

# Reliability of Integrating 2D Image Analysis Software with the Gait Assessment and Intervention Tool in Individuals with Stroke

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**Received** March 20, 2024  
**Accepted** July 24, 2024  
**Published** August 31, 2024

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## ABSTRACT

**Introduction:** The Gait Assessment and Intervention Tool (GAIT) is well-regarded for its intra-rater and inter-rater reliability and presents an ideal foundation for integration with 2D image analysis. This innovative combination aims to leverage the strengths of both subjective and objective assessment methods. While the psychometric properties of the GAIT tool, including its concurrent validity, have been previously explored, the potential of augmenting it with 2D image analysis for gait assessment has yet to be thoroughly investigated. This study aimed to validate the integration of the GAIT tool with 2D image analysis software, hypothesizing that this combination would provide a comprehensive and nuanced assessment of gait parameters in post-stroke individuals. The primary focus was to evaluate the reliability of gait parameter measurements derived from this integrated approach.

**Methods:** Nine post-stroke participants were assessed using the GAIT tool, augmented with 2D image analysis, at baseline and follow-up by a single experienced therapist. The study assessed intra-rater reliability using the Intra-class Correlation Coefficient (ICC), Standard Error of Measurement (SEM), and Minimal Detectable Change (MDC).

**Results:** The integrated approach of the GAIT tool and 2D image analysis demonstrated excellent intra-rater reliability. The total GAIT score exhibited an ICC of 0.99 (SEM = 1.06, MDC = 2.94). Subscores for stance and swing phases, stance phase alone, and swing phase alone showed high reliability with ICC values of 0.95, 1.00, and 0.99, respectively. SEMs ranged from 0.00 to 0.57, and MDCs from 0.00 to 1.58.

**Conclusion:** The combination of the GAIT tool and 2D image analysis shows promise for providing a reliable and detailed assessment of gait abnormalities in stroke survivors. The excellent intra-rater reliability underscores its potential utility in clinical and research settings, suggesting a significant advancement in gait assessment methodologies.

**Keywords:** Gait analysis; Image processing; Stroke rehabilitation; Reproducibility of results

## Introduction

Stroke remains one of the leading causes of disability worldwide, often resulting in gait abnormalities that significantly impact an individual's functional independence and quality of life [1]. The intricate process of gait rehabilitation in post-stroke individuals necessitates precise assessment tools that are both reliable and clinically applicable. Observational gait scales, including the Tinetti Gait Scale [2], Rivermead Visual Gait Assessment [3], and the Wisconsin Gait Scale [4], have been foundational in

evaluating gait deficits among stroke survivors. Despite their widespread use, current observational gait scales present significant limitations. Their subjective nature can lead to considerable variability in interpretation among different clinicians. Moreover, these scales may not fully capture the complex dynamics of gait abnormalities, thereby limiting their sensitivity and specificity. Such limitations underscore the necessity for more objective and precise tools in gait assessment. These scales provide valuable insights into the gait patterns of individuals with stroke. Among them, the

Gait Assessment and Intervention Tool (GAIT) has been distinguished as the preeminent scale, validated for its reliability and sensitivity to changes in the stroke-affected population [5, 6]. The GAIT Assessment Toolist is specifically designed to evaluate several critical gait parameters that are crucial in assessing the rehabilitation progress of stroke survivors. These include kinematic parameters involving detailed analyses of joint angles and limb trajectories. These parameters are particularly important for identifying common post-stroke gait abnormalities. The advent of 2D image analysis software in the realm of gait assessment offers an opportunity to address this need. This technological advancement allows for intricate gait analysis, potentially elevating the objectivity of assessments beyond what is currently possible with observational scales alone.

The GAIT, already established for its Intra-rater and inter-rater reliability [5, 7], presents an optimal foundation for integration with 2D image analysis. Such an integration has the potential to harness the strengths of both objective and subjective assessment methods. Although previous investigations have delved into the psychometric properties of the GAIT, including its capability for detecting response to gait training [2], the application of 2D image analysis as a complementary tool has not been thoroughly explored. Through this integration, we hypothesize that the multidimensional data provided by the 2D image analysis software will enrich the conventional GAIT, yielding a robust and nuanced assessment of gait parameters.

The 3D motion analysis is recognized as the gold standard for detailed motion characterization in gait analysis. However, the complexity, cost, and space requirements of 3D systems limit their widespread use, particularly in clinical and ambulatory settings. In response to these challenges, the dual-camera method for 2D gait analysis offers a viable alternative. This approach simplifies the experimental setup by using only two cameras to capture multiple perspectives, effectively supporting comprehensive gait assessments. Moreover, integrating a dual-camera setup with observational gait evaluation tools aligns with current methodologies for conducting visual and qualitative analyses [8]. This integration provides a practical and effective alternative to 3D systems, enhancing accessibility and applicability across various settings where extensive setups are impractical. Such an approach allows for the detailed assessment of gait abnormalities in environments that might not otherwise support high-cost, high-maintenance 3D gait analysis systems.

This study aimed to assess the accuracy of gait parameter measurements obtained from the combined use of GAIT and 2D image analysis software. The importance of this objective lies in its potential to enhance the precision and reliability of gait assessments.

Accurate gait parameter measurements were crucial for developing effective rehabilitation strategies tailored to the unique needs of stroke survivors. By improving the objectivity and precision of these measurements, we aimed to contribute to more personalized and effective rehabilitation outcomes.

## Methodology

### Participants

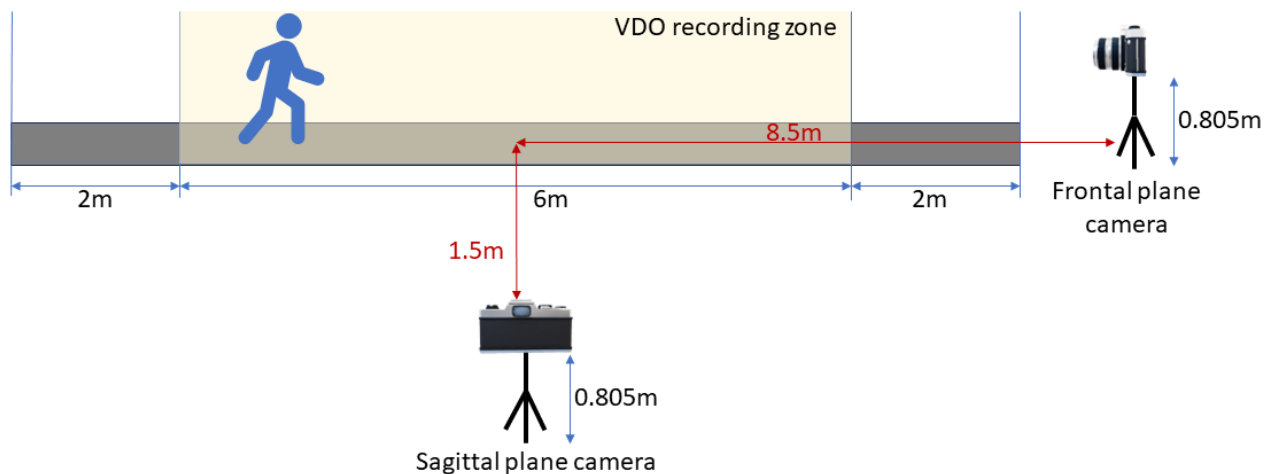
Nine individuals who had experienced a stroke participated in this reliability study, fulfilling the inclusion criteria and providing written informed consent. The sample size was determined based on the minimum acceptable reliability (Intra-class correlation coefficient, ICC) of 0.50 and an expected reliability of 0.9, with a significance level ( $\alpha$ ) of 0.05 and a power ( $1 - \beta$ ) of 80.0%. The calculation, conducted using a method by Wan Nor Arifin [9], indicated that a total of 9 participants was sufficient. Inclusion criteria included adults ( $\geq 18$  years) who had their first stroke, could understand simple instructions, had residual gait impairment for a minimum of three months, and were capable of independent walking. Exclusion criteria were the presence of comorbid neurological conditions such as Parkinson's disease or lower limb musculoskeletal disorders. Ethical approval for the study was obtained from the Minister of Health, Kano State, Nigeria, under reference NHREC/17/03/2018.

### Gait assessment and intervention tool (GAIT)

The GAIT employed in our study is a comprehensive 31-item observational scale specifically designed to assess gait abnormalities. This tool is meticulously organized into three distinct categories to evaluate different aspects of movement: upper limb and trunk, covered by four items (items 1-4); lower limb and trunk during the stance phase, covered by 14 items (items 5-18); and lower limb and trunk during the swing phase, covered by 13 items (items 19-31). Each item within the GAIT is scored on a scale from 0 to 3, where 0 indicates a normal movement pattern, and 1, 2, and 3 represent increasing degrees of deviation from the normal gait. These scores are designed to provide a precise measure of the severity of the deviation, with one indicating a slight deviation, two a moderate deviation, and three a severe deviation, thereby allowing clinicians and researchers to quantify the extent of gait abnormalities in a structured and reproducible manner [5, 6]. Psychometrics of the GAIT tool has been thoroughly investigated, showing excellent intra-rater reliability (ICC = 0.98; p-value = 0.0001; 95% CI = 0.95–0.99), inter-rater reliability (ICC = 0.83; p-value = 0.007; 95% CI = 0.32–0.96), and high consistency between experienced and inexperienced clinicians (ICC = 0.996; p-value = 0.0001; 95% CI = 0.986–0.999) [5].

Gait analysis was meticulously conducted through two-dimensional (2D) video recordings, employing the Kinovea® software package (version 0.8.15), which is accessible for free at <http://www.kinovea.org>. The setup involved two cameras: **Sagittal Plane Analysis:** One camera was mounted on a tripod, positioned 1.5 meters to the side of the walkway's center, at an elevation of 80.5 centimeters from the ground. This setup aimed to capture side views of the gait. **Frontal Plane Analysis:** The second camera

was placed 8.5 meters from the walkway's center, facing the direction of participant movement, to capture frontal gait dynamics (Figure 1). Both cameras recorded at a 60 Hz frame rate, producing MPEG-2 standard definition video. The walkway was consistently clear of any obstacles to ensure participant safety and prevent falls. Adequate lighting was provided to ensure clear video capture and minimize external noise to avoid distracting participants during their walk.



**Figure 1.** Setup for 2D Gait Analysis Using Dual-Camera System. This diagram illustrates the experimental setup for gait analysis in our study. Two cameras were employed to capture gait dynamics: the sagittal plane camera was positioned 1.5 meters lateral to the walkway's center and mounted at an elevation of 0.805 meters, aimed to capture side views of the gait. The frontal plane camera was placed 8.5 meters from the walkway's center, directly facing the walkway, to record frontal gait dynamics. Both cameras were recorded at a 60 Hz frame rate in MPEG-2 standard definition. The designated VDO recording zone spanned 6 meters within the walkway, which was kept clear of obstacles, well-lit, and isolated from external noises to ensure accurate and safe gait recording.

### Video processing and analysis

Kinovea was used to analyze the videos that were obtained. It is an easy-to-use, portable, and free tool that can be applied in real-world conditions; previous experience is not required to acquire accurate and reliable measurements. It is a valid tool for assessing time-related variables [10]. Previous studies have reflected inconclusive results regarding its reliability, with findings ranging from poor to excellent, emphasizing the importance of the setup [11, 12].

To ensure consistent and precise measurements, we calibrated the Kinovea software settings before each session, adjusting parameters such as frame rate, resolution, and marker tracking sensitivity. The cameras were positioned consistently for each session, and environmental conditions were controlled to minimize variations. We conducted multiple calibration trials to validate our setup's accuracy. Additionally, the software's configuration included setting reference points on the walkway to standardize measurements across different sessions. The

videos were analyzed to track gait markers, and algorithms were applied to interpolate and smooth data points, reducing noise and enhancing measurement reliability.

### Reliability protocol

In our study, the gait videos of participants were recorded only once. To ensure robust intra-rater reliability, a licensed physical therapist with over 15 years of experience analyzed each video twice using the Kinovea software. This program is specifically designed for motion analysis and was instrumental in our assessment. The first analysis session was conducted on the day the video was recorded, and the second followed one week later. This interval was strategically chosen to minimize potential learning effects and the therapist's recall bias, ensuring an independent assessment during the second analysis. During each analysis session, the therapist utilized Kinovea to thoroughly examine the gait parameters shown in the videos. This included thoroughly evaluating the overall GAIT score and individual subscores for the stance and swing phases.

### Statistical analysis

A second researcher, not involved in data collection, conducted all analyses using MedCalc version 19.1.5 (MedCalc Software Ltd, Ostend, Belgium). Participant characteristics were summarized using descriptive statistics. Intra-rater reliability was assessed using the ICC with 95% CIs. ICC values were interpreted as follows: < 0.50 indicated poor reliability,

0.50-0.75 moderate reliability, 0.75-0.90 good reliability, and > 0.90 excellent reliability. The standard error of measurement (SEM) was calculated as  $SEM = SD \times \sqrt{1 - ICC}$ , providing insights into measurement accuracy and absolute reliability. The minimal detectable change (MDC) at 95% confidence (MDC95) was calculated as  $MDC95 = 1.96 \times \sqrt{2} \times SEM$ , indicating the smallest change in score considered beyond measurement error.

### Results

Nine individuals participated in our study from baseline to follow-up, comprising six females (67.0%) and three males (33.0%), with ages ranging from 28 to 75 years (mean age=50.89 years, SD=14.55 years). The mean Body Mass Index (BMI) was 23.44 kg/m<sup>2</sup> (SD=5.10 kg/m<sup>2</sup>). Stroke types varied, with the majority being ischemic (67.0%), followed by unspecified types (22.0%), and hemorrhagic (11.0%). The average duration post-stroke was 50.56 weeks (SD = 24.98 weeks). A majority of participants (77.0%) experienced left-sided paralysis (Table 1).

**Table 1** Demographic characteristics of participants in the study (n=9)

| Characteristics                                 | Mean or number |
|-------------------------------------------------|----------------|
| Age (year); mean (SD)                           | 50.89 (14.55)  |
| Sex; n (%)                                      |                |
| Female                                          | 6 (67%)        |
| Male                                            | 3 (33%)        |
| Body mass index (kg/m <sup>2</sup> ); mean (SD) | 23.44 (5.10)   |
| Stroke types; n (%)                             |                |
| Ischemic                                        | 6 (67%)        |
| Hemorrhagic                                     | 1 (11%)        |
| Unspecified types                               | 2 (22%)        |
| Duration post-stroke (weeks); mean (SD)         | 50.56 (24.98)  |
| Paretic side; n (%)                             |                |
| Left                                            | 7 (67%)        |
| Right                                           | 2 (23%)        |

The primary focus of our results is the exceptional reliability of the GAIT tool, which is especially notable in the stance phase. The GAIT total score showed excellent reliability (ICC = 0.99, 95% CI: 0.99-1.00, SEM = 1.06, MDC = 2.94). Similarly, the subscores for the stance and swing phases demonstrated high reliability, with the stance phase subscore (Items 5-18) achieving perfect reliability (ICC = 1.00, 95% CI: 1.00 -1.00, SEM = 0.00, MDC = 0.00), highlighting its flawless consistency. The swing phase subscore (Items 19-31) also showed excellent reliability (ICC = 0.99, 95% CI: 0.99-1.00, SEM = 0.57, MDC = 1.58). These results are summarized in Table 2 for assessment means and standard deviations (Table 3).

**Table 2** Mean  $\pm$  Standard deviations of assessments (n = 9)

| Assessment                                       | First assessment | Second assessment |
|--------------------------------------------------|------------------|-------------------|
|                                                  | Mean (SD)        | Mean (SD)         |
| GAIT total score                                 | 11.44 (8.75)     | 11.22 (8.51)      |
| GAIT (Stance and swing phase subscore; Item 1-4) | 1.11 (1.17)      | 1.00 (0.87)       |
| GAIT (Stance phase subscore; Item 5-18)          | 5.22 (3.46)      | 5.22 (3.46)       |
| GAIT (Swing phase subscore; Item 19-31)          | 5.11 (4.68)      | 5.0 (4.61)        |

**Table 3** Intra-rater reliability (ICC<sub>3,1</sub>) of assessments and standard error of measurement (SEM), and minimal detectable change at 95%CI (MDC<sub>95</sub>)

| Assessment                                       | Intra-rater Reliability |              |      |                   |
|--------------------------------------------------|-------------------------|--------------|------|-------------------|
|                                                  | ICC                     | 95% CI       | SEM  | MDC <sub>95</sub> |
| GAIT total score                                 | 0.99                    | 0.99 to 1.00 | 1.06 | 2.94              |
| GAIT (Stance and swing phase subscore; Item 1-4) | 0.95                    | 0.79 to 0.99 | 0.30 | 0.82              |
| GAIT (Stance phase subscore; Item 5-18)          | 1.00                    | 1.00 to 1.00 | 0.00 | 0.00              |
| GAIT (Swing phase subscore; Item 19-31)          | 0.99                    | 0.99 to 1.00 | 0.57 | 1.58              |

These findings underscore the GAIT tool's precision and reliability, particularly its perfect score in assessing the stance phase. This confirms its effectiveness for consistent intra-rater evaluations of gait abnormalities in clinical and research settings.

## Discussion

Integrating the GAIT tool with 2 D image analysis represents a pivotal advancement in assessing gait abnormalities, particularly in post-stroke individuals. This study builds upon the foundational work by Daly et al. [5] and Molina-Rueda et al. [7], who have previously established the intra-rater and inter-rater reliability of the GAIT tool by exploring the added value of combining subjective assessment methods with objective 2D image analysis.

The rationale behind this integration is grounded in the potential to capture a more comprehensive and nuanced picture of gait dynamics than could be achieved through either method alone. For instance, 2D image analysis enables precise tracking of limb trajectories and joint angles during gait, which is critical for assessing subtle abnormalities often missed in subjective evaluations. Previous research, such as that by Zimbelman et al. [2], has delved into the psychometric properties of the GAIT, underscoring its utility in clinical settings. However, the application of 2D image analysis as a complementary tool to GAIT has not been extensively explored. By harnessing the strengths of both objective and subjective assessment methods, this research aimed to enrich the conventional GAIT assessment, thereby providing a robust framework for evaluating gait parameters.

The results demonstrate excellent reliability in the GAIT total score and its subscores when integrated with 2 D image analysis, enhancing the assessment's accuracy by providing quantifiable data that complements the subjective GAIT observations. Specifically, the near-perfect ICC values for both the total score and various subscores reflect the tool's potential for consistent application in clinical practice. The findings from this study demonstrate excellent intra-rater reliability of the GAIT tool when integrated with 2D image analysis, supporting the hypothesis that the combination of these assessment modalities enhances the reliability and depth of gait analysis. This not only corroborates the existing body of knowledge on the GAIT tool's reliability but also extends it by illustrating the potential for 2D image analysis to refine and augment gait assessments.

Moreover, the minimal SEM and MDC values reinforce the tool's precision and the meaningfulness of the detected changes in a patient's gait pattern. A low SEM indicates that the observed score variations are less likely to be due to measurement error and more likely to reflect actual changes in gait. Similarly, small MDC values suggest that even minor improvements or declines in gait are likely to represent true changes rather than random measurement variability.

Age is a critical factor in post-stroke recovery, as it may limit functional capabilities and the recovery of

activities of daily living (ADL). As previous study highlights, functional recovery continues for at least six months after a stroke, influenced by a variety of factors, including age, sex, the nature of the stroke event, motor impairments, and cognitive dysfunctions [13]. Notably, findings from Yoo, Hong et al. (2020) indicate that patients aged 70 years and above tend to exhibit a marked functional decline between six and thirty months post-stroke. This underscores the necessity for age-specific approaches in stroke rehabilitation to address the unique challenges faced by older adults [14]. The implications of this study are significant for clinical practice and research in stroke rehabilitation. The integrated assessment approach offers a promising avenue for developing more targeted and effective rehabilitation strategies by providing detailed insights into the mechanics of gait abnormalities. Furthermore, this methodological innovation could revolutionize gait assessment protocols, aligning with the growing emphasis on precision medicine and tailored rehabilitation interventions.

Despite the promising results, it is essential to acknowledge the current study's limitations. One key limitation is the absence of comparative analysis with other established gait assessment tools. While our findings suggest that the GAIT tool, enhanced by 2D image analysis, provides accurate and reliable data, we have not directly compared these results to those obtained from gold-standard methods such as 3D motion analysis. This comparison is essential to fully establish the validity of our tool within the broader context of gait assessment technologies. Additionally, the study's focus on a relatively small and homogenous group of post-stroke individuals limits the generalizability of our results. Future research should aim to validate these findings in larger, more diverse populations and explore the integration of the GAIT tool with 2D image analysis in other neurological conditions. This broader application could provide deeper insight into the tool's effectiveness across clinical scenarios. Moreover, further investigation into the training requirements for clinicians to effectively utilize this integrated approach is necessary. Proper training will be crucial for ensuring that the tool's implementation in clinical settings is both feasible and beneficial, particularly as we seek to expand its use beyond the initial research setting.

## Conclusion

Integrating the GAIT tool with 2D image analysis offers a novel and reliable method for assessing gait abnormalities, enriching the assessment process with multidimensional data. This study represents a step forward in the pursuit of enhancing stroke rehabilitation strategies and underscores the importance of continuous innovation in assessment methodologies. These findings have important clinical implications. First, by offering a more detailed and accurate assessment of gait abnormalities, clinicians can tailor rehabilitation

strategies more effectively to individual needs, potentially improving outcomes for patients with stroke. The precise data from 2D image analysis can help identify subtle gait deviations that might be overlooked with traditional methods, allowing for earlier interventions. Furthermore, the enhanced reliability of this integrated tool supports its use in routine clinical practice, providing clinicians with confidence in the consistency and accuracy of their assessments. This could lead to more standardized approaches in gait assessment across different clinical settings, promoting better patient care through improved diagnostic and treatment practices.

## Acknowledgments

This Research is funded by Thailand Science Research and Innovation Fund Chulalongkorn University (HEA663700089)

## Declaration of interest statement

All authors of this study declare no conflict of interest.

## References

- [1] Duncan PW, Goldstein LB, Matchar D, Divine GW, Feussner J. Measurement of motor recovery after stroke. Outcome assessment and sample size requirements. *Stroke*. 1992;23(8):1084-9.
- [2] Zimbelman J, Daly JJ, Roenigk KL, Butler K, Burdsall R, Holcomb JP. Capability of 2 gait measures for detecting response to gait training in stroke survivors: gait assessment and intervention tool and the tinetti gait scale. *Arch Phys Med Rehabil*. 2012;93(1):129-36.
- [3] Lord SE, Halligan PW, Wade DT. Visual gait analysis: the development of a clinical assessment and scale. *Clin Rehabil*. 1998;12(2):107-19.
- [4] Estrada-Barranco C, Cano-de-la-Cuerda R, Molina-Rueda F. Construct validity of the Wisconsin Gait Scale in acute, subacute and chronic stroke. *Gait Posture*. 2019;68:363-8.
- [5] Daly JJ, Nethery J, McCabe JP, Brenner I, Rogers J, Gansen J, et al. Development and testing of the gait assessment and intervention tool (G.A.I.T.): a measure of coordinated gait components. *J Neurosci Methods*. 2009;178(2):334-9.
- [6] Daly JJ, McCabe JP, Gor-Garcia-Fogeda MD, Nethery JC. Update on an observational, clinically useful gait coordination measure: the gait assessment and intervention tool (G.A.I.T.). *Brain Sci*. 2022;12(8).
- [7] Molina-Rueda F, Carratala-Tejada M, Cano de la Cuerda R, Alguacil-Diego IM, Miangolarra Page JC, Cuesta-Gomez A. Examination of the reliability of gait assessment and intervention tool in patients with a stroke. *Int J Rehabil Res*. 2018;41(1):84-6.

- [8] Ugbolue UC, Papi E, Kaliarntas KT, Kerr A, Earl L, Pomeroy VM, Rowe PJ. The evaluation of an inexpensive, 2D, video based gait assessment system for clinical use. *Gait Posture*. 2013;38(3):483-9.
- [9] Arifin WN. Sample size calculator (web) [Internet]. 2024 [cited 25 August 2024]. Available from: [https://wnarifin.github.io/ssc\\_web.html](https://wnarifin.github.io/ssc_web.html).
- [10] Balsalobre-Fernandez C, Tejero-Gonzalez CM, del Campo-Vecino J, Bavaresco N. The concurrent validity and reliability of a low-cost, high-speed camera-based method for measuring the flight time of vertical jumps. *J Strength Cond Res*. 2014;28(2):528-33.
- [11] Damsted C, Nielsen RO, Larsen LH. Reliability of video-based quantification of the knee- and hip angle at foot strike during running. *Int J Sports Phys Ther*. 2015;10(2):147-54.
- [12] Sanudo B, Rueda D, Pozo-Cruz BD, de Hoyo M, Carrasco L. Validation of a video analysis software package for quantifying movement velocity in resistance exercises. *J Strength Cond Res*. 2016;30(10):2934-41.
- [13] Kwakkel G, van Peppen R, Wagenaar RC, Wood Dauphinee S, Richards C, Ashburn A, et al. Effects of augmented exercise therapy time after stroke: a meta-analysis. *Stroke*. 2004;35(11):2529-39.
- [14] Yoo JW, Hong BY, Jo L, Kim JS, Park JG, Shin BK, Lim SH. Effects of age on long-term functional recovery in patients with stroke. *Medicina (Kaunas)*. 2020;56(9).