INFLUENCES OF ASYMMETRIC LOAD-CARRYING ON JOINT MOMENTS AND ANGULAR IMPULSES IN LOWER LIMBS

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The purposes of this study were to investigate whether angular impulse and pattern of the support moment for each leg change during walking with a load in one-hand, and whether relative contribution of each joint moment in the lower limbs to the support angular impulse changes along with the one-hand load-carrying. Walking with and without a bag were analyzed using a motion-capture system with six cameras and two force plates, then joint moments and angular impulses were calculated. Walking with an asymmetric load resulted in the increased support angular impulse, but no significant difference was found between legs. Hip angular impulses were identical despite of the bag-weight and the stance leg. Knee angular impulse increased with the bag-weight for the ipsilateral side, but not for the contralateral side.

KEY WORDS: gait, support moment, joint torque

INTRODUCTION:

Asymmetric load-carrying is one of the most popular activities in daily life. For athletes, they have frequent opportunities to carry their bag. They sometimes have to do it even they had some injuries in their lower limb. So far, it has been known that the asymmetric load-carrying results in the increased contralateral hip joint force and abduction torque and the decreased ipsilateral hip joint force and abduction torque (Bergmann, Graichen, Rohlmann, LInke, 1997; Matsuo, Hashimoto, Koyanagi, & Hashizume, in press). Further understanding of the asymmetric load-carrying helps prevent deterioration of the symptom owing to the asymmetric load-carrying, develop appropriate rehabilitation programs, or progress the quality of life for the patients with injuries in lower extremities.

In normal gait, ankle joint bears the primary role during stance phase (Kepple, Siegel, & Stanhope, 1997). As gait speed increases, contribution of hip joint increases (Riley, Croce, & Kerrigan, 2001). Since asymmetric load induces imbalance in the frontal plane, it is expected that relative contribution of a leg to propulsive function may differ from that of another leg, and that relative contribution of each joint may change.

The purposes of this study were to investigate 1) whether support angular impulse of one leg, which represents the support and forward propulsion capacity, is different from another leg during asymmetric load-carrying, and (ii) relative contribution of each joint to the support angular impulse of the corresponding leg changes with the asymmetric load-carrying.

METHOD:

Data Collection: Five young women (age:19.4 ± 0.9 years, height:1.61 ± 0.06 m, mass:56.8 ± 4.7 kg) participated in this study. They were all right-handed and free of any neurological or orthopedic pathologies. All participants read and signed an informed consent approved by the local ethics committee after the nature of the study was explained.

The participants were instructed to walk barefoot along an 8m walkway in which were embedded two force plates (BP600900; Advanced Mechanical Technology Inc., Watertown, USA). Thirty-one reflective markers (20 mm spheres) were placed at anatomical landmarks and 3 reflective markers were placed on the bag (a shopping bag with a handle, 0.31 X 0.28 X 0.085 m in size). Walking with and without the bag were analyzed using a six-camera VICON system at 120 Hz, and two force plates at 1080 Hz. There were three walking conditions: normal walking, walking with a 3-kg bag, and walking with an 8-kg bag. Five trials for each condition were performed. The order of the conditions was counterbalanced among participants.

Data Analysis: Position and ground reaction force data were filtered using a fourth-order Butterworth filter with a 6-Hz of cutoff frequency for the position data and 40 Hz for the ground reaction force data. Kinetics were calculated using the conventional inverse dynamics equations of Newton-Euler's method with estimated segmental inertia properties (Ae, Tang, Yokoi, 1992). The net summation of the moments at three joints (hip, knee, and ankle), support moment, was calculated. Joint angular impulses and support angular impulse were then calculated with positive and negative values separately. To evaluate similarity of the support moment pattern during the stance phase, cross-correlation coefficience between both legs in each walking condition and those among the walking conditions for each leg were calculated and averaged after Fisher Z-transformation. Relative contribution of each joint angular impuse to the support angular impulse were also calculated. Two-way ANOVA (leg x walking condition) were performed for each joint angular impulses and the support angular impluse. When the main effect was found, post-hoc pair-wise comparisons with Bonferroni corrections (significance level $\alpha = 0.05$) followed.

RESULTS:

The support moment patterns were basically same between legs and among the walking conditions (Figure 1). Mean cross-correlation coefficients between legs were .94, .90, and .89 for the normal walking, the 3-kg bag condition, and the 8-kg bag condition, respectively. Cross-correlation coefficients among the walking conditions in each leg ranged from .91 to .99. For the support angular impulse, main effect of the walking condition was significant, although no interaction effect or main effect of the leg was found. Walking with an asymmetric load increased the support angular impulse (load effect: $p < .000$, Figure 1 (a) & (e), Figure 2). The support angular impulse for the 8-kg bag carrying was significantly larger than normal walking and walking with 3-kg bag.

Both positive hip joint angular impulse for the contralateral side tended to increase with the bag-weight, no interaction effect or main effect of the walking condition were not provided (ps > .145, Figure 1 (b) & (f) , Figure 2). None of significances were found in both positive and negative hip angular impulses.

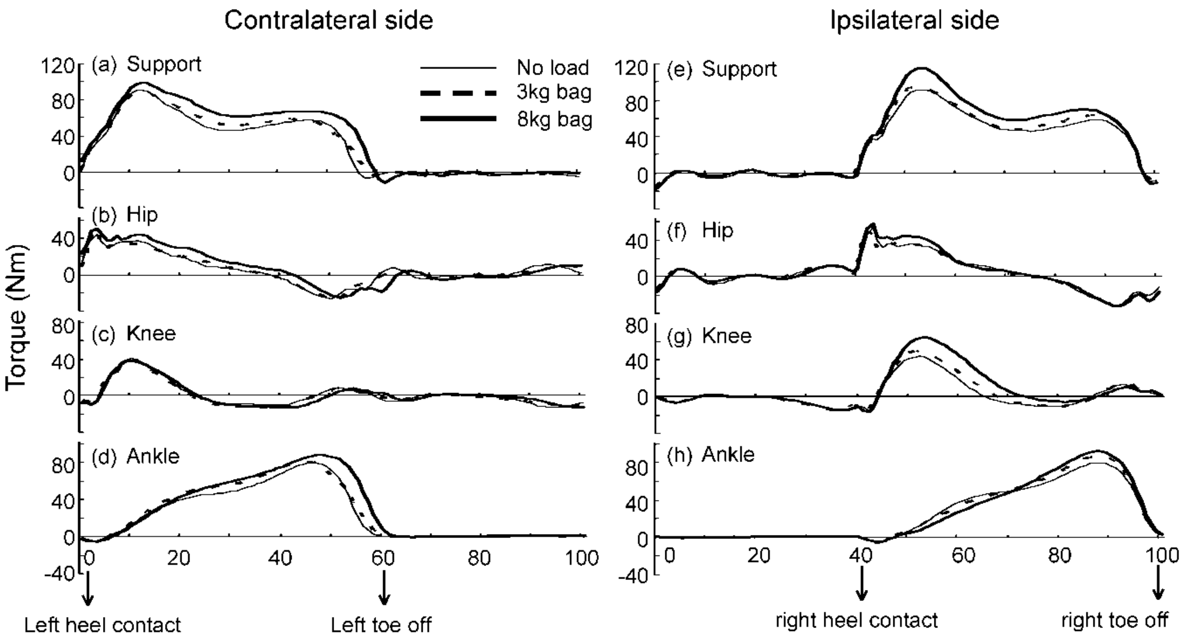

Figure 1: Means of support moment and joint moments of an exemplar. Positive values indicate extensor or plantar flexor moment. Time is normalized so as to 1 cycle is 100% and synchronized with the instant of heel contact.

For positive knee angular impulse, the interaction effect between the leg and the waking condition was significant (p = .001, Figure (c) & (g), Figure 2). As the weight of the bag increased, moment curve for the ipsilateral (right) knee angular impulse shifted upward (increased) during the stance phase (p = .004). The impulse for the 8-kg bag carrying was significantly larger than normal walking (p = .006) and walking with the 3-kg bag (p = .018). On the other hand, the knee angular impulse for the contralateral side did not change with the increased bag-weight. Main effect of leg was also significant because the increased ipsilateral knee impulse (p = .000). Negative knee angular impulse for the ipsilateral knee was smaller in absolute values than that of the contralateral knee (p = .004), especially in the middle or late stance phase.
For the ankle joint, both main effects of the leg and the walking condition were significant for the positive angular impulse (p = .001 and P = .018). The positive angle angular impulse for the contralateral ankle was larger than that for the ipsilateral side and that for the 8-kg bag carrying was larger than that for the normal walking.

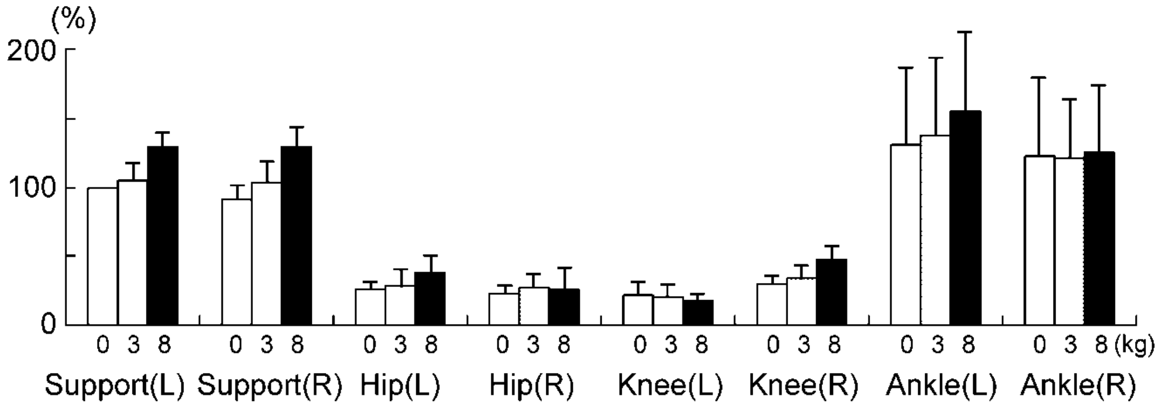

Figure 2: Means of support angular impulse and positive joint angular impulses. Only positive angular impulses were shown. Each value was normalized by the support angular impulse of the contralateral (left) leg.

DISCUSSION:
The support angular impulse of one leg in the normal walking was almost same as another leg. The trend was maintained even though they walked with the asymmetric load. As the support moment was the total moment which represent a total limb pattern to push away from the ground, the participants in this study gained almost same propulsive force from both legs, resulting in maintaining a similar walking speed for each leg. Allard, Lachance, Aissaoui, & Duhaime (1996) investigated joint moments, powers, and mechanical energies during normal walking and showed that the total positive work was similar for both limbs. Our previous study (Matsuo, et al., in press) showed that not only intralimb coordinations but also interlimb coordinations in the lower limbs, which included segment angular velocity, did not change with the increased bag-weight. Putting the results of the previous study with the current results indicates that close resemble power profiles for both legs may be obtained and expected that the total positive work was also similar for both legs.
Some researchers (Kepple, et al., 1997; Kerrigan, Todd, Della Croce, Lipsitz, & Collins, 1998) claimed that ankle joint produced primary torque for the forward progression. On the other hand, Riley et al. (2001) reported that the early part of the stance phase played the primary role of body forward propulsion and its contribution of hip joint increased as walking speed increased, using linear power and induced acceleration analyses. They conculded that hip joint made a primary contribution to the forward progression. The results of the current study showed that early part of the support angular impulse largely depended on both hip and knee angular impulses and late part of the support angular impulse largely depended on the ankle angular impulse. Therefore our results partly support both theories from the viewpoint of the support angular impulse. Further detailed investigation must be necessary in this issue.

When a weight was loaded on one side, the degrees of contribution of each joint to the support angular impulse changed. Pattern of the change completely varied between legs. For the contralateral side, the hip and the ankle angular impulses increased as the bag-weight increased, but the knee angular impulses did not change. On the other hand, for the ipsilateral side, only the knee angular impulse increased as the bag-weight increased, but the hip and the ankle angular impulses did not. It indicates that both legs have different function during the asymmetric load-carrying. DeVita & Hortobagyi (2000) illustrated that elderly adults had greater hip angular impulse and less knee and ankle angular impulses during normal walking, in comparison with young adults, even the support angular impulse for the elderly adults was nearly identical to that for the young adults. Similar reformation of the relative contribution has been observed in the individuals with injury in the lower limbs (Devita, Blankenship-Hunter, & Skelly, 1992; DeVita, Hortobagy, & Barrier, 1998). They concluded that functional decline by aging or injuries caused a shift in the locus of function in motor performance. The results of this study illustrated that the reformation differently occurred in both legs. The flexible reformation was verified in the able-bodied young adults, too. Total torque required to achieve the purpose may redistribute, depending on the relationship between capacity of locomotion system and external environment.

CONCLUSION:

This study illustrated that the asymmetric load-carrying did not differently affect both legs in terms of the support moment. However, the influence on the relative contribution of each joint to the support moment was much different between both legs. It implies that there is an appropriate side on which a bag is hold when a player with a certain injury in his leg carries a bag and that the side depends on the injured region.

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