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# KINETIC STUDY OF *SEITA*- FITTING

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We have already presented two studies of the traditional carrier frame, the *seita*. In our first study, we reported on *seita* users supporting loads not on the lumbar vertebrae but on the sacrum. In the second study, we showed that carrying a load on the sacrum was efficient in terms of metabolic rate, muscle activity, cadence and subjective responses. The purpose of this study was to verify the effect of carrying a load on the sacrum in terms of gait pattern. We compared the kinetic parameters produced while carrying a load on the sacrum (LOS) with those produced while carrying a load on the lumbar vertebrae (LOLV). Maximum propulsive force and medial impulse were significantly larger in LOS than in LOLV. These results suggested that a normal gait pattern was maintained more in LOS conditions than in LOLV conditions. This indicated that *seita*-fitting was efficient for carrying and transporting loads.
***Keywords:*** load carriage; backpack; gait pattern; force plate

## INTRODUCTION

We have reported two studies on the *seita*. *Seita* is the traditional carrier frame used for transporting loads on the back, by people in Nishiki-cho, Yamaguchi Prefecture, Japan (Kawahara et al., 1998a, Kawahara et al., 1998b). It is generally thought that supporting loads over a wide area of the back is better than over a small area. However, one of the characteristics of the *seita* is to support loads on a small lumbosacral area. In the first study, we investigated the relationships between body size and the dimensions of the *seita* (Kawahara et al., 1998a). This survey was conducted with 30 subjects at three mountain villages. We found that there were some significant correlations between body size and the dimensions of the *seita*. An additional survey using photographs indicated that subjects supported loads not on the lumbar vertebrae but on the sacrum with the *seitas*. We defined this load-supporting method with the *seita* as *seita*-fitting.

Next, to verify the effect of *seita*-fitting, we compared physiological measurements of two load-supporting conditions. One condition was to carry a load on the sacrum (LOS), based upon a *seita*-fitting. The other was to carry a load upon the lumbar vertebrae (LOLV), not based upon a *seita*-fitting. (In this study, we use the acronym LOLV instead of LOL used in Kawahara et al. (1998b). LOLV and LOL are the same.) We measured oxygen uptake, muscle activity, heart rate, cadence and subjective response (Kawahara et al., 1998b). The results showed that heart rate, oxygen uptake and integrated EMGs of some leg muscles were significantly lower in LOS than in LOLV. These things made it clear that carrying a load in LOS was more efficient than in LOLV in terms of metabolic cost, muscle activity and some other measurements.

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Although the physiological study was valuable in verifying the effects of a *seita*-fitting, it only dealt with one aspect of a *seita*-fitting. Pierrynowski et al. (1981) concluded that a biomechanical assessment could provide more information about load carrying and carrying devices than was possible from metabolic data alone. When we verify the effects of a *seita*-fitting, kinetic assessment will focus on another aspect of a *seita*-fitting and provide more information.

As mentioned above, we have shown that carrying in LOS based upon a *seita*-fitting kept the leg-muscle activity lower than in LOLV not based upon a *seita*-fitting. What does it mean? The leg muscles propel the body forward, resist the gravity, and fix and control ankle movement. They work in coordination to control the foot that is the contacting point between the body and the ground. However, it is difficult to understand the functional changes of leg muscle activity by a *seita*-fitting with electromyogram alone. The higher leg muscle activity does not always mean that the subject exerts a higher propelling force, nor higher vertical force. The kinetic data will provide us useful information to understand the functional change of the leg muscle activity by a *seita*-fitting.

Literature on the kinetics of load carriage is very sparse. Kinoshita (1985) compared a backpack with a double pack that distributed the load to the front and back, according to selected biomechanical parameters describing the walking gait. Martin and Nelson (1986) studied the carrying of a number of different loads, ranging from 0 to 36 kg, and found no significant difference between the single-leg support times under any condition. Lloyd and Cooke (2000) assessed kinetic changes associated with load carriage, using both a traditional and a new rucksack design incorporating front balance pockets.

The purpose of this study was to verify the effect of a *seita*-fitting on gait pattern in terms of kinetic parameters. In this study, we evaluate the kinetic changes associated with a *seita*-fitting, using a force plate.

## METHODS

*Subjects*

Ten healthy male subjects volunteered in this experiment. Their occupations were university students, graduate students and researchers. Although they were used to physical exercise, they had not engaged in load carriage. All subjects were informed of the purpose and procedures of the study and consented to participate. The age, height, and body mass of the subjects in mean ± SD were 24.3 ± 3.4 years old, 1735 ± 34 mm, and 67.0 ± 5.2 kg, respectively.

*Experimental conditions*

The experiment was conducted in the laboratory. The mean and SD of air temperature and relative humidity were 26.0 ± 0.6 C° and 89.2 ± 6.0 %RH, respectively. Subjects wore T-shirts, underpants, shorts, socks and sports shoes.

*Apparatus*

Experimental carrier frame, load condition and load supporting conditions were the same as used in our previous study (Kawahara et al., 1998b). The in-house-built carrier frame had a movable lumbar section as part of the carrier frame. The lumbar part could be fitted either on the sacrum (i.e., LOS position) or on the lumbar vertebrae (i.e., LOLV position), and the distance between the two positions was 60 mm (Figure 1). The mass of the experimental carrier frame and the load were 7.5 kg and 40 kg, respectively. As the variation of the subjects' physical strength and body size were small, this study was not considered to be affected by the fixed load mass or the fixed distance between the two positions.

To evaluate the kinetic changes, we used an in-house, purpose-built force plate. This force plate consisted of a footboard, four vertical-component sensors, three horizontal-component sensors, and a chassis. The force plate was built into a walking platform made of wood. Two strain gauges consti-

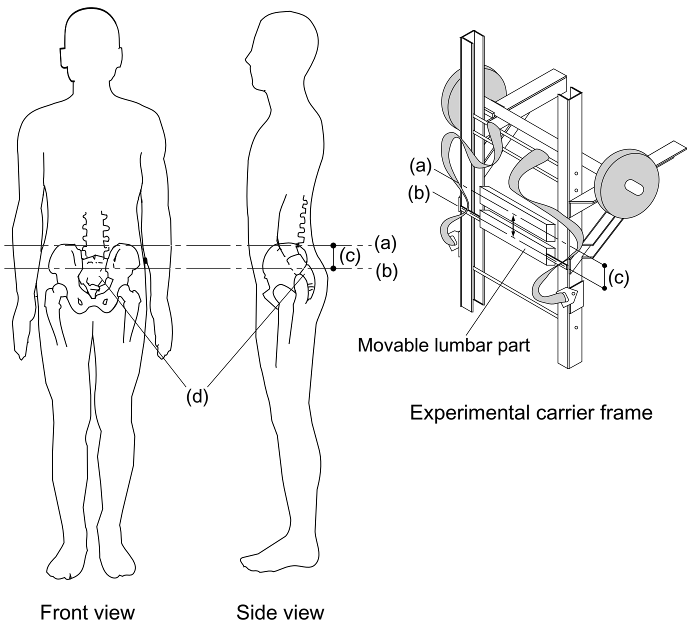


Fig. 1. LOLV position and LOS position.
(a) LOLV position, (b) LOS position, (c) distance between “a” and “b”, (d)sacrum.

tuted each sensor detecting the strain of the prop supporting the footboard. Vertical force was calculated from the data detected by four vertical-component sensors. Anteroposterior force and mediolateral force were calculated from the data detected by three horizontal-component sensors. The stress-strain correlation coefficient of each sensor was more than 0.9999, and the hysteresis of each sensor was less than 0.7 %. All of these sensors assured enough accuracy for this study.

The strain detected by the sensors was amplified and sampled by a sensor interface board (KYOWA Electric Instruments, PCD100A) and personal computer (NEC, PC9801RX). Sampling frequency and duration were 300 Hz and 5 sec, respectively. Figure 2 illustrates the outline of the experiment.

*Procedure*

We set two experimental load-supporting conditions, i.e., load-on-lumbar-vertebrae condition (LOLV), load-on-sacrum condition (LOS), and no-load condition (NL). Before the kinetic measurement, each subject adjusted the shoulder strap length for the lumbar part of the carrier frame to fit exactly on the sacrum. This was the LOS condition. Next, with the shoulder strap length fixed and with the lumbar part of the carrier frame moved to the LOLV position, subjects fixed the lumbar part of the carrier frame precisely on the lumbar vertebrae. This was the LOLV condition. This process was the same as in our previous study (Kawahara et al., 1998b). In NL, subjects carried nothing.

Measurement of the reaction forces during walking was repeated five times for each condition. Subjects were instructed to step on the footboard with the right foot. Before measurement, subjects adjusted the starting point to step on the footboard with the right foot, and then they practiced to walk on the walking platform many times. In this experiment, walking speed and step length were not controlled. Subjects walked at their own speed and with their own preferred step length. There were more than four steps from the starting point to the footboard. After stepping on the plate, subjects kept walking for a few meters. Each subject performed in a fixed order, LOLV, LOS, and NL.

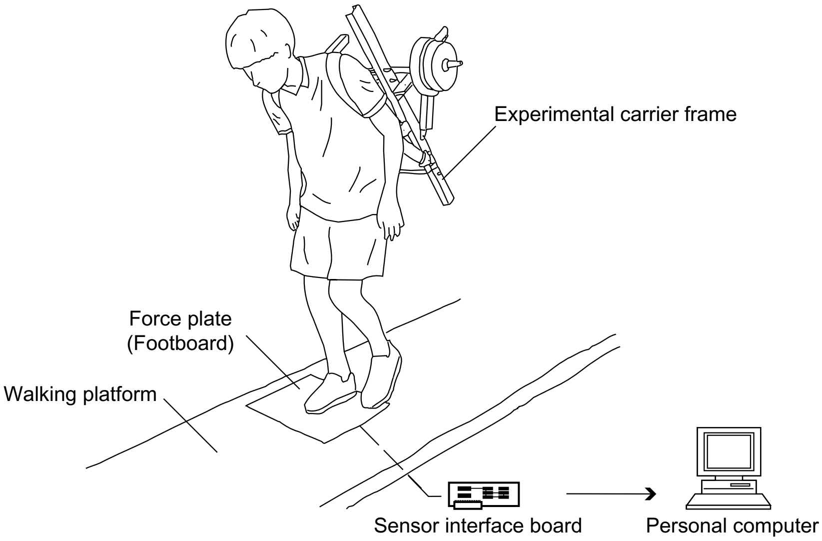


Fig. 2. Apparatus used in this experiment.

*Kinetic parameters and statistics*

Figure 3 illustrates the kinetic and temporal parameters chosen for analysis for vertical, anteroposterior and mediolateral forces. In vertical component, there appears one peak at heel contact and the other peak at push off in normal walking. In loaded conditions, the second peak often disappeared. So, we used only the first vertical peak to calculate the kinetic parameters. Although mediolateral forces were analyzed in the same way, maximum mediolateral forces and times to mediolateral forces provided no useful information. That was because the clear lateral or medial peaks often disappeared, especially in LOLV or LOS. As a result they are not included here.

Differences in load-supporting conditions were analyzed with one-way analysis of variance (ANOVA) followed by Fisher's Protected Least Significant Difference test (Post-hoc test). In all tests a significance level of 0.01 and 0.05 was used.

## RESULTS

*Walking gait and support time*

Figure 3 shows an example of the time-force curve in walking with load on the back. In walking without a load, the shape of time-force curve in a vertical component is characterized by its double-peaked curve with two local maxima and one local minimum. However, in walking with a load on the back, the second local maximum and the local minimum were typically not clear. For the anteroposterior component with a load, the braking impulse was often larger than the propulsive impulse. And for the mediolateral component, the medial impulse with a load tended to be far smaller than without a load, or sometimes disappeared.

The mean and SD for the support time (seconds) for each condition are shown in Figure 4. Statistical analysis showed no significant difference between the load-supporting conditions.

*Vertical component*

The mean and SD for vertical components for each condition are shown in Figure 5. Statistical analysis (ANOVA) showed significant differences between the load-supporting conditions for maxi-

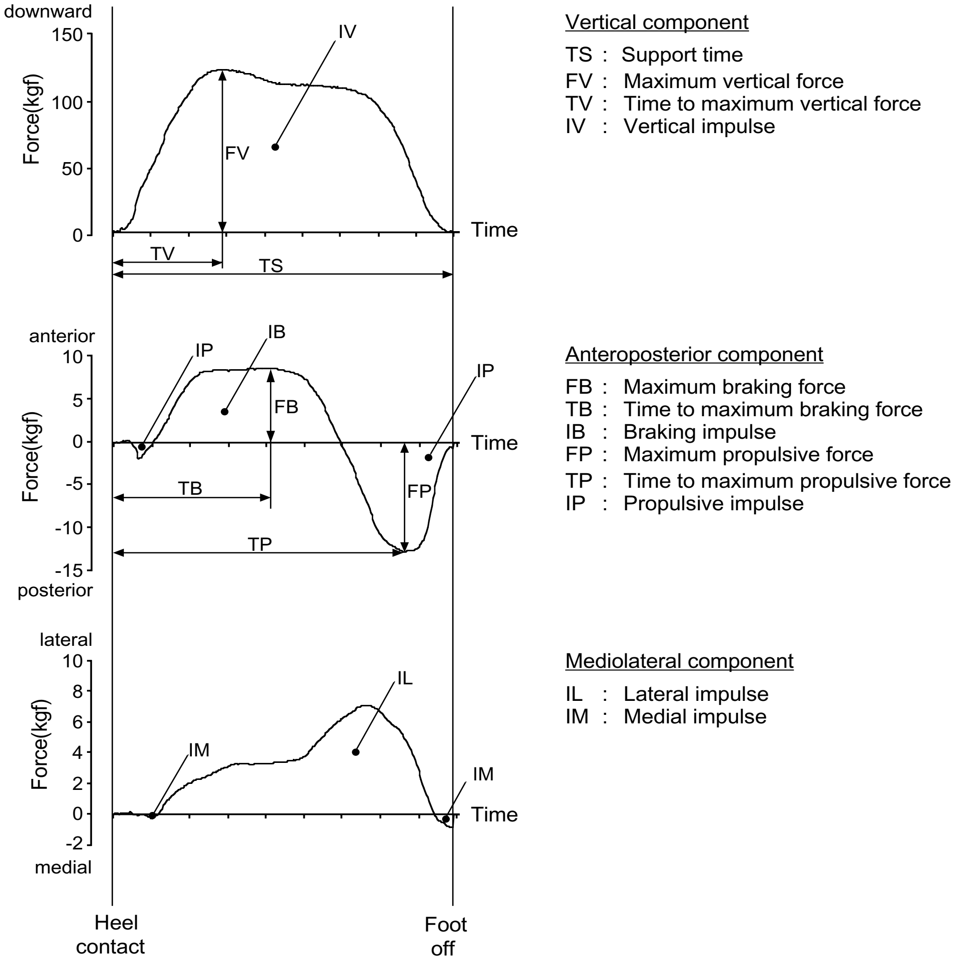


Fig. 3. Graphic representation of the typical forces in LOS condition with kinetic parameters.

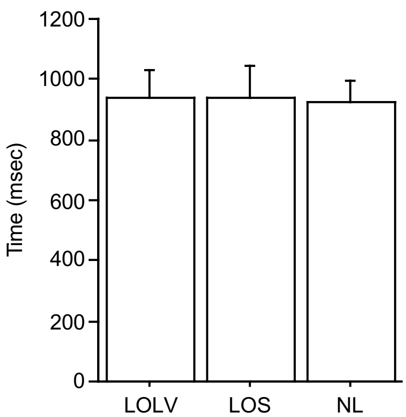


Fig. 4. Mean and SD of support time.
LOLV: load on lumbar vertebrae, LOS: load on sacrum, NL: no load.

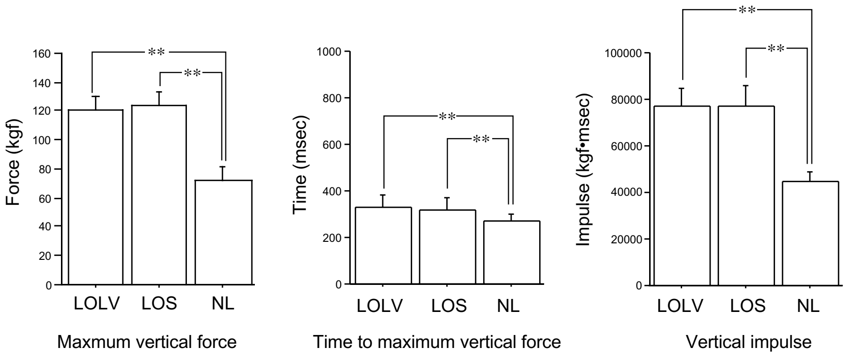


Fig. 5. Mean and SD of vertical parameters (** $P< 0.01$).
LOLV: load on lumbar vertebrae, LOS: load on sacrum, NL: no load.

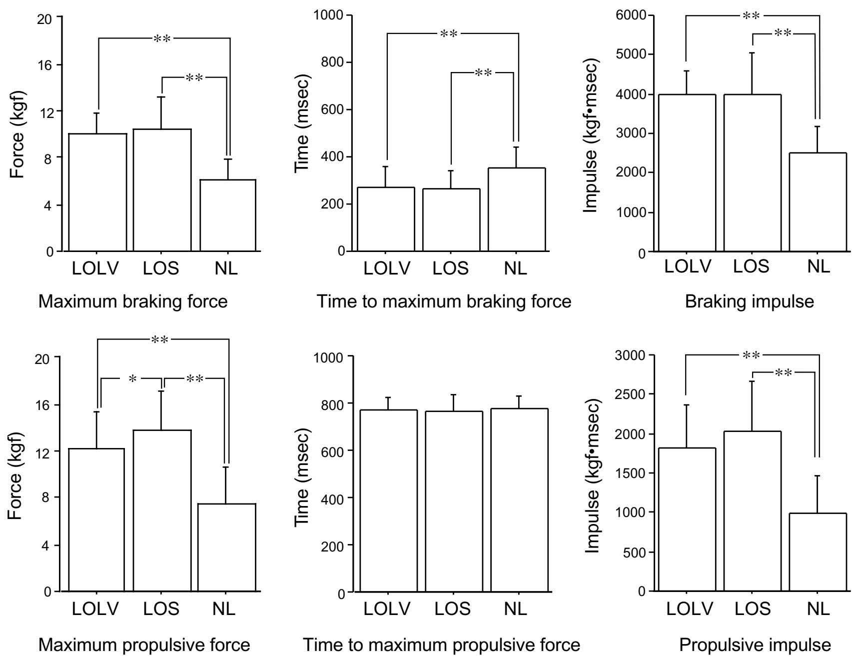


Fig. 6. Mean and SD of anteroposterior parameters (* $P< 0.05$, ** $P< 0.01$).
LOLV: load on lumbar vertebrae, LOS: load on sacrum, NL: no load.

mum vertical force, the time to maximum vertical force, and vertical impulse. Post-hoc testing indicated as follows: maximum vertical force and vertical impulse in LOS and LOLV were significantly larger than in NL; times to the maximum vertical force in LOS and LOLV were significantly longer than in NL.

*Anteroposterior component*

Means and SD for anteroposterior components for each condition are shown in Figure 6. Statistical analysis (ANOVA) showed significant differences between the load-supporting conditions for maximum braking force, time to maximum braking force, braking impulse, maximum propulsive

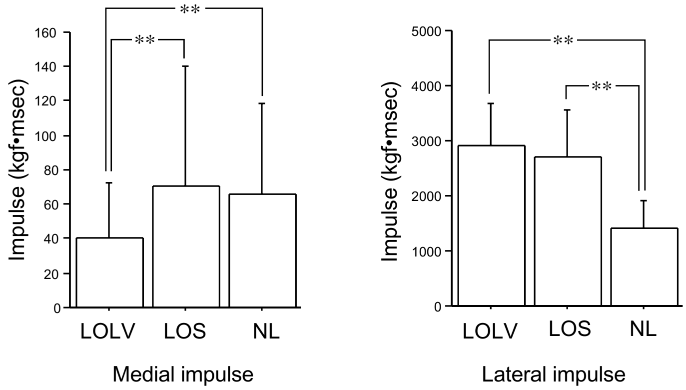


Fig. 7. Mean and SD of mediolateral parameters (** $P < 0.01$).
LOLV: load on lumbar vertebrae, LOS: load on sacrum, NL: no load.

force, and propulsive impulse. Post-hoc testing indicated as follows: maximum braking force and braking impulse in LOS and LOLV were significantly larger than in NL; times to maximum braking forces in LOS and LOLV were significantly shorter than in NL; maximum propulsive forces and propulsive impulse in LOS and LOLV were significantly larger than in NL; maximum propulsive forces in LOS were significantly larger than in LOLV.

*Mediolateral component*

Means and SD for mediolateral components for each condition are shown in Figure 7. Statistical analysis (ANOVA) showed significant differences between the load-supporting conditions for medial impulse and lateral impulse. Post-hoc testing indicated as follows: lateral impulse in LOS and LOLV were significantly larger than in NL; medial impulse in LOS and NL were significantly larger than in LOLV.

## DISCUSSION

The purpose of this study was to compare the kinetic parameters for LOS with those for LOLV. We have shown that maximum propulsive force and medial impulse in LOS were significantly larger than those in LOLV.

At first, we shall discuss support time. There was not a significant difference of support time between the load-supporting conditions. With increase of walking speed, support time shortens (Porada, 1993). Although subjects were not instructed on the walking speed in this study, from the result of support time, we infer that there was no difference in walking speed between the load-supporting conditions.

For the anteroposterior component, there was no significant difference in the propulsive impulse between LOS and LOLV. The result indicated that the same impulses were needed to transport the same weight for the two conditions. However, the maximum propulsive force during the push off was significantly larger in LOS than in LOLV, while there was no difference between the two conditions in support time and in propulsive impulse. Considering from these results of maximum propulsive force, propulsive impulse, and support time, it is suggested that propulsive time-force curve was sharp in LOS, and that it was dull in LOLV. In other words, these results suggest that subjects in LOS kicked the ground and propelled themselves forward with more momentary strength than in LOLV.

For the mediolateral component, the lateral impulses were significantly larger in LOLV and

LOS than in NL. Kinoshita (1985) reported that the lateral impulses increased as the carried load increased. Our result of the lateral impulse is in agreement with Kinoshita (1985). These increases of the lateral impulse may be explained by the increase of the stride width. The heavier the load the subject carries, the larger the stride width would be. To adapt a heavier load, the stride width might be larger. The larger stride width might cause a larger lateral impulse, because the center of mass has to move widely in a mediolateral direction. In contrast, the medial impulses were significantly larger in LOS and NL than in LOLV. The smaller medial impulse in LOLV might be explained by the knee flexion. If the knee flexion is greater in LOLV than in LOS, the medial impulse can be smaller in LOLV than in LOS. We cannot conclude because we have no data of the knee flexion. However, our result of the medial impulse indicated that subjects kept normal kinetic pattern in LOS and they did not keep it in LOLV.

Looking at the anteroposterior and mediolateral components together, it is suggested that the gait pattern might be maintained as a normal gait pattern more in LOS than in LOLV. We use the word "normal" to refer to "the state without load". From these kinetic data and the observation during the experiment, we infer that the gait in LOLV might be similar to walking with gliding steps. In walking with gliding steps, the sole of a foot moves horizontally, the knee flexion is considerable, and the vertical movement of the body is small. This walking pattern is effective in absorbing shock, and is one of the adaptations to a load. The propulsive power in walking with gliding steps would be less than walking normally. The body-plus-load center of mass over the rear foot is not moved by kicking the ground forcefully, but shifts gently to the front foot when both feet are contacting the ground. To adapt to a load, knee flexion increases after impact and vertical, anteroposterior and mediolateral movements of the body decrease. We make the inference that, in LOLV, subjects walked with gliding steps to adapt to a load carried with an unfitted carrier frame, and that, in LOS, subjects maintained the normal walking pattern more than in LOLV. There is room for further investigation using kinematic data to prove the inference.

Kawahara et al. (1998b) reported that leg muscles (tibialis anterior, soleus, and medial head of gastrocnemius) exhibited more activity in LOLV than in LOS when subjects walked on a treadmill at a fixed walking speed. In walking forward, the gastrocnemius, soleus, and tibialis anterior muscles cooperate to propel the body forward. In the present study, the propelling force was less in LOLV than in LOS at the uncontrolled walking speed. There was a difference of walking speed condition between the two studies. However, the smaller propelling force in LOLV can explain the higher activity in leg muscles in LOLV reported by Kawahara et al. (1998b) as follows: the higher activity of leg muscles in LOLV was not caused by the greater propelling force, but caused by the greater work to fix and control ankle movement that was necessary when a propelling force was exerted in LOLV; in contrast, the lower activity of leg muscles in LOS was caused because it was less necessary for leg muscles to fix and control ankle movement in propelling the body.

Now, we shall focus on the relationship between the difference of the load supporting point and the gait pattern. In general, the heavier a subject is loaded on the back, the greater forward inclination of the trunk is (Knapik et al., 1996). As the carried load increases and forward inclination of the trunk increases, the lumbar curvature disappears and the pelvis tilts posteriorly. However, it is likely that carrying in LOS (i.e., putting the load on the sacrum) can be effective in resisting these postural changes. Kim et al. reported that the atrophy of the psoas major muscle with age might make the step length shorter (Kim et al., 2000), and that the exercise of the psoas major muscle could make the step length longer in elderly people (Kim et al., 2001). The role of the psoas major muscle is to flex the hip joint, to accentuate the lumbar curvature, and to stabilize the pelvis (Kapandji, 1974; Andersson et al., 1995). Therefore, we can say that the force to strengthen the anterior inclination of the pelvis and the lumbar curvature could lead to the longer step length. Putting the load on the sacrum could fill the role of this force. Thus, it is possible that, in walking, carrying in LOS would let the leg move further forward and the step length be longer than in LOLV. This hypothesis helps account for the result of maximum propulsive force. In addition, we reported before that the cadence was less in LOS than in

LOL (that is the same as LOLV), which means that the step length was longer in LOS than in LOLV because the walking speed was fixed on the treadmill (Kawahara et al., 1998b). However, we cannot conclude here. To clarify the relationship between putting the load on the sacrum and its effects on the posture and the gait pattern, more biomechanical examinations are needed.

In this study, we verified the effect of a *seita*-fitting i.e., the effect of carrying a load on the sacrum, using kinetic parameters of gait patterns. Carrying a load on the sacrum makes it more possible to maintain the normal walking pattern than carrying it on the lumbar vertebrae. We arrive at the conclusion that a *seita*-fitting helps people walk as normally as possible with a load carried on the back, and that the normal walking pattern made possible through a *seita*-fitting gives *seita* carriers an efficient and safe method for transporting a load.

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