

# Relationship among gait parameters while walking with varying loads

著者	Demura Tomohiro, Demura Shinichi
journal or publication title	Journal of Physiological Anthropology
volume	29
number	1
page range	29-34
year	2010-01-01
URL	<a href="http://hdl.handle.net/2297/25032">http://hdl.handle.net/2297/25032</a>

doi: 10.2114/jpa2.29.29

Tuesday, November, 27, 2009

***Editors-in-Chief, Journal of PHYSIOLOGICAL ANTHROPOLOGY***

Japan Society of Physiological Anthropology,

International Academic Printing co., Ltd.

3-8-8 Takadanobaba, Shinjuku-ku,

Tokyo 169-0075, Japan

Dr. Editors-in-Chief

I am submitting a paper entitled "**Relationship among gait parameters while walking with varying loads**" for publication in the *Journal of PHYSIOLOGICAL ANTHROPOLOGY* as an original article (Full paper). This is the first submission of this material to any journal. This paper is co-authored by Professor Shin-ichi Demura (Kanazawa University) and myself.

The key point of this paper is that clarify the relationships between loads and gait changes and among gait parameters while walking with various loads. We feel that findings from this study will be of special interest to the readers of *Journal of PHYSIOLOGICAL ANTHROPOLOGY*. We strongly believe that your journal is the most appropriate journal in which our paper should be published and that your journal will provide our paper with the broad distribution that it deserves.

We hope that our manuscript meets the high standards of your journal. We are looking forward to receiving a favorable response from you regarding the acceptance of our manuscript.

Sincerely,

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**Original Article**

Title:

**Relationship among gait parameters while walking with varying loads**

Running Head:

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**Abstract**

This study aimed to clarify the relationships between loads and gait changes and among gait parameters while walking with various loads. Fifteen healthy young male adults (mean age:  $22.1 \pm 1.6$  years) walked with four kinds of loads based on each subject's body mass (0, 20, 40, and 60% of body mass: BM) on his back. Walking speed, cadence, stance time, swing time, double support time, step length, step width, walking angle, and toe angle were selected as gait parameters.

Walking speed, cadence, stance time, and double support time changed significantly with loads. The walking speed showed significant correlations with the swing time at 0% BM ( $r = -0.64$ ) and the walking angle at 60% BM ( $r = -0.52$ ). Significant correlations were found between swing time and double support time at 0, 20, and 40% BM ( $r = 0.53 \sim 0.63$ ) and between walking speed and step length at 40 and 60% BM ( $r = -0.61, -0.67$ ).

In conclusion, walking with loads produces large gait changes. The relationship between swing time, double support time, and walking speed, as well as between walking angle, step length, and walking speed changes greatly with loads. These changes may occur in order to maintain a stable posture.

*Keywords:* Gait; Human locomotion; Load

## 1. Introduction

Recently, aging has rapidly advanced in Japan and great interest has been paid to the health problems of the elderly. A decrease in physical function with age appears markedly in walking movement. Walking is an important basis for daily life and it represents a simple index of human health (Tang et al., 2002). The following changes have been reported to occur to walking with the progression of age: walking speed (Murray et al., 1969; 1970), the ratio of single leg and double leg support times in total contact time, step length, and joints angles of hips, knees, and ankles (Larish et al., 1988; Kaneko et al., 1991). Leg strength and balance ability have been regarded as the main factors related to a decrease in walking ability in the elderly (Montoye and Lamphiear, 1977; Murray et al., 1985; Frontera et al., 1991). Hence, the decrease of leg strength with age may have a large influence on gait.

Leg strength decreases gradually with age over a long period of time after adolescence. Hence, it is very difficult to examine the influence of decreasing leg strength on gait for a short period. On the other hand, walking with loads imposes a large burden on the lower limbs, even in young adults. With heavier loads, the burden imposed on the lower limbs is large. Ghori and Luckwill (1985) reported that leg muscles increase activity and discharge time extends while walking with loads. In addition, Yanagawa et al. (2002) reported that increased muscle activity and extended discharge times occur as characteristics of leg muscle activity in walking in the elderly. It is considered that walking with loads has a large influence on walking speed and gait also in young adults.

Until now, the problem of walking with loads has been mainly studied from a physiological or biomechanical standpoint. Pandof et al. (1977) and Epstein et al. (1987)

created equations for predicting the energy cost of walking with loads. Furthermore, they revealed that the following changes occur by holding loads: leg muscle activity increases (Ghori and Luckwill, 1985; Harman et al., 1992), gait, body trunk inclines (Kinoshita, 1985; Martin and Nelson, 1986), and ground reaction force increases (Kinoshita, 1985; Harman et al., 1992). It is assumed that a larger burden is imposed on the lower limbs with larger loads and that gait is greatly influenced.

However, the relationships between loads and their effect on gait have been little studied. Strictly speaking, walking in young adults may be affected differently by carrying loads, but it is thought to provide beneficial insight into walking in the elderly.

This study aimed to clarify the relationships between loads and gait changes and among gait parameters while walking with various loads.

## **2. Methods**

### **2. 1. Subjects**

Fifteen healthy young male adults without extremity disorders participated in this study (age:  $22.1 \pm 1.6$  years, height:  $172.5 \pm 4.9$ cm, body mass:  $67.6 \pm 5.0$  kg). Before the measurements, the purpose and procedure of this study were explained in detail and informed consent was obtained from all subjects.

### **2. 2. Material**

Gait properties were measured by a gait analysis system (Walk Way MG-1000, Anima, Japan). The MG-1000 with plate sensors can determine time, dimensions, and the distance of the foot or feet when the foot touches the sheet surface and can measure grounding/non-

grounding on the bearing surface as an on/off signal. Data were recorded into a personal computer at 100 Hz.

### 2. 3. Procedures

In this study, we imposed weight relative to the subject's body mass on the subjects and caused a decrease of their leg strength through temporary exertion. The four kinds of loads (0, 20, 40, and 60% BM), selected in reference to previous studies (Ghori and Luckwill, 1985), were strapped closely on each subject's back by a belt so as to be fixed in place (see Fig. 1). The trial order of each load condition was randomized.

Posture and movement manner during measurement were explained to subjects before measurement. Subjects walked straight for eleven meters as usual. To eliminate the influence of fatigue, the subjects performed each load condition three times with a one-minute rest. In addition, we used only the middle 5 meters of data, excluding the first and final 3 meters, in our analysis.

\*\*\* Figure 1 near here \*\*\*

### 2. 4. Data Analysis

Figs. 1, 2, and 3 show the parameters of gait properties selected in reference to previous studies (Murray et al., 1964). In particular, we used walking speed and cadence to show the number of steps per minute as parameters. These parameters are relevant to falls in the elderly and are widely used to assess walking ability (Bath and Morgan, 1999).

Stance time equals the duration that the body is supported by single or double feet, that

is, the phase in which one foot or both feet contact the floor (see Fig. 1). Swing time equals the duration that one foot swings, that is, one foot is raised off the floor (see Fig. 1). This time agrees with single support time. Double support time equals the duration in which both feet contact the floor (see Fig. 2). Step length is the distance between anterior-posterior patterns (one step length). Step width is the distance between both feet (see Fig. 3). Walking angle is the angle between the direction of movement and bilateral pattern line. Toe angle is the angle between the direction of movement and the foot axis (see Fig. 4).

\*\*\* Figure 2 near here \*\*\*

\*\*\* Figure 3 near here \*\*\*

\*\*\* Figure 4 near here \*\*\*

Mean differences among parameters in load conditions were tested by one-way analysis of variance (ANOVA). Tukey's HSD method was selected for multiple comparisons. Pearson's correlations were calculated to examine the relationships between walking speed and each parameter and the significance was tested. A probability level of 0.05 was indicative of statistical significance.

### **3. Results**

Table 1 shows the results of one-way ANOVA and multiple comparisons for gait parameters in each load condition. Significant differences were found in walking speed, cadence, stance, swing, and double support time. Walking speed, cadence, step length, and swing time showed a maximal value at 0% BM and a minimum value at 60% BM. Stance



and double support times showed a maximal value at 60% BM and a minimum value at 0% BM.

\*\*\* Table 1 near here \*\*\*

Table 2-1 shows correlations between walking speed and each parameter in each load condition. The walking speed showed significant and medium correlations with stance time ( $r = -0.63 \sim -0.71$ ) and significant and high correlations with the step length ( $r = 0.80 \sim 0.90$ ) in all load conditions. In addition, the walking speed showed significant and medium correlations with the swing time in 0% BM and with the walking angle in 60% BM ( $r = -0.63 \sim -0.71$ ).

Table 2-2 shows correlations between cadence and each parameter in each load condition. The cadence showed significant and high negative correlations with the stance, swing, and double support times ( $r = -0.78 \sim -0.99$ ) in all load conditions.

\*\*\* Table 2-1 near here \*\*\*

\*\*\* Table 2-2 near here \*\*\*

Table 3-1 shows correlations between each parameter in each load condition. Except for the swing time and double support time at 60% BM, significant and medium correlations were found between each parameter ( $r = 0.53 \sim 0.98$ ).

Table 3-2 shows correlations between each parameter in each load condition. The significant and high correlations were found between step width and walking angle in all

load conditions ( $r = 0.98$ ). Furthermore, the significant and medium correlations were found between the step length and the walking angle at 40% and 60% BM ( $r = -0.61 \sim -0.67$ ).

\*\*\* Table 3-1 near here \*\*\*

\*\*\* Table 3-2 near here \*\*\*

#### **4. Discussion**

Subjects walked with four loads relative to the subject's body mass (0, 20, 40, and 60%BM) attached closely to the subject's back. Walking speed, cadence, swing time, and step length decreased, and stance time and double support time increased significantly while carrying loads. It has been reported that step length and walking speed decreased while walking with a heavy load (Imms and Edholm, 1981; Menz et al., 2003; Oberg et al., 1993; Lord et al., 1996). The present results supported the results of these previous studies. The characteristics of the EMG of leg muscles while walking in the elderly (Yanagawa et al., 2002) are similar to those of young adults while walking with loads (Ghori and Luckwill, 1985). From the above, it is believed that by carrying loads, walking patterns in young adults appear similar to those in the elderly.

A decrease in leg strength is closely related to a decrease in walking speed and is considered to be a main cause of gait change as we age (Daubney and Culham, 1999; Wolfson et al., 1995). Ferrandez et al. (1990) reported that if walking speed is the same, gait movements of the elderly will not be different from those of young adults. Thus, the gait changes may have been caused by a decrease in walking speed. In addition, decreases

in walking speed and step length in the elderly (Murray et al., 1964; Hageman and Blanke, 1986) have been reported to contribute to keeping a stable posture (Patla, 1997). Also in this study, similar changes in gait of young adults were confirmed while walking with loads.

From the above, it is judged that to keep a stable posture while walking, similar gait changes in the elderly were produced in young adults by walking with loads, and these effects increased with the loads.

Walking speed showed a significant relationship with cadence ( $r = 0.63 \sim 0.70$ ) and step length ( $r = 0.80 \sim 0.90$ ) in all load conditions, but with the walking angle only at 60% BM ( $r = -0.52$ ). The cadence is the number of steps per unit of time. The walking speed is decided by the number of steps and step length. The present results suggest that walking speed is more influenced by step length than by the number of steps taken. These results agree with those in studies (Murray et al., 1969; Elble et al., 1991) where a decreased walking speed is attributed to a decreased step length. Furthermore, walking angle increases with age (Murray et al., 1964). This gait change relates to an increase in base support and walking stability. In addition, as stated above, the decrease in walking speed and step length increases walking stability. The inverse relationship between walking speed and walking angle has been judged to be a part of a strategy to compensate for the instability created by walking with loads. The effect of loads was observed to be prominent when it reached greater than 60% BM while such a relationship was not seen when the load was less than 60% BM.

The walking speed showed a significant relationship with stance and double support times in all load conditions ( $r = -0.52 \sim -0.82$ ), but only with the swing time at 0% BM ( $r =$

-0.64). Meanwhile, the swing time increased significantly only at 0% and 20% BM, but walking speed decreased with loads. Thus, it is inferred that the effect of holding loads while walking on walking speed and swing time differs and the walking speed showed an insignificant relationship with the swing time in heavy loads. In addition, although the swing time was unchanged, the step length shortened. The following is inferred: as loads increase, to keep a stable posture while walking, subjects made the step length and the rate of swing time to stride time decrease, i.e., it made the double support time increase (Murray et al., 1964; Imms and Edholm, 1981; Menz et al., 2003).

It was reported that an increase in double support time and a decrease in swing time occur in order to maintain a stable posture (Imms and Edholm, 1981; Menz et al., 2003; Oberg et al., 1993; Lord et al., 1996; Bohannon, 1997). The double support time showed significant relationships ( $r = 0.53 \sim 0.63$ ) with the swing time except for 60% BM. Thus, for load conditions under 40% BM, as double support time is longer, swing time is longer. In short, this means that each subject's walking cycle affects gait. However, for heavy loads over 60% BM, it is thought that significant relationships between double support time and swing time were not found, because some subjects made swing time shorter to keep a stable posture.

Step length decreases with load (Imms and Edholm, 1981; Menz et al., 2003; Oberg et al., 1993; Lord et al., 1996; Bohannon, 1997). In addition, walking angle increases with age (Murray et al., 1964). The significant relationships between step length and walking angle were found only while walking with heavy loads of 40% and 60% BM ( $r = -0.61, -0.67$ ). Namely, it is considered that step length decreases and walking angle increases when using heavy loads.

From the above, it was suggested that the gait change becomes greater when imposing a burden on the lower limbs, particularly at 60% BM. Thus, it is considered that a decrease in leg strength is one important factor of unstable walking in the elderly. Although the gait changes were similar, walking in young adults when temporarily decreasing leg strength by carrying loads may not always be the same as walking in the elderly with varying decreased physical function in addition to leg strength. Therefore, when interpreting the present results, the above will have to be sufficiently considered.

The relationship between the measurement of postural stability (e.g., center of gravity and center of plantar pressure trajectory) index and the gait parameters should be examined as a future research topic.

## **5. Conclusion**

Walking speed, cadence stance time, swing time, double support time, and step length changed while walking with loads. The relationship between swing and double support times and between step length and walking angle change as loads change.

In addition, the relationship between swing time, double support time, and walking speed, as well as between walking angle, step length, and walking speed change greatly with loads. These changes may occur in order to maintain a stable posture.

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156

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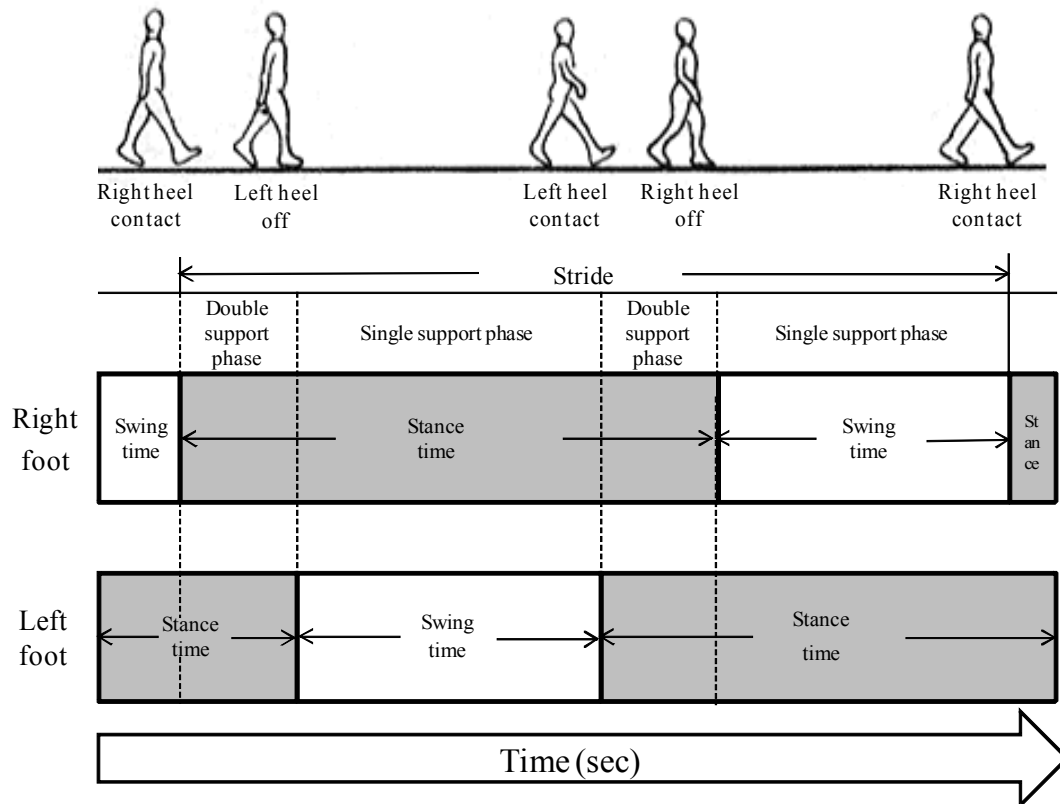


**List of Figures**

- Figure 1. Load attachment
- Figure 2. Gait parameters regarding time
- Figure 3. Gait parameters regarding distance and width
- Figure 4. Gait parameters regarding angle
- 
- Table 1. Results from analysis of variance and multiple comparisons for each gait parameter in each load condition
- Table 2-1. Correlations between walking speed and gait parameter with each load
- Table 2-2. Correlations between cadence and gait parameter with each load
- Table 3-1. Correlations between each gait parameter (regarding time)
- Table 3-2. Correlations between each gait parameter

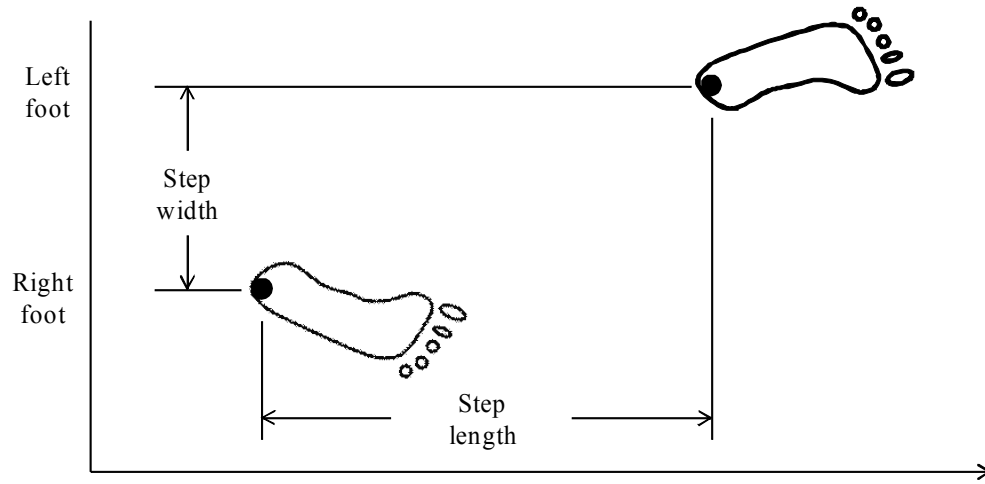


**Fig. 1 Load attachment**



**Fig. 2** Gait parameters regarding time

Centimeters

**Fig. 3** Gait parameters regarding distance and width

Centimeter

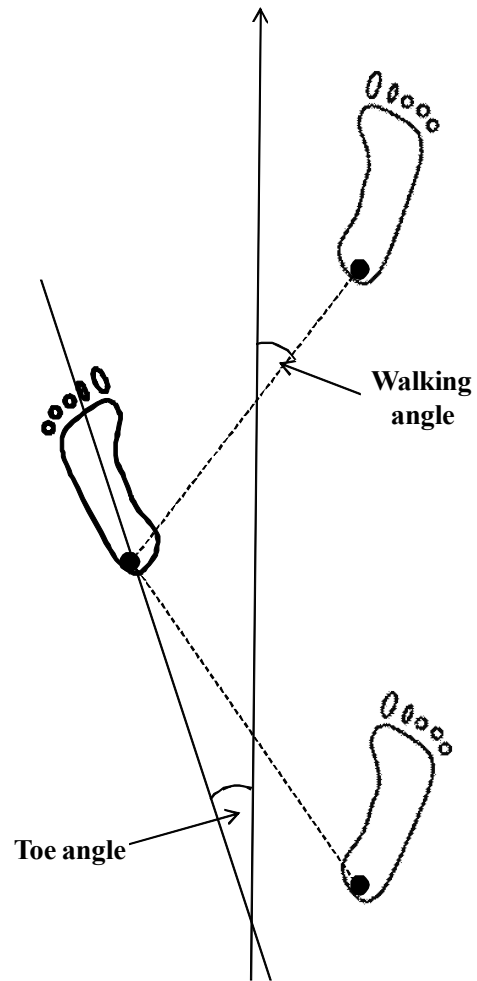


Fig. 4 Gait parameters regarding angle

**Table 1. Results form analysis of variance and multiple comparisons for each gait parameter in each load condition**

Parameters	Load condition								ANOVA		Post-hoc
	0%BM		20%BM		40%BM		60%BM		F-value	p-value	Tukey's HSD
	Mean	SD	Mean	SD	Mean	SD	Mean	SD			
<b>Walking speed (cm/sec)</b>	128.99	11.50	122.96	9.68	118.42	10.03	110.37	12.88	36.44	0.00	0>20,40>60
<b>Cadence (steps/min)</b>	116.03	4.70	116.12	5.28	114.47	5.64	111.99	6.20	12.39	0.00	0,20,40>60
<b>Stance time (sec)</b>	0.63	0.03	0.64	0.04	0.66	0.04	0.68	0.05	19.12	0.00	0,20<40,60
<b>Swing time (sec)</b>	0.41	0.01	0.40	0.01	0.40	0.01	0.40	0.02	9.27	0.00	0>20,40,60
<b>Double support time (sec)</b>	0.11	0.01	0.12	0.01	0.14	0.01	0.15	0.02	36.50	0.00	0,20<40,60
<b>Step length (cm)</b>	66.59	4.54	63.46	3.79	62.13	4.18	59.33	5.50	25.46	0.00	0>20,40>60
<b>Step width (cm)</b>	7.17	2.45	7.99	2.19	7.47	2.70	7.50	3.53	0.78	0.51	
<b>Walking angle ( ° )</b>	6.26	2.20	7.29	2.08	7.11	2.65	7.60	3.71	2.14	0.11	
<b>Toe angle ( ° )</b>	5.94	2.75	5.89	3.69	5.65	2.95	4.59	3.45	3.02	0.04	

Note. %BM: relative loads based on body mass (BM)

**Table 2-1. Correlations between walking speed and gait parameter with each load(n=15)**

<b>Parameters / Loads</b>	<b>Walking speed</b>			
	<b>0%BM</b>	<b>20%BM</b>	<b>40%BM</b>	<b>60%BM</b>
<b>Stance time (sec)</b>	-0.63 *	-0.66 *	-0.71 *	-0.69 *
<b>Swing time (sec)</b>	-0.64 *	-0.38	-0.41	-0.15
<b>Double Support time (sec)</b>	-0.52 *	-0.70 *	-0.78 *	-0.82 *
<b>Step length (cm)</b>	0.90 *	0.81 *	0.80 *	0.89 *
<b>Step width (cm)</b>	-0.05	0.08	-0.26	-0.34
<b>Walking angle (°)</b>	-0.24	-0.10	-0.40	-0.52 *
<b>Toe angle (°)</b>	-0.03	-0.01	-0.20	0.00

Note. \*:  $p < 0.05$

**Table 2-2. Correlations between cadence and gait parameter with each load(n=1**

<b>Parameters / Loads</b>	<b>Cadence</b>			
	<b>0%BM</b>	<b>20%BM</b>	<b>40%BM</b>	<b>60%BM</b>
<b>Stance time (sec)</b>	-0.97 **	-0.98 **	-0.97 **	-0.97 **
<b>Swing time (sec)</b>	-0.87 **	-0.86 **	-0.90 **	-0.78 **
<b>Double Support time (sec)</b>	-0.82 **	-0.91 **	-0.89 **	-0.80 **
<b>Step length (cm)</b>	0.32	0.11	0.07	0.20
<b>Step width (cm)</b>	0.27	0.40	0.18	0.10
<b>Walking angle (°)</b>	0.16	0.33	0.12	0.01
<b>Toe angle (°)</b>	0.15	0.27	0.25	0.30

Note. \*:  $p < 0.05$



**Table 3-1. Correlations between each gait parameter (regarding time) (n=15)**

	0%BM		20%BM		40%BM		60%BM	
	1	2	1	2	1	2	1	2
<b>1. Stance time (sec)</b>								
<b>2. Swing time (sec)</b>	0.78 *		0.79 *		0.81 *		0.63 *	
<b>3. Double support time (sec)</b>	0.91 *	0.53 *	0.94 *	0.60 *	0.95 *	0.63 *	0.90 *	0.28

Note. \*:  $p < 0.05$

**Table 3-2. Correlation between each gait parameter (regarding distance and angle) (n=15)**

	0%BM			20%BM			40%BM			60%BM		
	1	2	3	1	2	3	1	2	3	1	2	3
<b>1. Step length (cm)</b>												
<b>2. Step width (cm)</b>	-0.26			-0.22			-0.47			-0.51		
<b>3. Walking angle (°)</b>	-0.43	0.98 *		-0.41	0.98 *		-0.61 *	0.98 *		-0.67 *	0.98 *	
<b>4. Toe angle (°)</b>	-0.12	0.33	0.33	-0.24	0.17	0.20	-0.46	0.24	0.26	-0.17	0.48	0.44

Note. \*:  $p < 0.05$