J. Phys. Ther. Sci. 28: 2059–2062, 2016

The Journal of Physical Therapy Science

Original Article

Influence of load and carrying method on gait, specifically pelvic movement

Eun-Ju Hyung, MS, PT[1)], Hyun-Ok Lee, PhD, PT[1)], Yu-Jeong Kwon, MS, PT[2)*]

[1)] *Department of Physical Therapy, Catholic University of Pusan, Republic of Korea*
[2)] *Department of Physical Therapy, Dong-Eui Institute of Technology: 54 Yangji-ro, Busanjin-gu, Busan 614-715, Republic of Korea*

Abstract. [Purpose] The purpose of this study was to examine how carrying methods and load affects pelvic movement while walking. [Subjects and Methods] Sixteen healthy subjects (age 20.68 ± 1.95 years, height 167.56 ± 8.46 cm, weight 60.25 ± 9.37 kg) volunteered. The items carried included a hand bag, shoulder bag, cross bag, and a back pack. The load weights were 0%, 5%, 10% and 15% of body weight. G-Walk was used to record and analyze pelvic movement while the participants walked with different loads. [Results] In the case of hand bags and shoulder bags, pelvic tilt increased along with weight. In particular, when compared with the 0%, 5% and 10% load conditions, the 15% load of a hand bag induced a significant increase. Pelvic rotation showed a tendency to decrease as the weight increased. [Conclusion] Lateral pelvic tilt is thought to increase when the weight exceeds 15% of body weight, thereby resulting in decreased efficiency of gait. The pelvic rotation is thought to decrease as the weight increases, causing restricted upper limb movements.
Key words: Carrying method, Pelvic movement, Gait

(This article was submitted Feb. 5, 2016, and was accepted Apr. 7, 2016)

INTRODUCTION

Gait is a body movement pattern wherein the nervous and musculoskeletal systems, among others, are comprehensively used based on human body movements. These processes are basic forms of movements in which the center of the body is moved through the lower limbs, pelvis, trunk, upper limbs, and for interconnectivity, resulting in continuous and repetitive motions that require high degrees of coordination[1, 2)].

For daily living, humans carry bags of various forms and differing weights. Depending on their weight, shape, carrying method, and location, bags may induce abnormal postures and affect the musculoskeletal system, thereby leading to pain and spinal lesions[3–6)]. To move outside loads to the centerline of the body and maintain stability, the humans postural control mechanism acts on many segments leading to abnormal postural alignment and changes in gait patterns[1, 7, 8)].

According to Pascoe et al.[9)], as the weight of a bag increases and the load becomes more asymmetrical, not only do stride length and step length shorten, but the contact time of the weight-bearing foot also increases. Yu et al.[10)] stated that as the weight of the backpack increases, the step width increases, and a mechanism to reduce the speed and cadence occurs to stabilize gait. Son's study showed that bag carrying methods do not influence temporal and spatial gait variables[11)], and no differences in plantar foot pressure were exhibited between backpacks and shoulder bags[12)]. Finally, Yoon[13)] studied correlations between muscle activities and strap length for various types of school bags carried while walking.

Previous studies altered the shapes and weight of bags to present basic data on appropriate bag weight. However, in these studies, the shapes of bags were limited, and a certain load was applied as bag weight without taking into account the subjects' weights. As for gait patterns, most studies examined strides, step counts, and speed during a gait cycle. However, few studies have been undertaken on pelvic movements while walking, where bag weights were applied according to the

*Corresponding author. Yu-Jeong Kwon (E-mail: yjkwon@dit.ac.kr)

body weights of the subjects.

In the present study, using the G-Walk gait analyzer (BTS Bioengineering SpA, Italy), pelvic movements are examined with loads of 5%, 10%, and 15% of body weight and with different shapes of bags.

SUBJECTS AND METHODS

The purpose and methods of the study were explained to all potential subjects, and each of them voluntarily agreed to participate. Specifically, written informed consent was obtained from each subject. This study was approved by the Institutional Review Board of the Catholic University of Pusan (CUPIRB-2015-006) and conducted in accordance with the ethical principles of the Declaration of Helsinki, good clinical practices, and applicable laws and regulations. Sixteen subjects were selected with leg-length discrepancies of less than 0.5 cm, and no pathological issues related to the ankle joint, knee joint, hip joint, or back (age, 20.68 ± 1.9 years [mean ± standard deviation (SD)]; height, 167.56 ± 8.46 cm; weight, 60.25 ± 9.37 kg).

In the present study, a G-Walk gait analyzer, which enables measurement of walking distances, speed, pelvic movements, and so on, was used as the measuring tool. The inertial sensor was attached using a semi-elastic belt, at lumbar 5, and accelerations were provided along three orthogonal axes. Acceleration data were transmitted via Bluetooth to a PC and processed using dedicated software (BTS G-Walk).

Four types of bags were used: a hand bag, shoulder bag, cross bag, and back pack, and weights corresponding to 5%, 10%, and 15% of each subject's body weight were employed for measurement of pelvic movements. The subjects' gaits were evaluated when they were not carrying any type of bag to identify their gait patterns at normal times. Thereafter, the subjects' pelvic movements were measured according to the shapes of individual bags with different weights applied. The subjects were instructed to carry the bag with their dominant hand.

In the present study, the subjects were instructed to travel 10 m back and forth on a hard floor free from any object that would obstruct the subjects' gaits, and their pelvic movements were measured. The subjects performed the movement three times and the mean pelvic tilt and pelvic rotation of each instance was presented. To prevent muscle fatigue during the measurement, the subjects were allowed to take a rest for 2 minutes each time the shape of the bag was changed.

Data were processed using SPSS 18 for Windows. To compare pelvic tilt and pelvic rotation in bags with loads of 5%, 10% and 15% of each subject's body weight, repeated measures analysis of variance (ANOVA) was used. To identify differences for each muscle, Bonferroni's post hoc test was performed. Statistical significance was accepted for values of $p<0.05$.

RESULTS

For hand bags and shoulder bags, pelvic tilt increased along with weight. In particular, for hand bags, left pelvic tilt significantly increased at a weight corresponding to 15% of body weight. For shoulder bags, right pelvic tilt significantly increased at a weight corresponding to 15% of the body weight. Pelvic rotation showed a tendency to decrease as the weight increased. In particular, pelvic rotation significantly decreased at a weight corresponding to 15% of body weight when a shoulder bag was carried.

In the case of cross bags and back packs, pelvic tilting showed a tendency to increase as the weight increased, but the differences were not significant, and pelvic rotation significantly decreased at weights corresponding to 10% and 15% of body weight (Table 1).

DISCUSSION

The purpose of the present study was to examine changes in pelvic movements while walking, when different shapes of bags and weights corresponding to 5%, 10%, and 15% of body weight were carried. Subjects with asymmetrical muscle activity due to a particular carrying method should be mindful of pain or posture transformation[14)]. Heavy bags are becoming a cause of disorders of the musculoskeletal system, affecting areas such as the neck, shoulder, and back. The pelvis can be said to be the control point with the largest effect on gait efficiency. As a region that supports the abdomen, connects the spine and the lower limbs with each other, and is attached to the lower limb muscles, the pelvis bears the body weight while sitting and supports the weight from the spine to the lower limbs when standing[7)]. According to Kapandji[15)] the pelvis can make forward, backward, leftward, and rightward tilting and rotational movements and acts to bear and support body weight. Moreover, as Hodges and Richardson[7)] reported, the basis of trunk movements is the action of the pelvis, and the activity of the trunk muscles is an essential element that plays a major role for pelvic and lower limb movements.

In the present study, since bag weights were determined to potentially have an effect relative to subjects' force or physical strength, weights corresponding to 5%, 10%, and 15% of the subject's body weight were applied, instead of identical weights. These weights were loaded into four shapes of bags to examine their effects on pelvic tilts and rotation. Changes in leftward or rightward pelvic tilts showed a tendency to increase as the weight increased when a load was placed on one side via a hand bag or shoulder bag. In particular, pelvic tilts significantly increased when the weight was approximately 15% of body weight. When walking with an excessive unilateral load, the trunk is tilted, moving the centerline of gravity into the basal plane so that the leftward or rightward pelvic tilt increases[16)]. Therefore, lateral weight shifts while walking are thought to

Table 1. Differences in pelvic tilt and pelvic rotation for each experimental condition (N=16, units:°)

Bag types		0%	5%	10%	15%
Hand bag	Right pelvic tilt	1.63 ± 0.50	1.68 ± 0.52	1.73 ± 0.66	2.03 ± 0.85
	Left pelvic tilt	1.63 ± 0.50*	1.66 ± 0.50	1.78 ± 0.66	2.59 ± 0.79*
	Rotation right	5.25 ± 1.57	5.15 ± 1.36	4.90 ± 1.48	4.82 ± 1.62
	Rotation left	5.26 ± 1.59	5.14 ± 1.37	4.96 ± 1.46	4.85 ± 1.61
Shoulder bag	Right pelvic tilt	1.63 ± 0.50*	2.01 ± 0.97	2.12 ± 1.09	2.22 ± 1.16*
	Left pelvic tilt	1.63 ± 0.50	1.98 ± 0.90	2.10 ± 1.09	2.2 ± 1.09
	Rotation right	5.25 ± 1.57*	5.09 ± 1.81	4.50 ± 1.57	3.98 ± 1.24*
	Rotation left	5.26 ± 1.59*	5.03 ± 1.82	4.50 ± 1.63	4.16 ± 1.39*
Cross bag	Right pelvic tilt	1.63 ± 0.50	1.72 ± 0.65	1.70 ± 0.74	1.76 ± 0.64
	Left pelvic tilt	1.63 ± 0.50	1.75 ± 0.65	1.71 ± 0.74	1.79 ± 0.69
	Rotation right	5.25 ± 1.57*	4.5 ± 1.75	4.14 ± 1.77*	4.08 ± 0.95*
	Rotation left	5.26 ± 1.59*	4.59 ± 1.70	4.22 ± 1.64*	4.06 ± 0.95*
Back pack	Right pelvic tilt	1.63 ± 0.50	2.12 ± 0.86	1.98 ± 0.86	2.15 ± 1.20
	Left pelvic tilt	1.63 ± 0.50	2.26 ± 1.00	2.00 ± 0.87	2.11± 1.18
	Rotation right	5.25 ± 1.57*	4.78 ± 1.67	4.44 ± 1.11*	4.15 ± 1.33*
	Rotation left	5.26 ± 1.59*	4.79 ± 1.75	4.47 ± 1.14*	4.18 ± 1.39*

Each value represents the mean ± SD.
*Statistically significant, $p<0.05$.

increase, leading to increased energy consumption and increases in unnecessary trunk movements. In contrast, for cross bags and back packs, since the bags are in contact with the trunk, the load is applied to both shoulders. As a result, the lateral pelvic tilt did not show any significant change in this study.

Changes in the anterior posterior pelvic rotation showed a tendency to decrease gradually as the bag weight increased. Pelvic rotation refers to a cross-section of pelvic movements which are related to trunk rotation. That is, as upper limb movements show a tendency to decrease as bag weight increased, trunk and upper limb movements are not thought to be natural. Given these results, when the bag is heavier, the efficiency of gait based on alternating movements of the upper limbs and the trunk may decrease.

A limitation of the present study is that since the values were measured with subjects walking while carrying bags of different weights during short periods, changes that may appear with subjects walking for long periods while carrying a bag of set weight cannot be known. Therefore, future studies should examine changes appearing in gait cycles and pelvic movements after walking for a long period of time.

When the study results are considered comprehensively, in cases where a bag is unilaterally carried by the shoulder or the hand, such as with a hand bag or a shoulder bag, lateral pelvic tilts are thought to increase when weight exceeding 15% of body weight is carried, leading to increases in the movement of the center of the body, and such that the efficiency of gait would decrease. For cross bags and backpacks, rather than lateral pelvic tilt, pelvic rotation is thought to decrease as the weight increases, such that upper limb movements are restricted.

ACKNOWLEDGEMENT

This study was supported by the Basic Science Research fund from Dong-Eui Institute of Technology.

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