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Postprint

This is the accepted version of a paper published in *The British Journal of Visual Impairment*. This paper has been peer-reviewed but does not include the final publisher proof-corrections or journal pagination.

Citation for the original published paper (version of record):

Santos, D., Abrantes, J., Lewis, P., Macedo, A F. (2018)
Influence of the use of cane on the gait cycle of individuals who are blind
The British Journal of Visual Impairment, 36(3): 251-261
<https://doi.org/10.1177/0264619618782576>

Access to the published version may require subscription.

N.B. When citing this work, cite the original published paper.

Permanent link to this version:

<http://urn.kb.se/resolve?urn=urn:nbn:se:lnu:diva-76363>

Abstract

Purpose: The aim of this study was to perform a biomechanical characterization of the gait cycle in individuals who are blind. **Methods:** Five individuals with ages between 16 and 19 years participated in this study. The task consisted of walks of 12 metres measured in two conditions: 1) with cane and 2) no cane; a total of 20 walks in each condition were performed. During walks participants were monitored with a Vicon 3D-motion capture system. Spatial-temporal, kinematic, kinetic and dynamic parameters were recorded and compared between the two conditions. **Results:** We observed an interaction between the condition and ankle angular measures ($p=0.003$); the interaction was due to differences induced by condition in instants "opposite toe off" ($p=0.045$) and "opposite initial contact" ($p=0.019$). We also obtained a significant difference in the negative ankle-joint-power measures between conditions ($p=0.044$). **Conclusion:** Our study showed that the use of cane changes the gait pattern in individuals who are blind. The subtle changes in ankle behaviour when walking with a cane, compared with no cane, suggest better application of the force during the initial stages of support leading to a more comfortable gait. This type of assessment of gait may be important to improve mobility training and rehabilitation strategies.

Keywords

(1) Visual impairment (2) Gait (3) Biomechanics (4) Orientation and Mobility (5) Cane

1 Introduction

Persons who are blind often show differences in gait variables when compared to persons with normal vision (Hallemans, Beccu, Van Look, Ortibus, & Truijen, 2009; Moura e Castro, 1993; Rosen, 2010). Gait is known as a sequence and standardized reproduction of movements between the lower limbs interaction and the total body mass, allowing the individual to move from one point to another (Baker, 2013; Perry, 2005). The gait cycle is a set of events occurring during the time interval between the accomplishment of a determined contact of a foot and the repetition of the same type of contact with the same foot (Gabriel, 2001). For a representation of the cycle see Supplementary methods, Appendix Figure 1. Studies investigating gait in individuals with vision impairment (we use vision impairment when referring groups that can include blind or low vision subjects) found a significant heterogeneity in the gait cycle (Long, 2010; Pereira, 1984; Rosen, 2010). In these studies that has been attributed to the absence or reduction of vision leading to a limited amounts of motor experiences. Gait difficulties can be so debilitating that some individuals with vision impairment avoid walking without a human guide when performing their daily activities because they are afraid of falls and bumping into objects (Mason & McCall, 2013; Moura e Castro, 1993). The use of mobility devices is an alternative to a human guide.

Mobility devices such as a cane, used by individuals with impaired vision, can interfere with the biomechanical aspects of gait (Geruschat & Smith, 2010). A cane provides the user with sensory information that helps him/her to detect what lies ahead and, in this way, will have a great influence on the motor response and consequently on its gait cycle (LaGrow, 2010). As such, a cane can help to increase confidence and eventually motivation to initiate independent and faster movements leading to a change in the biomechanical aspects of gait (Geruschat & Smith, 2010). At this point is important to define biomechanics as a complementary diagnostic tool used to study movements and forces associated with human motion (Winter, 1987). Movements and forces result from mechanical relations established and controlled by the individual. There is evidence in the literature that gait patterns can predict the risk of falls, reduction in quality of life, and eventually increased risk of mortality (Hallemans, Beccu, Van Look, Ortibus, & Truijen, 2009; Hallemans, Ortibus, Meire, & Aerts, 2010; Hallemans, Ortibus, Truijen, & Meire, 2011; Iosa, Fusco, Morone, & Paolucci, 2012; Ramsey, Blasch, Kita, & Johnson, 1999).

1 Some studies analysed the gait cycle of persons with impaired vision in laboratories
2 equipped with modern biomechanical methods that allow the analysis of three-
3 dimensional aspects of the cycle (Hallemans et al., 2009; Hallemans et al., 2010;
4 Hallemans et al., 2011; Iosa et al., 2012). For a representation of the gait cycle please
5 look at Supplementary methods, Appendix Figure 1. The gait cycle of persons with
6 impaired vision, not using a cane, is characterised by low speed, short stride length and
7 with long double support periods (Hallemans et al., 2009; Hallemans et al., 2010;
8 Nakamura, 1997). Other authors measured different parameters but also observed
9 characteristics similar to immature gait patterns such as longer stride width, flexed knees,
10 decreased "initial contact" (stance sub-phase) and a large degree of out-toeing when
11 compared with normal sighted individuals (Rosen, 2010). However, these studies did not
12 clarify what happens to the gait cycle of the same person with impaired vision when
13 using a cane compared with not using it. Better understanding of the impact of the cane in
14 the gait cycle can help with the decisions that need to be taken by patients and therapists
15 during vision rehabilitation.

16 The aim of this study was to understand the impact of using a cane on gait variables
17 of individuals who are blind. We investigated this by comparing biomechanical variables
18 when individuals who are blind walked with or without a cane.

19 **Methods**

20 *Participants*

21 All participants had vision impairment from birth, at the time of the study vision
22 was reduced to light perception and therefore can be classified as blind. Exclusion criteria
23 included existence of psychiatric conditions, physical disabilities and communication
24 difficulties. Information recorded included: weight and height, length of both legs and
25 time as an independent cane user. The leg length it was measured from the anterior
26 superior iliac spine to the medial malleolus, passing through the knee joint. These results
27 are summarized in Table 1, all participants were right-hand dominant and the cane was
28 held in the dominant hand. All five participants (3 were females) attended or had finished
29 high school at the time of the study; their school is a reference school for education of

visually impaired students in Braga, Portugal. The study conformed to the tenets of the Declaration of Helsinki. Participants or their legal guardians signed the informed consent form after receiving oral information about the purpose and agreeing to take part in the study.

Table 1: Demographic information of the five participants. SD = standard deviation; Min = minimum; Max = maximum. All participants were right-dominant and therefore results for the right limbs can interpreted as results for the dominant limb and for the left as results for the non-dominant limb.

	Age (years)	Weight (N)	Height (mm)	Left Leg Length (mm)	Right Leg Length (mm)	Cane user (years)
Mean	18	652.1	1633	872	872	4
SD	1.4	150.0	91	48	50	1.6
Min	16	413.8	1559	825	820	2
Max	19	840.4	1763	945	950	6

Equipment for biomechanical assessment

The biomechanical assessment of gait was performed at Movlab - the Motion Capture Lab in Universidade Lusófona de Humanidades e Tecnologias, in Lisbon.

Motion capture was supported by the Vicon 3D-motion capture MX system. This system was based on 10 MX cameras (8*1.3 GBytes; 2*2.0 GBytes) connected to the MXUltraneet controlling hardware unit which was used to track the motion of 41 spherical reflective markers (9.5 mm in diameter) placed on anatomical standardized landmarks of the participants represented in Figure 1 (Model PlugInGait - Full Body). Anthropometric data were measured with a SECA 764 balance and by anthropometric instruments from Siber Hegner. Kinematic and kinetic data was recorded at 200 Hz. A force plate (AMTI-OR6) was mounted on the floor of the capture volume recording the ground reaction force data at 1000 Hz. The force plate was connected to a strain gauge amplifier (AMTI MSA-6 MiniAmp) and to the Vicon® MXControl in order to synchronize the Vicon MXUltraneet. A host computer ran the data acquisition and processing software Nexus-1.7, from Vicon®. The software supported data acquisition and kinematic, kinetic and dynamic data processing.

Figure 1: Plug-in-Gait Marker Placement ("Vicon's Plug-in-Gait Marker Placement,") and an example the subject viewer with a Software Vicon (Vicon Nexus Reference Guide, 2016)

Procedure for data collection

Spatial-temporal, kinematic, kinetic and dynamic information of gait pattern was recorded with and without a cane. Each participant used his own cane that is normalized according with the height of the user. Walks were performed within a rectangle in which the force platform was located, see Figure 2. A full recognition of space was performed before the measurements to ensure that participants were confident and informed about the direction of motion during the measurements. Carpets, market in Figure 2, helped with tactile discrimination on the path and provided information about direction of motion.

Figure 2: Scheme showing the walking path and the approximate location of the force platform. The force platform is close to the start of the path because, according with the experience of our laboratory, that leads to a better constancy (reduces the number of invalid trials) of the measurements for the support values (Gabriel, Monteiro, Moreira, Faria, & Abrantes, 2010; L. Santos & Abrantes, 2010).

Participants were wearing appropriate clothing - bathing or bikini shorts - barefoot and passive retroreflective marks glued with antiallergenic adhesive tape on the body, according with the method described for the biomechanical assessment (Plug-In-Gait - Full Body). Each participant performed 40 walks under two conditions: 20 walks with a cane and 20 walks without a cane. In each condition: 10 walks were performed with the left foot making contact with the force platform and 10 with the right foot. The first foot in contact with the ground was chosen by the participant. Participants were instructed to walk at their normal (preferred) walking speed. Each measurement took approximately 30 seconds (including preparation and walking). Measurements were performed alternately with/without the cane, walks in which the measurements in the force platform failed were repeated.

Variables analysed

Eighteen gait variables divided into 4 categories were studied. The distribution by category is: **Spatiotemporal variables** - 1) step width, 2) step length, 3) stride length, 4) center of gravity's velocity, 5) cadence, 6) speed, 7) stance time, 8) swing time, 9) double support time; **Kinematic variables** - 10) pelvic tilt angle, 11) hip angle, 12) knee angle,

13) maximum value of knee flexion, 14) ankle angle; **Kinetic variables** - 15) ground reaction force anteroposterior dynamic: 16) vertical component; **Dynamic variables** - 17) maximum value of positive and 18) negative ankle joint power.

The description of the variables is given in Figures 3-4 and Appendix I (see also Santos, 2012) and the results in Table 2-4. When applicable, variables were measured and compared for four instants of the gait cycle.

The 4 instants of the gait cycle are shown in Figure 3 and are defined as: "initial contact" (IC - 3A) which correspond to instant of 0% of cycle gait when the foot makes contact with the ground, "opposite toe off" (oTO - 3B) which corresponds to instant of 10% of cycle gait when the contralateral foot leaves the ground, "opposite initial contact" (oIC - 3C) which correspond to instant of 50% of cycle gait when the contralateral foot hits the ground and "toe off" (TO - 3D) corresponding to instant of 60% of cycle gait when the foot leaves the ground.

Statistical procedures

The mean value of both feet for each run and variable was used for statistical analysis because there were no statistically significant differences between right and left feet. Repeated measures were analysed with linear mixed-models (LMM) (SPSS, v22). LMM are one of the recommended methods to analyse repeated measures in small samples; a detailed explanation with mathematical details can be found in the literature (Muth et al., 2015; Skene & Kenward, 2010). For each outcome measure we used 40 measurements of each participant giving a total of 200 measurements. For LMM, participants were defined as "random factor" and "condition" as fixed factor. Two conditions were defined with condition 1 = cane (C) and condition 2 = no cane (NC). According to the outcome, other fixed factors were defined. For example, to analyse all but maximum knee angle in the kinematic variables (shown in Table 3) the "instant of the gait cycle" with four levels was defined as fixed factor.

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Figure 3: (A-D) Representation of the four instants of the gait cycle described and analysed in this study. (E) Lateral perspective of the gait cycle for the right leg. IC = "initial contact" = right foot hits the ground; oTO = "opposite toe off" = contralateral foot (left foot) leaves the ground; oIC = "opposite initial contact" = contralateral foot (left foot) hits the ground; TO = "toe off" = right foot leaves the ground. (F) Interior perspective of the gait cycle for the right leg.

Results

Spatiotemporal results

A summary of the values obtained for the 9 spatiotemporal variables analysed in provided in **Table 2**. Descriptive statistics results about the within-participant variability are available in Supplementary results. For spatiotemporal variables, the mean differences (mDif) between condition C (higher values for C) and NC were: mDif=0.013m for step length, mDif=0.009m for stride length, mDif=0.025m/s for speed, mDif=0.011s for stance time, mDif = 0.011s for swing time and mDif = 0.009s for double support time. Lower values were obtained for C when compared with NC for: step width, mDif=0.010m and cadence, mDif=1.3stride/min. The trend observed when using a cane was that participants moved faster (increased speed, step length, stride length and reduced cadence) and had better stability (reduced step width). Spatiotemporal values in both conditions assessed seem to differ from the expected values obtained in normal sighted persons (Neumann, 2002).

Table 2: Summary of the spatiotemporal variables for all participants and trials divided by condition (C=cane; NC=no cane). Legend: CoG=center of gravity; IC=initial contact; oTO=opposite toe off; oIC=opposite initial contact; TO=toe off. Negative mean differences indicate a reduced value during walks with a cane compared to walks without a cane. Differences are considered statistically significant for p-values less than 0.05.

Spatiotemporal variables	Condition		Mean difference	P-value
	NC (Mean $\pm$ SD)	C (Mean $\pm$ SD)		
Step width (m)	0.096 $\pm$ 0.056	0.086 $\pm$ 0.060	-0.010	p=0.230
Step length (m)	0.629 $\pm$ 0.130	0.642 $\pm$ 0.106	0.013	p=0.430
Stride length (m)	1.257 $\pm$ 0.215	1.266 $\pm$ 0.185	0.009	p=0.748
CoG velocity				
IC (m/s)	1.111 $\pm$ 0.351	1.197 $\pm$ 0.996	0.086	p=0.417
oTO (m/s)	1.286 $\pm$ 0.976	1.186 $\pm$ 0.331	-0.100	p=0.333
oIC (m/s)	1.185 $\pm$ 0.338	1.161 $\pm$ 0.299	-0.024	p=0.596
TO (m/s)	1.261 $\pm$ 0.341	1.239 $\pm$ 0.300	-0.022	p=0.636
Cadence (stride/min)	54.77 $\pm$ 7.159	53.51 $\pm$ 6.235	-1.260	p=0.186
Speed (m/s)	1.140 $\pm$ 0.278	1.160 $\pm$ 0.322	0.025	p=0.563
Stance time (s)	0.676 $\pm$ 0.116	0.687 $\pm$ 0.170	0.011	p=0.481
Swing time (s)	0.438 $\pm$ 0.046	0.449 $\pm$ 0.047	0.011	p=0.079
Double support time (s)	1.257 $\pm$ 0.215	1.266 $\pm$ 0.185	0.009	p=0.748

Kinematic results

Kinematic results are summarized in **Table 3** and show an interaction between conditions (C and NC) and instants of the gait cycle for the ankle angle. The interaction is shown in **Figure 4** and was due to the ankle angles obtained for instants oTO ($p=0.045$) and oIC ($p=0.019$). No other statistically significant differences between the two conditions were observed for the remaining variables. However, compared with the expected curve, there was shift of the curve that show a tendency towards an exaggerated ankle dorsiflexion at all instants of the gait cycle.

Table 3: Summary of the kinematic variables for all participants and trials divided by condition (C=cane; NC=no cane). Legend: IC=initial contact; oTO=opposite toe off; oIC=opposite initial contact; TO=toe off; Max. knee flexion=Maximum value of knee flexion. Negative mean differences indicate a reduced value during walks with a cane compared to walks without a cane. Differences are considered statistically significant for p-values less than 0.05.

Kinematic variables	Condition		Mean difference	P-value
	NC (Mean $\pm$ SD)	C (Mean $\pm$ SD)		
<i>Pelvic tilt angle</i>				
IC (°)	11.3 $\pm$ 4.0	11.2 $\pm$ 3.5	-0.2	$p=0.761$
oTO (°)	11.1 $\pm$ 3.7	10.7 $\pm$ 3.3	-0.4	$p=0.375$
oIC (°)	10.7 $\pm$ 4.4	10.6 $\pm$ 4.0	-0.1	$p=0.861$
TO (°)	10.2 $\pm$ 4.0	9.8 $\pm$ 3.5	-0.4	$p=0.440$
<i>Hip angle</i>				
IC (°)	34.6 $\pm$ 5.1	34.8 $\pm$ 5.6	0.2	$p=0.812$
oTO (°)	32.2 $\pm$ 5.5	32.7 $\pm$ 6.4	0.5	$p=0.590$
oIC (°)	-8.4 $\pm$ 4.6	-8.6 $\pm$ 3.8	-0.2	$p=0.708$
TO (°)	-3.1 $\pm$ 4.7	-3.4 $\pm$ 4.8	-0.3	$p=0.667$
<i>Knee angle</i>				
IC (°)	6.7 $\pm$ 5.8	4.4 $\pm$ 6.7	-2.3	$p=0.247$
oTO (°)	14.8 $\pm$ 4.3	14.2 $\pm$ 14.8	-0.6	$p=0.748$
oIC (°)	10.7 $\pm$ 5.8	9.3 $\pm$ 10.7	-1.4	$p=0.480$
TO (°)	32.2 $\pm$ 4.8	30.7 $\pm$ 32.2	-1.5	$p=0.439$
<i>Max. knee flexion (°)</i>	56.4 $\pm$ 5.8	55.2 $\pm$ 18.6	-1.2	$p=0.546$
<i>Ankle angle</i>				
IC (°)	3.8 $\pm$ 4.7	2.8 $\pm$ 4.1	-1.0	$p=0.098$
oTO (°)	0.8 $\pm$ 4.2	-0.4 $\pm$ 3.8	-1.1*	$p=0.045^*$
oIC (°)	14.1 $\pm$ 8.3	16.6 $\pm$ 6.5	2.5*	$p=0.019^*$
TO (°)	-6.8 $\pm$ 10.6	-4.2 $\pm$ 8.8	2.6	$p=0.063$

Figure 4: Values of the ankle angle for four instants of the gait cycle (IC=initial contact, oTO=opposite toe off, oIC=opposite initial contact, TO=toe off). The two conditions tested were: cane (C=tick line) and no cane (NC=dotted line); the error bars represent one standard deviation of the mean and are plotted above the line for C and below the line for NC. The expected curve (thin line) has been adapted from The Pathokinesiology Service and the Physical Therapy Department (1996).

Kinetic and dynamic results

Kinetic and dynamic values are summarized in **Table 4**. For dynamic variables, the maximum value of negative ankle joint power was different for the two conditions (mean difference=-0.190W/Kg, $p=0.044$). In this parameter, the blind participants using the cane show statistically significant higher values.

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Table 4: Summary of the kinetic and dynamic variables for all participants and trials divided by condition (C=cane; NC=no cane). Legend: oTO=opposite toe off; oIC=opposite initial contact; GRF VERT/AP=Ground reaction force vertical/anteroposterior component; Max. positive/negative AJP=Maximum value of positive/negative ankle joint power. Negative mean differences indicate a reduced value during walks with a cane compared to walks without a cane. Differences are considered statistically significant for p-values less than 0.05.

Kinetic / Dynamic variables	Condition		Mean difference	P-value
	NC (Mean ± SD)	C (Mean ± SD)		
Kinetic variables				
GRF VERT				
oTO (N/Kg)	533.81 ± 186.16	550.83 ± 188.62	17.02	p=0.521
oIC (N/Kg)	593.47 ± 153.74	611.92 ± 135.47	18.45	p=0.369
GRF AP				
oTO (N/Kg)	-102.52 ± 57.84	-110.71 ± 64.38	-8.19	p=0.345
oIC (N/Kg)	123.85 ± 67.32	135.53 ± 63.15	11.69	p=0.207
Dynamic variables				
Max. positive AJP (W/Kg)	3.49 ± 1.64	3.55 ± 1.54	0.06	p=0.788
Max. negative AJP (W/Kg)	-0.74 ± 0.83	-0.93 ± 0.44	-0.19*	p=0.044*

9 Discussion and conclusions

This study was motivated by the current limited knowledge regarding gait patterns of blind people whilst using a cane. The specific objective of the study was to provide evidence about the influence of use cane in biomechanical parameters and, eventually, gather evidence that the use of cane leads to better control of gait. We found differences between the two conditions studied, cane and no cane, for two of the variables analysed: ankle angle and maximum value of negative ankle joint power.

Our study shows that the amplitude of ankle movement increases when using a cane compared with no cane, which is indicative of increased stability and is associated with reduced plantar contact of the foot and improvement in shock absorption. That is, when participants walked with cane the necessity of sensory exploration reduced and the foot was used less to provide haptic feedback information about the ground. This suggests a shift in strategy from a cautious gait towards a more relaxed gait.

Results for the dynamic variables in Table 4 (Maximum value of positive/negative ankle joint power (AJP)) reinforce the idea of a more relaxed gait with cane. Joint power reflects the net rate of generating or absorbing energy by all muscles and other connective

1 tissues crossing a joint. A positive value indicates power generation, which reflects a
2 concentric muscle activation and a release of energy from the previously elongated
3 connective tissues. Whereas a negative value indicates power absorption, which reflects
4 an eccentric muscle activation and the passive stretching of the connective tissues
5 (Neumann, 2002; Winter, 1987). In our case, the range (the difference between maximum
6 and minimum AJP) increased with the cane mostly due to a significant increase in the
7 Negative AJP. Thus, our results with cane show higher values of absorption, which
8 demonstrate a more efficient absorption of energy by the antagonistic muscles, giving the
9 inferior limb more stability and better shock absorption. As other authors have shown in
10 individuals with normal vision, higher absolute values of maximum negative ankle joint
11 power are associated with comfortable walking and absolute values for this variable tend
12 to reduce when adults with gait problems are forced to walk quickly (Graf, Judge,
13 Ounpuu, & Thelen, 2005).

14 The methodology used in this study is a major strength, the Plug-In-Gait Model of
15 Vicon represents the entire body allowing a detailed knowledge of the integrated motor
16 behaviour in three dimensions. We recognize some limitations, namely the small sample
17 size and the lack of a control group. These limitations will be taken in consideration in
18 future studies.

19 To conclude, in this study we showed that biomechanics analysis can be
20 successfully used to characterize gait patterns in individuals who are blind. This precise
21 and objective technique captured subtle changes in ankle behaviour when participants
22 walked with the cane (when compared with no cane). The observed changes indicate that
23 individuals would be able to stop the movement due to better application of the force
24 during the initial stages of support. This type of assessment of gait may be important in
25 improving mobility training and rehabilitation strategies.

26 **Acknowledgement**

27 We are highly grateful to Dr. Ivo Fialho Roupá for providing the expertise for using
28 the Vicon system. His dedication made possible the collection, processing and analysis of
29 the data.

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Appendix - Supplementary methods

Measurement criteria of variables studied

1. Spatiotemporal variables

Appendix Figure 1. Lateral perspective of the gait cycle for the right leg. IC = "initial contact" = right foot hits the ground; oTO = "opposite toe off" = contralateral foot (left foot) leaves the ground; oIC = "opposite initial contact" = contralateral foot (left foot) hits the ground; TO = "toe off" = right foot leaves the ground

Appendix Figure 2. Interior perspective of the gait cycle for the right leg

Step width was measured from the value of the difference of midlateral component of instants IC and oIC. (see Appendix Figures 1 and 2)

Step length was measured from the value of the difference between the anteroposterior component of instants IC and oIC. **Stride length** was measured from the value of the difference between anteroposterior component of instants IC and the subsequent initial contact of the right foot. **Center of gravity's velocity** was measured from the value of the difference of anteroposterior, mid-lateral and vertical components of instants IC to TO. **Cadence** was measured by the number of strides per minute. **Speed** was determined from the multiplication of the variables "cadence" and "stride length". **Stance time** corresponds to the period of time when the foot is in contact with the ground. **Swing time** corresponds to the period of time when the foot is elevated relative to the ground. **Double support time** corresponds to the period of time when the both feet are in contact with the ground. (see Appendix Figure 1)

2. Kinematic variables

Appendix Figure 3. Kinematic angles (adapted from Plug-in Gait Reference Guide, 2016)

Pelvic tilt angle is measured as the angle between the projected sagittal pelvic axis (v1) and the sagittal laboratory axis (v2). **Hip angle** is measured as the angle between the projected sagittal thigh axis (v4) and the projected sagittal pelvic axis (v3). **Knee angle** is measured as the angle between the projected sagittal shank axis into the plane perpendicular to the knee flexion axis (v5) and the sagittal thigh axis (v4). **Maximum value of knee flexion**. **Ankle angle** is measured as the angle between the foot vector (v6) and the sagittal axis of the shank (v5). (see Appendix Figure 3)

3. Kinetic variables

Ground reaction force (GRF) anteroposterior component was measured from the values of the anteroposterior component of the GRF of instants IC to TO. **GRF vertical component** was measured from the values of vertical component of the GRF of instants IC to TO. (see Appendix Figure 1)

4. Dynamic variables

Maximum value of positive ankle joint power (AJP) corresponds to the maximum value of positive energy produced per unit of time divided by the weight of the performer, which represents the maximum value of the muscular work, which is predominantly concentric. **Maximum value of negative AJP** corresponds to the maximum value of negative energy produced per unit of time divided by the weight of the performer, which represents the maximum value of the muscular work, which is predominantly eccentric.

Plug-in Gait Reference Guide. (2016). Retrieved 18.08.2017, from Vicon Motion Systems Limited
[https://docs.vicon.com/display/Nexus25/PDF+downloads+for+Vicon+Nexus?preview=/34899296/34899965/Plug-in Gait Reference Guide.pdf](https://docs.vicon.com/display/Nexus25/PDF+downloads+for+Vicon+Nexus?preview=/34899296/34899965/Plug-in+Gait+Reference+Guide.pdf)

Appendix - Supplementary results

Intra individual variability of gait biomechanical parameters

Participant_1

Appendix Table 1: Summary of intra individual variability of spatiotemporal variables for participant 1. Trials divided by condition (C=cane; NC=no cane) and by segment (Left; Right). Legend: CoG=center of gravity; IC=initial contact; oTO=opposite toe off; oIC=opposite initial contact; TO=toe off.

Spatiotemporal variables	Coefficient of variety								
	NC		C			NC	C		
	LEFT	RIGHT	LEFT	RIGHT					
Step width (m)	29%	<	59%	50%	>	25%	44%	>	38%
Step length (m)	11%	>	7%	13%	=	13%	14%	>	13%
Stride length (m)	9%	>	5%	6%	>	2%	11%	>	5%
CoG velocity									
IC (m/s)	9%	=	9%	5%	<	9%	9%	>	7%
oTO (m/s)	7%	<	8%	6%	<	7%	7%	=	7%
oIC (m/s)	7%	=	7%	7%	>	4%	11%	>	9%
TO (m/s)	6%	=	6%	7%	>	4%	13%	>	12%
Cadence (stride/min)	3%	<	5%	5%	=	5%	4%	<	5%
Stance time (s)	4%	<	9%	8%	=	8%	7%	=	7%
Swing time (s)	15%	>	4%	4%	=	4%	10%	=	10%
Double support time (s)	15%	>	10%	9%	=	9%	17%	>	9%

Appendix Table 2: Summary of intra individual variability of kinematic variables for participant 1. Trials divided by condition (C=cane; NC=no cane) and by segment (Left; Right). Legend: IC=initial contact; oTO=opposite toe off; oIC=opposite initial contact; TO=toe off.

Kinematic variables	Coefficient of variety								
	NC			C					
	LEFT		RIGHT	LEFT		RIGHT	NC		C
<i>Pelvic tilt angle</i>									
IC (°)	15%	>	13%	18%	>	10%	15%	<	16%
oTO (°)	15%	>	9%	19%	>	10%	15%	=	15%
oIC (°)	6%	<	14%	13%	<	17%	14%	<	15%
TO (°)	9%	<	15%	15%	<	8%	15%	<	16%
<i>Hip angle</i>									
IC (°)	7%	>	5%	5%	=	5%	8%	>	6%
oTO (°)	11%	>	9%	7%	<	10%	11%	>	8%
oIC (°)	91%	>	28%	94%	>	17%	158%	>	76%
TO (°)	25%	<	330%	42%	<	201%	155%	<	376%
<i>Knee angle</i>									
IC (°)	142%	>	30%	83%	>	41%	86%	>	76%
oTO (°)	31%	>	23%	15%	>	10%	31%	>	26%
oIC (°)	21%	>	15%	23%	>	18%	22%	>	10%
TO (°)	9%	>	6%	6%	>	5%	9%	>	7%
<i>Max. knee flexion (°)</i>	8%	>	3%	6%	>	5%	13%	>	9%

Kinematic variables (cont.)	Coefficient of variety						
	NC		C				
	LEFT	RIGHT	LEFT	RIGHT	NC	C	
<i>Ankle angle</i>							
IC (°)	98%	>	27%	30%	>	16%	66% > 45%
oTO (°)	637%	>	51%	312%	>	84%	122% < 138%
oIC (°)	8%	>	7%	7%	<	6%	11% > 10%
TO (°)	22%	<	53%	37%	<	89%	39% < 62%

Appendix Table 3: Summary of intra individual variability of kinetic / dynamic variables for participant_1. Trials divided by condition (C=cane; NC=no cane) and by segment (Left; Right). Legend: oTO=opposite toe off; oIC=opposite initial contact; GRF VERT/AP=Ground reaction force vertical/anteroposterior component; Max. positive/negative AJP=Maximum value of positive/negative ankle joint power.

Kinetic / Dynamic variables	Coefficient of variety						
	NC		C				
	LEFT	RIGHT	LEFT	RIGHT	NC	C	
Kinetic variables							
GRF VERT							
oTO (N/Kg)	15%	>	11%	9%	<	10%	13% = 13%
oIC (N/Kg)	5%	<	6%	4%	<	6%	7% < 8%
GRF AP							
oTO (N/Kg)	19%	<	32%	20%	<	32%	26% < 27%
oIC (N/Kg)	26%	>	25%	36%	>	17%	44% > 34%
Dynamic variables							
Max. positive AJP (W/Kg)	32%	>	20%	33%	>	18%	43% > 35%
Max. negative AJP (W/Kg)	19%	<	28%	24%	=	24%	24% < 26%

Participant_2

Appendix Table 4: Summary of intra individual variability of spatiotemporal variables for participant_2. Trials divided by condition (C=cane; NC=no cane) and by segment (Left; Right). Legend: CoG=center of gravity; IC=initial contact; oTO=opposite toe off; oIC=opposite initial contact; TO=toe off.

Spatiotemporal variables	Coefficient of variety						
	NC		C				
	LEFT	RIGHT	LEFT	RIGHT	NC	C	
<i>Step width (m)</i>	59%	<	76%	47%	<	103%	81% < 83%
<i>Step length (m)</i>	5%	=	5%	4%	>	3%	7% > 5%
<i>Stride length (m)</i>	2%	<	5%	2%	<	3%	4% > 3%
<i>CoG velocity</i>							
IC (m/s)	6%	>	4%	4%	=	4%	5% > 4%
oTO (m/s)	4%	=	4%	4%	=	4%	4% = 4%
oIC (m/s)	4%	<	7%	3%	<	5%	7% > 4%
TO (m/s)	2%	<	6%	3%	<	4%	6% > 4%
<i>Cadence (stride/min)</i>	4%	>	2%	5%	>	2%	3% < 4%
<i>Stance time (s)</i>	3%	>	2%	5%	>	3%	3% < 4%
<i>Swing time (s)</i>	6%	>	3%	5%	>	4%	5% = 5%
<i>Double support time (s)</i>	14%	>	10%	7%	<	12%	13% > 10%

Appendix Table 5: Summary of intra individual variability of kinematic variables for participant_2.
Trials divided by condition (C=cane; NC=no cane) and by segment (Left; Right). Legend: IC=initial
contact; oTO=opposite toe off; oIC=opposite initial contact; TO=toe off.

Kinematic variables	Coefficient of variety								
	NC		C		NC		C		
	LEFT	RIGHT	LEFT	RIGHT					
<i>Pelvic tilt angle</i>									
IC (°)	15%	>	13%	9%	<	11%	14%	>	12%
oTO (°)	17%	>	13%	7%	<	8%	17%	>	7%
oIC (°)	9%	<	14%	13%	>	10%	12%	>	11%
TO (°)	13%	<	14%	14%	>	10%	15%	<	18%
<i>Hip angle</i>									
IC (°)	8%	>	7%	3%	<	5%	12%	<	16%
oTO (°)	8%	=	8%	3%	<	5%	8%	<	12%
oIC (°)	16%	>	12%	11%	>	6%	21%	>	17%
TO (°)	22%	>	11%	25%	>	18%	20%	<	24%
<i>Knee angle</i>									
IC (°)	49%	<	858%	67%	<	80%	121%	<	2563%
oTO (°)	16%	<	28%	10%	<	18%	28%	<	32%
oIC (°)	27%	>	23%	11%	<	27%	28%	>	20%
TO (°)	12%	>	7%	22%	>	21%	10%	<	22%
<i>Max. knee flexion (°)</i>	4%	>	3%	3%	=	3%	5%	<	6%
<i>Ankle angle</i>									
IC (°)	665%	>	34%	3409%	>	58%	167%	<	171%
oTO (°)	42%	<	862%	35%	<	36%	146%	>	49%
oIC (°)	7%	<	24%	7%	<	11%	18%	>	11%
TO (°)	666%	>	23%	133%	<	145%	107%	<	1123%

Appendix Table 6: Summary of intra individual variability of kinetic / dynamic variables for
participant_2. Trials divided by condition (C=cane; NC=no cane) and by segment (Left; Right).
Legend: oTO=opposite toe off; oIC=opposite initial contact; GRF VERT/AP=Ground reaction force
vertical/anteroposterior component; Max. positive/negative AJP=Maximum value of
positive/negative ankle joint power.

Kinetic / Dynamic variables	Coefficient of variety								
	NC		C		NC		C		
	LEFT	RIGHT	LEFT	RIGHT					
Kinetic variables									
GRF VERT									
oTO (N/Kg)	11%	>	8%	11%	<	17%	12%	<	15%
oIC (N/Kg)	26%	>	7%	17%	<	22%	19%	=	19%
GRF AP									
oTO (N/Kg)	14%	>	8%	11%	>	8%	16%	>	15%
oIC (N/Kg)	84%	>	19%	9%	<	14%	53%	>	13%
Dynamic variables									
Max. positive AJP (W/Kg)	21%	<	28%	36%	<	38%	28%	<	40%
Max. negative AJP (W/Kg)	25%	<	499%	8%	<	17%	174%	>	14%

Participant_3

Appendix Table 7: Summary of intra individual variability of spatiotemporal variables for participant_3. Trials divided by condition (C=cane; NC=no cane) and by segment (Left; Right). Legend: CoG=center of gravity; IC=initial contact; oTO=opposite toe off; oIC=opposite initial contact; TO=toe off.

Spatiotemporal variables	Coefficient of variety								
	NC			C					
	LEFT		RIGHT	LEFT		RIGHT	NC		C
Step width (m)	46%	>	29%	40%	<	222%	38%	<	43%
Step length (m)	19%	>	6%	5%	<	10%	14%	>	8%
Stride length (m)	12%	>	6%	4%	<	13%	9%	<	10%
CoG velocity									
IC (m/s)	16%	>	10%	12%	=	12%	17%	<	19%
oTO (m/s)	21%	>	5%	7%	<	16%	15%	<	16%
oIC (m/s)	20%	>	8%	5%	<	15%	15%	>	11%
TO (m/s)	18%	>	7%	5%	<	13%	13%	>	10%
Cadence (stride/min)	10%	>	5%	4%	<	5%	9%	>	5%
Stance time (s)	12%	>	5%	6%	>	2%	10%	>	5%
Swing time (s)	4%	<	6%	5%	>	1%	12%	>	8%
Double support time (s)	40%	<	44%	10%	<	24%	41%	>	18%

Appendix Table 8: Summary of intra individual variability of kinematic variables for participant_3. Trials divided by condition (C=cane; NC=no cane) and by segment (Left; Right). Legend: IC=initial contact; oTO=opposite toe off; oIC=opposite initial contact; TO=toe off.

Kinematic variables	Coefficient of variety								
	NC		C		NC		C		
	LEFT	RIGHT	LEFT	RIGHT					
<i>Pelvic tilt angle</i>									
IC (°)	10%	>	7%	7%	<	11%	10%	>	9%
oTO (°)	11%	>	8%	6%	<	12%	11%	>	9%
oIC (°)	7%	<	8%	10%	<	14%	7%	<	13%
TO (°)	7%	=	7%	9%	<	16%	7%	<	16%
<i>Hip angle</i>									
IC (°)	9%	>	4%	5%	<	9%	8%	<	9%
oTO (°)	15%	>	5%	8%	<	12%	12%	<	13%
oIC (°)	46%	>	14%	28%	>	20%	33%	>	32%
TO (°)	118%	<	268%	194%	>	140%	162%	<	164%
<i>Knee angle</i>									
IC (°)	13%	<	21%	19%	<	603%	17%	<	5060%
oTO (°)	13%	<	15%	15%	<	1464%	14%	<	591%
oIC (°)	16%	>	15%	12%	<	857%	21%	<	640%
TO (°)	11%	>	5%	6%	<	396%	9%	<	151%
<i>Max. knee flexion (°)</i>	3%	<	4%	3%	<	135%	8%	<	75%
<i>Ankle angle</i>									
IC (°)	42%	>	36%	176%	>	154%	39%	<	162%
oTO (°)	205%	>	108%	57%	<	77%	147%	>	65%
oIC (°)	94%	<	878%	23%	<	56%	178%	>	41%
TO (°)	64%	>	20%	40%	>	20%	44%	<	45%

Appendix Table 9: Summary of intra individual variability of kinetic / dynamic variables for participant_3. Trials divided by condition (C=cane; NC=no cane) and by segment (Left; Right). Legend: oTO=opposite toe off; oIC=opposite initial contact; GRF VERT/AP=Ground reaction force vertical/anteroposterior component; Max. positive/negative AJP=Maximum value of positive/negative ankle joint power.

Kinetic / Dynamic variables	Coefficient of variety							
	NC		C				NC	C
	LEFT	RIGHT	LEFT	RIGHT				
Kinetic variables								
GRF VERT								
oTO (N/Kg)	17%	> 7%	14%	< 28%			14%	< 24%
oIC (N/Kg)	23%	> 15%	11%	< 12%			19%	> 12%
GRF AP								
oTO (N/Kg)	45%	> 16%	38%	< 45%			32%	< 55%
oIC (N/Kg)	21%	> 10%	12%	< 17%			17%	> 14%
Dynamic variables								
Max. positive AJP (W/Kg)	35%	> 13%	12%	< 19%			25%	> 15%
Max. negative AJP (W/Kg)	19%	< 42%	11%	< 28%			34%	> 21%

Participant_4

Appendix Table 10: Summary of intra individual variability of spatiotemporal variables for participant_4. Trials divided by condition (C=cane; NC=no cane) and by segment (Left; Right). Legend: CoG=center of gravity; IC=initial contact; oTO=opposite toe off; oIC=opposite initial contact; TO=toe off.

Spatiotemporal variables	Coefficient of variety							
	NC		C				NC	C
	LEFT	RIGHT	LEFT	RIGHT				
Step width (m)	46%	< 55%	68%	< 98%			53%	< 85%
Step length (m)	32%	> 6%	9%	> 6%			22%	> 9%
Stride length (m)	11%	> 5%	8%	> 6%			8%	> 7%
CoG velocity								
IC (m/s)	11%	< 27%	21%	> 11%			21%	> 19%
oTO (m/s)	10%	< 26%	21%	> 11%			20%	> 19%
oIC (m/s)	14%	< 18%	19%	> 12%			16%	= 16%
TO (m/s)	12%	< 18%	18%	> 10%			16%	= 16%
Cadence (stride/min)	9%	< 19%	13%	> 8%			15%	> 13%
Stance time (s)	9%	< 19%	13%	> 12%			15%	> 14%
Swing time (s)	19%	> 12%	14%	> 9%			12%	< 13%
Double support time (s)	17%	< 36%	22%	> 18%			29%	> 21%

Appendix Table 11: Summary of intra individual variability of kinematic variables for participant_4. Trials divided by condition (C=cane; NC=no cane) and by segment (Left; Right). Legend: IC=initial contact; oTO=opposite toe off; oIC=opposite initial contact; TO=toe off.

Kinematic variables	Coefficient of variety							
	NC		C				NC	C
	LEFT	RIGHT	LEFT	RIGHT				
Pelvic tilt angle								
IC (°)	10%	< 16%	9%	> 6%			13%	> 12%
oTO (°)	13%	< 22%	8%	< 9%			17%	> 13%
oIC (°)	9%	< 22%	12%	> 8%			18%	> 10%
TO (°)	12%	< 22%	13%	> 11%			21%	> 13%

Kinematic variables (cont.)	Coefficient of variety								
	NC				C				
	LEFT		RIGHT	LEFT		RIGHT	NC		C
Hip angle									
IC (°)	7%	<	13%	5%	<	6%	10%	>	5%
oTO (°)	12%	<	14%	11%	<	13%	12%	<	13%
oIC (°)	43%	>	26%	26%	>	16%	35%	>	22%
TO (°)	823%	>	91%	171%	>	125%	181%	<	366%
Knee angle									
IC (°)	286%	>	214%	173%	<	578%	242%	<	244%
oTO (°)	43%	>	21%	33%	>	30%	33%	>	32%
oIC (°)	5277%	>	81%	892%	>	60%	186%	>	178%
TO (°)	8%	<	20%	10%	<	15%	15%	>	12%
Max. knee flexion (°)	10%	>	6%	4%	<	5%	8%	>	6%
Ankle angle									
IC (°)	111%	<	112%	89%	<	117%	545%	<	619%
oTO (°)	411%	>	124%	479%	>	99%	199%	>	170%
oIC (°)	17%	<	77%	18%	<	78%	55%	>	50%
TO (°)	79%	<	108%	143%	>	28%	107%	>	76%

Appendix Table 12: Summary of intra individual variability of kinetic / dynamic variables for participant_4. Trials divided by condition (C=cane; NC=no cane) and by segment (Left; Right). Legend: oTO=opposite toe off; oIC=opposite initial contact; GRF VERT/AP=Ground reaction force vertical/anteroposterior component; Max. positive/negative AJP=Maximum value of positive/negative ankle joint power.

Kinetic / Dynamic variables	Coefficient of variety								
	NC			C					
	LEFT		RIGHT	LEFT		RIGHT	NC		C
Kinetic variables									
GRF VERT									
oTO (N/Kg)	13%	=	13%	14%	<	15%	13%	<	15%
oIC (N/Kg)	5%	<	37%	7%	<	23%	26%	>	17%
GRF AP									
oTO (N/Kg)	25%	<	27%	27%	>	16%	30%	>	27%
oIC (N/Kg)	27%	<	40%	24%	>	22%	33%	>	25%
Dynamic variables									
Max. positive AJP (W/Kg)	31%	<	61%	41%	>	37%	46%	>	38%
Max. negative AJP (W/Kg)	49%	<	1095%	28%	<	62%	760%	>	45%

Participant_5

Appendix Table 13: Summary of intra individual variability of spatiotemporal variables for participant_5. Trials divided by condition (C=cane; NC=no cane) and by segment (Left; Right). Legend: CoG=center of gravity; IC=initial contact; oTO=opposite toe off; oIC=opposite initial contact; TO=toe off.

Spatiotemporal variables	Coefficient of variety								
	NC			C					
	LEFT		RIGHT	LEFT		RIGHT	NC	C	
Step width (m)	49%	<	68%	72%	>	63%	57%	<	66%
Step length (m)	6%	>	3%	3%	<	6%	5%	=	5%
Stride length (m)	4%	=	4%	4%	>	3%	4%	=	4%
CoG velocity									
IC (m/s)	7%	=	7%	5%	>	4%	7%	>	5%

Spatiotemporal variables (cont.)	Coefficient of variety							
	NC			C				
	LEFT		RIGHT	LEFT		RIGHT	NC	C
oTO (m/s)	7%	>	5%	4%	=	4%	6%	= 6%
oIC (m/s)	7%	>	4%	6%	=	6%	6%	= 6%
TO (m/s)	5%	>	3%	6%	>	5%	4%	< 5%
<i>Cadence (stride/min)</i>	3%	=	3%	5%	>	4%	4%	= 4%
<i>Stance time (s)</i>	5%	=	5%	4%	>	3%	5%	> 4%
<i>Swing time (s)</i>	1%	<	6%	19%	>	2%	7%	< 8%
<i>Double support time (s)</i>	16%	>	15%	12%	>	9%	16%	> 10%

Appendix Table 14: Summary of intra individual variability of kinematic variables for participant_5. Trials divided by condition (C=cane; NC=no cane) and by segment (Left; Right). Legend: IC=initial contact; oTO=opposite toe off; oIC=opposite initial contact; TO=toe off.

Kinematic variables	Coefficient of variety								
	NC				C				
	LEFT		RIGHT	LEFT		RIGHT	NC		C
<i>Pelvic tilt angle</i>									
IC (°)	13%	<	30%	125%	<	24%	26%	>	19%
oTO (°)	11%	<	20%	16%	<	20%	20%	>	16%
oIC (°)	33%	>	20%	27%	<	29%	29%	<	33%
TO (°)	29%	>	11%	20%	<	28%	25%	<	26%
<i>Hip angle</i>									
IC (°)	4%	<	5%	3%	<	4%	6%	<	9%
oTO (°)	7%	>	3%	8%	>	5%	5%	<	10%
oIC (°)	17%	>	6%	16%	<	20%	30%	>	20%
TO (°)	15%	<	223%	50%	<	89%	88%	>	69%
<i>Knee angle</i>									
IC (°)	22%	>	9%	15%	>	7%	30%	<	33%
oTO (°)	10%	>	7%	10%	>	7%	16%	=	16%
oIC (°)	31%	>	21%	34%	>	16%	35%	<	36%
TO (°)	11%	<	15%	16%	=	16%	18%	=	18%
<i>Max. knee flexion (°)</i>	3%	=	3%	2%	=	2%	6%	=	6%
<i>Ankle angle</i>									
IC (°)	45%	>	31%	70%	>	45%	38%	<	57%
oTO (°)	93%	>	77%	491%	>	63%	476%	>	253%
oIC (°)	28%	>	9%	17%	>	11%	26%	>	17%
TO (°)	36%	<	75%	57%	<	98%	55%	<	75%

Appendix Table 15: Summary of intra individual variability of kinetic / dynamic variables for participant_5. Trials divided by condition (C=cane; NC=no cane) and by segment (Left; Right). Legend: oTO=opposite toe off; oIC=opposite initial contact; GRF VERT/AP=Ground reaction force vertical/anteroposterior component; Max. positive/negative AJP=Maximum value of positive/negative ankle joint power.

Kinetic / Dynamic variables	Coefficient of variety								
	NC			C					
	LEFT		RIGHT	LEFT		RIGHT	NC		C
Kinetic variables									
GRF VERT									
oTO (N/Kg)	12%	<	13%	14%	>	13%	12%	<	13%
oIC (N/Kg)	15%	>	7%	9%	<	12%	11%	>	10%
GRF AP									
oTO (N/Kg)	18%	>	16%	13%	>	11%	20%	>	14%
oIC (N/Kg)	21%	>	12%	18%	<	19%	16%	<	18%
Dynamic variables									
Max. positive AJP (W/Kg)	23%	<	27%	23%	<	24%	25%	>	23%
Max. negative AJP (W/Kg)	28%	>	27%	47%	>	16%	28%	<	33%