PTK
Physical Therapy Korea
https://doi.org/10.12674/ptk.2023.30.4.268
pISSN: 1225-8962 eISSN: 2287-982X
Phys Ther Korea. 2023;30(4):268-274

Original Article

Assessment of Gait Ability of Subjects With Chronic Ankle Instability During an Inter-trial Variability Gait Task According to Changes in Gait Speed

Jeonghan Kwon[1], PT, BPT, Jongduk Choi[2], PT, PhD

[1]Rehabilitation Center, Catholic Kwandong University International St. Mary's Hospital, Incheon, [2]Department of Physical Therapy, College of Health and Medical Science, Daejeon University, Daejeon, Korea

Article Info
Received November 5, 2023
Revised November 13, 2023
Accepted November 14, 2023

Corresponding Author
Jongduk Choi
E-mail: choidew@dju.kr
https://orcid.org/0000-0002-9663-4790

Key Words
Ankle joint
Gait
Joint instability
Time and motion studies

Background: Ankle sprains occur frequently among humans who undertake various body movements. Diverse walking environments and dual tasks, that can affect ankle sprains, have been studied. However, there is a lack of research on inter-trial variability according to the changes in gait speed.

Objects: The purpose of this study was to compare the adaptive ability of walking between the subjects with chronic ankle instability and healthy adults while performing a walking task with different walking speeds.

Methods: In this study, 24 people in the chronic ankle instability group and 24 people in the healthy ankle group were selected as subjects. The length of the pre-measurement and the actual walking measurement were both set to 4.6 m. Once the subjects entered the measurement section, they changed their gait speed according to the randomly assigned speed change. Gait was measured twice and the average value was used for the analysis.

Results: The coefficient of variation (CV) of cycle time in subjects with chronic ankle instability showed a significant difference in all cases except when the subjects changed their speed from preferred to slow and from slow to preferred. The CV of step length demonstrated a significant difference in all cases except for the change from slow to preferred and from preferred to fast. The cycle time and step length differential showed a significant difference only when the subjects changed the speed from slow to fast.

Conclusion: The subjects with chronic ankle instability were found to have significantly reduced walking adaptability while performing inter-trial variability tasks with different gait speeds compared to healthy subjects.

INTRODUCTION

Ankle sprains occur during almost all movements, but more frequently during active movements, such as running, jumping, and landing [1]. More than 70% of individuals who have once experienced an ankle sprain experience similar symptoms such as additional and repetitive instabilities, including repeated injuries and dysfunctions [2]. Despite the high recurrence rates, only 6.8% of ankle sprain patients receive physical and exercise therapies within a month after being diagnosed with an ankle sprain by a doctor [3]. This lack of early treatment for injuries leads to the development of long-term chronic ankle instability [4]. Chronic ankle instability is a condition in which pain and swelling occur along with a persistent feeling of tweaking or giving way [5]. Repetitive damage to the ankle joint affects the afferent nerves, causing muscle contraction, a lack of proprioception for ankle movements, peroneal, inverter, and tibialis anterior muscle weakness, and abnormal lower-extremity alignment, subsequently causing a continuous decline in performance [6].

Based on previous studies, ankle joint injuries are accompanied by various problems, such as lower performance and functional disorders, with a high risk of re-injury. Therefore, preventive approaches and management after ankle joint injuries are required [7]. Monaghan et al. [8] compared the gait of subjects with chronic ankle instability with that of normal individuals and found that gait was more affected in the presence of ankle instability. They argued that subjects with ankle

instability had poorer ankle control, an increased risk of falls and injuries during walking, and the possibility of damage to the ankle joint structure itself by repeated injuries.

Walking is one of the most common forms of human locomotor movement, and is a natural, habitual, and automated behavior [9,10]. It is a continuous and repetitive movement in which one limb maintains a stable stance phase while the other limb moves the body forward through a complex process of the nervous and musculoskeletal systems [11]. Of the various walking conditions, gait speed is one of the essential factors that has the largest effect on walking [12-14]. Walking requires the ability to adapt to various environments, including level ground, uneven ground, spaces with obstacles, and narrow places [15]. However, subjects with chronic ankle instability have an overall lower level of adaptability in the sensorimotor system than normal individuals. Thus, they are likely to have a higher risk resulting from lowered performance than normal individuals.

Inter-trial variability is defined as a change in the properties of a task due to the environment and other factors that can affect the task while it is being performed. If the environment in which a task is performed and the required elements for the task are constant when transitioning from one movement to another, there will be no inter-trial variability [16]. However, actions such as talking while walking, sending a mobile phone message, and crossing the street while checking traffic signals are part of the scenarios likely to occur commonly in our daily lives [17]. To complete an inter-trial variability task, individuals must adapt to a new environment by continuing to detect changing environmental requirements by strategizing the use of various movements. However, lowered performance and proprioception in those with chronic ankle instability can cause negative results on their ability to adapt to variability tasks.

A range of previous studies have evaluated the function of walking through the diversity of walking environments and the application of dual tasks. The results of these studies indicate that: 1) dual tasks in subjects with chronic ankle instability could have a greater impact on the temporal variables [18-20], variability, and balance of gait, thereby increasing the risk of falls during walking, and 2) changes in gait speed influence the evaluation of gait variables [21,22]. The majority of these studies were conducted based on dual tasks. However, no studies have evaluated the walking ability according to inter-trial variability tasks using gait speed changes. In addition, comparative studies on subjects with chronic ankle instability and normal subjects remain inadequate.

Accordingly, the purpose of this study was to select the gait speed commonly used in the daily lives of adults with ankle joint instability and healthy individuals as an element of variability and compare the adaptive ability of walking between the two groups through changes in their gait speed while performing walking tasks.

This study hypothesizes that the group of subjects with chronic ankle instability would have a reduced ability to adapt their walking during an inter-trial variability task compared with the healthy ankle group.

MATERIALS AND METHODS

1. Subjects

The number of subjects was calculated using G*Power version 3.1.9.4 (Kiel University) a sample size calculation program according to Cohen's sampling formula. According to the results of a preliminary study, the significance level was set at 0.05, the effect size at 0.86, and the power at 0.80. The subsequent calculation of the sample size resulted in a minimum sample size of 22 subjects per group. The subjects of this study were young males and females enrolled at Daejeon University. A total of 52 people participated in the experiment. After the study's purpose and methods were explained, their consent was obtained to proceed with the study.

The inclusion criteria for the subjects were as follows: 1) individuals who scored 5 points or higher according to the Ankle Instability Instrument (AII) survey; 2) individuals who had experienced an ankle sprain for more than 3 months and less than 12 months; 3) individuals who had experienced giving away in the ankle; and 4) individuals who had experienced repetitive sprains and ankle instability. The exclusion criteria were as follows: 1) individuals who had stopped physical activities for at least one day due to a sprain in the lower extremity within the past 3 months; 2) individuals who had experienced a lower-extremity fracture; 3) individuals who had undergone surgery for problems with bones, joints, or nerves of the lower extremity; and 4) individuals who currently complain of pain in the ankle joint and lower extremity.

Among the participants, two were excluded from the study due to a history of lower-extremity fractures and surgery. An-

other two were excluded because of their acute ankle injuries that occurred within 3 months. This study was approved by the Daejeon University Ethics Committee (IRB no. 1040647-202304-HR-003-02).

2. Research Design

In this study, 24 people in the chronic ankle instability group and 24 people in the healthy ankle group, who met the selection criteria, were selected as subjects. These subjects performed walking by changing their gait speeds according to the randomly assigned speed changes that appeared on the front screen during walking, while randomization was conducted using a randomization website (www.randomization.com). After the experiment, a comparative analysis was conducted on each measured value. The research design is shown in Figure 1.

3. Experimental Methods

This study intended to examine whether there were differences in gait variables by exposing the chronic ankle instability and healthy ankle groups to the same inter-trial variability task. In total, six conditions were set according to gait speed changes: 1) walking from one's preferred speed to the slowest possible speed; 2) walking from the fastest possible speed to the slowest possible speed; 3) walking from the slowest possible speed to the preferred gait speed; 4) walking from the fastest possible speed to the preferred gait speed; 5) walking from the slowest possible speed to the fastest possible speed; and 6) walking from the preferred gait speed to the fastest possible speed.

The gait distance for each of the pre-measurement and measurement sections was set at 4.6 m. When a subject entered the measurement section, the experimenter asked the subject continue walking by changing the gait speed according to the randomly assigned speed changes. The affected side was measured for subjects with chronic ankle instability. When any of them had bilateral injuries within the experimental period, the most recently damaged side was measured. By contrast, the dominant side was measured for the healthy ankle group. The experiment was conducted after plenty of practice, and the average value of two walking measurements was used as a measured value.

4. Assessment Tools

1) Ankle Instability Instrument

The AII survey was used to evaluate ankle instability. This survey consists of nine questions that could be answered with "yes" or "no." The AII score was calculated as 1 point if the answer was "yes" and 0 if the answer was "no." According to its evaluation system, a total score of 0 indicated no ankle injury, a score of 1 to 4 denoted slight ankle instability, and a score of 5 or higher ankle instability. The reliability and validity of this evaluation tool were high at 0.95 and 0.96, respectively.

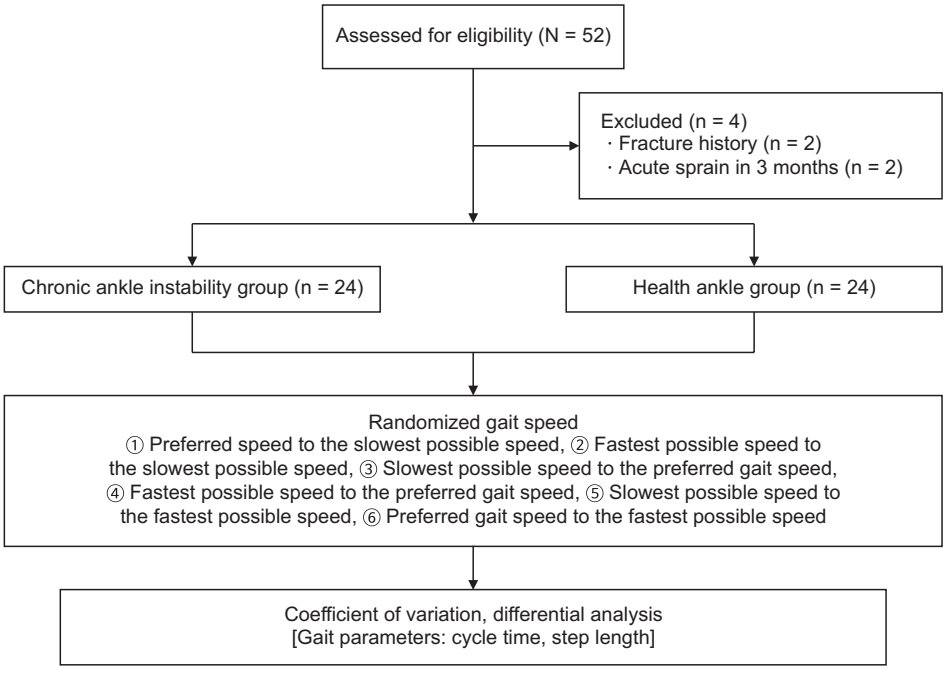

Figure 1. Flow chart of the study.

2) Gait Evaluation System

The GAITRite System (CIR Systems Inc.) was employed to evaluate the subjects' gait variables. In this study, gait cycle time, a temporal variable of gait, was measured using the equipment along with step length, a spatial variable. In addition, gait variability variables, such as gait cycle time coefficient of variation (CV) step length were measured. The reliability of the evaluation items was high in the range of 0.82 to 0.92 and demonstrated high validity in comparison with other equipment (Clinical Stride Analyzer, Vicon Motion Analysis System; Vicon).

5. Analytical Methods

All the data collected from the subjects of this study were statistically processed using the IBM SPSS statistics version 27.0 for windows (IBM Co.). The general characteristics of the subjects were presented with mean and standard deviation using descriptive statistics, and the Shapiro–Wilk test was performed to test the normality of the measured variables. Independent t-tests were used to compare the levels of measured variables between the chronic ankle instability and healthy ankle groups. The statistical significance level of this study was set at 0.05.

RESULTS

1. General Characteristics of the Subjects

This study involved a total of 48 subjects, consisting of 24 subjects in the chronic ankle instability group and 24 subjects in the healthy ankle group. There were no significant differences in sex, age, height, and weight between the two groups, whereas some significant differences were observed in the AII questionnaire (Table 1).

2. Comparison of Gait CVs Between the Two Groups According to Gait Speed Changes

In a comparison of the gait CVs between the chronic ankle instability and normal ankle groups according to changes in gait speed, there were significant differences in the CV values of cycle time between the two groups, excluding those for walking at preferred to slow gait speeds and walking at slow to preferred gait speeds. In the CV values of step length, there were significant differences between the groups, excluding

Table 1. General characteristic of the subjects

Variable	CAI group (n = 24)	Normal group (n = 24)	p-value
Sex (male/female)	12/12	12/12	1.00
Age (y)	21.29 ± 1.96	20.88 ± 2.05	0.48
Height (cm)	166.67 ± 9.20	169.08 ± 9.25	0.37
Weight (kg)	64.79 ± 15.88	62.54 ± 12.01	0.58
AII (score)	6.79 ± 1.35	0.42 ± 0.71	0.00*

Values are presented as number only or mean ± standard deviation. CAI, chronic ankle instability; AII, Ankle Instability Instrument. *p < 0.05.

Table 2. Changes in the coefficients of variation of gait parameters according to changes in gait speed

Variable	Change gait speed	CAI group (n = 24)	Normal group (n = 24)	p-value
Cycle time CV	PS	4.78 ± 3.28	3.78 ± 2.82	0.25
	FS	12.01 ± 5.81	4.76 ± 3.98	0.00*
	SP	4.33 ± 2.95	2.90 ± 2.42	0.07
	FP	4.72 ± 3.06	2.94 ± 2.39	0.03*
	SF	9.96 ± 5.29	3.35 ± 2.83	0.00*
	PF	4.32 ± 2.19	3.06 ± 2.00	0.04*
Step length CV	PS	3.65 ± 2.61	2.32 ± 1.85	0.05*
	FS	8.18 ± 5.88	3.15 ± 2.43	0.00*
	SP	2.94 ± 1.56	3.28 ± 1.78	0.49
	FP	4.44 ± 3.30	2.69 ± 1.88	0.03*
	SF	4.73 ± 4.25	2.02 ± 1.83	0.00*
	PF	2.62 ± 2.64	2.02 ± 1.81	0.37

Values are presented as mean ± standard deviation. CAI, chronic ankle instability; CV, coefficient of variation; PS, change gait speed from preferred speed to slowest speed; FS, change gait speed from fastest speed to slowest speed; SP, change gait speed from slowest speed to preferred speed; FP, change gait speed from fastest speed to preferred speed; SF, change gait speed from slowest speed to fastest speed; PF, change gait speed from preferred speed to fastest speed. *p < 0.05.

those for walking at slow to preferred gait speeds and walking at preferred to fast gait speeds (Table 2).

3. Comparison of Gait Coefficient Differentials Between the Two Groups According to Gait Speed Changes

In a comparison of gait coefficient differentials between the chronic ankle instability and normal ankle groups according to changes in gait speed, a significant difference in both the cycle time differential and step length differential values was only observed in the slow-to-fast gait speed change (Table 3).

DISCUSSION

Most studies on gait speed have been conducted at comfortable speeds [23], with some suggesting that gait analysis at various speeds is necessary to fully understand and instruct the walking patterns of patients [24]. Therefore, the current study provided an inter-trial variability task using speed changes to an experimental group of 24 subjects with chronic ankle instability and a control group of 24 subjects with healthy ankles. The study was conducted to prevent the risk of re-injury in subjects with chronic ankle instability and provide preventive information by examining the effect of speed changes on the temporal, spatial, and variability variables of gait and comparing any differences between the two groups. The results confirmed significant differences in the temporal, spatial, and variability variables between the two groups when performing the inter-trial variability task according to speed changes.

The temporal variables of gait significantly increased in the chronic ankle instability group, showing a significant difference between the two groups. This finding is attributed to the reduced ability to adapt to given situations due to decreased proprioception and performance, although it was necessary to quickly recognize and adapt to them to continue walking. A previous study reported that in subjects with chronic ankle instability, the paired movement pattern between the ankle and the shin bone was deformed, thereby increasing the temporal variables of gait on the affected side, which could increase the probability of inversion injuries [25].

The spatial variables of gait significantly increased in the chronic ankle instability group, along with a significant difference between the two groups. The chronic ankle instability group showed larger values resulting from speed changes than the healthy ankle group, which also appears to have stemmed from a failure to adapt quickly to given situations. This finding supports the argument from previous studies that changes in the spatial variables of gait decrease balance ability. This result can support the claim that changes in the spatial variables of gait increase due to a decline in balance ability [26].

The two groups exhibited a significant difference in the gait CV when the gait speed was changed from slow to fast in the chronic ankle instability group. This result is consistent with the finding that both elderly and healthy adult groups yielded large CVs when the gait speed was changed from slow to fast and can support the research result that gait control is difficult when the body is abruptly moved forward [27]. According to the results of previous studies, the ability to increase or

Table 3. Changes in the gait parameters differentials according to changes in gait speed

Variable	Change gait speed	CAI group (n = 24)	Normal group (n = 24)	p-value
Cycle time differential	PS	0.06 ± 0.54	0.05 ± 0.52	0.66
	FS	0.06 ± 0.07	0.06 ± 0.04	0.63
	SP	0.04 ± 0.03	0.03 ± 0.03	0.16
	FP	0.04 ± 0.04	0.05 ± 0.04	0.31
	SF	0.06 ± 0.48	0.03 ± 0.25	0.02*
	PF	0.03 ± 0.03	0.03 ± 0.02	0.80
Step length differential	PS	1.97 ± 1.32	2.15 ± 1.51	0.48
	FS	2.53 ± 1.92	2.30 ± 2.18	0.71
	SP	2.42 ± 2.35	1.55 ± 1.63	0.14
	FP	3.09 ± 2.60	1.95 ± 1.88	0.09
	SF	2.93 ± 2.26	1.69 ± 1.16	0.03*
	PF	2.21 ± 2.46	1.41 ± 0.80	0.14

Values are presented as mean ± standard deviation. CAI, chronic ankle instability; PS, change gait speed from preferred speed to slowest speed; FS, change gait speed from fastest speed to slowest speed; SP, change gait speed from slowest speed to preferred speed; FP, change gait speed from fastest speed to preferred speed; SF, change gait speed from slowest speed to fastest speed; PF, change gait speed from preferred speed to fastest speed. *p < 0.05.

decrease the gait speed is an important factor in individuals moving around their communities, and high levels of physical and cognitive control that can adjust the gait speed to the environmental factors are required to avoid danger [27,28].

The findings of this study confirmed that the ankle instability group is more likely to be exposed to re-injury than the healthy ankle group while performing an inter-trial variability task according to changes in gait speed during walking through changes in gait variables. Accordingly, the hypothesis that the ability for walking adaptation in subjects with chronic ankle instability would be reduced when performing an inter-trial variability task according to gait speed changes was supported with a statistically significant difference proven through a comparative analysis with the healthy ankle group.

Given the limitations of the current study, future research will be necessary to compensate for these limitations. First, the subjects of this study were limited to young adults in their 20s, which made it difficult to generalize the study results for all ages. Second, given that only part of the gait variables were measured in this study, analysis of additional gait variables will be necessary. Third, the findings of this study were measured in a relatively safe indoor setting; thus, systematic research will be necessary to determine whether the results can also be applied to actual outdoor walking.

CONCLUSIONS

Inter-trial variability tasks had a greater negative effect on the gait patterns of the subjects with chronic ankle instability than those with healthy ankles. This indicates that changes in the sensation and mobility of ankle joints can increase the risk of re-injury by decreasing the ability to adapt to unpredictable situations during walking. The results of this study can be used as valuable information to reduce the risk of chronic ankle re-injury in patients with chronic ankle instability and can be considered by experts when making plans to improve gait abilities.

FUNDING

None to declare.

ACKNOWLEDGEMENTS

None.

CONFLICTS OF INTEREST

No potential conflicts of interest relevant to this article are reported.

AUTHOR CONTRIBUTION

Conceptualization: JC. Data curation: JK. Formal analysis: JK. Investigation: JK, JC. Methodology: JK, JC. Supervision: JC. Visualization: JK. Writing - original draft: JK, JC. Writing - review & editing: JC.

ORCID

Jeonghan Kwon, https://orcid.org/0009-0002-6292-9264

REFERENCES

1. **Linz JC, Conti SF, Stone DA.** Foot and ankle injuries. In: Fu FH, Stone DA editors. Sports injuries: mechanisms, prevention, treatment. 2nd ed. Lippincott Williams & Wilkins; 2001;1135-63.
2. **Anandacoomarasamy A, Barnsley L.** Long term outcomes of inversion ankle injuries. Br J Sports Med 2005;39(3):e14; discussion e14.
3. **Feger MA, Glaviano NR, Donovan L, Hart JM, Saliba SA, Park JS, et al.** Current trends in the management of lateral ankle sprain in the United States. Clin J Sport Med 2017;27(2):145-52.
4. **Hintermann B, Boss A, Schäfer D.** Arthroscopic findings in patients with chronic ankle instability. Am J Sports Med 2002; 30(3):402-9.
5. **Hubbard TJ, Hertel J.** Mechanical contributions to chronic lateral ankle instability. Sports Med 2006;36(3):263-77.
6. **Suda EY, Sacco IC.** Altered leg muscle activity in volleyball players with functional ankle instability during a sideward lateral cutting movement. Phys Ther Sport 2011;12(4):164-70.
7. **Choi WS, Choi JD.** Effect of the confusion level of dual-tasks using a smartphone on the gait of subjects with chronic

ankle instability while walking. J Korean Soc Phys Med 2020;15(3):99-108.
8. **Monaghan K, Delahunt E, Caulfield B.** Ankle function during gait in patients with chronic ankle instability compared to controls. Clin Biomech (Bristol, Avon) 2006;21(2):168-74.
9. **Murray MP.** Gait as a total pattern of movement. Am J Phys Med 1967;46(1):290-333.
10. **Magill RA.** Motor learning and control: concepts and applications. 8th ed. McGraw-Hill; 2006.
11. **Liebenson C.** Spinal stabilization training: the transverse abdominus. J Bodyw Mov Ther 1998;2(4):218-23.
12. **Murray MP, Kory RC, Clarkson BH, Sepic SB.** Comparison of free and fast speed walking patterns of normal men. Am J Phys Med 1966;45(1):8-23.
13. **Grillner S, Halbertsma J, Nilsson J, Thorstensson A.** The adaptation to speed in human locomotion. Brain Res 1979;165(1):177-82.
14. **Cavanagh PR, Gregor RJ.** Knee joint torque during the swing phase of normal treadmill walking. J Biomech 1975;8(5):337-44.
15. **Yang JJ, Song YH.** Gait variability of children according to walking path width and motor development level. Korean J Elem Phys Educ 2019;24(4):97-108.
16. **Kisner C, Colby LA, Borstad J.** Therapeutic exercise: foundations and techniques. 7th ed. F.A. Davis; 2018;31-40.
17. **Yang L, He C, Pang MY.** Reliability and validity of dual-task mobility assessments in people with chronic stroke. PLoS One 2016;11(1):e0147833.
18. **Springer S, Gottlieb U.** Effects of dual-task and walking speed on gait variability in people with chronic ankle instability: a cross-sectional study. BMC Musculoskelet Disord 2017;18(1):316.
19. **Nyska M, Shabat S, Simkin A, Neeb M, Matan Y, Mann G.** Dynamic force distribution during level walking under the feet of patients with chronic ankle instability. Br J Sports Med 2003;37(6):495-7.
20. **Rosen AB, Than NT, Smith WZ, Yentes JM, McGrath ML, Mukherjee M, et al.** Attention is associated with postural control in those with chronic ankle instability. Gait Posture 2017;54:34-8.
21. **Choi JS, Kang DW, Tack GR.** Effects of walking speeds and cognitive task on gait variability. Korean J Sport Biomech 2008;18(2):49-58.
22. **Kim DY, Park C, Choi YS, Moon JY, Lim JY, Kim DY, et al.** Effect of slow walking speed on gait. J Korean Acad Rehabil Med 2007;31(3):317-23.
23. **Schmid A, Duncan PW, Studenski S, Lai SM, Richards L, Perera S, et al.** Improvements in speed-based gait classifications are meaningful. Stroke 2007;38(7):2096-100.
24. **Polese JC, Teixeira-Salmela LF, Nascimento LR, Faria CD, Kirkwood RN, Laurentino GC, et al.** The effects of walking sticks on gait kinematics and kinetics with chronic stroke survivors. Clin Biomech (Bristol, Avon) 2012;27(2):131-7.
25. **Drewes LK, McKeon PO, Paolini G, Riley P, Kerrigan DC, Ingersoll CD, et al.** Altered ankle kinematics and shank-rear-foot coupling in those with chronic ankle instability. J Sport Rehabil 2009;18(3):375-88.
26. **Martin CL, Phillips BA, Kilpatrick TJ, Butzkueven H, Tubridy N, McDonald E, et al.** Gait and balance impairment in early multiple sclerosis in the absence of clinical disability. Mult Scler 2006;12(5):620-8.
27. **Boripuntakul S, Kamnardsiri T, Lord SR, Maiarin S, Worakul P, Sungkarat S.** Gait variability during abrupt slow and fast speed transitions in older adults with mild cognitive impairment. PLoS One 2022;17(10):e0276658.
28. **Soni S, Lamontagne A.** Characterization of speed adaptation while walking on an omnidirectional treadmill. J Neuroeng Rehabil 2020;17(1):153. Erratum in: J Neuroeng Rehabil 2021;18(1):40.