International Journal of Advanced Smart Convergence Vol.9 No.2 49-57 (2020)
http://dx.doi.org/10.7236/IJASC.2020.9.2.49

IJASC 20-2-6

Effect of Gender Difference on the Functional Asymmetry during Preferred Walking Speed

Seunghyun Hyun[1], Checheong Ryew[2†]

[1]*Instructor, Department of Kinesiology, College of Natural Science, Jeju National University, Instructor Republic of Korea*
[2]*Professor, Department of Kinesiology, College of Natural Science, Jeju National University, Professor Republic of Korea*
hshyun0306@jejunu.ac.kr, †ryew@jejunu.ac.kr

Abstract

We have not identified on what gender difference during gait at a pace of one's preferred velocity effects on the function of bilateral lower limb. This study was undertaken to investigate a difference of gait strategy by gender during gait at a one's preferred velocity of participants of adult male and female (n=20). Cinematographic data for motion analysis, ground reaction force (GRF) variables, and muscle volume of lower limb were analyzed. Significant difference of variables on movement of center of mass whole body, joint angle and moment of lower limb, and ground reaction force were tested by 2-way ANOVA analysis (P<0.05). Male group showed more muscle volume than female, and both showed more volume in dominant leg than non-dominant. Main effect by bilateral leg during gait showed higher difference in right than left leg in change of vertical position of center of mass (maximal, minimal). Main effect by gender in vertical change of position and velocity of center of mass showed higher difference in male than female (maximal, minimal). Hip joint showed more flexed and extended angle in male than female, and also dorsiflexion of ankle and flexion moment of knee and hip joint showed higher in male than female group. Therefore, this result was assumed that dominant showed furthermore more contribution for propulsive function than non-dominant leg. Gender difference showed in strategy controlling of biomechanical characteristics, and perhaps influenced by muscle volume.

Keywords: *Gait, Gender Difference, Asymmetry, Functional, Joint Moment*

1. Introduction

Interaction between various inter-muscle and central nerve system enables human to move in stable periodical pattern keeping up an erect posture and erect bipedalism [1]. Promotion of enhanced understanding on gait motion of human is important factor for development of intensified exercise rehabilitation protocol [2]. Human have a tendency mobilizing at one's preferred side of body segment in performing voluntary action. its tendency was referred to preferential trait [3]. Those who utilize preferentially hand or foot extremities related with motor skill has a lateral preference frequently [4]. Thus asymmetry between bilateral leg on a

Manuscript Received: March. 25, 2020 / Revised: March. 28, 2020 / Accepted: April. 3, 2020
Corresponding Author: ryew@jejunu.ac.kr
Tel: +82-64-754-3588
Professor, Dept. of Kinesiology Jeju National University, Korea

standard gait posture had been explained extensively in aspects of kinematic [5] and kinetics [6], but its cause of mechanism was yet unclear. Also effect by gender during standard gait was not unclear, but rather showed similarity with velocity [7, 8].

Dominant preference had relation with inconsistency of leg length, imbalance of muscular strength, or asymmetry of muscle activation [9-14]. But difference between bilateral extremity caused functional asymmetry and its difference referred to functional inconsistency between dominant and non-dominant [1, 15]. The theory was referred that non-dominant plays a role supporting body weight and dominant plays a propulsive role proportionally during gait [1].

Difference of gait characteristics by gender has been paid attention to various clinic field [16]. Difference by gender was related closely with occurrence of ostarthritis [17], ACL tears [18, 19], and low back pain [20]. In particular left anterior cruciate ligament (ACL) had been more raptured injury frequently than right ACL regardless of physical activity, but had not been investigated on this mechanism [19]. Thus it was predicted that close observation of lower limb during gait enable to provide an insight ability on strategy of gait exercise and to investigate difference by gender [21]. As theoretical basis of the assertion, impulse force occurred from surface played an important role in deciding level of attenuation on mechanical perturbation of lower limb, pelvis and vertebrae and because its impulse force transferred to head and neck segment [21-23]. Thus it is necessary to consider both ground reaction force and kinematic data simultaneously to investigate characteristics of gait by gender and bilateral lower limbs on functional asymmetry. And this condition should be considered that constant velocity may not maintained during human locomotion, and thus may induce functional asymmetric trait of gait when evaluated by one’s preferred velocity [2]. Fact on whether asymmetry or not during gait is important for clinic decision on patient who requires rehabilitation on physical activity and lower limb of bi or one lateral.

Consequently the aim of this study was to test the assumption that gender difference may influence on function between bilateral lower limb during one’s preferred gait velocity. That is, the first assumption is that functional asymmetry of gait does not come from abnormality, but rather will be due to performance difference between bilateral on propulsion and control. The second assumption is that it of male in preferred velocity gait will faster than that of female, which due to difference of functionality on lower limbs.

2. Material & Methods

2.1 Subjects

Total adult male and female (n=20, male: 10, mean age: 21.10±1.72 years, mean heights: 176.97±5.21 cm, mean weights: 74.52±5.13 kg, mean body mass index 23.77±0.98; female: 10, mean age: 21.10±0.87 years, mean heights: 160.41±5.32 cm, mean weights: 57.74±5.73 kg, mean body mass index 22.48±2.51) participated in the study. Homogeneity between group was confirmed through BMI ($P>0.145$). Prior to experiment, all participants was understood on the range of study, and was performed after agreement of consent letter voluntarily. Preference of lower limbs was decided on ball kick [24, 25], who was all right dominant.

2.2 Experimental

All participant was tested on muscle volume necessary for assumption test of bilateral leg on propulsion and controlling work (Inbody 720, Biospace, Seoul, Korea). After completion of measurement, gait of one’s preferred velocity was measured in indoor laboratory which force plate (2) (AMTI-OR-7, Advanced Mechanical Technology Inc., Watertown, MA, USA) and motion capture camera(12) (Vicon MX Giganet) were installed. Reflex marker to obtain kinematic data and center of mass (COM) of whole body was attached on head (3 markers), trunk (4 markers), upper extremities (14 markers), and lower extremities (22 markers). Position of each reflex marker attached was digitized at 100 Hz and stored to analysis soft package (Nexus, Vicon Motion System Ltd., UK), and ground reaction force data was sampled at 1,000 Hz (Gain: 4 k, Voltage: 5 V). Prior to experiment, enough warm-up walking over 5 min. was performed. Motion of bilateral arm with fore-upwarded eyes was kept to fulfill a natural pendulum motion to prevent intentional touch-down on force plate. Each 10 times was measured repeatedly at preferred velocity, and was guided to experiment procedure by then research assistant after observation of individual's step and stride length. Data of motion capture and ground reaction force of natural preferred velocity on selected all trials was stored into the analysis software program.

2.3 Definition of analysis phase

- Each left or right supporting phase was analyzed for evaluation functional asymmetry of bilateral during gait. Setting of spatial coordinates is shown in Figure 1.

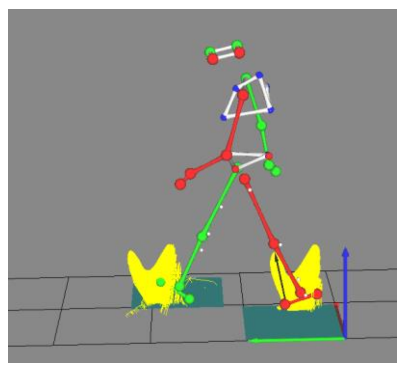

Figure 1. Butterfly shape shown bilateral foot during gait. 3D spatial coordinates in posterior

And data of ground reaction force was analyzed on 1st peak vertical force, mid stance, and 2nd peak vertical force by consideration a characteristics generated like butterfly shape. Force (N) was normalized by body weight.

- Anterior-posterior ground reaction force was normalized by body weight, which was analyzed on point of breaking force at initial touch down and propulsive force for pushing phase.

- Angle of lower limbs was defined as relative angle.

Angle of hip joint : relative angle between pelvis and thigh on hip joint center

Angle of knee joint : relative angle between thigh and shank on knee joint center

Angle of ankle joint : relative angle between shank and foot on ankle joint center

- Velocity of foot (right, left) during supporting phase was presented as maximal and minimal, and mean

- Moment of lower limbs was defined as positive (+) of plantar flexion of ankle joint, positive (+) of extension of knee and hip joint.

To decide whether it's similarity or not of lower limbs, statistical approach can remove main limiting factor of ratio index (%) [1]. Thus after calculation of Mean ±SD on gait variables, 2 way ANOVA (PASW 21.0 program IBM., Chicago, IL, USA) was treated at $\alpha=0.05$ level.

3. Results

3.1 Kinematics of CM

In analysis of muscle volume of lower limbs (Table 1).

Table 1. Result of leg muscle mass on gender difference and bilateral legs

Section	Male		Female		2-way ANOVA		
	Left leg	Right leg	Left leg	Right leg	Interaction	Gender	Bilateral
Muscle mass (kg)	9.91±0.96	10.02±0.92	6.16±0.28	6.20±0.30	NS (*P*=0.880)	Male>Female (*P*=0.001)	NS (*P*=0.738)

NS, not significant

Male showed more muscle volume in main effect of gender than female. Interaction effect of gender × bilateral leg in main effect of bilateral leg did not showed difference.

In analysis of kinematic variable during gait (Table 2).

Table 2. Kinematic result of gender difference and functional asymmetry by preferred walking

Section	Male		Female		2-way ANOVA		
	Left leg	Right leg	Left leg	Right leg	Interaction	Gender	Bilateral
Min. CM position-Z axis (m)	0.94 ±0.03	0.97 ±0.03	0.85 ±0.04	0.88 ±0.04	NS (*P*=0.536)	Male>Female (*P*=0.001)	Right>Left (*P*=0.006)
Max. CM position - Z axis (m)	0.98 ±0.03	1.01 ±0.03	0.89 ±0.05	0.91 ±0.04	NS (*P*=0.612)	Male>Female (*P*=0.001)	Right>Left (*P*=0.027)
Min. CM velocity-Y axis (m/sec)	1.25 ±0.14	1.26 ±0.13	1.14 ±0.14	1.19 ±0.13	NS (*P*=0.692)	Male>Female (*P*=0.041)	NS (*P*=0.513)
Max. CM velocity-Y axis (m/sec)	1.63 ±0.16	1.65 ±0.15	1.54 ±0.17	1.58 ±0.14	NS (*P*=0.851)	NS (*P*=0.124)	NS (*P*=0.531)
Mean CM velocity-Y axis (m/sec)	1.43 ±0.11	1.44 ±0.13	1.31 ±0.15	1.35 ±0.13	NS (*P*=0.550)	Male>Female (*P*=0.022)	NS (*P*=0.768)
Min. hip joint angle (degree)	116.76 ±8.03	118.37 ±6.32	108.83 ±6.12	107.71 ±5.17	NS (*P*=0.511)	Female>Male (*P*=0.001)	NS (*P*=0.905)
Max. hip joint angle (degree)	150.15 ±7.32	152.58 ±6.41	144.86 ±6.64	145.48 ±6.44	NS (*P*=0.673)	Male>Female (*P*=0.006)	NS (*P*=0.477)
Min. knee joint angle (degree)	137.79 ±6.59	143.67 ±4.51	138.07 ±8.59	138.81 ±9.43	NS (*P*=0.287)	NS (*P*=0.341)	NS (*P*=0.172)
Max. knee joint angle (degree)	174.32 ±2.92	173.33 ±3.00	173.86±3.16	170.43 ±5.39	NS (*P*=0.314)	NS (*P*=0.166)	NS (*P*=0.071)
Min. ankle joint angle (degree)	89.67 ±4.16	90.84 ±2.03	88.25 ±4.46	87.46 ±6.02	NS (*P*=0.488)	NS (*P*=0.093)	NS (*P*=0.892)
Max. ankle joint angle (degree)	117.24 ±6.42	118.16 ±4.28	122.2 ±10.07	119.36 ±9.77	NS (*P*=0.463)	NS (*P*=0.232)	NS (*P*=0.707)

Male showed higher maximal and minimal vertical position of COM than female in main effect by gender. Mean maximal and minimal velocity of COM of male showed faster than that of female. While minimal angle of hip joint of female showed more flexed than that of male, but male showed more extended in maximal angle of it than female.

Minimal and maximal vertical position of COM of right leg showed higher than left in main effect of bilateral leg. Interaction effect of gender × bilateral leg did not show.

In analysis of kinematic variables during gait (Table 3).

Table 3. Kinetic result of gender difference and functional asymmetry by preferred walking

Section	Male		Female		2-way ANOVA		
	Left leg	Right leg	Left leg	Right leg	Interaction	Gender	Bilateral
1st peak vertical force (N/BW)	1.16 ±0.12	1.13 ±0.11	1.12 ±0.1	1.1 ±0.09	NS (*P*=0.872)	NS (*P*=0.268)	NS (*P*=0.530)
Mid stance (N/BW)	0.64 ±0.14	0.72 ±0.1	0.72 ±0.09	0.73 ±0.08	NS (*P*=0.308)	NS (*P*=0.156)	NS (*P*=0.196)
2nd peak vertical force (N/BW)	1.12 ±0.08	1.1 ±0.12	1.14 ±0.06	1.12 ±0.08	NS (*P*=0.962)	NS (*P*=0.586)	NS (*P*=0.522)
1st peak anterior-posterior force (N/BW)	-0.22 ±0.05	-0.21 ±0.05	-0.21 ±0.06	-0.21 ±0.05	NS (*P*=0.738)	NS (*P*=0.777)	NS (*P*=0.764)
2nd peak anterior-posterior force (N/BW)	0.24 ±0.04	0.25 ±0.04	0.26 ±0.04	0.26 ±0.05	NS (*P*=0.791)	NS (*P*=0.367)	NS (*P*=0.455)
Min. hip joint moment (Nm/kg)	-0.06 ±0.01	-0.05 ±0.02	-0.05 ±0.01	-0.04 ±0.01	NS (*P*=0.910)	Male>Female (*P*=0.013)	NS (*P*=0.261)
Max. hip joint moment (Nm/kg)	0.09 ±0.02	0.1 ±0.02	0.09 ±0.01	0.09 ±0.01	NS (*P*=0.715)	NS (*P*=0.241)	NS (*P*=0.320)
Min. knee joint moment (Nm/kg)	-0.03 ±0.01	-0.03 ±0.01	-0.02 ±0.01	-0.02 ±0.01	NS (*P*=0.968)	Male>Female (*P*=0.003)	NS (*P*=0.752)
Max. knee joint moment (Nm/kg)	0.06 ±0.02	0.06 ±0.02	0.06 ±0.03	0.07 ±0.03	NS (*P*=0.460)	NS (*P*=0.401)	NS (*P*=0.755)
Min. ankle joint moment (Nm/kg)	-0.14 ±0.01	-0.13 ±0.02	-0.11 ±0.01	-0.12 ±0.02	NS (*P*=0.539)	Male>Female (*P*=0.001)	NS (*P*=0.760)
Max. ankle joint moment (Nm/kg)	0.01 ±0.01	0.01 ±0.00	0.01 ±0.01	0.01 ±0.01	NS (*P*=0.455)	NS (*P*=0.503)	NS (*P*=0.899)

Vertical (Z-axis) and anterior-posterior (Y-axis) ground reaction force in main effect of bilateral leg did not show difference. Male in flexion moment of hip and knee joint and dorsiflexion of ankle showed higher value than female. Interaction effect of gender × bilateral leg on kinematic variables did not show.

4. Discussion

Functional movement related exercise rehabilitation by gender showed significant difference [26, 27], Data evaluated in functional aspect on asymmetry between bilateral extremity was suited as appropriate rehabilitation tool. That is, injuried side on bilateral leg aims to rehabilitate and improve to the same prior level of function of muscle strength and flexibility as which the other leg possessed [28].

Change of minimal and maximal vertical position of COM during gait showed higher in male than female, but this was considered as due to difference of standing height. Vertical position of COM during supporting phase of right leg showed higher than that of left leg in main effect of bilateral leg. Interaction effect between COM and supporting leg enables to adjust precisely for balancing of body posture by controlling trajectory of COM [29]. Also proper coordination of muscular contraction induces not only minimal expenditure of energy but also stable motion trajectory during walking, which requires optimistic neuro- muscular response [30]. Thus mechanism on difference of vertical position of COM between bilateral leg could be explained by analysis result of lower limbs and ground reaction force data of this study.

Ground reaction force data between gender and bilateral leg did not show significant difference, but during mid-stance of supporting phase, male showed higher position than that of female. Muscle contraction made possible vertical supporting and forward progress of body and thus make stable gait [31]. Also muscle greatly contributed to acceleration of COM and had close relation with ground reaction force data [31]. Like the theory, velocity of COM of this study showed faster pattern in supporting phase of right leg than that of left. Thus difference of muscle volume between bilateral leg influenced on vertical position and velocity of COM, and generated action and reaction force during mid-stance. Consequently non-dominant (left leg) more contributed to supporting of body weight, while dominant (right leg) to progression of COM, which satisfied the first assumption of this study. All participant of this study was required one's preferred pace of velocity during gait. Forward movement velocity by gender showed significant difference. Minimal and maximal forward movement velocity showed faster in male than female. And velocity difference of COM maybe influenced by muscle volume, kinematic data of lower limbs, and joint moment.

Some researchers attributed increase of forward velocity of COM to dorsiflexion of ankle in later part of supporting phase during gait [32-34]. Angle of ankle joint by gender in this study did not show significant difference, but showed in maximal-minimal angle of hip by gender. That is, maximal extension-flexion angle of hip joint during supporting phase showed larger range in male than female. Thus faster gait velocity of male may be related closely with increase of vertical ground reaction force at initial touch down and increase of range of motion of hip and knee joint [35, 36].

Also change of joint moment of lower limbs between bilateral leg did not show difference. Abnormal pedestrian showed significant difference in joint moment of lower limbs [37], but did not show asymmetry of moment in case of normal of this study. But asymmetry of moment of lower limbs by gender showed significant difference, and coincided with previous study [37-41], which increase of gait velocity cause moment of hip and knee joint to increase. Therefore the second assumption that preferred velocity gait of male may show faster pattern than female, with which attributed to functionality of lower limbs, was satisfied.

5. Conclusion

This study was undertaken to investigate a difference of gait strategy by gender during gait at a one's preferred velocity. We found that the right leg has close relation with propulsive function during one's preferred velocity gait, but in result, bilateral leg performed keeping up function of balance. It may assume that symmetry of leg function by gender during gait did not show difference in variables which did not show significant difference in 1^{st} peak anterior-posterior force, 2^{nd} peak anterior-posterior force, angle of knee joint angle and ankle joint., but might mobilize each other strategy of propulsion by gender in healthful adult.

Acknowledgement

This research was supported by the 2020 scientific promotion program funded by Jeju National University

References

[1] H. Sadeghi, P. Allard, F. Prince, and H. Labelle, "Symmetry and limb dominance in able-bodied gait: a review," *Gait & posture,* vol. 12, no. 1, pp. 34-45, 2000. DOI; https://doi.org/10.1016/S0966-6362(00)00070-9.

[2] M. K. Seeley, B. R. Umberger, and R. Shapiro, "A test of the functional asymmetry hypothesis in walking," *Gait & posture,* vol. 28, no. 1, pp. 24-28, 2008. DOI: https://doi.org/10.1016/j.gaitpost.2007.09.006.

[3] F. P. Carpes, C. B. Mota, and I. E. Faria, "On the bilateral asymmetry during running and cycling–A review considering leg preference," *Physical therapy in sport,* vol. 11, no. 4, pp. 136-142, 2010. DOI: https://doi.org/10.1016/j.ptsp.2010.06.005.

[4] D. J. Serrien, R. B. Ivry, and S. P. Swinnen, "Dynamics of hemispheric specialization and integration in the context of motor control," *Nature Reviews Neuroscience,* vol. 7, no. 2, p. 160, 2006. DOI: https://doi.org/10.1038/nrn1849.

[5] P. Allard, R. Lachance, R. Aissaoui, and M. Duhaime, "Simultaneous bilateral 3-D able-bodied gait," *Human Movement Science*, vol. 15, no. 3, pp. 327-346, 1996. DOI: https://doi.org/10.1016/0167-9457(96)00004-8.

[6] W. Herzog, B. M. Nigg, L. J. Read, and E. Olsson, "Asymmetries in ground reaction force patterns in normal human gait," *Med Sci Sports Exerc,* vol. 21, no. 1, pp. 110-114, 1989. DOI: https://doi.org/10.1249/00005768-198902000-00020.

[7] D. C. Kerrigan, M. K. Todd, and U. C. Della, "Gender differences in joint biomechanics during walking: normative study in young adults," *American journal of physical medicine & rehabilitation,* vol. 77, no. 1, pp. 2-7, 1998. DOI: https://doi.org/10.1097/00002060-199801000-00002.

[8] R. Richard *et al.*, "Spatiotemporal gait parameters measured using the Bessou gait analyzer in 79 healthy subjects. Influence of age, stature, and gender. Study Group on Disabilities due to Musculoskeletal Disorders (Groupe de Recherche sur le Handicap de l'Appareil Locomoteur, GRHAL)," *Revue du rhumatisme (English ed.),* vol. 62, no. 2, pp. 105-114, 1995.

[9] I. Bautmans, B. Jansen, B. Van Keymolen, and T. Mets, "Reliability and clinical correlates of 3D-accelerometry based gait analysis outcomes according to age and fall-risk," *Gait & posture,* vol. 33, no. 3, pp. 366-372, 2011. DOI: https://doi.org/10.1016/j.gaitpost.2010.12.003.

[10] M. G. Benedetti, L. Berti, S. Maselli, G. Mariani, and S. Giannini, "How do the elderly negotiate a step? A biomechanical assessment," *Clinical biomechanics,* vol. 22, no. 5, pp. 567-573, 2007. DOI: https://doi.org/10.1016/j.clinbiomech.2007.01.010.

[11] A. Stacoff, C. Diezi, G. Luder, E. Stüssi, and I. A. Kramers-de Quervain, "Ground reaction forces on stairs: effects of stair inclination and age," *Gait & posture,* vol. 21, no. 1, pp. 24-38, 2005. DOI: https://doi.org/10.1016/j.gaitpost.2003.11.003.

[12] C.-C. Ryew, A.-R. Lee, and S.-H. Hyun, "Effect of muscle mass asymmetric between upper and lower limbs on the postural stability and shock attenuation during landing," *Journal of exercise rehabilitation,* vol. 15, no. 3, p. 488, 2019. DOI: https://doi.org/10.12965/jer.1938188.094.

[13] H. K. Lee and J. C. Lee, "Comparison of Triceps Surae EMG in Plantar Flexion Test of MMT at Different Knee Angles," *International Journal of Internet, Broadcasting and Communication,* vol. 10, no. 1, pp. 40-47, 2018. DOI: https://doi.org/10.7236/IJIBC.2018.10.1.6.

[14] K. H. Kim, B. K. Kim, and H. J. Jeong, "Effect of Functional Pressure Garments on EMG Response of the Agonist during the Resistance Exercise of the Wrist and Elbow Joint," *International Journal of Internet, Broadcasting and Communication,* vol. 12, no. 1, pp. 81-89, 2020. DOI; https://doi.org/10.7236/IJIBC.2020.12.1.81.

[15] J. Vanden-Abeele, "Comments on the functional asymmetries of the lower extremities," *Cortex,* vol. 16, no. 2, pp. 325-329, 1980. DOI: https://doi.org/10.1016/S0010-9452(80)80069-4.

[16] D. A. Bruening, R. E. Frimenko, C. D. Goodyear, D. R. Bowden, and A. M. Fullenkamp, "Sex differences in whole body gait kinematics at preferred speeds," *Gait & posture,* vol. 41, no. 2, pp. 540-545, 2015. DOI: https://doi.org/10.1016/j.gaitpost.2014.12.011.

[17] K. A. McKean, S. C. Landry, C. L. Hubley-Kozey, M. J. Dunbar, W. D. Stanish, and K. J. Deluzio, "Gender differences exist in osteoarthritic gait," *Clinical Biomechanics,* vol. 22, no. 4, pp. 400-409, 2007. DOI: https://doi.org/10.1016/j.clinbiomech.2006.11.006.

[18] C. C. Prodromos, Y. Han, J. Rogowski, B. Joyce, and K. Shi, "A meta-analysis of the incidence of anterior cruciate ligament tears as a function of gender, sport, and a knee injury–reduction regimen," *Arthroscopy: The Journal of Arthroscopic & Related Surgery,* vol. 23, no. 12, pp. 1320-1325. e6, 2007. DOI: https://doi.org/10.1016/j.arthro.2007.07.003.

[19] R. J. Negrete, E. A. Schick, and J. P. Cooper, "Lower-limb dominance as a possible etiologic factor in noncontact

anterior cruciate ligament tears," *Journal of Strength and Conditioning Research,* vol. 21, no. 1, p. 270, 2007. DOI: https://doi.org/10.1519/00124278-200702000-00048.

[20] R. B. Fillingim, C. D. King, M. C. Ribeiro-Dasilva, B. Rahim-Williams, and J. L. Riley III, "Sex, gender, and pain: a review of recent clinical and experimental findings," *The journal of pain,* vol. 10, no. 5, pp. 447-485, 2009. DOI; https://doi.org/10.1016/j.jpain.2008.12.001.

[21] C. Mazzà, M. Iosa, P. Picerno, and A. Cappozzo, "Gender differences in the control of the upper body accelerations during level walking," *Gait & posture,* vol. 29, no. 2, pp. 300-303, 2009. DOI: https://doi.org/10.1016/j.gaitpost.2008.09.013.

[22] A. Cappozzo, "Low frequency self-generated vibration during ambulation in normal men," *Journal of Biomechanics,* vol. 15, no. 8, pp. 599-609, 1982. DOI: https://doi.org/10.1016/0021-9290(82)90071-9.

[23] D. A. Winter, "Human balance and posture control during standing and walking," *Gait & posture,* vol. 3, no. 4, pp. 193-214, 1995. DOI: https://doi.org/10.1016/0966-6362(96)82849-9.

[24] C. Gabbard and S. Shart, "A Question of Foot Dominance," *The Journal of General Psychology* vol. 123, no. 4, pp. 289-296, 2010. DOI: https://doi.org/10.1080/00221309.1996.9921281.

[25] W.-H. Lin, Y.-F. Liu, C. C.-C. Hsieh, and A. J. Lee, "Ankle eversion to inversion strength ratio and static balance control in the dominant and non-dominant limbs of young adults," *Journal of Science and Medicine in Sport,* vol. 12, no. 1, pp. 42-49, 2009. DOI: https://doi.org/10.1016/j.jsams.2007.10.001.

[26] E.-S. Sung and J.-H. Kim, "Relationship between ankle range of motion and Biodex Balance System in females and males," *Journal of exercise rehabilitation,* vol. 14, no. 1, p. 133, 2018. DOI: https://doi.org/10.12965/jer.35146.573.

[27] S.-H. Cho, S.-H. Kim, and S.-Y. Park, "Effect of the body mass index and sexual difference on the muscle activity during trunk exercise: a preliminary study," *Journal of exercise rehabilitation,* vol. 14, no. 5, p. 778, 2018. DOI: https://doi.org/10.12965/jer.1836330.165.

[28] K. Lanshammar and E. L. Ribom, "Differences in muscle strength in dominant and non-dominant leg in females aged 20–39 years–A population-based study," *Physical Therapy in Sport,* vol. 12, no. 2, pp. 76-79, 2011.DOI: https://doi.org/10.1016/j.ptsp.2010.10.004.

[29] Y. Jian, D. A. Winter, M. G. Ishac, and L. Gilchrist, "Trajectory of the body COG and COP during initiation and termination of gait," *Gait & Posture,* vol. 1, no. 1, pp. 9-22, 1993. DOI: https://doi.org/10.1016/0966-6362(93)90038-3.

[30] G. Abbud, K. Li, and R. DeMont, "Attentional requirements of walking according to the gait phase and onset of auditory stimuli," *Gait & posture,* vol. 30, no. 2, pp. 227-232, 2009. DOI: https://doi.org/10.1016/j.gaitpost.2009.05.013.

[31] M. Q. Liu, F. C. Anderson, M. G. Pandy, and S. L. Delp, "Muscles that support the body also modulate forward progression during walking," *Journal of biomechanics,* vol. 39, no. 14, pp. 2623-2630, 2006. DOI: https://doi.org/10.1016/j.jbiomech.2005.08.017.

[32] T. M. Kepple, K. L. Siegel, and S. J. Stanhope, "Relative contributions of the lower extremity joint moments to forward progression and support during gait," *Gait & Posture,* vol. 6, no. 1, pp. 1-8, 1997. DOI: https://doi.org/10.1016/S0966-6362(96)01094-6.

[33] R. R. Neptune, F. Zajac, and S. Kautz, "Muscle force redistributes segmental power for body progression during walking," *Gait & posture,* vol. 19, no. 2, pp. 194-205, 2004. DOI: https://doi.org/10.1016/S0966-6362(03)00062-6.

[34] D. Sutherland, L. Cooper, and D. Daniel, "The role of the ankle plantar flexors in normal walking," *JBJS,* vol. 62, no. 3, pp. 354-363, 1980.

[35] M.-J. Chung and M.-J. J. Wang, "The change of gait parameters during walking at different percentage of preferred walking speed for healthy adults aged 20–60 years," *Gait & posture,* vol. 31, no. 1, pp. 131-135, 2010. DOI: https://doi.org/10.1016/j.gaitpost.2009.09.013.

[36] M.-C. Chiu and M.-J. Wang, "The effect of gait speed and gender on perceived exertion, muscle activity, joint motion of lower extremity, ground reaction force and heart rate during normal walking," *Gait & posture,* vol. 25, no. 3, pp. 385-392, 2007. DOI; https://doi.org/10.1016/j.gaitpost.2006.05.008.

[37] M. W. Creaby, K. L. Bennell, and M. A. Hunt, "Gait differs between unilateral and bilateral knee osteoarthritis," *Archives of physical medicine and rehabilitation,* vol. 93, no. 5, pp. 822-827, 2012. DOI: https://doi.org/10.1016/j.apmr.2011.11.029.

[38] B. Stansfield, S. Hillman, M. Hazlewood, and J. Robb, "Regression analysis of gait parameters with speed in normal children walking at self-selected speeds," *Gait & posture,* vol. 23, no. 3, pp. 288-294, 2006. DOI: https://doi.org/10.1016/j.gaitpost.2005.03.005.

[39] A. Van Hamme, A. El Habachi, W. Samson, R. Dumas, L. Cheze, and B. Dohin, "Gait parameters database for

young children: The influences of age and walking speed," *Clinical Biomechanics,* vol. 30, no. 6, pp. 572-577, 2015. DOI: https://doi.org/10.1016/j.clinbiomech.2015.03.027.

[40] J. L. Lelas, G. J. Merriman, P. O. Riley, and D. C. Kerrigan, "Predicting peak kinematic and kinetic parameters from gait speed," *Gait & posture,* vol. 17, no. 2, pp. 106-112, 2003. DOI: https://doi.org/10.1016/S0966-6362(02)00060-7.

[41] L. Alcock, N. Vanicek, and T. O'Brien, "Alterations in gait speed and age do not fully explain the changes in gait mechanics associated with healthy older women," *Gait & posture,* vol. 37, no. 4, pp. 586-592, 2013. DOI: https://doi.org/10.1016/j.gaitpost.2012.09.023.