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The Mechanism Study of Gait on a Load and Gender Difference

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Abstract

Gait kinematics and kinetics have a similar tendency between men and women, yet it remains unclear how walking while carrying a load affects the gait mechanism. Twenty adults walked with preferred velocity on level ground of 20 m relative to change of a load carriage (no load, 15%, 30% of the body weights) aimed to observe gait mechanism. We measured gait posture using the three-dimensional image analysis and ground reaction force system during stance phase on left foot. In main effect of gender difference, men showed increased displacement of center of gravity (COG) compared to women, and it showed more extended joint angle of hip and knee in sagittal plane. In main effect of a load difference, knee joint showed more flexed postuel relative to increase of load carriage. In main effect of load difference on the kinetic variables, medial-lateral force, anterior-posterior force (1st breaking, 2nd propulsive), vertical force, center of pressure (COP) area, leg stiffness, and whole body stiffness showed more increased values relative to increase of load carriage. Also, men showed more increased COP area compared to women. Interaction showed in the 1st anterior-posterior force, and as a result of one-way variance analysis, it was found that a load main effect had a greater influence on the increase in the magnitude of the braking force than the gender. The data in this study explains that women require little kinematic alteration compared to men, while men in more stiff posture accommodate an added load compared to women during gait. Additionally, it suggests that dynamic stability is maintained by adopting different gait strategies relative to gender and load difference.

Keywords: *Gait, a Load, Gender, Leg stiffness, Whole body stiffness*

1. Introduction

It was difficult for human to determine the most efficient method in carrying an external weight [1], but previous studies as guideline, recommended symmetric not asymmetric carrying method [2-4]. Also when weight was positioned closest to COG (Center of Gravity) of body, it may be maintained a similar load distribution evenly of body system with static posture of unloaded condition [5, 6]. When walking under unloaded condition, characteristics of kinetic and kinematic data was appeared a similar pattern in both genders

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[7], while when it was maintained a symmetric distribution closely to COG with an added external weight, difference of gait mechanism of both gender was not yet clear.

External weight including front pack, back pack and double pack (front and back) during gait might be profitable means to induce a comprehensive kinematic, kinetic and physiological response against light and heavy load [1]. Front pack was preferred because back pack less induced muscular activity of trunk and spine compression [8, 9], double pack had a superiority against front or back pack in an aspect of minimizing a physical stress [9]. But wearing of bag altered a gait pattern to meet a various needs requiring for a postural balance due to position, inertia, velocity and forward progress of COG positioned newly of body trunk [10]. Thus it is necessary gait model which can minimize an alteration of gait characteristics due to change of loaded position of external weight.

According to anthropometric data necessary for analysis of human movement, segment length, mass, position of COG and moment of inertia etc. by genders showed significant difference [11]. These facts illustrate a possibility that difference in gait mechanism by genders may occur. But human machine system in a view of passive and active system may reduce an impulse force acting on body system [12]. Negative system were composed of pad of heel, ligament, articulate, joint cartilage, vertebrae disc plate, and non-contraction structure like bone, while impulse force in active system was attenuated by strategic interaction of between mechanics of lower limb and neuro-skeletal tissue [13]. Thus injury of neuro-muscular system by pain may influence negatively on reduction of impulse force occurred by heel impact against ground contact. That is, Thus arthritis of knee joint has relation with disability of neuro-muscular function during gait [14], and with load of excessive impulse. Particularly because occurrence rate of arthritis of knee joint in female was higher than that of male, difference by genders in mechanism of occurrence and reduction of impulse load was considered to be significant [15].

Consequently, it is necessary to understand a transferring strategy of load and gait controllability preferred by genders on biomechanical characteristics on falling injury and efficiency that may occur during gait and to compare with strategy of load absorption in condition under closest position to COG of body for quantification on these characteristics. Therefore the aim of this study was to verify the assumption on weather external weight (0%, 15%, 30% of body weight) and genders may influence on the stability index and rigidity of body.

2. Material and Methods

2.1 Subjects

Participants of this study were consisted of adult male and female (n=20) (male=10, mean year 23.00±1.41 yrs, mean stature=1.76±0.03 m, mean body weight= 74.98±3.90 kg, female=10, mean year=23.90±0.99 yrs, mean stature=1.62±0.04 m, mean body weight=59.22±6.74 kg). All participants was verified through question and prior test whether normal gait under 30% loading of body weight prior to experiment may be or not. Those with Injury or operation of ankle and knee within past 1 year before consenting agreement for the study exclude in the experiment. Also all study procedure was proceeded in accordance with JRN guideline (JJNU-IRB-2020-029).

2.2 Experimental approach

Maximum load weight was set at 30% of body weight that can alter rigidity of leg or maintain momentum of body during running [16] and was applied randomly in order of no load, 15% and 30% load of body weight respectively to all participants. Attire was wore with T-shirt and tight semi-pant of black color and weight was attached on trunk with Health-Plaza Weight Vest (China). Vertical position of the vest was heighten to expose during filming reflex marker of pelvis and weight was equally distributed between front and back of trunk and was maintained position closest to COG of whole body.

Analysis of gait motion was performed with total 12 camera of infra-red, sampling rate of each camera was set at 100 Hz. Captured camera data was stored to analysis software (Nexus, Vicon Motion System Ltd., UK) after converting to digital signal through (Vicon MX Giganet). 2nd Low Pass Filter to remove digitizing error and noise was utilized, and Euler's algorithm was applied to extract relative angle of each joint. 2 flatform plate (AMTI-OR-7, Advanced Mechanical Technology Inc., Watertown, MA, USA) was installed on mid- point of gait path and was induced to walk at one's preferred phase and was sampled at 1,000 Hz.

2.3 Definition of analysis phase

Analysis block was set at supporting phase of left foot, which defined from initial touch-down of left heel to take-off of forefoot.

Rigidity of whole body ($K_{\text{whole body}}$) devised newly in this study interact leg rigidity during gait.

$$K_{whole\ body}\ \frac{Peak\ vertical\ force\ (BW)}{(W_0 - W_{min})/W_0}$$

W_o was normalized value on the change rate of whole body and W_{min} was minimum length of whole body. During stance period. Length of trunk was estimated point from 1/2 point of both shoulder point to center of pressure point.

All data calculated using PASW 21.0 program (SPSS Inc., Chicago, IL, USA) was presented as M±SD. Also 2way repeated ANOVA analysis on effect by gender and added weight (No load, 15%, 30%) was performed. Interaction on the main effect was interpreted through one way ANOVA.

3. Results

3.1 Kinetic and leg length

Kinematic variance relative to loaded weights and genders during supporting phase of left foot was as Table 1. Main effect by genders showed longer pattern in male than female in forward displacement of COG, which followed significant difference statistically, but did not show in gait velocity. Main effect by genders showed more extended pattern in male than female in angle of hip and knee joint, which followed significant difference statistically. Main effect by loaded weights showed more flexed pattern in knee joint relative to load increase, which followed significant difference statistically.

Table 1. Kinematic variables by a load and gender difference during gait

Variable	Gender(G)	A load (L)			Total	*Sourc*	*F*	*p*
		No load	15%	30%	average	*e*		
Displacement in Y axis (m)	Female	0.81±0.09	0.83±0.07	0.82±0.07	0.82±0.07	*L*	0.593	0.549
	Male	0.88±0.05	0.87±0.06	0.9±0.07	0.88±0.06	*G*	5.781	0.027*
	Total	0.84±0.08	0.85±0.06	0.86±0.08	0.85±0.07	*L×G*	2.024	0.101
Mean Velocity	Female	1.32±0.15	1.39±0.14	1.37±0.12	1.36±0.13	*L*	1.047	0.361

of COM (m/s)	Male	1.42±0.14	1.39±0.16	1.44±0.16	1.41±0.15	*G*	0.855	0.367
	Total	1.37±0.15	1.39±0.15	1.4±0.14	1.39±0.14	*L×G*	2.179	0.127
Hip joint angle (degree)	Female	130.43±6.65	130.1±6.66	129.51±6.57	130.01±6.4	*L*	3.006	0.062
	Male	137.26±7.6	137.73±7.17	136.59±7.57	137.2±7.2	*G*	5.302	0.033*
	Total	133.84±7.78	133.92±7.79	133.05±7.8	133.6±7.67	*L×G*	0.819	0.532
Knee joint angle (degree)	Female	164.44±4.22	162.97±5.54	162.09±3.52	163.17±4.46	*L*	4.480	0.018*
	Male	164.7±3.37	163.89±2.94	163.25±4.18	163.94±3.46	*G*	0.644	0.012*
	Total	164.57±3.72	163.43±4.35	162.67±3.81	163.56±3.98	*L×G*	0.265	0.769
Ankle joint angle (degree)	Female	99.59±3.72	99.6±3.4	98.86±3.52	99.35±3.44	*L*	1.379	0.265
	Male	99.18±3.35	98.84±2.06	98.84±3.04	98.95±2.77	*G*	0.082	0.778
	Total	99.38±3.45	99.22±2.76	98.85±3.2	99.15±3.11	*L×G*	0.644	0.531

Kinetic variance relative to loaded weights and genders during supporting phase of left foot was as Table 2. Main effect by loaded weights showed increased pattern relative to load increase in GRF of normalized medial-lateral, anterior-posterior(breaking force, propulsive force), and vertical direction, which followed significant difference statistically, but did not show by genders. Particularly interaction effect showed in breaking force of anterior-posterior direction, that is, which loaded weights rather than genders contributed to increase of breaking force (F=3.431, p=.009) through one way ANOVA..

COP area, leg rigidity and rigidity of whole body relative to increase of load weight in main effect of load weight showed more increasing pattern, which followed significant difference statistically. Main effect by loaded weights and genders and interaction effect in COP area and rigidity variable did not show.

Table 2. Kinetic variables by a load and gender difference during gait

Variable	Gender (G)	A load (L)			Total average	*Source*	*F*	*p*
		No load	15%	30%				
Medial-lateral GRF (N/BW)	Female	0.11±0.02	0.13±0.03	0.13±0.03	0.12±0.03	L	21.384	0.001***
	Male	0.11±0.02	0.13±0.02	0.14±0.02	0.13±0.02	G	0.130	0.722
	Total	0.11±0.02	0.13±0.02	0.14±0.03	0.12±0.03	L×G	0.182	0.834
1st anterior-posterior GRF (N/BW)	Female	-0.21±0.06	-0.26±0.07	-0.26±0.07	-0.25±0.07	L	32.846	0.001***
	Male	-0.22±0.05	-0.25±0.07	-0.31±0.06	-0.26±0.07	G	0.323	0.577
	Total	-0.21±0.06	-0.26±0.07	-0.29±0.07	-0.25±0.07	L×G	6.341	0.004*
2nd anterior-posterior GRF (N/BW)	Female	0.26±0.04	0.3±0.05	0.35±0.06	0.3±0.06	L	52.982	0.001***
	Male	0.24±0.04	0.28±0.05	0.33±0.05	0.28±0.06	G	1.022	0.325
	Total	0.25±0.04	0.29±0.05	0.34±0.06	0.29±0.06	L×G	0.803	0.101
Vertical GRF (N/BW)	Female	1.18±0.06	1.37±0.13	1.48±0.1	1.34±0.16	L	134.052	0.001***
	Male	1.2±0.1	1.39±0.1	1.58±0.14	1.39±0.19	G	1.245	0.279
	Total	1.19±0.08	1.38±0.11	1.53±0.13	1.37±0.18	L×G	2.683	0.823
COP area (cm^2)	Female	25.6±10.09	39.79±20.54	48.8±9.49	38.06±16.87	L	7.972	0.001***

	Male	46.15±9.47	52.06±13.33	59.76±27.29	52.66±18.6	G	8.255	0.010**
	Total	35.88±14.21	45.93±17.99	54.28±20.66	45.36±19.08	L×G	0.636	0.535
Leg stiffness	Female	16.74±4.99	20.74±7.24	22.56±9.05	20.01±7.45	L	10.135	0.001***
	Male	14.57±6.63	18.14±8.05	22.94±11.88	18.55±9.47	G	0.207	0.655
	Total	15.65±5.82	19.44±7.57	22.75±10.28	19.28±8.48	L×G	0.520	0.599
Whole body stiffness	Female	28.14±13.02	30.9±9.54	37.68±22.05	32.24±15.76	L	5.992	0.006**
	Male	22.43±9.64	23.2±9.27	36.8±24.45	27.48±16.91	G	0.704	0.413
	Total	25.28±11.53	27.05±9.97	37.24±22.66	29.86±16.39	L×G	0.442	0.514

4. Discussion

Gait activity of human carrying with packed weight additionally except for body weight is common function in not only daily life, various job environment, but also in military training [17]. Until now, despite many researcher of biomechanics had done their best to determine a model for prevention of injuries and efficient carrying strategy of weight under various conditions during gait, yet there is an inconsistency in kinematics between gait and leg. This result may be attributed to difference in occurring rate of arthritis, loading level on joint, mechanism of impulse absorption, over body weight and weakness of muscle strength by genders [15]. Therefore this study was undertaken to investigate mechanism on how to alter a mechanics of leg and transferring strategy of loaded weight by genders after loading additional weight equally on anterior-posterior direction of trunk.

As a result of the study, load weight of 15%-30% compared with no-load during gait increased forward displacement of COG proportionally, which followed significance difference in main effect by genders. Specifically forward displacement of COG showed apparent difference in male rather than female. This result meant that initial touch-down was performed in shorter period than that of no load condition causing increase of proportion of supporting phase between foot and ground surface to secure dynamic stability and propel and break momentum in forwarding direction, which suggested an increase of forward displacement based on inverted pendulum model. Like this, gait kinematics (displacement) can be altered on the basis of result of COP area and components of GRF analyzed in this study.

COP area of dynamic stability variable showed significant difference in main effect of loaded weights and genders, which required more wide of COP area in male rather than female due to increase of 52.66 cm. 15%-30% of body weight showed maximum change at range of COP area of 54.28 cm2 compared with no-load. Thus result of the study was consistent partially with previous study [18, 19] which space-time function and velocity of COP relative to genders did not show difference. But it was coincided with previous studies [20, 21] that gait pattern by increased risk of falling injury and slipping due to instability may be altered when interacted with loaded weights rather than main effect by gender only. Consequently male required more alteration of kinematics and adopted the other strategy to accept an added weight except for body weight under gait condition interacted with loaded weight.

2nd assertion that gait kinematics was altered to break and propel the momentum of body supported that GRF component in medial-lateral, anterior-posterior and vertical direction relative to main effect of loaded weights was altered, which followed significant difference. As result normalization of GRF by body weight in order to simplify a comparison on interaction effect of between genders and loaded weights, gait carrying with loaded weight increased bilateral shearing force between foot and ground surface, and also propulsive force at final push-off and breaking force occurring at initial touch-down. Particularly interaction effect between loaded weights (0.33 N/BW) and genders (0.3 N/BW) in propulsive force (AP GRF 2) appeared, but increase of propulsive force showed sensitive influence on loaded weight rather than genders (F=3.431, p=.009). thus controllability of human movement may be altered as means of strategy for energy conservation when increased physical exertion existed [17].

Magnitude of GRF (normalization or raw data) during gait showed increasing pattern relative to added loaded weights [22, 23], but each individual can utilize the GRF force of 3 dimension through strategy increased, reducing and altering it [23, 24]. In view of altering rate of leg length sensitive to change of rigidity, maximum angle of hip joint in main effect of loaded weights showed more extended pattern and in male rather than female particularly. While angle of knee joint in main effect of loaded weights showed more flexed pattern and in female rather than male. This change of kinematics of lower leg was coincided with previous study [17] that may reduce vertical displacement by inducing more extended joint and erected posture relative to loaded weights gradually during gait. The increase of vertical displacement of COM meant that stiffness posture was maintained without significant sway motion in inverted pendulum model, which influenced on rigidity of leg and whole body analyzed in this study. That is, alteration in rigidity of leg by genders did not show difference, but 30% loaded weight of body weight increased proportionally rigidity of leg and whole body, which was influenced by crouching posture during gait, and related with alteration and magnitude of maximum vertical GRF [16, 24].

So far most researchers of biomechanics focused on alteration of rigidity of leg under various condition during gait. But the study on loaded weights gradually provided theoretical ground contributable to increase of vertical GRF and of motion of whole body and of rigidity of whole body system downward vertically during erect posture. But as a result of maximal control of GRF and trunk and thigh segment, with all more influenced on torque of trunk rather than thigh, control of thigh displacement had close relation with change of vertical GRF than control of trunk (James et al., 2015). Thus it is necessary to analyze the relation of rigidity variables including movement of body segment, torque etc. through following study.

Considering the above, it was spotted that female could more attenuate efficiently the loaded impulse than male under a weight model condition loaded on trunk equally during gait. While male required more alteration of kinematics and increased components of GRF along with rigidity posture. Therefore this result suggested that alteration of kinematic and kinetic variables was influenced by mechanism of absorption of body weight at an initial stage of touch-down of foot on ground surface. Furthermore dynamic stability was maintained successfully by adopting the other strategy of gait relative to genders and loaded weights.

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