SUMMARY
The purpose of this study was to investigate kinematics of lower limb during walking while pushing a wheelchair. Five healthy male subjects were asked to execute to walk normally, walk while pushing a wheelchair with no weight, and walk while pushing a wheelchair loaded with a weight. The hip joint was flexed larger and extended smaller while pushing a wheelchair regardless of the weight. It seems that the differences depend on the forward tilt angle of the thorax.

INTRODUCTION
Transportation using a wheelchair is a commonly used method for a person with lower limb disorder, an elderly person, and others. The elderly population has been increasing in advanced nations, so it is expected that persons who need to use wheelchairs for mobility will be increasing too. Most elderly persons with using a wheelchair need support by another person to drive the wheelchair. Although such support to drive a wheelchair is important, there has been little research to investigate the motions of pushing a wheelchair [1, 2]. The purpose of this study was to investigate kinematics of lower limbs during walking while pushing a wheelchair.

METHODS
Five healthy male subjects (age: 20.6 ± 1.0 years, height: 1.71 ± 0.07 m, mass: 56.2 ± 5.2 kg) volunteered for participation. All the subjects signed an informed consent form. All experimental protocols were approved by the research ethics board of Hyogo University of Health Sciences. Each subject was required to walk normally, walk while pushing a wheelchair with no weight, and walk while pushing a wheelchair loaded with a 60 kg weight. Each condition was performed until five succeed trials were collected. Order of the conditions was randomized. An 8-camera motion capture system (Vicon MX, Vicon Motion Systems; Oxford, UK) operating at 100 Hz was used to collect all kinematic data. On each subject were attached 34 retroreflective markers, at bony landmarks of the Plug-in-gait model (Vicon Motion Systems; Oxford, UK). Kinematic parameters were then calculated by using the Plug-in-gait model. Analysis of variance (ANOVA) was performed for spatial and temporal descriptors and angles. Post hoc analyses for significant parameters were performed using Tukey’s multiple comparison test. The level of significance was set at less than 0.05.

RESULTS
Stride time and stride length were not significantly different among three conditions (Table 1). Velocity of walking while pushing the weighted wheelchair was significantly smaller than that of normal walking (p < 0.05) (Table 1). Figure 1 shows the peak flexion and extension angles of the hip. The peak flexion angle of the hip of normal walking was significantly smaller than when pushing a wheelchair, either with or without the weight (p < 0.01). The peak extension angle of the hip of the normal walking was significantly smaller (more extended) than in the other two conditions (p < 0.01).

### Table 1: Temporal and spatial descriptors of three conditions.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Stride Time (s)</th>
<th>Stride Length (m)</th>
<th>Velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>normal walk</td>
<td>1.03 ± 0.05</td>
<td>1.43 ± 0.08</td>
<td>1.39 ± 0.09</td>
</tr>
<tr>
<td>wheelchair</td>
<td>1.03 ± 0.08</td>
<td>1.39 ± 0.15</td>
<td>1.35 ± 0.13</td>
</tr>
<tr>
<td>wheelchair with weight</td>
<td>1.10 ± 0.07</td>
<td>1.38 ± 0.16</td>
<td>1.25 ± 0.10</td>
</tr>
</tbody>
</table>

*: Significant different (p < 0.05) between normal walk and wheelchair with weight.

Figure 2 shows the peak flexion and extension angles of the knee. The peak flexion angle of the knee of walking with the weighted wheelchair was significantly smaller than in the other two conditions (p < 0.05). There was no difference among three conditions in the peak extension angle of the knee.

Figure 3 shows the peak plantar and dorsiflexion angles of the ankle. There were no significant differences among the three conditions in either peak dorsi or plantar flexion angle of the ankle.
Figure 4 shows the average forward tilt angle of the thorax. The average forward tilt angle of the thorax during normal walking was significantly smaller than in the other two conditions (p < 0.01).

DISCUSSION
Although the stride time of walking while pushing the weighted wheelchair was a little longer and the stride length a little shorter, these two descriptors were not significantly different among the three conditions. The velocity of walking with the weighted wheelchair involved increases in both stride time and stride length, resulting in slower than normal walking. Because acceleration and deceleration of a larger mass requires greater work, it was thought that in the condition with the weight would result in a smaller velocity than for conditions requiring less change in acceleration. The peak flexion and extension angles of the hip and the average forward tilt angle of the thorax during walking while pushing a wheelchair were greater than in normal walking. These results show that the hip flexion and extension angles depended on the forward tilt angle of the thorax. A person who pushes a wheelchair must maintain a forward bending position to grasp the grips of the wheelchair. Since no significant differences were seen between walking with and without the wheelchair, these changes appear to have depended on the structure of the wheelchair, not on weight. Large hip flexion was needed when pushing the wheelchair, suggesting that a large hip flexion torque might be required. The differences in knee flexion were statistically significant but small in magnitude. Forward tilt the thorax when pushing the weighted wheelchair was a little larger than when the weight was removed. This forward tilt might have provided extra space between the subject’s lower body and the back of the wheelchair, making it possible to keep extended knee during walking with pushing wheelchair.

CONCLUSIONS
This study investigated kinematics of the lower limbs during walking while pushing a wheelchair. The hip joint flexed more and extended less during the pushing of a wheelchair. This change in the hip joint angle was partly due to a forward tilt of the thorax. Kinematic differences in the lower limbs between weighting the wheelchair and having it empty were small if the wheelchair was being pushed at a constant speed.

ACKNOWLEDGEMENTS
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REFERENCES