation tests, target stimuli were presented on A4 paper (210 mm × 297 mm), and patients were instructed to cross out all lines, letters "E" and "R," and small stars. No time limit was imposed, and the number of missed targets was 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 points, with a cutoff of 3.

In the line bisection test, three 20 cm horizontal lines were presented on A4 paper. Patients were asked to mark the midpoint of each line as accurately as possible. Scoring was based on distance between the mark and true center: 0-3 points per line (mark deviating <1 cm = 3 points; 1-2 cm = 2 points; 2-3 cm = 1 point; >3 cm = 0 points). Maximum score was 9 points, with a cutoff of 7.

For representational drawing, patients drew a clock, a person, and a butter-

fly from memory on A4 paper. Each drawing was scored for symmetry (0 = asymmetrical, 1 = symmetrical), with a maximum of 3 points and cutoff of 2.

One professional rehabilitation therapist (XYL) completed all clinical assessments, blinded 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 ($\bar{x}\pm s$), otherwise as median (P25, P75). For outcome measures, independent samples t-tests were used for normally distributed data, otherwise Mann-Whitney U tests. Paired t-tests or Wilcoxon signed-rank tests analyzed left-right gaze percentage differences within USN and non-USN groups. Pearson correlation analysis examined relationships between right gaze percentage and BIT-C total score for normally distributed data, otherwise Spearman's rank correlation was used. Cohen's Kappa test with paired chi-square analysis evaluated consistency between BIT-C, CBS, and eye-tracking dynamic task results. Statistical significance was set at $P<0.05$.

Results

Participant Characteristics

Among the 30 subacute stroke patients, 19 were male and 11 female; age ranged 34-78 years (mean $60.3\$\pm11.5 years$). $Most patients were right-handed (96.7\pm40.7. Lesion locations: right hemisphere in 19 cases, left hemisphere in 5, bilateral in 6. One subjecte$ on the MMSE.

Eye-Tracking Dynamic Task Results

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

USN patients showed significantly higher right-side screen gaze percentage compared to non-USN patients ($Z=-4.776$, $P<0.001$). Within-group comparison revealed significant differences between left and right screen gaze percentages in USN patients ($Z=-3.49$, $P<0.001$) (Table 2).

Clinical Scale Assessment Results

All patients completed BIT-C and CBS assessments. BIT-C identified 15 USN patients (total score <129) and 15 non-USN patients. CBS assessment revealed 16 patients with varying USN severity and 14 non-USN patients (Table 1).

Consistency and Correlation Analysis

The BIT-C and dynamic eye-tracking task showed high consistency in USN detection (Kappa=0.933, P<0.001). Spearman's rank correlation analysis revealed a negative correlation between right-side gaze percentage 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).

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

Discussion

USN is a common disabling condition after stroke [32] and other brain injuries [33-34]. During 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 demonstrate that dynamic eye-tracking tasks have considerable potential for monitoring USN and guiding rehabilitation 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 and delete static stimuli. While they directly demonstrate reduced target search performance on one side, they provide limited information about how patients dynamically scan and explore space. Eye-tracking devices can record the dynamic assessment process in real-time and visually display eye movement trajectories (search and fixation), enabling clinicians to evaluate visual search patterns and analyze aspects such as time spent exploring left versus right space or number of fixations on each side to identify significant spatial difficulties associated with post-stroke USN. Moreover, dynamic tasks simulate active human perception of environmental dynamics, offering greater ecological validity than static tasks [37]. Research indicates that USN patients retain the ability to extract low-level feature information while complex search performance is impaired [38-39]. Dynamic tasks impose additional cognitive demands that may better assess USN patients.

Previous studies show USN patients tend to exhibit repetitive behaviors in ipsilesional space [40] and demonstrate ipsilesional attentional bias. In typical visual behavior, eye movements and spatial attention are closely related [37]; the spatial bias of eye movements (search and fixation) may be a hallmark of USN. During visual search for static stimuli, left USN patients rarely detect targets in the left-outer region [41]. Our study 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, with marked differences from non-USN patients' right-side fixation percentages (Z=-4.766, P<0.001). Furthermore, fixation distribution spatial bias 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. While gaze point spatial distribution may not completely accurately diagnose patients with mild neglect, overall diagnostic results showed high consistency with BIT-C. Right-side fixation percentage also negatively correlated with BIT-C total score, with more severely neglectful patients showing more fixations in the right visual field, even confined to the right-outer zone.

Dynamic stimulation paradigms with free eye movement demonstrate greater ecological validity than static stimuli. Therefore, we also analyzed consistency between ecological assessment results and dynamic eye-tracking 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 good consistency between CBS and the eye-tracking dynamic task in identifying USN patients (Kappa=0.867). One patient diagnosed with mild neglect on CBS (showing limb awareness deficits) was not identified by either the eye-tracking dynamic task or BIT-C. This suggests that visual-based and behavior-observation-based unilateral neglect assessments may yield dissociated results, confirming that USN is a complex neuropsychological syndrome for which no single test can provide completely accurate identification [42].

Specific directional eye movement characteristics may offer an effective way to quantify neglect symptoms. However, as a preliminary study, our research has limitations including small sample size, requiring expansion in future studies. Additionally, we primarily examined the assessment utility of the dynamic eye-tracking task in subacute stroke patients; its sensitivity and reliability for acute or chronic stroke patients require further investigation. Relying solely on gaze point spatial distribution to diagnose USN may be insufficient, as evidenced by missed diagnosis of mild neglect patients. However, given our small sample size and lack of stratified analysis by neglect severity, we cannot yet determine the sensitivity of the dynamic eye-tracking task for mild neglect patients. Furthermore, we used a simple-level dynamic task; whether higher difficulty levels (faster target movement, more simultaneous targets) could more sensitively detect mild neglect requires further study. Future research should continue exploring eye movement characteristics in USN patients to develop more precise diagnostic criteria.

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