

DOI: <https://doi.org/10.36489/saudecoletiva.2021v11i68p7191-7202>

Spatio-temporal, kinematic and kinetics gait analysis in post-stroke individuals

Análisis espacial temporal, cinemático y cinético de la marcha en individuos de accidentes vasculares postragenaes
Análise espaço-temporal, cinemática e cinética da marcha em indivíduos pós-acidente vascular cerebral

ABSTRACT

Objective: To analyze the spatio-temporal, kinematic and kinetic characteristics of gait in post-stroke individuals. The sample consisted of 16 individuals (10 from the Post-stroke group and 6 from the Control group). The analysis of gait variables, range of motion, moment and power of the ankle were obtained using Qualysis Track Manager®, with 10 cameras, filming a 5-meter course. **Results:** The Post-stroke group showed a speed approximately 50% lower than the Control group ($p < 0.0001$). With respect to kinetics, the non-paretic side of ankle moment and power were higher than paretic side, but lower than control group. ($p < 0.05$). In kinematics there was no intergroup difference. **Conclusion:** Changes in gait in the post-stroke period may have occurred due to muscle disuse on the paretic side, probably triggering the phenomenon of muscle plasticity, in which changes in the phenotypic expression of muscle fibers occur.

DESCRIPTORS: Gait Analysis; Stroke; Neuronal Plasticity.

RESUMEN

Objetivo: Analizar las características espacio-temporales, cinemáticas y cinéticas de la marcha en individuos post-ictus. **Métodos:** La muestra estuvo formada por 16 individuos (10 del grupo Post ictus y 6 del grupo Control). El análisis de las variables de la marcha, rango de movimiento, momento y potencia del tobillo se obtuvo mediante Qualysis Track Manager®, con 10 cámaras, filmando un recorrido de 5 metros. **Resultados:** El grupo Post-ACV mostró una velocidad aproximadamente un 50% menor que el grupo Control ($p < 0,0001$). En cuanto a la cinética, el momento y la potencia del tobillo en el lado no parético fue mayor que en el parético, pero menor que en el grupo Control ($p < 0,05$). Sin embargo, en cinemática no hubo diferencia entre grupos. En cinemática no hubo diferencia intergrupala. **Conclusión:** Los cambios en la marcha en el período posterior al ictus pueden haber ocurrido debido al desuso muscular en el lado parético, probablemente desencadenando el fenómeno de plasticidad muscular, en el cual ocurren cambios en la expresión fenotípica de las fibras musculares.

DESCRIPTORES: Análisis de la marcha; Accidente vascular cerebral; Plasticidad Neuronal.

RESUMO

Objetivo: Analisar as características espaço-temporais, cinemáticas e cinéticas da marcha em indivíduos pós-AVC. **Métodos:** A amostra foi composta por 16 indivíduos (10 do grupo Pós-AVC e 6 do grupo Controle). A análise das variáveis da marcha, a amplitude de movimento, o momento e a potência do tornozelo foram obtidas por meio do Qualysis Track Manager®, com 10 câmeras, filmando um percurso de 5 metros. **Resultados:** O grupo Pós-AVC apresentou uma velocidade, aproximadamente, 50% menor que o grupo Controle ($p < 0,0001$). Em relação aos cinéticos, o momento e a potência do tornozelo do lado não-parético foi maior que o parético, mas menor que o grupo Controle ($p < 0,05$). Entretanto, na cinemática não ocorreu diferença intergrupo. Na cinemática não ocorreu diferença intergrupo. **Conclusão:** As alterações da marcha no pós-AVC podem ter ocorrido por desuso da musculatura no lado parético, provavelmente desencadeando o fenômeno da plasticidade muscular, no qual ocorrem mudanças na expressão fenotípica de fibras musculares.

DESCRITORES: Análise de Marcha; Acidente Vascular Cerebral; Plasticidade Neuronal.

RECEIVED ON: 03/20/2021 APPROVED ON: 04/09/2021



Camila Maria Mendes Nascimento

Physiotherapist, Master's Student in Gerontology at the Federal University of Pernambuco, Recife, Pernambuco, Brazil.
ORCID: 0000-0002-2223-4196

Ricardo Vinícius de Carvalho Santana

Physiotherapist, Multiprofessional Residency in Physiotherapy in Intensive Care, Hospital Agamenon Magalhães, Recife, Pernambuco, Brazil.

ORCID: 0000-0003-4791-1154

Ana Paula Silva de Oliveira

Physiotherapist, Multiprofessional Residency in Physiotherapy in Intensive Care, Hospital Agamenon Magalhães, Recife, Pernambuco, Brazil.

ORCID: 0000-0003-3746-7504

Maria das Graças Rodrigues de Araújo

Physiotherapist, Professor at the Department of Physiotherapy, Federal University of Pernambuco, Recife, Pernambuco, Brazil.

ORCID: 0000-0002-9980-6172

Marcelo Renato Guerino

Physiotherapist, Professor at the Department of Physiotherapy, Federal University of Pernambuco, Recife, Pernambuco, Brazil.

ORCID: 0000-0002-3439-9166

Maria das Graças Paiva

Physiotherapist, Professor at the Department of Physiotherapy, Federal University of Pernambuco, Recife, Pernambuco, Brazil.

ORCID: 0000-0001-6913-8639

INTRODUCTION

Walking is one of the functions most used by people; it makes it possible to move around, carry out daily activities, maintain independence and quality of life. There may be pathological changes that contribute to reduced efficiency and increased energy expenditure, such as cerebrovascular accident (CVA), where, after the injury, difficulties in voluntary control of movement occur, compromising muscle strength, tone, coordination, balance and perception.¹

About 70% resume their ability to walk, although without adequate muscle synergism, in addition to muscle metabolic disorders, which occurred on the paretic side, associated with the development of spasticity, causing sensorimotor changes, thus changing the plasticity of the affected muscles.²

Skeletal muscle plasticity is highly malleable and exhibits a remarkable ability to adjust when the muscle undergoes contraction, being susceptible to modifying its phenotypic characteristics and providing better functional adaptation.³ Among the changes resulting from stimuli applied to the muscle, we have the transition from slow to fast fibers on the paretic side and greater stimula-

tion for slow fibers on the non-paretic side. Thus, in bipedestation, the center of gravity of these individuals is shifted to this side and, associated with deficits in balance, proprioception and selective control, causes a decrease in weight distribution on the paretic side.⁴ This results in reductions in speed, cadence and stride length, in addition to relative increases in the duration of the gait cycle and in double support periods.⁵

Several tools are used to investigate the biomechanics of movement. The three-dimensional analysis of this event is a resource used as a method of research and assessment of normal or pathological gait, allowing the verification of spatiotemporal characteristics such as length, stride duration and speed.⁶ Speed can be defined as the distance the body travels forward in the unit of time; the length of the stride, as the time from the initial contact of a member to the next initial contact of the same member; and stride length is the distance covered by two successive strokes of the same foot.⁷

The study of the biomechanics of gait after stroke provides a basis for understanding the possible changes in movement mechanisms and the quantitative analysis of this gait can be used as an instrument for kinetic-functional diagnosis, as well as for physical therapy

planning, considering the individuality of each case. Thus, the aim of this study was to quantitatively analyze the kinematic and kinetic characteristics of gait in post-stroke individuals, characterizing and differentiating their spatiotemporal patterns.

METHOD

A cross-sectional exploratory study was carried out at the Human Agility Laboratory, Department of Physical Therapy and Human Movement Sciences, Northwestern University, Chicago – Illinois (USA). Individuals from the Rehabilitation Institute of Chicago (RIC), of both genders and between 50 and 70 years of age, were selected for the two groups from May to July 2015. Post-stroke group (n=10): individuals were eligible by a period greater than or equal to 12 months of injury, without any surgical intervention in the last 24 months since the start of data collection, with the ability to walk without the use of a walking aid device during the experiment. As exclusion criteria, individuals with any other neurological injury, cognitive deficit, or osteomyoarticular injury in the lower limb. Control Group (n=6): consisted of healthy individuals, without any neurological or orthopedic

Statistical analysis was performed using BioEstat v software.

5.3. Mean and standard deviation (SD) were calculated for all parameters studied.

trauma. All participants signed the Informed Consent Form, which was previously approved by the Institutional Review Board of Northwestern University (IRB # STU00200422).

The anthropometric data evaluated were height and weight. Height was measured, in centimeters (cm), using the Visual 3D[®] v software. 5.0 (C-Motion, Inc., Germantown, MD, USA), and the weight, verified, in kilograms (Kg), by an AMTI[®] force platform (Force and Motion, Inc., Watertown, MA, USA), of precision, associated with Qualisys Track Manager[®] software - (QTM) v. 2.1 (Motion Capture Systems, Inc., Gothenburg, SWEDEN). The gait analysis was performed using the QTM to obtain its spatiotemporal, kinematic and kinetic parameters. This program is a video-based photogrammetry analysis system consisting of 10 optoelectronic cameras. It allows three-dimensional reconstruction of the image with spherical reflective markers located at 46 points on the body, for analysis in an upright position, according to a skeletal model created in Visual 3D[®].

Before starting the experiment, the subjects were instructed to walk at a comfortable speed, traveling 5 meters

in length. During the course there were six AMTI[®] force platforms to capture the kinetic variables. All performed 20 attempts, the first being considered as familiarization of the experimental environment. Subjects wore an adjustable vest, to which a Zero G Lite v support device was attached. 2.0[®] (Aretech LLC, Ashburn, VA, USA), in order to prevent falls or imbalance, but there would be no weight support.

All data were calculated in Visual 3D[®] and Matlab[®] v. 8.5 (The Mathworks, Natick, MA, USA). In Visual 3D, the spatiotemporal parameters underwent a Butterworth low-pass filter, with a cutoff frequency of 6Hz, in addition to being normalized on a scale from 0 to 100% of the gait cycle. In Matlab, the average data of the kinematic and kinetic parameters were obtained. The spatiotemporal data calculated were: gait speed, stride width, stance phase time, swing phase time and double stance time. The kinematics and kinetics were: angle, moment and ankle power, respectively, and were calculated during the stance phase of each lower limb in each group. Only data in the sagittal plane were analyzed to identify the most frequent changes in post-stroke individuals.

Statistical analysis was performed using BioEstat v software. 5.3. Mean and standard deviation (SD) were calculated for all parameters studied. The Kolmogorov-Smirnov normality test was performed prior to the statistical analysis to

confirm the normal distribution of data. Only the support phase time variable, when comparing the paretic and non-paretic sides of the Post-stroke group, showed a non-parametric distribution. Then, for this parameter, the Wilcoxon test was performed. As for the other parameters, the Student T-test (parametric test) was subsequently performed for related samples in intra group analyses, and the Student T-test for independent samples in intergroup analyses. Statistical analysis was performed, relating the right lower limb to the left one in the Control group. As there was no significant difference, intergroup comparisons were performed with the mean of the members of the Control group. The level of significance was maintained with a value of $p < 0.05$.

RESULTS

The mean age among participants was $60,10 \pm 4,20$ years in the Post-stroke group and $62,50 \pm 4,42$ in the Control group. There was a homogeneous distribution regarding sex, height and body mass in both groups, the records were similar, as described in table 1.

All spatiotemporal parameters showed a statistically significant difference ($p < 0,05$) when analyzed between groups. All individuals in the Post-stroke group presented speed approximately 50% lower than the individuals in the control group ($p < 0,0001$). On the

Table 1. General characteristics of the sample stratified according to the Post-stroke and Control groups.

VARIABLES	POST-STROKE GROUP (N=10) MEAN (SD)	CONTROL GROUP (N=6) MEAN (DP)
Gender (M/F)	5/5	3/3
Age (Years)	60,10±4,20	62,50±4,42
Mass (kg)	75,25±13,63	72,19±15,27
BMI (kg/m ²)	26,50±3,93	24,87±2,84
Paretic Side (R/L)	7/3	-
Injury Time (months)	140,60±98,13	-

Source: the researcher (2016); SD= Standard Deviation; M=Male; F= Female; BMI= Body Mass Index; R=Right; L= Left

other hand, the Post-stroke group spent about twice as much time with their feet on the floor ($p=0,0069$) at the beginning of the gait cycle (time of double support), in addition to greater stride width ($p=0,001$), in relation to the Control group, seen in table 2.

In general, the paretic and non-paretic sides of the Post-stroke group showed a significant difference in the other verified parameters, such as the times of the stance and swing phases. In fact, the paretic side had a shorter support time than the non-paretic side ($p=0,0051$), corroborated by a longer swing time ($p=0,0011$). When compared to the Control, they presented longer support time and longer swing, both on the paretic side ($p=0,0259$; $p=0,0052$) and on the non-paretic side ($p=0,0115$; $p=0,0047$), as shown in table 3.

The mean range of motion (ROM) of the ankle was homogeneous when

comparing the paretic ($p=0,0967$) and non-paretic ($p=0,4507$) sides and the Control group, with no significant difference being observed. However, when comparing the paretic and non-paretic sides, the means recorded were 73,00 (7,64) and 82,43 (5,67), respectively. Ankle ROM on the paretic side was considerably lower ($p=0,0075$) than on the non-paretic side.

Regarding ankle moment and power, both intra- and inter-group means showed a significant difference. The ankle moment on the paretic side was significantly lower ($p=0,0031$) than on the non-paretic side. However, the Control group showed around twice the moment on the paretic side ($p=0,0005$), being also greater than on the non-paretic side ($p=0,0485$). With regard to joint power, we noticed a sensitive difference in both limbs of post-stroke individuals ($p<0,0001$), as well as the non-

-paretic side was smaller ($p=0,0108$) than in the Control group, but also five times higher in the Control group on the paretic side ($p<0,0001$), according to table 4.

DISCUSSION

Gait speed is often used to characterize post-stroke individuals, being the reference parameter for assessment and treatment. On the contrary, Lauzière et al. (2014) stated that 60% of post-stroke individuals present spatiotemporal asymmetry, and the times of stance and swing phases and double stance are generally investigated, as evidenced in our study.⁸

In fact, we found a lower speed of the post-stroke individuals, causing shorter time in the balance phase in the Control group and in the non-paretic side of the Post-stroke group and, consequently, longer duration of the support phase in the Post-stroke group compared to the Control, being some of the strategies taken to maintain body stability. In the research by Lopes et al. (2015) it was observed that the non-paretic side of 21 post-stroke individuals spent less time swinging than the paretic side, attributing this to a difference in muscle strength and perception of the paretic side, altering gait symmetry.⁹

On the other hand, Dyer et al. (2014) stated that there was less support time on the paretic side compared to the non-paretic side and also to the Control group. Evidence suggests that both exercise and age are factors that contribute to the variation in the proportion of muscle fibers, in which type II fibers start to have type I properties, which modifies their phenotype. However, after a stroke, the muscle fibers on the paretic side are more likely to change their characteristics from type I to type II, a phenomenon called muscle plasticity.¹¹

Sheffler et al. (2014) suggested that these findings are influenced not only by the level of injury, but above all by a reduced velocity. In their study, cor-

Table 2. Spatiotemporal parameters of the Post-stroke and Control groups

SPACE-TIME PARAMETERS		POST-STROKE GROUP	CONTROL GROUP
March Speed (m/s)	Mean (SD)	0,58 (0,16)*	1,25 (0,22)*
Double Support Time (s)	Mean (SD)	0,54 (0,28)*	0,23 (0,07)*
Width Stride (m)	Mean (SD)	0,20 (0,05)*	0,13 (0,01)*

Source: The researcher (2016); SD: Standard Deviation *significant difference ($p<0,05$)

Table 3. Intra- and inter-group spatiotemporal parameters.

SPACE-TIME PARAMETERS		PARETIC SIDE	NON-PARETIC SIDE	CONTROL GROUP
Space-Time Parameters	Mean (SD)	0,91 (0,29)*	1,10 (0,38)*	0,66 (0,09)*
Support Phase Time (s)	Mean (SD)	0,57 (0,13)*	0,37 (0,06)*	0,43 (0,04)*
Balance Phase Time (s)	Mean (SD)	0,20 (0,05)*	0,13 (0,01)*	

Source: The researcher (2016); SD: Standard Deviation *significant difference ($p<0,05$)

Table 4. Kinematic and kinetic parameters of the ankle in the Post-stroke and Control groups.

KINEMATIC PARAMETER		PARETIC SIDE	NON-PARETIC SIDE	CONTROL GROUP
Ankle ROM (°)	Mean (SD)	73,00 (7,64)*	82,43 (5,67)	79,90 (7,28)
Kinetic Parametersf				
Ankle Moment (Nm/Kg)	Mean (SD)	0,46 (0,16)*	0,64 (0,16)*	0,81 (0,11)*
Ankle Power (W/Kg)	Mean (SD)	0,27 (0,16)*	0,93 (0,39)*	1,47 (0,30)*

Source: The researcher (2016); ROM: range of motion; SD: Standard Deviation *significant difference ($p<0,05$)

roborating our outcomes, they found a decrease in speed and cadence, longer double support time and shorter stride length in 108 individuals, with no association of these results with an increase in the BMI of those involved, relating the negative effects of this increase at a longer walking time or distance.¹² However, other studies have stated that there is no significant difference in the time of double support between post-stroke individuals and healthy individuals.¹³

We observed in our findings that the Post-stroke group had greater stride width than the Control group. This fact may be due to the motor strategies chosen to adapt to the demands of the task. By not being able to carry out the proper weight transfer, there is a decrease in speed and an increase in the time where the weight is transferred to the paretic side, resulting in a longer stride. Some authors draw attention to the shorter support time and the longer stride on the paretic side, and these compensations produce an abnormal shift in the center of gravity, resulting in greater energy expenditure.¹⁴

In addition to spatiotemporal parameters, some studies report kinematic changes. In our study, we focused on the ankle joint, where its range of motion on the paretic side was smaller than on the non-paretic side, demonstrating a loss in the quality of movement symmetry of this joint. Milovanovic (2012) explains that these facts are consistent with the abnormal pattern characteristic of the joints of these individuals, due to the elevation of the pelvis and circumvention of the contralateral hip during the swing phase.¹⁴

However, no kinematic differences were found between the groups in our research. Burdett et al (1988) found, in 19 individuals with and without orthosis, greater plantar flexion in the initial contact and medium balance, and less in the removal of the fingers.¹⁵

Kinetic changes were also observed as compensation mechanisms for the

We observed in our findings that the Post-stroke group had greater stride width than the Control group. This fact may be due to the motor strategies chosen to adapt to the demands of the task. By not being able to carry out the proper weight transfer, there is a decrease in speed and an increase in the time where the weight is transferred to the paretic side, resulting in a longer stride.

stability of individuals. In our analysis, we noticed a smaller joint moment on the paretic side, both intra- and intergroup. This can be explained by the fact that, on average, 70% of post-stroke individuals show biomechanical changes in the ankle, preventing its proper positioning and making foot dorsiflexion difficult during the stance phase.¹⁶

Kim (2003) selected 20 post-stroke individuals and identified that the paretic side had lower hip, knee and ankle moments than the non-paretic side. The average of moments on the paretic side ranged from 21% to 83% in relation to the non-paretic side, with the greatest asymmetry found in the ankle.¹⁷ Kim (2003) selected 20 post-stroke individuals and identified that the paretic side had lower hip, knee and ankle moments than the non-paretic side. The average of moments on the paretic side ranged from 21% to 83% in relation to the non-paretic side, with the greatest asymmetry found in the ankle.¹⁸

Other researchers evaluated the ankle power of 12 post-stroke individuals and 10 healthy individuals, subdivided into two groups, according to their speed. They explained that, on the paretic side, there is greater generation of power in the hip to supply the muscle weakness of the plantar flexors, due to disuse and alteration of its slow muscle fibers to fast ones.¹⁹

Among the difficulties and limitations found in this study, one refers to the sample size, which, when presented in a small number, may have prevented more accurate and consistent results with reports in the literature. Furthermore, it was observed that although the study of the locomotion of post-stroke individuals has motivated many studies, most of them disregard the variability that can occur between the gait of these individuals, despite the visual appearance showing similarities.

Despite this, the difference in our research refers to the fact that the proposal was not restricted to comparing the possible differences in gait param-

ters between the post-stroke and Control groups. Certainly, the changes that occurred on one side, said “affected”, of the post-stroke individuals, with the said “non-affected”, and then with the Control, were taken into account. Thus, we observed the functional variations in gait at not only an intergroup level, but also an intragroup level, envisioning new perspectives of physical therapy approach for this type of patient.

Even so, it is suggested that more complex studies, using tools such as Electromyography, can provide more precise answers regarding what happens in the lower limbs of these individuals, at the muscular level, to elucidate the causes of the observed changes and explain the relationship with the pheno-

Certainly, the changes that occurred on one side, said “affected”, of the post-stroke individuals, with the said “non-affected”, and then with the Control, were taken into account.

menon of muscle plasticity. Such knowledge may contribute to professionals being able to differentiate the primary deficits from the compensations arising from the adjustments that will appear over the time of performing the gait in the post-stroke.

CONCLUSION

The gait analysis method used in this study was able to verify the changes observed in the evaluated parameters, both intra- and intergroup. Thus, understanding these changes can contribute to monitoring the evolution and treatment of individuals after a stroke, as well as devising better therapeutic strategies in each situation. ■

REFERENCES

- Westpha PJ, Ferreira J, Schimit VM, Cecheti F, Bonetti LV, Sacani R. Análise cinemática da marcha em indivíduos com hemiparesia espástica após acidente vascular cerebral. *Sci Med*. 2016;26(2):1-7.
- Hood DA, Irrcher I, Ljubicic V, Joseph AM. Coordination of metabolic plasticity in skeletal muscle. *J Exp Biol*. 2006;209(12):2265-75.
- Boff SR. A fibra muscular e fatores que interferem no seu fenótipo. *Acta fisiátrica*. 2008; 15(2):111-116.
- Styer-Acevedo J. Fisioterapia para crianças com paralisia cerebral. In: Tecklin JS, editor. *Fisioterapia pediátrica*. 3a ed. Porto Alegre: Artmed; 2002. p. 98-140.
- Araújo AGN, Andrade LM, Barros RML. Sistema para análise cinemática da marcha humana baseado em videogrametria. *Fisioter Pes*. 2005;11(1):3-10.
- Moura EWD, Lima E, Borges D, Silva PDAC. Fisioterapia: aspectos clínicos e práticos da reabilitação. In *Fisioterapia: aspectos clínicos e práticos da reabilitação*. Artes Médicas. 2010, p.615-42.
- Shumway-Cook A, Woollacott MT. *Controle Motor. Teoria e Aplicações*. São Paulo: Manole, 2003, p. 289-380.
- Lauziere S, Betschart M, Aissaoui R, Nadeau S. Understanding spatial and temporal gait asymmetries in individuals post stroke. *Int J of Phys Med & Rehabil*, 2014: 1-11.
- Lopes PG, Lopes JA, Brito CM, Alfieri FM, Rizzo Battistella L. Relationships of Balance, Gait Performance, and Functional Outcome in Chronic Stroke Patients: A Comparison of Left and Right Lesions. *Biomed Res Int*. 2015: 1-8.
- Dyer JO, Maupas E, de Andrade Melo S, Bourbonnais D, Nadeau S, Forget R. Changes in activation timing of knee and ankle extensors during gait are related to changes in heteronymous spinal pathways after stroke. *J Neuroeng Rehabil*. 2014;11(148): 1-17.
- Scherbakov N, Von Haehling S, Anker SD, Dirnagl U, Doehner W. Stroke induced Sarcopenia: muscle wasting and disability after stroke. *International journal of cardiology*. 2013;170(2), 89-94.
- Sheffler LR, Bailey SN, Gunzler D, Chae J. Effect of body mass index on hemiparetic gait. *PMC*. 2014;6(10):908-13.
- Lucarelli PRG, Greve JMA. An Alteration of the load-response mechanism of the knee joint during hemiparetic gait following stroke analyzed by 3-dimensional kinematic. *Clinics* 2006;61(4):295-300.
- Milovanović I, Popović DB. Principal component analysis of gait kinematics data in acute and chronic stroke patients. *Comput Math Methods Med*. 2012;1-8.
- Burdett RG, Borello-France D, Blatchly C, Potter C. Gait comparison of subjects with hemiplegia walking unbraced, with ankle-foot orthosis, and with Air-Stirrup brace. *Phys Ther*. 1988;68(8):1197-203.
- Oken O, Yavuzer G. Spatio-temporal and kinematic asymmetry ratio in subgroups of patients with stroke. *Eur J Phys Rehabil Med*. 2008;44(2):127-32.
- Kim CM, Eng JJ. The relationship of lower-extremity muscle torque to locomotor performance in people with stroke. *Phys Ther*. 2003;83(1):49-57.
- Jonkers I, Delp S, Patten C. Capacity to increase walking speed is limited by impaired hip and ankle power generation in lower functioning persons post-stroke. *Gait Posture*. 2009;29(1):129-37.
- Boudarham J, Roche N, Pradon D, Bonnyaud C, Bensmail D, Zory R. Variations in kinematics during clinical gait analysis in stroke patients. *PLoS One*. 2013;8(6):1-9.