Research Article

BIOMEDICAL
Journal of Scientific & Technical Research

ISSN: 2574 -1241

DOI: 10.26717/BJSTR.2020.25.004232

A 3D Joint Position Matching Protocol for Post-Stroke Proprioceptive Assessment

Camila Roza Gonçalves, Ítalo Gustavo Sampaio Fernandes, Ana Carolina Torres Cresto, Andrei Nakagawa Silva, Eber Lawrence Souza Gouveia, Sérgio Ricardo de Jesus Oliveira and Alcimar Barbosa Soares*

Biomedical Engineering Lab, Faculty of Electrical Engineering, Uberlândia, Brazil

***Corresponding author:** Alcimar Barbosa Soares, Biomedical Engineering Lab, Faculty of Electrical Engineering, Campus Sta Mônica, Brazil

ARTICLE INFO

Received: February 06, 2020

Published: February 14, 2020

Citation: Camila Roza Gonçalves, Ítalo Gustavo Sampaio Fernandes, Ana Carolina Torres Cresto, Andrei Nakagawa Silva, Eber Lawrence Souza Gouveia, Sérgio Ricardo de Jesus Oliveira, Alcimar Barbosa Soares. A 3D Joint Position Matching Protocol for Post-Stroke Proprioceptive Assessment. Biomed J Sci & Tech Res 25(4)-2020. BJSTR. MS.ID.004232.

Keywords: Stroke; Proprioception deficits; Rehabilitation; 3D tracking

Abstract

Several methods have been discussed to assess and quantify proprioceptive deficits. Most clinical assessments are based on categorical or ordinal results which are not sensitive to subtle changes or subtle deficits observed in different patients. In this paper, we propose a quantitative protocol for post-stroke proprioceptive assessment based on three-dimensional inertial tracking. The system is based on a network of five inertial sensors that are attached to the subjects' upper limbs. Validation of our approach was based on a set of upper-limb experiments performed by thirty healthy subjects and six stroke patients. Three angles for the shoulder joint and three angles for the elbow joint were evaluated in a randomized manner. While blindfolded, the volunteers were instructed to move the non-dominant (for healthy subjects) or the affected limb (for stroke subjects) to a target angle, and then were instructed to replicate the contralateral movement. The results obtained from the healthy group were used to establish a baseline for proprioceptive normality and comparisons. Finally, the results of the stroke group were also compared with standard clinical scales. Our findings suggest that the quantitative measure provided by our approach can be much more sensitive to subtle variations in proprioceptive variations than standard clinical scales.

Abbreviations: MRI: Magnetic Resonance Imaging; CT: Computed Tomography; FMA: Fugl-Meyer Assessment; NSA: Nottingham Sensory Assessment; SPSS: Statistical Package for Social Sciences

Introduction

Proprioception has an essential role in motor control, both for the feedback mechanism, when rapid adaptations must occur during a given task, as well as for the feedforward mechanism, when anticipation, preparation, and planning of a given response is required [1]. The term proprioception is defined as the ability to identify or perceive joint position or body movement in three-dimensional space in the absence of the visual field [2-4]. As such, proprioceptive information provided by mechanoreceptors in muscles, tendons, joints, and skin is crucial for movement and control [5]. Natural proprioceptive losses due to aging are common in individuals over 60 years of age [6-11]. However, several pathologies, such as the cerebrovascular accident (stroke) [11-15], and peripheral neuropathies [11], may also cause important proprioceptive deficits. About 60% of stroke patients develop proprioceptive deficits [14], which are highly correlated with poor functional motor recovery of the affected limb [15-18]. Patients with Parkinson's disease have shown a significant decrease in frontal proprioception-related potentials (EEG events), as well as reduced sensitivity to detected changes in limb position at distal and proximal arm joints. Similarly, patients in advanced stages of peripheral neuropathies show notable proprioceptive deficits leading to gait ataxia and imbalance with eyes closed [19,20].

The most common approaches to evaluate proprioception involve the assessment of active or passive joint position. Usually,

DOI: 10.26717/BJSTR.2020.25.004232

the therapist passively moves a finger, or another proximal joint of the subject to a particular position and asks the subject to match that position with the contralateral (unaffected) hand or limb, with the vision occluded [21]. Several studies described in the literature also seek to evaluate the sensory and motor functions of individuals with neuromotor sequelae using quali-quantitative methods. These methods include the Fugl-Meyer Assessment Scale and the Nottingham Sensory Assessment scale. These scales are the most common approaches for quali-quantitative clinical assessment of proprioceptive deficits. However, their limitations are recognized by the community as they do not allow for the precise identification of changes in proprioceptive deficits during rehabilitation since they often provide only a few discrete values to quantify the deficit. Furthermore, the correct application of the scales depends heavily on the experience of the evaluator.

In an attempt to provide a more quantitative measure, several techniques using computational and electronic devices have been proposed [22-24]. For instance, Fuentes and Bastian used a robot exoskeleton to study proprioception in different arm configurations across three matching tasks executed by healthy subjects. The results showed that, even for healthy subjects, there are systematic biases in position sense that are independent of task demands, with a significant overestimation of joint angles for extreme positions (fully flexed and fully extended). Dukelow also evaluated upper limb proprioception sense in stroke patients using an exoskeleton. The authors reported that the robotic technology provided excellent interrater reliability but with limited compliance with clinical thumb localizing tests. Although very precise in terms of measurement, those techniques rely on non-portable expensive equipment, being restricted mostly to research facilities [24-26]. There is still no consensus towards a gold standard protocol for proprioceptive measurement (Han 2016). As described before, current literature shows a wide variety of methods usually developed around four constructs: active joint position detection; passive joint position detection; passive motion detection; and motion direction discrimination.

In a systematic review published in 2015, Hillier et al. studied the different approaches and tried to identify the clinical relevance of the various techniques to measure proprioceptive acuity. The authors report that "whatever the need, proprioceptive tools are generally poorly evaluated in clinical settings and further research is required to establish reliability and validity as a starting point in the existing tests". Indeed, much work is still required to improve the robustness of current techniques, to avoid biases due to external factors, such as cutaneous stimulation (cues) provided by therapists during the task protocols, and to reduce errors during the evaluation process [27-30]. In this paper, we propose a protocol for proprioceptive evaluation based on a three-dimensional inertial sensor system. The protocol provides accurate measures while minimizing external biases. The system has been tested on a group of healthy subjects and a group of stroke patients. Furthermore, we compared the proposed measure with standard scales used by clinicians in routine clinical practice.

Methods

Subjects

Thirty healthy right-handed and six post-stroke volunteers were recruited to participate in this study. The healthy participants were randomly distributed in three groups according to their ages: Control Group 1 (CG1) - 10 volunteers aged between 20 and 39 years; Control Group 2 (CG2) - 10 volunteers aged between 40 and 59 years old; and Control Group 3 (CG3) - 10 volunteers aged 60 to 80 years old. The post-stroke participants were recruited at the Rehabilitation Sector of local Public hospital. The inclusion criteria for the healthy volunteers included: no neurological impairment or orthopedic pathologies associated with upper limbs; good cognitive capacity (assessed by the Mini-Mental State Examination - score above 25 points [31]); and no pain in the upper limbs. The inclusion criteria for the post-stroke volunteers included: stroke diagnosed by Magnetic Resonance Imaging (MRI) or Computed Tomography (CT); good cognitive capacity (assessed by the Mini-Mental State Examination - score above 25 points); no contracture of the shoulder or elbow joints. Participants were to be excluded from the research if they reported pain during the experiments. All volunteers signed the Informed Consent Form. The research was approved by the Ethics Committee of the Federal University of Uberlandia, Uberlandia, MG, Brazil (Protocol 64313416.8.0000.5152).

Proposed Proprioceptive Assessment Tool

In this work, a network of five 10-axis inertial measurement units (GY-88 - Shenzhen UMEAN Technology Co., Ltd.) was used to track limb position and motion. One sensor was placed on the subject's sternum (as a reference), and the other sensors were fastened to the right upper arm, right forearm, left upper arm, and left forearm. Data from the sensors were collected and used to generate a three-dimensional representation of the subject's body and limb configuration. The sensors were read at a rate of 240Hz each. A digital low pass filtered (20Hz) was applied to remove artifacts. The sensors were mounted to track the motion and angles of the shoulders and elbows. The associated hardware and software continuously updated the body representation in real-time and displayed the joint positions and angles on a graphical user interface, creating a virtual depiction of the subject's 3D workspace and the current positions and angles of both limbs (Figure 1).

Proposed Proprioceptive Assessment Protocol

Preparation: With the subject seated comfortably in the upright position, the motion tracking sensors are positioned, as shown in Figure 1.

Calibration: The subject must remain with the shoulders in horizontal abduction and maximum extension of the elbow (Figure 1) for five seconds, while the sensors are calibrated (autozero -

software controlled). This calibration will ensure that the relative 3D position of each sensor with regards to the others and the angles among them are correctly captured in the next stages.

Figure 1: Proposed 3D inertial-sensing network and positioning of the sensors on the subject's body.

Data collection: The protocol is based on matching shoulder and elbow joint positions over three different angles each. Each joint is evaluated separately, starting from the calibration position (Figure 1), as follows:

A. Shoulder

a) The subject is blindfolded to ensure that, in the next stages, he/she relies exclusively on proprioception.

b) From the initial position, the subject is verbally instructed to move the affected limb (post-stroke), or the non-dominant limb (healthy subjects) slowly until reaching a specified angle (45o, 75o, or 90o) for the shoulder joint while maintaining the elbow extended (Figure 2a). The therapist relying on the feedback provided by the graphical user interface, will instruct the subject to stop the motion at the desired angle.

c) The subject is instructed to perform a mirrored motion with the contralateral limb. The subject must verbally confirm that the final mirrored position was reached.

For each angle, steps a-c must be executed three times, in random order.

B. Elbow

a) The subject is blindfolded to ensure that, in the next stages, he/she relies exclusively on proprioception.

b) From the initial position, the subject is verbally instructed to move the affected limb (post-stroke), or the non-dominant limb (healthy subjects) slowly until reaching a specified angle (45o, 90o, or 110o) for the elbow joint while maintaining the shoulder abducted (Figure 2b). The therapist, relying on the feedback provided by the graphical user interface, will instruct the subject to stop the motion at the desired angle.

c) The subject is instructed to perform a mirrored motion with the contralateral limb. The subject must verbally confirm that the final mirrored position was reached.

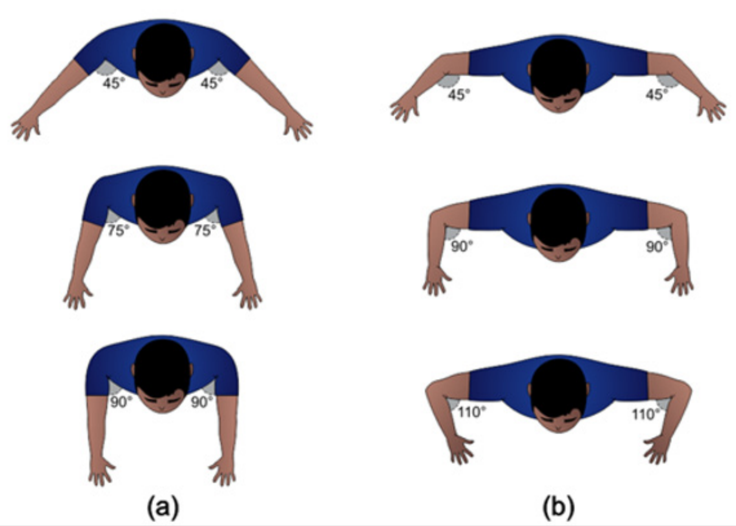

Figure 2: Shoulder and elbow positions used for the proposed proprioceptive assessment protocol.

a) Shoulder at 45o, 75o, and 90o.

b) Elbow at 45o, 90o, and 110o.

For each angle, steps a-c must be executed three times, in random order. The estimated difference between the angles of both limbs is then measured for future processing and evaluation of proprioceptive integrity.

Experimental Procedure - Validation

To validate the proposed system and protocol, all volunteers executed the proprioceptive evaluation protocol as defined before. Besides executing the proposed proprioceptive assessment protocol, the post-stroke volunteers were also assessed using two standard clinical scales: Nottingham Sensory Assessment scale [31-33]. The Fugl-Meyer Assessment (FMA) scale aims to evaluate the synergistic patterns of subjects after stroke, being the most used outcome measure for research and clinical practice in the area. FMS has cumulative numerical scores and allows the evaluation of several clinical aspects, including proprioception, for a total of eight joints: shoulder, elbow, wrist, thumb, hip, knee, ankle, and hallux. In this research, we evaluated shoulder and elbow, yielding scores equal to (0) absence, (1) impaired, or (2) intact. The Nottingham Sensory Assessment (NSA) scale was specifically designed to assess sensory deficits related to tactile sensation, stereognosis, and kinesthesia (proprioception). The total score for proprioception is defined according to the accuracy of execution, direction, and joint position of the movements. Each movement is graded as 0 (no movement/proprioception), 1 (movement occurs, but the direction is incorrect, 2 (movement occurs in the correct direction, but is inaccurate in the final position), or 3 (movement occurs in the correct direction, and it is accurate within 10o in the final position).

Data Analyses

The absolute error between each matched angle trial was calculated, and a descriptive analysis was performed for each variable (elbow and shoulder angles). The difference between the three healthy groups (G1, G2, G3) was measured, and a regression curve was determined in an attempt to verify if a normality curve could be established, showing possible degradation of proprioceptive sense with normal healthy aging. The absolute errors for the post-stroke volunteers were then visually and statistically compared to that normality curve and with the results from the standard clinical scales. Spearman rank-order correlation coefficients analyses were computed to measure the correlation between absolute errors and the scores from the clinical scales (Statistical Package for Social Sciences (SPSS), version 22.0 for Windows; SPSS Inc., Chicago, IL, USA).

Results

Control and Experimental Groups

The main characteristics of the three groups of healthy volunteers are described in Table 1. Overall, the mean (± standard deviation) ages are e of 26.80 ± 3.68 (CG1), 48.50 ± 4.34 (CG2) and 67.90 ± 5.82 (CG3). Besides, all volunteers are right-handed. In total, eleven stroke patients were initially included in the experimental group (EG). However, during the experiments, five participants were excluded from the research due to intra-articular shoulder pain. As such, we report the results for the remaining six volunteers (Table 2).

Table 1: Characteristics of the volunteers included in the control groups.

CG1			CG2			CG3		
Age	**Gender**	**Dominance**	**Age**	**Gender**	**Dominance**	**Age**	**Gender**	**Dominance**
20	M	R	41	M	R	60	F	R
22	M	R	44	M	R	62	F	R
23	M	R	45	M	R	64	F	R
27	M	R	46	M	R	65	M	R
28	F	R	48	F	R	66	F	R
28	F	R	50	M	R	67	F	R
28	M	R	50	M	R	68	M	R
30	M	R	52	F	R	72	M	R
30	F	R	53	M	R	75	F	R
32	M	R	56	M	R	80	M	R

Table 2: Characteristics of the volunteers included in the experimental group (EG).

Subject	Age	Gender	Stroke Type	Time from Injury	Affected side
1	34	F	I	79 days	R
2	41	F	I	15 days	R
3	58	M	I	75 days	L
4	68	M	I	76 days	R
5	71	M	I	62 days	R
6	72	M	I	70 days	L

Proprioceptive Measures

In order to evaluate possible proprioceptive deficits, the absolute mean errors (Δ) between the angles of a specific joint for both arms were calculated, as shown in Equations 1 and 2.

$$\Delta Elbow_{Angle\_\phi} = \frac{1}{3}\sum_{t=1}^{3}(Angle\_\phi_{Right(t)} - Angle\_\phi_{left(t)}), \phi = 45^\circ, 90^\circ, 110^\circ \quad (1)$$

$$\Delta Shoulder_{Angle\_\phi} = \frac{1}{3}\sum_{t=1}^{3}(Angle\_\phi_{Right(t)} - Angle\_\phi_{left(t)}), \phi = 45^\circ, 75^\circ, 90^\circ \quad (2)$$

A. Shoulder Joint at 45 Degrees: Table 3 shows details of the main results for the experimental group with shoulder joint at 45 degrees. No correlation was found between the results obtained by the experimental protocol with the Fugl-Meyer scale. The Spearman correlation between the experimental protocol and the Nottingham scale showed a correlation coefficient of -0.828, being in the area above 0.70 (p = 0.042), indicating a strong positive correlation.

Table 3: Values obtained for the post-stroke patients using the proposed system, the Fugl-Meyer scale and the Nottingham scale, for shoulder joint at 45°.

Subject	Age	Proprioceptive Protocol MAE	Fugl-Meyer scale	Nottingham scale
1	34	5,13°	1	3
2	41	11,50°	1	2
3	58	6,92°	1	3
4	68	31,87°	1	2
5	71	19,11°	1	2
6	72	33,46°	1	2

B. Shoulder Joint at 75 Degrees: Table 4 shows details of the main results for the experimental group with shoulder joint at 75 degrees. No correlation was found between the results obtained by the experimental protocol with the Fugl-Meyer scale. The Spearman correlation between the experimental protocol and the Nottingham scale showed a correlation coefficient of -0.393, being in the area above -0.30, with a moderate negative correlation level (p = 0.441).

Table 4: Values obtained for the post-stroke patients using the proposed system, the Fugl-Meyer scale and the Nottingham scale, for shoulder joint at 75°.

Subject	Age	Proprioceptive Protocol MAE	Fugl-Meyer scale	Nottingham scale
1	34	16,19	1	2
2	41	14,06	1	2
3	58	15,49	1	2
4	68	8,95	1	3
5	71	7,53	1	2
6	72	10,22	1	2

C. Shoulder Joint at 90 Degrees: The main results for the experimental group with shoulder joint at 90 degrees are shown in Table 5. No correlation was found between the results obtained by the experimental protocol with the Fugl-Meyer scale. The Spearman correlation between the experimental protocol and the Nottingham scale also did not show any correlation.

Table 5: Values obtained for the post-stroke patients using the proposed system, the Fugl-Meyer scale and the Nottingham scale, for shoulder joint at 90°.

Subject	Age	Proprioceptive Protocol MAE	Fugl-Meyer scale	Nottingham scale
1	34	8,06	1	3
2	41	16,72	1	2
3	58	24,86	1	2
4	68	3,26	1	2
5	71	3,54	1	3
6	72	3,42	1	2

D. Elbow Joint at 45 Degrees: Table 6 shows the main results for the experimental group with elbow joint at 45 degrees. No correlation was found between the results obtained by the experimental protocol with the Fugl-Meyer scale. The Spearman correlation between the experimental protocol and the Nottingham scale showed a correlation coefficient of -0.393, being in the area above -0.29, with a moderate negative correlation level (p = 0.441).

Table 6: Values obtained for the post-stroke patients using the proposed system, the Fugl-Meyer scale and the Nottingham scale, for elbow at 45°.

Subject	Age	Proprioceptive Protocol MAE	Fugl-Meyer scale	Nottingham scale
1	34	10,26	2	3
2	41	21,94	1	2
3	58	0,73	1	2
4	68	37,14	1	2
5	71	34,31	1	2
6	72	25,34	1	2

E. Elbow Joint at 90 Degrees: Table 7 shows the results obtained for the elbow joint at 90 degrees. Spearman's correlation between the values of the experimental protocol and both scales were similar at -0.393, being in the zone above -0.30, considered moderate positive correlations (p = 0,441).

Table 7: Values obtained for the post-stroke patients using the proposed system, the Fugl-Meyer scale and the Nottingham scale, for elbow at 90°.

Subject	Age	Proprioceptive Protocol MAE	Fugl-Meyer scale	Nottingham scale
1	34	2,83	1	2
2	41	2,37	2	3
3	58	19,09	1	2
4	68	8,86	1	2
5	71	33,81	1	2
6	72	15,26	1	2

F. Elbow Joint at 110 Degrees: For the elbow joint at 110 degrees (Table 8), the Spearman correlation between the values of the experimental protocol and the two scales were again similar at -0.878, being in the zone above -0.70, considered strong negative correlations (p = 0.021).

Table 8: Values obtained for the post-stroke patients using the proposed system, the Fugl-Meyer scale and the Nottingham scale, for elbow at 110°.

Subject	Age	Proprioceptive Protocol MAE	Fugl-Meyer scale	Nottingham scale
1	34	3,39	2	3
2	41	6,70	2	3
3	58	32,12	1	2
4	68	16,47	2	3
5	71	20,47	1	2
6	72	18,09	1	2

Discussion

This study aimed to propose a protocol for the evaluation of proprioception based on three-dimensional inertial sensors. The results demonstrated that all individuals after acute stroke presented significant proprioceptive impairments that were not easily distinguishable using traditional scales (Fugl-Meyer and Nottinh scales). However, those different deficits were promptly detected when using the proposed protocol, as shown in Figures 3-8, and Tables 3-8. In a recent systematic review aimed to identify clinical tools for evaluation of proprioception, 32 different tools or methods to quantify proprioception were reported. However, clinometric properties were poorly rated for those systems - which generally showed low precision, and most were not really feasible for clinical practice [34-37]. On the other hand, the proposed proprioceptive evaluation protocol is shown as a promising quantitative measure for both assessment and monitoring of the clinical evolution of subjects with somatosensory deficits throughout rehabilitation therapies. Furthermore, the evaluation of the results for the healthy subjects demonstrated the expected trend between proprioceptive degeneration with age, again indicating the feasibility of the system for the proposed aim.

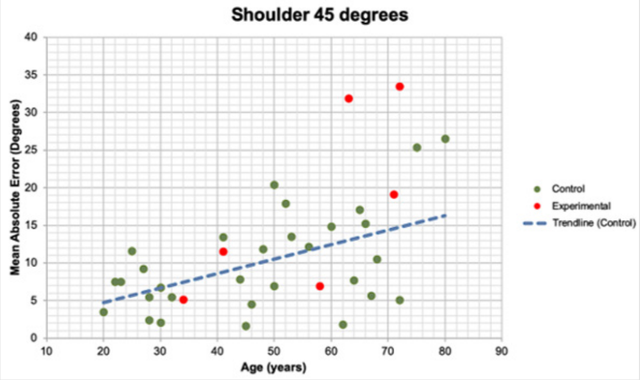

Figure 3: The green dots show the mean absolute errors for the errors of each volunteer of the control groups when executing the protocol with the shoulder at 45°. The dotted line is a regression curve for all control subjects. The red dots show the mean absolute errors for post-stroke patients.

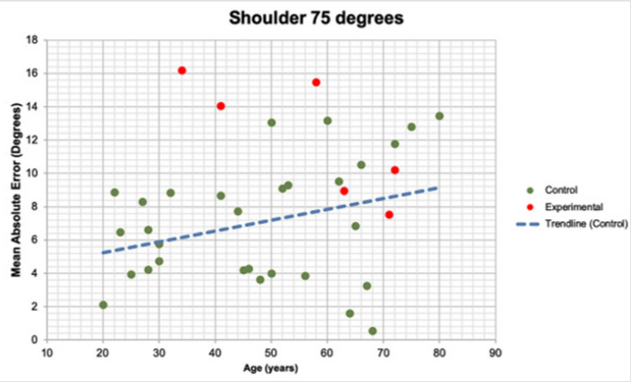

Figure 4: The green dots show the mean absolute errors for the errors of each volunteer of the control groups when executing the protocol with the shoulder at 75°. The dotted line is a regression curve for all control subjects. The red dots show the mean absolute errors for post-stroke patients.

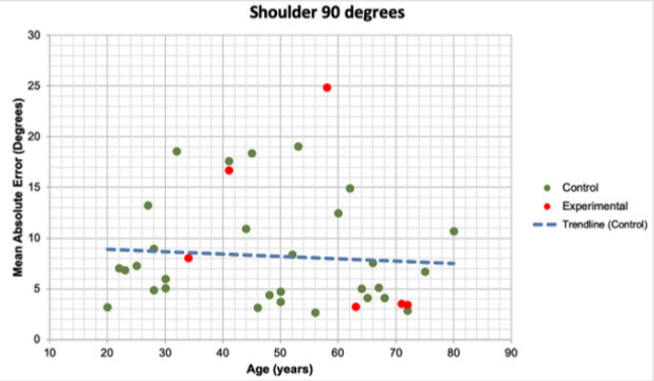

Figure 5: The green dots show the mean absolute errors for the errors of each volunteer of the control groups when executing the protocol with the shoulder at 90°. The dotted line is a regression curve for all control subjects. The red dots show the mean absolute errors for post-stroke patients.

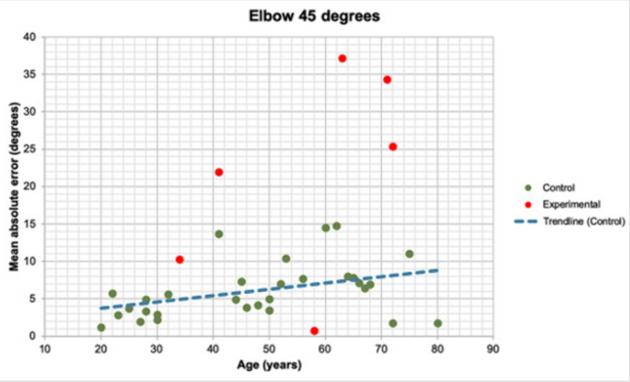

Figure 6: The green dots show the mean absolute errors for the errors of each volunteer of the control groups when executing the protocol with the elbow at 45°. The dotted line is a regression curve for all control subjects. The red dots show the mean absolute errors for post-stroke patients.

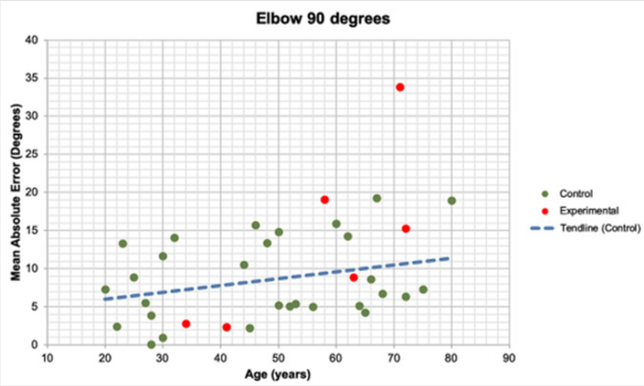

Figure 7: The green dots show the mean absolute errors for the errors of each volunteer of the control groups when executing the protocol with the elbow at 90°. The dotted line is a regression curve for all control subjects. The red dots show the mean absolute errors for post-stroke patients.

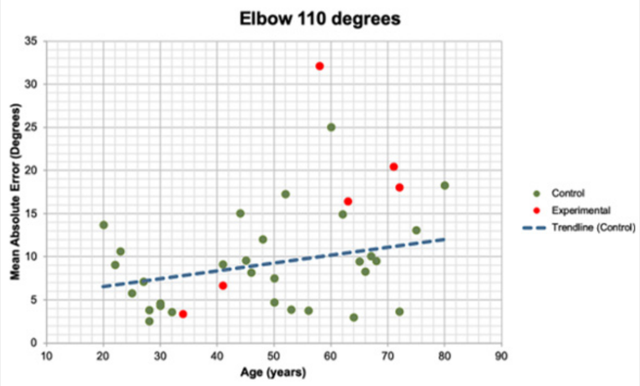

Figure 8: The green dots show the mean absolute errors for the errors of each volunteer of the control groups when executing the protocol with the elbow at 110°. The dotted line is a regression curve for all control subjects. The red dots show the mean absolute errors for post-stroke patients.

The quali-quantitative scales applied in this study also showed proprioceptive deficits for all stroke patients, but in a less precise way. That is, the results of those scales would not allow other therapists to distinguish between different patients (as shown in Tables 3-8), although they showed clear differences, as reported by the therapist that performed the assessments. This limitation has also been reported in previous works, and Henriques and Cressman (2012). As such, the proposed system may be useful in various application related to the neuro-rehabilitation of stroke patients. A more accurate assessment of proprioception can provide new insights for the implementation of novel therapeutic plans, which may reduce rehabilitation time, and provide better outcomes for the patients [38,39].

Conclusion

In this paper we described a tool and a proprioceptive assessment protocol aimed at post-stroke rehabilitation programs. The tool and protocol are able to detect minor changes in proprioceptive status. Future work will be performed to verify the applicability of the system during medium to long-term rehabilitation protocols.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgment

The authors thank the Coordination for the Improvement of Higher Education Personnel (CAPES) and the National Council for Scientific and Technological Development (CNPq), Brazil, for financial support.

References

1. Abbruzzese G, Berardelli A (2003) Sensorimotor integration in movement disorders. Mov Disord 18(3): 231-240.
2. Aman JE, Elangovan N, Yeh IL, Konczak J (2015) The effectiveness of proprioceptive training for improving motor function: A systematic review. Front. Hum. Neurosci 8: 1075.
3. Au Yeung SSY, Hui Chan CWY (2009) Predicting recovery of dextrous hand function in acute stroke. Disabil Rehabil 31(5): 394-401.
4. Balasubramanian S, Colombo R, Sterpi I, Sanguineti V, Burdet E (2012) Robotic assessment of upper limb motor function after stroke. Am J Phys Med Rehabil 91(Suppl 3): S255-269.
5. Bevan L, Cordo P, Carlton L, Carlton M (1994) Proprioceptive coordination of movement sequences: discrimination of joint angle versus angular distance. J Neurophysiol 71(5): 1862-1872.
6. Bhanpuri NH, Okamura AM, Bastian AJ (2012) Active force perception depends on cerebellar function. J Neurophysiol 107(6): 1612-1620.
7. Bullock Saxton JE, Wong WJ, Hogan N (2001) The influence of age on weight-bearing joint reposition sense of the knee. Exp Brain Res 136(3): 400-406.
8. Connell LA, Lincoln NB, Radford KA (2008) Somatosensory impairment after stroke: Frequency of different deficits and their recovery. Clin Rehabil 22(8): 758-767.
9. Connell LA, Tyson SF (2012) Measures of sensation in neurological conditions: a systematic review. Clin Rehabil 26(1): 68-80.
10. Cuomo F, Birdzell MG, Zuckerman JD (2005) The effect of degenerative arthritis and prosthetic arthroplasty on shoulder proprioception. J Shoulder Elb Surg 14(4): 345-348.
11. Debnath U, Narkeesh A, Raghumahanti R (2010) Formulation of integrated proprioceptive screening scale and testing of its sensitivity, reliability and validity. J Exerc Sci Physiother 6(2): 78-87.
12. Dukelow SP, Herter TM, Moore KD, Demers MJ, Glasgow JI (2010) Quantitative assessment of limb postion sense following stroke. Neurorehabil. Neural Repair 24(2): 178-187.
13. Findlater SE, Dukelow SP (2016) Upper extremity proprioception after stroke: Bridging the gap between neuroscience and rehabilitation. J Mot Behav 49(1): 27-34.
14. Fuentes CT, Bastian AJ (2010) Where is your arm? Variations in proprioception across space and tasks. J Neurophysiol 103(1): 164-171.
15. Goble DJ (2010) Proprioceptive acuity assessment via joint position matching: from basic science to general practice. Phys Ther 90(8): 1176-1184.
16. Goble DJ, Coxon JP, Wenderoth N, Van Impe A, Swinnen SP (2009) Proprioceptive sensibility in the elderly: Degeneration, functional consequences and plastic-adaptive processes. Neurosci Biobehav R. 33(3): 271-278.

17. Gordon U, Polsky A, Schiller J (2006) Plasticity compartments in basal dendrites of neocortical pyramidal neurons. J Neurosci. 26(49): 12717-12726.
18. Han J, Waddington G, Adams R, Anson J, Liu Y (2016) Assessing proprioception : A critical review of methods. J Sport Heal Sci 5(1): 80-90.
19. Hillier S, Immink M, Thewlis D (2015) Assessing proprioception: A systematic review of possibilities. Neurorehabil Neural Repair 29(10): 933-949.
20. Kandel ER, Schwartz JH, Jessell TM, Siegelbaum SA, Hudspeth AJ (2012) Principles of Neural Science. In: Mc Graw Hill (Ed.), (5th edn.).
21. Konczak J, Corcos DM, Horak F, Poizner H, Shapiro M (2009) Proprioception and motor control in Parkinson's disease. J Mot Behav 41(6): 543-52.
22. Kusoffsky A, Wadell I, Nilsson BY (1982) The relationship between sensory impairment and motor recovery in patients with hemiplegia. Scand J Rehabil Med 14(1): 27-32.
23. Lee NK, Kwon YH, Son SM, Nam SH, Kim JS (2013) The effects of aging on visuomotor coordination and proprioceptive function in the upper limb. J Phys Ther Sci 25(5): 627-629.
24. Li K, Wu Y (2014) Clinical evaluation of motion and position sense in the upper extremities of the elderly using motion analysis system. Clin Interv Aging 4(9): 1123-1131.
25. Lima DHF, Queiroz AP, De Salvo G, Yoneyama SM, Oberg TD (2010) Versão Brasileira da Avaliação Sensorial de Nottingham: Validade, concordância e confiabilidade. Rev Braz Fisioter 14(2):166-174.
26. Lincoln N, Crow J, Jackson J, Waters G, Adams S (1991) The unreliability of sensory assessments. Clin Rehabil 5(4): 273-282.
27. Lourenço RA, Veras RP (2006) Mini-Mental State Examination: Psychometric characteristics in elderly outpatients. Rev Saúde Públ 40(4): 712-719.
28. Maki T, Quagliato EMAB, Cacho EWA, Paz LPS, Nascimento NH (2006) Estudo de confiabilidade da aplicação da escala de Fugl-Meyer no Brasil. Rev Bras Fisioter 10(2): 177-183.
29. Maschke M, Gomez CM, Tuite PJ, Konczak J (2003) Dysfunction of the basal ganglia, but not the cerebellum, impairs kinaesthesia. Brain 126: 2312-2322.
30. Morris JH, Van Wijck F, Joice S, Donaghy M (2013) Predicting health related quality of life 6 months after stroke: The role of anxiety and upper limb dysfunction. Disabil Rehabil. 35(4): 291-299.
31. Oliveira R, Cacho EWA, Borges G (2006) Post-stroke motor and functional evaluations: A clinical correlation using Fugl-Meyer assessment scale, Berg balance scale and Barthel index. Arq Neuropsiquiatr. 64(3b): 731-735.
32. Richardson JK (2002) The clinical identification of peripheral neuropathy among older persons. Arch Phys Med Rehabil 83(11): 1553-1558.
33. Shumway Cook A, Woollacott MH (2017) Motor control: Translating research into clinical practice. LWW (Ed.); 5th Edition. 2017.
34. Silva MB, Silva AN, Naves ELM, Palomari ET, Soares AB (2016) An improved approach for measuring the tonic stretch reflex response of spastic muscles. Computers in Biology and Medicine 80: 166-174.
35. Sullivan JE, Hedman LD (2008) Sensory dysfunction following stroke: Incidence, significance, examination, and intervention. Top Stroke Rehabil 15(3): 200-217.
36. Tyson SF, Hanley M, Chillala J, Selley AB, Tallis RC (2008) Sensory loss in hospital-admitted people with stroke: Characteristics, associated factors, and relationship with function. Neurorehabil Neural Repair. 22(2): 166-172.
37. Watson JC, Dyck PJB (2015) Peripheral Neuropathy: A practical approach to diagnosis and symptom management. Mayo Clin Proc 90(7): 940-951.
38. Winward CE, Halligan PW, Wade DT (2002) The Rivermead Assessment of Somatosensory Performance (RASP): Standardization and reliability data. Clin Rehabil 16(5): 523-533.
39. Whitney JC, Lord SR, Close JCT (2005) Streamlining assessment and intervention in a fall's clinic using the Timed Up and Go Test and Physiological Profile Assessments. Age Ageing 34(6): 567-571.

ISSN: 2574-1241

DOI: 10.26717/BJSTR.2020.25.004232

Alcimar Barbosa Soares. Biomed J Sci & Tech Res