Biological motion perception in post-stroke patients

Percepção do movimento biológico em pacientes pós-acidente vascular cerebral

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Abstract

Introduction: The perception of biological motion refers to the ability to perceive the moving shape of a human figure from points of light. This ability may be altered under various conditions that compromise human perceptual and visual capabilities, such as following a stroke, impairing the acquisition of motor skills. **Objective:** To evaluate whether biological motion perception in post-stroke patients is compromised. **Methods:** This article is characterized as a cross-sectional and analytical study with a quantitative approach. Two groups were formed: one consisting of 10 post-stroke patients and the other of 10 healthy elderly individuals. Study participants were clinically characterized using instruments assessing muscle tone, sensorimotor function, laterality, and cognitive status. Subsequently, they judged tasks involving presentations of natural-shaped light point stimuli divided into three categories: movements without objects, movements with objects, and social interactions. To analyze participants' biological motion perception, we calculated each participant's number of correct judgments and response times. **Results:** The control group had higher correct judgments in most tasks (70 - 90%) compared to the post-stroke group (40 - 60%). No significant statistical differences were found, but response times were shorter in controls. For the waving task, the mean time was 1.2 seconds for controls and 2.5 seconds for the post-stroke group ($p = 0.0022$). In walking (anterior-posterior view), it was 1.5 versus 3.0 seconds ($p = 0.0006$). **Conclusion:** Biological motion perception in post-stroke participants appears to be slower, however, there seems to be no compromise in judgment capability.

Keywords: Association learning. Visual perception. Motion perception. Stroke.

Resumo

Introdução: *A percepção do movimento biológico refere-se à capacidade de perceber a forma em movimento de uma figura humana a partir de pontos de luz. Essa capacidade pode estar alterada em várias condições que comprometem a capacidade perceptiva e visual humana, como após um acidente vascular cerebral (AVC), prejudicando a aquisição de habilidades motoras.* ***Objetivo:*** *Avaliar se a percepção do movimento biológico em pacientes pós-AVC está comprometida.* ***Métodos:*** *Trata-se de um estudo transversal e analítico de caráter quantitativo. Dois grupos foram formados, um formado por 10 pacientes pós-AVC e outro por 10 idosos saudáveis. Os participantes do estudo foram caracterizados clinicamente por instrumentos que avaliaram o tônus muscular, função sensório-motora, lateralidade e estado cognitivo. Em seguida, eles realizaram o julgamento das tarefas com apresentação dos estímulos de pontos de luz de formas naturais divididos em três categorias: movimentos sem objetos, movimentos com objetos e interações sociais. Para analisar a percepção do movimento biológico dos participantes, calculou-se o número de acertos de cada participante e o tempo de resposta.* ***Resultados:*** *O grupo controle apresentou um maior número de julgamentos corretos na maioria das tarefas (70-90%) em comparação com o grupo pós-AVC (40-60%). Embora não tenham sido encontradas diferenças estatísticas significativas, os tempos de resposta foram menores no grupo controle. Para a tarefa de acenar, o tempo médio foi de 1,2 segundos no grupo controle e 2,5 segundos no grupo pós-AVC (p = 0,0022). Na caminhada (visão anteroposterior), os tempos foram de 1,5 versus 3,0 segundos (p = 0,0006).* ***Conclusão:*** *A percepção do movimento biológico nos participantes pós-AVC parece estar mais lenta, no entanto, parece não haver comprometimento da capacidade de julgamento.*

Palavras-chave: *Aprendizagem por associação. Percepção visual. Percepção de movimento. Acidente vascular cerebral.*

Introduction

Relearning motor abilities is essential for rehabilitating patients with neurological disorders.[1] It is well-accepted that observing actions performed by other people activates the same neural structures responsible for the actual execution of these actions in the observer.[2] Several studies, as discussed in the review by Rizzolatti et al.,[3] have shown that action observation is an effective way to learn or improve the performance of specific motor skills, facilitating motor learning and the construction of a motor memory trace in healthy adults and post-stroke patients.

Studies using demonstration learning methods are based on biological motion perception, which is associated with the ability to perceive the motion form of a human figure through a limited amount of stimuli, such as point-light on joints of a moving body.[4,5] The method known of such stimuli, the point-light display, proposed by Johansson in 1973, produces images that create different motion patterns (e.g., walking, dancing, sitting, and standing) recognizable by the observer. Additionally, the observer can recognize the identity, age, gender, vulnerability, and emotions of the human figure.[6,7]

Previous studies showed that movement execution and motion perception of other people are affected by a compromised action plan. In this sense, theories proposing physical representations shared by the motor and visual systems, such as the mirror neuron system, allow the observer to understand the action of another individual during observation by combining the visual description with motor representation.[8,9] Therefore, considering that the motor system is involved in motion perception, dysfunctions in visual-motor representations shared in the motor system could lead to impaired human motion perception, as observed in patients with pre-motor or motor areas injury, Parkinson's disease, and stroke.[2,10,11]

Post-stroke patients may present temporary or permanent functional disabilities and changes in motor, sensory, and cognitive activities. Motor deficits impair motor performance in activities of daily living and are mainly associated with muscle weakness, incoordination, spasticity, and significant changes in kinesthetic, proprioceptive, and visual functions.[12] Although movement production is suggested as a non-essential prerequisite for biological motion perception in patients with neurological conditions, impaired movement production may affect motion perception.[11]

In this context, action observation is an effective method for learning and improving the performance of specific motor skills, facilitating motor learning and the development of a motor memory trace. However, post-stroke patients may experience difficulties in biological motion perception, raising questions about the impact of this condition on their relearning abilities.

The hypothesis of this study is that post-stroke individuals have impaired biological motion perception. Therefore, this study aims to evaluate whether biological motion perception in post-stroke patients is indeed compromised.

Methods

This study is characterized as cross-sectional and analytical with a quantitative approach. Twelve post-stroke patients and twelve healthy older adults participated in the study. Non-probability, convenience, and purposive sampling was chosen to recruit participants. Patients registered at the Faculty of Health Sciences of Trairi, Universidade Federal do Rio Grande do Norte (UFRN), were contacted via telephone. Those with a clinical diagnosis of chronic stroke (more than six months) of any etiology, undergoing a therapeutic follow-up, and with preserved cognitive function that allowed understanding and executing commands were included in the post-stroke group. We excluded patients with other neurological disorders or unable to complete the tests.

Age- and gender-matched healthy older adults who voluntarily agreed to participate in the study composed the control group. Two patients post-stroke and two healthy older adults were excluded because they did not meet the Minimum Mini-mental State Exam (MMSE) score, resulting in a final sample of ten individuals in each group. The methodology of this cross-sectional study followed the STROBE (Strengthening the Reporting of Observational Sudies in Epidemiology) guidelines.[13]

All participants signed the informed consent form and the authorization term for image use. The study was approved by the Research Ethics Committee of UFRN (CAAE No. 30565520.6.0000.5568).

Procedures

Two previously trained evaluators assessed participants. The assessments consisted of filling out clinical and sociodemographic data in the evaluation form and applying the clinical scales to categorize individuals according to the degree of sensorimotor impairment. All participants were assessed separately. Participants in the post-stroke group started with muscle tone assessment (Modified Ashworth Scale - MAS), followed by motor impairment (Fugl-Meyer Assessment - FMA), sensitivity (Nottingham Sensory Assessment - ASN), hand dominance (Portuguese version of the Edinburgh Handedness Inventory - EHI), and cognitive function (MMSE). Those in the control group were assessed using the EHI and MMSE. Then, all participants performed the biological motion perception task separately.

Participants were instructed to sit in a chair with backrest and feet on the floor; a table was positioned in front of participants to perform the proposed task. The biological motion perception assessment was conducted using a laptop (Lenovo Ideapad 330, 15.6") positioned approximately 80 cm from the participant. The procedure was performed in a closed room to ensure no external information interfered with the concentration of the participant during the task.

The biological motion perception task was performed based on recent studies and started with written instructions on the laptop screen, followed by the presentation of the stimuli. Written instructions were presented on the black background screen for 5 seconds, followed by the presentation of the stimulus. The duration of the stimulus presentation was 14 seconds. After each stimulus presentation, the response instructions were presented for up to ten seconds on the screen. A blank interval (500 milliseconds) between the stimuli was set to avoid possible interferences.[10,11,14,15]

Thirteen stimuli consisting of punctual animations of natural forms of human beings (male and female) were presented. During the presentations, participants were requested to judge the biological pattern as quickly as possible to determine if the stimulus represented natural movement. Right after the response, participants were asked to verbally describe the observed movements to confirm their recognition of the natural movement.

Stimuli (Biological motion perception task)

Human biological motion stimuli were created from movements captured using a Microsoft Kinect sensor (version 2.0) connected to the Kinect-based Biological Motion Capture System software[16] of eight volunteers (four men and four women; mean age of 32.50 ± 9.07 years), through a video in mp4 format, with a total duration of 6 minutes and 45 seconds.

Videos from the following movements were collected and divided into three categories: 1) movements with-out contact with objects - walking (anterior-posterior and side views), high jumping (in the same place), long jumping, sitting and standing, pedaling a stationary bicycle (side view); 2) movements involving objects - kicking a 22 cm diameter soccer ball, throwing a soccer ball with the upper extremity, picking up a soccer ball from the floor, sweeping the floor (using a broom), and drinking from a disposable water bottle in your mouth; 3) social relationships and interpersonal functioning - waving, and handshake (between two people).

Nine of thirteen stimuli were recorded in the anterior-posterior view and five in side view; all were presented as white dots on a black background on the laptop screen. Objects were not visualized in tests. Assessments were recorded to analyze the response time in movement perception tasks.

Clinical evaluation

Hand dominance was assessed using the EHI. The instrument aims to assess the domain of an individual's right and left hands in daily activities. It consists of ten items and the individual must indicate which hand they prefer to use in carrying out the activities. Scoring consists of marking "++" (2 points) in the column referring to the hand that the subject indicates using and, if this use is indifferent, marking a "+" (1 point) in both columns. The handedness quotient can vary between -100 (preference "strongly left") and +100 (preference "strongly right"), and the formula applies: LQ = [(R - L)/(R + L)] x 100, where LQ is the laterality quotient, and R & L refer to the total number of "+" marked on the right and left side respectively.[17]

Participants' cognitive status was assessed using the MMSE. It is composed of seven categories that assess aspects such as temporal orientation, spatial orientation, registration of three words, attention and calculation, recall of the three words, language and visual constructive ability. The MMSE score has a minimum value of 0 points and a maximum of 30 points. A score greater than or equal to 13 points for illiterates, 18 for low and medium schooling and 26 for high schooling was considered to identify cognitive deficits.[18]

The muscle tone was assessed using the MAS, which is performed by passively moving muscle groups through their range of motion. The scoring can vary across six levels, where zero indicates no increase in muscle tone, and four signifies rigidity in the affected parts during flexion or extension.[19] Seven muscle groups (extensors, adductors, shoulder internal rotators, elbow flexors, forearm pronators, wrist and finger flexors) were evaluated in the upper extremity (MAS-UE), with a maximum total score of 28 points. Five muscle groups (hip extensors, adductors, internal rotators, knee extensors, and plantar flexors) were evaluated in the lower extremity (MAS-LE), with a maximum total score of 20 points.

Motor impairment was assessed using the FMA, which seeks to identify selective activity and synergistic patterns of movement and by the domains of joint range of motion, pain and sensitivity. Data are scored on a 3-point ordinal scale (0 = cannot be performed; 1 = partially performed; 2 = completely performed) applied to each item. It has a total of 100 points for normal motor function, in which the maximum score for the upper extremity is 66 points and for the lower extremity is 34 points.[20]

Sensitivity was assessed using the ASN. The instrument aims to identify post-stroke sensory deficits and monitor their recovery. It is an instrument for the assessment of protopathic and epicritical sensory modalities in four subscales (tactile sensation, proprioception, stereognosis, and two-point discrimination), in 20 items. Tactile sensation can be scored from 0 to 2 on nine items, with a total score for the affected hemibody ranging from 0 to 108 points. Proprioception is assessed on seven items, and scored from 0 (absent) to 3 (normal), where the total score can range from 0 to 21. Stereognosy is assessed on 11 objects and scored from 0 (stereognosia) to 2 (stereognosia), with a total score from 0 to 22. And the two-point discrimination was evaluated in the palm of the hand and fingertips, where absence (0) and normal function (2) were observed, and a total score of 0 to 4.[21]

Data analysis

The outcome variables used to identify the biological motion perception were the number of correct answers, the number of times each participant recognized and described the natural movement, and response time (time in which the participant informed the movement, naturally or not). The JASP software (version 0.17.1.0) was used for statistical analysis.

The Shapiro-Wilk test assessed data normality related to the number of correct answers and response time. Demographic and clinical variables were analyzed descriptively, while the Mann-Whitney test was used to compare the number of correct responses in each biological perception task and the response time between the two groups (control group and post-stroke group).

The Spearman test was conducted to assess the association between the outcome variables and the clinical instruments used in the study (MAS, FMA, ASN and their subsections). The correlation coefficient was interpreted using the following values: 0.00 - 0.25 indicates little or no correlation; 0.26 - 0.49 indicates low correlation; 0.50 - 0.69 indicates moderate correlation; 0.70 - 0.89 indicates high correlation; and 0.90 - 1.00 indicates very high correlation.[22] The significance level adopted was 5%.

Results

Ten individuals diagnosed with clinical stroke were selected (post-stroke group); most were males (60%), with median age of 68 years old and a median MMSE score of 23 points. The control group was composed of ten healthy older adults, most male (60%), with median age of 72.5 years old and a median MMSE score of 25.5 points. Table 1 shows the clinical characteristics of participants.

Fifty percent of the control group stated they did not complete elementary school, 20% completed elementary school, 10% did not complete high school, and 20% completed higher education. In the post-stroke group, 10% were illiterate, 40% completed elementary school, and 50% completed high school.

We observed that patients in the post-stroke group fit into the chronic phase of the disease according to FMA results: marked motor impairment (between 50 and 84 points) in 70% of patients, most in the left hemibody (70%), and ischemic etiology (80%).

The EHI/LQ scores showed a greater preference of participants from both groups for using the right upper extremity during activities of daily living. No statistical differences were observed between groups regarding other sociodemographic data.

We observed that the control group presented a greater number of correct judgments in most tasks (walking - anterior-posterior view, lateral view -, high jump, long jump, cycling, kicking, throwing a ball, picking up an object from the floor, and handshake) when compared to the post-stroke group. However, no statistical differences were found. In the other tasks (waving, sitting and standing, and bringing a bottle of water to the mouth), there was no difference between the groups (Table 2).

Table 1 - Clinical characteristics of participants

Variables	Post-stroke group	Control group
Gender (female/male)*	4/6	4/6
Age (years)	68.0 (63.50 - 72.50)	72.50 (67.00 - 80.75)
Mini-Mental State Exam	23.0 (21.75 - 25.75)	25.50 (22.50 - 27.25)
Time of injury, in months	60 (48.00 - 81.00)	-
Affected hemisphere (right/left)*	3/7	-
Stroke type (ischemic/hemorrhagic)*	8/2	-
Nottingham Sensory Assessment	154 (139.75 - 155.00)	-
Edinburgh Handedness Inventory/Laterality quotient (right/left)*	(9/1)	(10/0)
Fugl-Meyer Assessment (upper extremity)	60.0 (53.00 – 61.75)	-
Fugl-Meyer Assessment (lower extremity)	24.00 (20.50 – 26.75)	-
Total Fugl-Meyer Assessment	81.00 (77.25 – 85.25)	-
Modified Ashworth Scale (upper extremity)	5.0 (4.00 – 10.37)	-
Modified Ashworth Scale (lower extremity)	4.00 (2.50 – 5.37)	-
Total Modified Ashworth Scale	8.75 (4.75 - 15.75)	-

Note: Data presented as median (quartile 1 - quartile 3), except for (*).

Table 2 - Number of correct judgments and response time of the biological motion perception task

Biological motion perception task	Post-stroke group		Control group	
	Correct judgments (n)	Time (s) Median (Q1-Q3)	Correct judgments (n)	Time (s) Median (Q1-Q3)
Actions without objects				
Walking (anterior-posterior view)	7	7.0* (6.25 - 8.00)	9	4.0 (3.25 - 4.75)
Walking (side view)	6	6.5* (6.00 - 8.00)	10	5.5 (5.00 - 6.00)
High jumping	8	5.5 (4.25 - 7.00)	10	5.0 (4.00 - 5.00)
Long jumping	6	5.5 (5.00 - 6.75)	9	5.5 (5.00 - 6.75)
Sitting and standing	6	7.5* (6.25 - 8.00)	6	5.0 (5.00 - 6.75)
Pedaling	2	9.0* (7.25 - 9.00)	3	7.5 (5.25 - 8.00)
Actions with objects				
Kicking	0	8.5* (8.00 - 9.00)	3	6.5 (5.25 - 8.00)
Throwing a ball	1	7.0 (5.25 - 7.75)	4	7.0 (6.00 - 8.00)
Picking up an object from the floor	4	8.5* (7.00 - 9.00)	8	6.0 (5.00 - 7.75)
Sweeping	0	9.0* (8.25 - 10.00)	0	8.0 (7.00 - 8.75)
Drink water	2	7.5 (5.25 - 8.00)	2	7.5 (6.25 - 8.75)
Social interaction actions				
Waving	7	7.5* (4.00 - 8.00)	2	5.0 (4.25 - 5.00)
Handshake	7	6.5 (5.25 - 7.75)	8	4.5 (3.25 - 5.00)
Total number of correct judgments	56	7.5 (6.25 - 8.25)	74	5.5 (5.00 - 7.00)

Note: Q1 = Quartile 1; Q3 = Quartile 3. *Significant difference between post-stroke group and control group for response time ($p < 0.05$).

Regarding the mean response time, the control group showed a significantly shorter response time in the following tasks: waving (p = 0.0022), walking (anterior-posterior view: p = 0.0006; side view: p = 0.0376), kicking (p = 0.0284), picking up an object from the floor (p = 0.0284), sitting and standing (p = 0.0452), pedaling (p = 0.0233), and sweeping (p = 0.0257).

In the analysis of the relationships between clinical measures in the post-stroke group (MAS, ASN, and FMA) and the number of correct judgments in biological perception tasks, a moderate negative correlation was observed between the handshake task and MAS-UE (r = -0.656). Other observed relationships included a high positive correlation between walking in the anteroposterior view and ASN (r = 0.732), and the sit-to-stand task, which showed a positive correlation with MAS-LE (r = 0.656).

Discussion

This study compared biological motion perception between post-stroke patients and healthy older adults to develop new strategies for neurological rehabilitation using action observation. The results indicate that post-stroke patients exhibit impaired biological motion perception compared to their healthy counterparts. These findings highlight the potential challenges faced by this population, as such perceptual deficits may affect the effectiveness of rehabilitation strategies that utilize action observation.

The number of correct judgments per task was not different between groups. However, the control group presented a high number of correct judgments in bio-biological motion perception tasks, indicating that the post-stroke group presented the highest error rate. Regarding the mean response time, significant differences were found between the post-stroke group and control group for the following tasks: waving, walking (anterior-posterior and side views), kicking, picking up an object on the floor, sitting and standing, pedaling, and sweeping.

Although our findings did not show significant differences between the groups, they are consistent with the findings of Saygin,[23] who observed significant impairment in biological motion perception in chronic post-stroke patients with unilateral lesions. A recent study claimed that point-light tasks requiring global processing were susceptible to learning, while motor production, practice, and experience play an important role in motion perception.[24]

Also, post-stroke patients experience motor deficits daily and are less physically active than healthy individuals. Therefore, these patients may present deficits in biological motion perception.

The pedaling task presented a low rate of success and longer response time in both groups, suggesting that individuals had difficulties identifying this task. This result differs from other recent studies, which consider that biological motion tasks (e.g., walking and pedaling) are automatic and involve only a default mode network instead of requiring a strong activation of cortical sensorimotor areas.[25-27]

This study shows that movements involving objects were more difficult to identify than those without objects. None of the participants in the study (both groups) identified the sweeping task, while none of the participants in the post-stroke group identified the kicking movement. In addition, the movements of throwing a ball, picking up an object from the floor, and drinking water were also difficult to identify by both groups. These results corroborate a recent study evaluating the identification of point-light biological motion in neurotypical adults and adults with autism spectrum disorder.[28] We observed that both groups found it more difficult to recognize actions involving invisible objects, which can be justified by the need for greater global processing to integrate information from body parts and invisible objects.

There is evidence that action perception and production are related (perception-action coupling), and that the motor system partially regulates action perception by simulating or incorporating observed actions.[2,29] Some studies suggest that clinical disorders affecting sensorimotor function are associated with reduced ability to judge biological motion.[30] In the present study, we aimed to relate sensorimotor deficits to biological motion perception tasks to understand whether motor simulation, a central feature of motion perception,[31] was compromised due to sensorimotor impairments. Our results indicate associations only between measures of muscle tone in the upper and lower limbs, respectively, with the handshake task and the sit-to-stand task. In addition, sensory deficits correlated with gait perception (antero-posterior view). However, these findings, isolated, do not appear to establish a relationship between sensorimotor deficits and biological perception capacity.

The fact that both groups are elderly and have errors in judging stimuli can be explained by the fact that biological motion perception changes according to age, considering that older people present a slow movement performance. In addition, their ability to detect and discriminate point-light animations is impaired, and the recognition of point-light actions or emotions is less accurate than in young adults. The perceptual processing in older people can be affected by sensory, cognitive, and motor impairments.[32,33] In addition, a previous study demonstrated that patients with hemiplegia presented deficits in the analysis of action perception of other people, mainly due to the influence of the motor system on action understanding. These deficits may also be more severe when the processing involves actions performed with limbs on the affected side than on the less affected side.[30]

The perception of biological motion is significantly impacted by age, as aging is associated with a decline in the ability to process visual information efficiently. This phenomenon is particularly relevant in the clinical context of physiotherapy, where conditions such as stroke can exacerbate these perceptual deficits. The coexistence of aging and the experience of stroke leads to an additional deterioration in motion perception, compromising patients' ability to recognize and imitate motor actions. This interaction underscores the importance of considering the impact of age when formulating rehabilitation interventions. Therapeutic strategies should be adapted to address not only the sequelae of stroke but also the perceptual limitations inherent to the aging process.[32,33] Future studies are needed to investigate how these variables interact and influence the effectiveness of rehabilitation practices, aiming to optimize functional outcomes in geriatric populations.

Other aspects to consider in this relationship between biological motion perception and stroke include pre- and post-injury dominant side and the compromised brain areas. Firstly, regarding dominance, we observed that out of the ten participants in the post-stroke group, only one had left-sided dominance before the stroke, and this individual was the only one who changed dominance after the stroke.

All others, even those with motor impairment of the dominant limb (usually the right), maintained their pre-injury dominance. Recent studies showed the need to assess how stroke lateralization could influence the response to action observation, suggesting that the original dominance plays a significant role in determining the responses of post-stroke patients.

In unilateral and focal lesions, the neural substrates for action observation are affected differently according to the affected he-misphere (dominant vs. non-dominant). When the do-minant hemisphere is affected, action observation mainly recruits intact adjacent regions ipsilateral to the lesion. In contrast, when the non-dominant hemisphere is affected, increased frontoparietal contralesional activity is usually activated.[2, 27]

In recent decades, extensive research has been conducted on how the brain responds to biological motion, particularly in the context of action observation. It is known that repeated observation of action, coupled with physical practice, can increase neural reactivity and induce neuroplastic changes to promote the formation of motor memories in the primary motor córtex.[34] However, it remains unclear whether lesions in the premotor and inferior frontal regions compromise biological motion perception, despite neuroimaging studies showing activation in these areas (or the so-called "mirror neuron system") during action observation. Due to the lack of access to brain imaging of lesioned cortical areas following strokes in the present study, it was not possible to directly correlate judgments of biological motion perception with specific brain regions affected by the lesions.

In addition to motor difficulties, cognitive deficits, particularly in attention functions, play a critical role in the perception of biological motion in post-stroke patients. These deficits, often overlooked, include impairments in divided and selective attention, which are common in this population and significantly affect the ability to process visual information efficiently. As a result, there may be a reduction in the ability to identify and interpret movements, interfering not only with the perception of others' actions but also with the execution of movements during rehabilitation.

Therefore, understanding how these cognitive deficits impact motion perception is essential for developing interventions that integrate focused attention strategies, thereby enhancing the effectiveness of rehabilitation practices.[32,34] Future studies should investigate the relationship between the severity of cognitive deficits and motion perception to identify approaches that can simultaneously address motor and cognitive limitations.

The practice of observing others' actions has proven beneficial in the post-stroke motor learning process, especially when combined with physical practice.[35] The findings that repeated demonstration of movements benefit motor learning are crucial for developing post-stroke rehabilitation practices, just as understanding how these individuals perceive the movements demonstrated to them and required of them is essential. Therefore, implementing methods based on point-light stimuli for analyzing biological motion perception may be useful to improve techniques based on action observation for the rehabilitation of post-stroke patients. For future research, we suggest that the correlation between the degree of sensorimotor impairment of these patients and the perception of biological movements be analyzed.

The limitations of the present study include the inability to generalize the findings primarily due to the limited sample size and the insufficient specificity regarding the types and locations of strokes, factors that may contribute to increased variability within the sample. Furthermore, the study did not include criteria for selecting patients based on specific stroke types or lesion sites, nor did it account for individuals in the acute or subacute phases of the condition, potentially exacerbating variability among the participants.

Conclusion

The perception of biological motion in post-stroke participants appears to be slower, however, there seems to be no compromise in judgment capability. Therefore, the implementation of methodologies utilizing point-light stimuli for the analysis of biological motion perception may prove advantageous in enhancing action observa-tion techniques within the rehabilitation protocols for post-stroke patients.

In clinical practice, it is imperative for physical therapists to evaluate the capacity of patients to effectively learn through action observation during therapeutic training. By incorporating action observation techniques into rehabilitation strategies, physical therapists can more effectively tailor interventions to optimize motor learning outcomes, thereby ensuring that patients are actively engaged in the learning process.

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Authors' contributions

MCO, DSA and EWAC contributed with the study conceptualization; MCO, PCB, RLB and EWAC, with methodology; MCO and DSA, with data curation and investigation; PCB and RLB, with software analysis; ROC and EWAC, with formal analysis, reviewing and editing. MCO wrote the original draft, and EWAC supervised the study. All authors actively participated in the discussion, review, and approval of the final version of the manuscript.

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