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Research article

Frontal and parietal cortices activation during walking is repeatable in older adults based on fNIRS

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ABSTRACT

Purpose: This study aimed to explore the test-retest reliability of fNIRS in measuring frontal and parietal cortices activation during straight walking and turning walking in older adults, in order to provide a theoretical foundation for selecting assessment tools for clinical research on motor control and some diseases such as Parkinson's disease in older adults.
Methods: 18 healthy older participants (69.1 ± 0.7 years) were included in this study. The participants completed straight walking and figure-of-eight turning walking tasks at self-selected speeds. Intra-class correlation coefficients (ICCs) and Bland-Altman scatter plots were used to assess the test-retest reliability of oxyhemoglobin (HbO_2) changes derived from fNIRS. $p < 0.05$ was considered statistically significant.
Results: The test-retest reliability of HbO_2 in prefrontal cortex (ICC, 0.67–0.78) was good and excellent, in frontal motor cortex (ICC, 0.51–0.61) and parietal sensory cortex (ICC, 0.53–0.62) is fair and good when the older adults performed straight and turning walking tasks. Bland-Altman diagram shows that the data consistency is fair and good.
Conclusion: fNIRS can be used as a clinical measurement method to evaluate the brain activation of the older adults when walking in a straight line and turning, and the results are acceptable repeatability and consistency. However, it is necessary to strictly control the testing process and consider the possible changes in the repeated measurements.

1. Introduction

Functional near-infrared spectroscopy (fNIRS) is a non-invasive technique that visualizes the brain activation by measuring changes in hemodynamic parameters, such as the concentration of oxygenated hemoglobin (HbO_2) and deoxygenated hemoglobin (Hbb) in the cortical areas of our brain [1]. Over the past 25 years, fNIRS has gradually been applied to studying the activation patterns of human cerebral cortex during exercise [2,3], revealing highest correlation to functional magnetic resonance imaging BOLD measures and providing reliable results [4]. Currently, this technology has become one of the preferred tools for assessing brain activation in different age groups or populations with varying health statuses when performing tasks such as walking, running, and balance control [5].

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However, environmental factors, exercise tasks, and test subjects may lead to changes in the scalp environment, probe positioning, and abnormal light-scalp coupling, which may reduce the accuracy of cerebral hemodynamic measurements [3,6]. Therefore, the test-retest reliability of fNIRS measurements is important. Studies have found that the fNIRS measurements exhibit good reliability in measuring resting-state functional connectivity of healthy individuals (ICC>0.60) [7], fair-to-good reliability in resting-state and bilateral finger-sequence movement task-based fNIRS scan of the somatosensory cortex (SSC) (ICC>0.46) [8], fair-to-excellent reliability in measuring the activation of prefrontal cortex (PFC),SSC, frontal eye fields and motor cortices in healthy older adults during postural and finger-tapping tasks (ICC≥0.48) [9], and good reliability in measuring PFC activation in individuals with normal blood pressure and primary hypertension during postural changes (standing to supine and inverted) (ICC>0.63) [10]. When used in young adults for walking and turning tasks, the technology demonstrated good reliability in measuring PFC activation (ICC = 0.67) [11]. Recently, fNIRS have been widely used in older adults [12,13]. A study utilizing a combination of different parameters and Mayer wave suppression filters during data processing derived from fNIRS reported excellent reliability in measuring PFC activation in older adults performing single and double walking tasks [14]. However, no studies on the test-retest reliability of brain activation measurements using fNIRS during turning walking in healthy older adults have been found.

This technology is frequently used in studies of gait rehabilitation in older patients with Parkinson's disease and stroke [15]. As walking activities occur in various environments and tasks, with turning walking accounting for 20%–50 % of daily gait difficulties, and with declining skin tactile and scalp perception abilities along with a decrease in brain neural networks in aging individuals [16], questions have been raised regarding the reliability of measuring brain activation during simple and complex walking tasks in older adults [3]. It has found that multiple cerebral cortices related to cognition, movement and sensation in frontal and parietal cortex participate in human gait control, including the PFC, premotor cortex (PMC), supplementary motor area (SMA), primary motor cortex (M1), primary somatosensory cortex (S1), and somatosensory association cortex (SAC), which are responsible for planning and regulating walking motions, planning, execution, learning, and posture control [1,17–19]. Testing the reliability of measuring brain activation during different walking tasks in older adults can enhance the credibility of articles concerning older adults published using this technology, and prompt researchers to further explore the changes in cerebral cortex activation during movement across different age groups.

Therefore, the aim of this study was to investigate the test-retest reliability of measuring the activation of the frontal and parietal cortices using fNIRS technology during straight and turning walking in older adults. Our goal was to provide a theoretical foundation for selecting testing methods in motor control and clinical research in older adults. We hypothesized that the test-retest reliability of measuring the activation of PFC, motor cortex, and sensory cortex using fNIRS technology during straight and turning walking in older adults was good. This will be manifested by good intra-group correlation coefficients (ICC) for two tests, good data consistency, and no significant differences.

2. Research methods

2.1. Subjects

With ICC = 0.8, $\alpha = 0.05$, power = 0.8, and 2 measurements, the minimum sample size was calculated to be 15 using Gpower [20]. For this study, 18 healthy older adults (8 females and 10 males) were recruited from the local community through the distribution of leaflets, with an average age of 69.1 ± 0.7 years, height of 163.8 ± 1.5 cm, and weight of 63.7 ± 2.5 kg.

The inclusion criteria were: older adults aged 65 and over; able to understand oral and written information; able to walk and turn independently; clear consciousness and ability to express their own intentions normally; no history of falls or surgery in the past 6 months; no history of any neurological medications. Exclusion criteria were: abnormal neuro-muscular system function; severe cardiovascular and cerebrovascular diseases, respiratory system diseases, and mental disorders; vestibular functional disorders and visual system diseases affecting posture control; coordination disorders and lower limb joint replacement surgery, arthritis, etc.; MMSE score less than 25.

2.2. Experimental procedure

Each participant visited the laboratory 2 times. The same tests were conducted during the 2 visits with a 7-day interval. The 2 tests were referred as Test 1 and Test 2. The tests were administered by the same personnel using identical equipment, settings, and procedures. Prior to each test, the equipment underwent calibration by the same staff member. On arrival, participants were briefed on the procedures and provided with standardized testing attire. Then the participants' scalps were cleaned and the fNIRS device was fitted by the same staff member to ensure the correct positioning of the probes. To cover as many areas of interest in the brain as possible, all probes were initially placed in the prefrontal cortex. Participants were then asked to perform two randomized motor tasks at a self-selected comfortable pace, with each task repeated three times. The duration of each test was 30 s, followed by a 30-s rest period. After the prefrontal cortex assessment, all probes were repositioned during the participants' rest period to cover the frontal and parietal cortices. 30 min later, the participants were asked to perform the two motor tasks again at a self-selected comfortable pace.

2.3. Motor task protocol

(1) Straight Walking: Participants were instructed to walk back and forth along a 10 m straight line on the ground as a guide for 30 s each time.

(2) Figure-eight Walking: Participants were instructed to walk continuously, following the guidance of two tangent circles with a diameter of 1.66 m marked on the ground for 30 s each time [21]. The participants were free to choose their starting direction from the points where the circles intersect.

Prior to the formal trial, each participant underwent two familiarization trials. Participants were instructed to maintain silence and empty their minds before start, to begin the test while hearing the "start" command, and to end the test while hearing the "stop" command. Afterwards, participants returned to the starting line and resumed the next test after a 30-s rest period. Throughout the test, the laboratory staff were required to keep silence.

2.4. Data collection

Brain activation data were collected using the fNIRS device (LIGHTNIRS, Shimadzu Corp., Kyoto, Japan), which comprised 8 emitters and 8 detectors, with a sampling frequency of 13.3 Hz. The device had laser diodes with wavelengths of 780 nm, 805 nm, and 830 nm, and the distance between optodes was 30 mm. According to the requirements of the international 10/10 system, all optodes were arranged in a 2×8 configuration to form 22 channels covering the prefrontal cortex. The optodes were then rearranged in a 4×4 configuration to form 20 channels covering the frontal and parietal cortices. Using 3D digitizer (FASTRAK, Polhemus, Vermont), according to the Brodmann area map, the channel coordinates of the Montreal Institute of Neurology (Fig. 1) and the corresponding channel of the region of interest (ROI) were determined. The frontal lobe ROI was the motor cortex, and the channels were 1–6, 11–16, including PMC, SMA and M1; the parietal lobe ROI was the sensory cortex, and the channels were 7–10 and 17–20, including S1 and SAC. To ensure the analysis of only good quality signals, the signal intensity data of all channels collected by each participant were well connected and determined by the automatic adjustment of fNIRS Shimadzu system.

2.5. Data processing

The hemodynamic data signals were first processed using the Homer2 toolbox based on MATLAB. The specific steps included (Fig. 2): (1) Converting the original data into optical density; (2) Using principal component analysis (PCA) for signal filtering; (3) Using Motion standard deviation and spline interpolation methods to remove motion artifacts, and excluding stimuli that fall within the time points identified as motion artifacts from hemodynamic response function calculation [22]; (4) Using bandpass filtering (0.01 Hz–0.1HZ) to remove physiological noises such as respiration, heartbeat, blood pressure and baseline deviation; (5) Converting optical density to changes in blood oxygen concentration using the modified Beer-Lambert law (with a partial path length factor (PPF) of 6.0 [23,24]); (6) Eliminating irrelevant stimuli outside the defined variables; (7) Using the block-average method, with the average concentration in the first 5 s [25,26] before the task begins used as the baseline, and averaging the concentration for all sample points within the first 25 s post-task initiation; (8) For baseline correction, selecting the most sensitive HbO_2 index with a larger variation range and better signal-to-noise ratio to represent the hemodynamic changes in the brain region, and subtracting baseline HbO_2 from HbO_2 within 25 s post-task initiation for normalization [27,28]. The resulting $\triangle HbO_2$ mean value represents the brain activation during the task. The average $\triangle HbO_2$ value of all channels within each region of interest was employed to depict the activation of that particular brain cortex region [29]. During data processing, the signal data from the two tests underwent visual inspection by the same staff member. Channels that showed multiple sharp spikes or flat line traces, indicating sudden and significant deviations from the expected signal were manually excluded. Participants with more than 10 % of the total number of deleted channels were not included in this study (n = 2) [29,30]. Finally, the data underwent an independent visual inspection by another staff member.

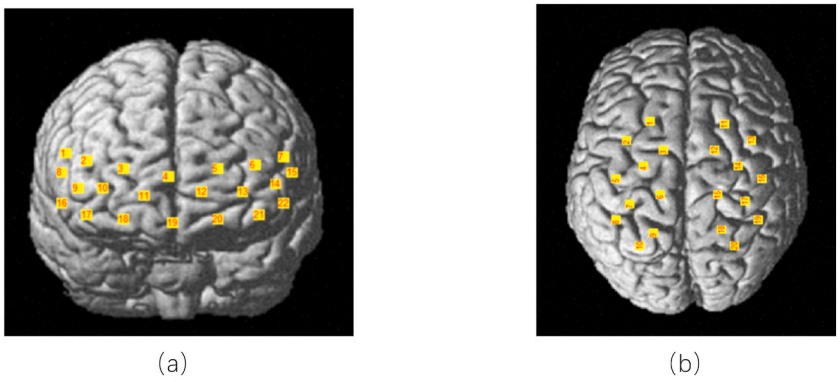

Fig. 1. Schematic diagram of data collection channels for regions of interest
(a) prefrontal region (b) frontal and parietal regions.

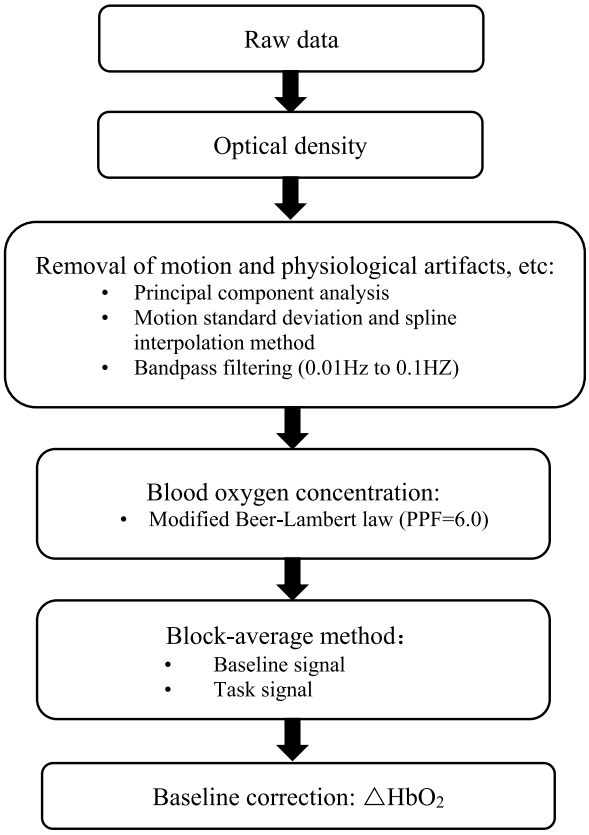

Fig. 2. A participant's signal data processing flow.

2.6. Statistical analysis

SPSS 25.0 was used for data analysis, and the results were expressed as mean ± standard deviation. Paired t-tests were conducted to verify the significance of differences between the two test sessions [11]. ICC value was used to evaluate the test-retest reliability of the data: poor ($0 < ICC \leq 0.40$), fair ($0.40 \leq ICC < 0.59$), good ($0.60 \leq ICC < 0.74$), and excellent ($0.75 \leq ICC < 1.0$) [31]. Bland-Altman plots were used to assess the distribution and differences in the mean values of the two test data sets [32]. $P < 0.05$ was considered statistically significant.

3. Results

3.1. Test-retest reliability of prefrontal cortex activation in older adults

During straight walking, there was no significant difference in the results of $\triangle HbO_2$ concentration of prefrontal cortex between the two tests in older adults ($p = 0.12$). The ICC value was 0.78, with a mean difference of -1.24×10^{-7} (Table 1). The Bland-Altman test showed a consistency range of -7.46×10^{-7} to 4.98×10^{-7}, with 94.44 % of data points falling within the 95 % confidence interval (Fig. 3a). After removing 1 outlier data point outside the 95 % confidence interval, the ICC increased to 0.85 ($P = 0.00$) [33].

Table 1
Test-Retest reliability results of HbO_2 concentration in different cerebral cortices in older adults under two walking conditions.

Regions of Interest	Task	Trial1 ($\times 10^{-7}$)	Trial2 ($\times 10^{-7}$)	Mean Difference ($\times 10^{-7}$)	Intraclass Correlation Coefficient			T-Test
					ICC	95%CI	P	P
Prefrontal Cortex	Straight Walking	1.64 ± 4.72	2.88 ± 2.73	−1.24	0.78	(0.43,0.92)	0.00	0.12
	Turning Walking	2.97 ± 4.67	3.42 ± 3.95	−0.45	0.67	(0.11,0.88)	0.02	0.62
Motor Cortex	Straight Walking	2.02 ± 2.96	1.32 ± 2.23	0.70	0.51	(-0.29,0.82)	0.08	0.37
	Turning Walking	1.31 ± 2.86	0.86 ± 3.59	0.45	0.61	(-0.06,0.86)	0.03	0.59
Sensory Cortex	Straight Walking	1.01 ± 2.97	0.39 ± 2.07	0.62	0.62	(-0.01,0.86)	0.03	0.34
	Turning Walking	0.60 ± 2.33	1.46 ± 2.66	−0.86	0.53	(-0.21,0.82)	0.06	0.22

Additionally, there was a trend of linear distribution of data points, indicating fair consistency in $\triangle HbO_2$ concentration between the two tests, with the difference potentially increasing as the measured values increased [34].

During turning walking, there was no significant difference in the results of $\triangle HbO_2$ concentration of prefrontal cortex between the two tests in older adults ($p = 0.62$). The ICC value was 0.67, with a mean difference of -0.45×10^{-7} (Table 1). The Bland-Altman test showed a consistency range of -7.87×10^{-7} to 6.96×10^{-7}, with 94.44 % of data points falling within the 95 % confidence interval (Fig. 3b). After removing 1 outlier data point outside the 95 % confidence interval, the ICC increased to 0.75 ($P = 0.00$) [33]. Furthermore, the data points were in a state of basic average distribution, indicating good consistency in $\triangle HbO_2$ concentration between the two tests [34].

3.2. Test-retest reliability of motor cortex activation in older adults

During straight walking, there was no significant difference in the results of $\triangle HbO_2$ concentration of motor cortex between the two tests in older adults ($p = 0.37$). The ICC value was 0.51, with a mean difference of 0.70×10^{-7} (Table 1). The Bland-Altman test showed a consistency range of -5.18×10^{-7} to 6.59×10^{-7}, with all data points falling within the 95 % confidence interval (Fig. 4a). The data points displayed a state of basic average distribution, indicating good consistency in $\triangle HbO_2$ concentration between the two tests [34].

During turning walking, there was no significant difference in the results of $\triangle HbO_2$ concentration of motor cortex between the two tests in older adults ($p = 0.59$). The ICC value was 0.61, with a mean difference of -0.45×10^{-7} (Table 1). The Bland-Altman test showed a consistency range of -6.35×10^{-7} to 7.25×10^{-7}, with all data points falling within the 95 % confidence interval (Fig. 4b). The data points displayed a state of basic average distribution, indicating good consistency in $\triangle HbO_2$ concentration between the two tests [34].

3.3. Reliability of retesting results for sensory cortex activation in older adults

During straight walking, there was no significant difference in the results of $\triangle HbO_2$ concentration of sensory cortex between the two tests in older adults ($p = 0.34$). The ICC value was 0.62, with an average difference of 0.62×10^{-7} (Table 1). The Bland-Altman test results showed a consistency interval of $-4.67 \times 10^{-7} \sim 5.91 \times 10^{-7}$, with 94.44 % of the data falling within the 95 % confidence interval (Fig. 5a). After removing 1 outlier outside the 95 % confidence interval [33], the ICC increased to 0.68 ($P = 0.01$). Additionally, the data points showed a basic average distribution, indicating good consistency in the data of $\triangle HbO_2$ concentration obtained from the two tests [34].

During turning walking, there was no significant difference in the results $\triangle HbO_2$ concentration of sensory cortex between the two tests in older adults ($p = 0.34$). The ICC value was 0.53, with an average difference of -0.86×10^{-7} (Table 1). The Bland-Altman test results showed a consistency interval of $-6.37 \times 10^{-7} \sim 4.66 \times 10^{-7}$, with 88.89 % of the data falling within the 95 % confidence interval (Fig. 5b). After removing 2 outliers outside the 95 % confidence interval [33], the ICC increased to 0.61 ($P = 0.04$). Additionally, the data points showed a basic average distribution, indicating good consistency in the data of $\triangle HbO_2$ concentration obtained from the two tests [34].

4. Discussion

The aim of this study was to investigate the test-retest reliability of measuring the activation of the frontal and parietal cortices

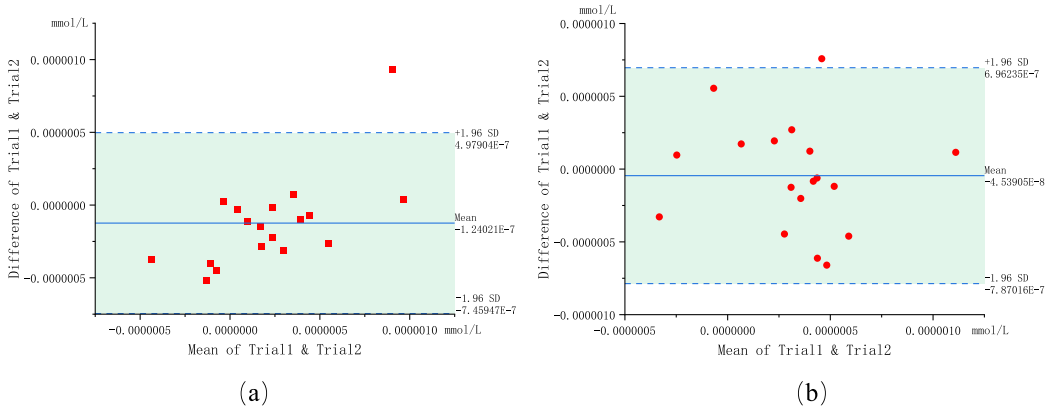

Fig. 3. Bland Altman plot of prefrontal cortex activation results in older adults under two walking conditions (a: straight walking, b: turning walking).

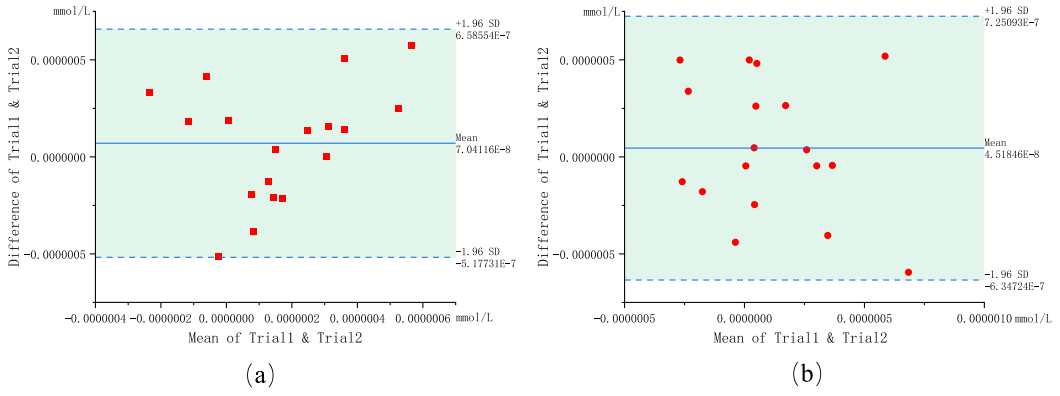

Fig. 4. Bland Altman plot of motor cortex activation results in older adults under two walking conditions (a: straight walking, b: turning walking).

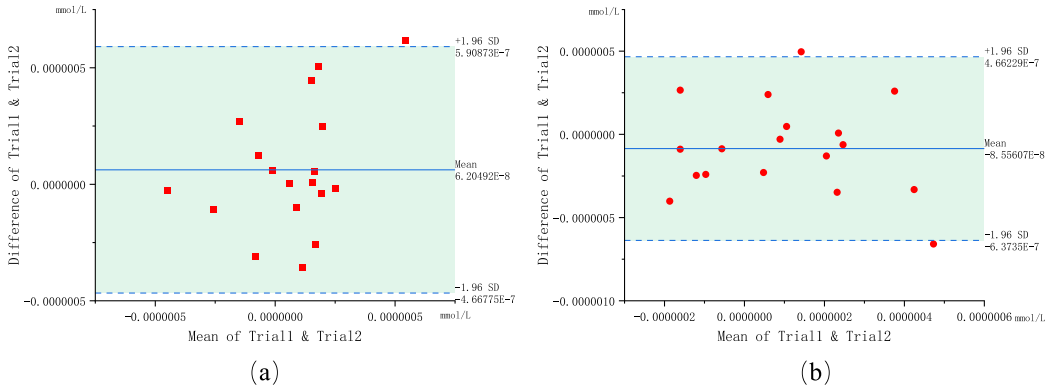

Fig. 5. Bland Altman plot of sensory cortex activation results in older adults under two walking conditions (a: straight walking, b: turning walking).

using fNIRS technology during straight and turning walking in older adults. This study found that during straight and turning walking task, the ICC test-retest reliability of HbO_2 signal of frontal and parietal cortices was fair to excellent, and the data consistency was generally good, which basically accepted our research hypothesis.

4.1. Reliability analysis

The results of this study showed that in straight and turning walking, there was no significant difference in the $\triangle HbO_2$ concentration of prefrontal cortex in participants between the two tests. The ICC was good or above, and after removing outlier data, the ICC was excellent. The data consistency was fair or above, and overall test-retest reliability was good or above, thus supporting the research hypothesis. Our results were consistent with Izzetoglu et al. 's findings that reported excellent test-retest reliability (ICC≥0.90) for the prefrontal cortex activation during single and double walking tasks in older adults [14], and Stuart et al.'s findings that reported good test-retest reliability (ICC = 0.67) for the prefrontal cortex activation during walking and turning tasks in young adults [11]. Previous studies on the test-retest reliability of fNIRS during motor tasks have primarily focused on hand movements, such as grip tasks in people with traumatic brain injury [33], and finger tapping tasks in older adults [9], all of which reported good or excellent test-retest reliability of prefrontal cortex activation obtained during localized body movements.

Furthermore, our results showed that there was no significant difference in the $\triangle HbO_2$ concentration of sensory cortex in participants between the two tests, with an ICC ranging from fair to good and increased to good after removing outlier values. The overall test-retest reliability was also good thus supporting the research hypothesis. While the ICC for the $\triangle HbO_2$ concentration of motor cortex was fair to good, with good consistency, the overall test-retest reliability was fair or above. Our results were consistent with the results of Dravida et al., who reported fair to excellent test-retest reliability (ICC>0.51) for measuring HbO_2 of motor cortex (including PMC, SMA, M1) of young adults performing four right-hand digit manipulation tasks [35], also consistent with the results of de Rond

et al., who reported fair to excellent test-retest reliability (ICC>0.48) for measuring HbO_2 of PMC, SMA and SSC of older adults performing postural and finger-tapping tasks [9]. Previous studies have not included the use of fNIRS to measure the test-retest reliability of motor and sensory cortex activation during walking and other motor tasks. We speculate that this may be related to the motor associative function of the frontal motor cortex. Research has found that the posterior SMA of the motor cortex is part of the cortico-striatal-thalamo-cortical loop, with the associative cortex and limbic cortex entering this loop through the striatum. In combination with the high variability of M1, the motor cortex may become a site for the formation of motor associations [36,37]. Therefore, it is possible that the participants had already initiated motor associations before the second test, leading to a slight difference in the activation of the frontal motor cortex compared to the results of the first test, thus affecting the test-retest reliability of the motor cortex. Additionally, the test-retest reliability could also be affected by learning or attenuation [3]. Previous studies have observed a decrease in cortical activity with repeated exposure in older adults [38,39]. We provided participants with two familiarization trials before the test to alleviate this issue. We still observed a fair or above test-retest reliability in the motor cortex, with all data points falling within the 95 % consistency limit, indicating good reproducibility.

While previous studies using the Bland-Altman plot have primarily focused on observing the 95 % confidence interval of outliers in the data, our study found a linear trend in the Bland-Altman plot of older adults during straight walking. We observed that the greater the average value of the data from the two tests, the greater the difference between the tests might be. Upon examining the data of each participant, it is speculated that during the initial test, participants utilized more brain resources to adapt to and complete the walking task, as they were unfamiliar with the experiment, leading to greater activation of prefrontal cortex. In contrast, during the retest, the participants might be familiar with the straight walking task due to the influence of learning effects and require minimal attention resources from the prefrontal cortex, potentially leading to lower brain activation compared to the initial test. As a result, greater activation exhibited by participants during the initial straight walking task led to a higher average value of the data from the two tests and a greater difference between the tests. This demonstrated a linear trend and slightly decreased the accuracy of prefrontal cortex activation, affecting data consistency.

In summary, studies using fNIRS to investigate the reliability of HbO_2 in multiple cortical cortices during motor tasks have consistently reported acceptable reliability outcomes in healthy individuals. Similarly, studies in individuals with diseases, such as Ranchet et al., found fair reliability of the dorsolateral prefrontal cortex during normal walking over two sessions in patients with Parkinson's disease [40]. However, a study by Bro et al. examining the inter-session reliability of the prefrontal cortex during walking in multiple sclerosis patients and healthy individuals revealed limited reliability in multiple sclerosis patients, with only the right and left frontopolar cortex showing fair reliability (ICC >0.54) for HbO_2, while HbR exhibited better reliability. In healthy individuals, most prefrontal cortices showed fair to excellent inter-session reliability (ICC >0.47) [27]. Therefore, the conclusions of HbO_2 reliability in diseased older adults were not consistent in the literature.

4.2. Clinical application

Many researchers have studied the activation patterns of different brain cortex regions during walking, yielding a wealth of research findings to explain the brain's resource allocation mechanism [38,41]. This study focuses on simulating walking paths in daily life and exploring the test-retest reliability of activation parameters of prefrontal cortex, motor cortex, and sensory cortex in older adults during straight and turning walking. The study confirms the results reliable. Therefore, researchers in the fields of basic and clinical can refer to the results of this study when studying changes in brain activation patterns during walking in healthy older adults. They can use the HbO_2 parameter exported by fNIRS to assess the activation of various brain regions, and should also consider the linear changes in the HbO_2 data during straight walking tests in older adults.

To our knowledge, this is the first study to validate the test-retest reliability of brain activation using fNIRS-exported HbO_2 concentration parameters in older adults during straight and continuous turning walking, providing evidence to support further research using fNIRS to measure cerebral hemodynamic responses in older adults during exercise. This will enable researchers to gain confidence in the measurement methods, improve the complexity of test scenarios, explore changes in brain activation during human movement, and provide theoretical support for the selection of testing methods in clinical research related to motor control in older adults.

4.3. Limitations

The limitations of this study include the fact that the subjects were all healthy older adults with a limited sample size, leading to potentially biased and limited data, which may reduce the reliability of the research results. Thus, future studies could involve comparisons with older adults at different disease severity levels to obtain more accurate results. Second, the study focused solely on walking exercises; in the future, test-retest studies could also be conducted on balance, running, and other physical activities. Third, the lack of collection of kinematic parameters, such as walking speed, resulted in a weak explanation for the general results. Future studies could include the simultaneous observation of body posture and gait parameters. Fourth, our fNIRS setup lacked short separation channels, which could have minimized the impact of blood flow on the surface of scalp and skull tissues, leading to more precise measurements of changes in blood oxygen levels in the brain. Future fNIRS studies could benefit from incorporating short separation channels to enhance the reliability of brain activation data.

5. Conclusion

The results of the study using functional near-infrared spectroscopy to measure the activation of the frontal and parietal cortices in older adults during straight and turning walking tasks generally demonstrate acceptable repeatability and consistency. This technology can be recommended as a measurement on brain activation during straight and turning walking in clinical assessments of older adults. However, strict control of the testing process is necessary, and the potential for variation in the data of the prefrontal cortex and motor cortex during repeated measurements of straight walking in older adults should be considered.

Ethical statement

All participants provided written informed consent, and the study was approved by the Medical Ethics Committee of Shandong Sport University (Approval No: 2022025) and registered in the Chinese Clinical Trial Registry (Registration No: ChiCTR2300072287).

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Data availability statement

Data is available while the data was prepared to conduct a meta-analysis study, and the data sharing obtain proposal was approved by an independent review committee. The name of the repository is OneDrive and the accession username is dyq879687502@163.com. The validity period of the time is 9 months–36 months after publishing. Please contact the corresponding author to send you the password if you need help.

CRediT authorship contribution statement

Yuqi Dong: Writing – original draft, Formal analysis, Data curation. **Min Mao:** Writing – review & editing, Supervision, Methodology, Formal analysis. **Yunzhi Wu:** Writing – original draft, Investigation, Formal analysis, Data curation. **Chengzhang Che:** Writing – original draft, Software, Data curation. **Qipeng Song:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Formal analysis. **Wei Sun:** Writing – review & editing, Supervision, Methodology, Funding acquisition. **Cui Zhang:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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