Gender differences in joint torque focused on hip internal and external rotation during a change in direction while walking

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Abstract. [Purpose] To investigate lower-extremity joint torque during walking direction changes, focused on gender differences in pelvic width. [Subjects and Methods] Healthy males and females (n=10) changed direction while walking by side-stepping (SS) and crossover stepping (CS), stepping the left leg to the left or right, respectively, over the right leg. Movements were recorded using four infrared cameras, and ground reaction force of each lower extremity measured using two force platforms. Joint torque of each lower extremity was calculated, and each joint peak torque among walking, SS and CS was compared between genders. Moreover, correlation between joint torque showed a gender difference and width of pelvis normalized by width of shoulder (P/S ratio) was examined. [Results] Right external and internal rotation torques during CS were higher in males. Left- and right-ankle plantar flexion torques were also higher in males during CS, while the P/S ratio was larger in females, with a positive correlation between P/S ratio and hip external and internal rotation torques. [Conclusion] No gender differences were found in joint torque during walking and SS, but only during CS. The hip external and internal rotators are necessary for smooth CS in females in terms of P/S ratio.

Key words: Walking, Joint torque, Gender difference

INTRODUCTION

When walking it is necessary not only to move straight ahead but also to perform starts and stops in addition to changes in direction. Some patients seems to fall as they change direction during walking, and it is known that falling during a change in direction is 7.9 times as likely as when walking straight1). There have been some studies concerning changes in direction2–5) in addition to joint torque too6–8). Concerning joint torque, we investigated lower extremity joint torque during a change in direction while walking6). In our previous research, subjects employed two methods of changing direction; side step (SS) and crossover step (CS). Hip extension, external and internal rotation torque in the stance leg were all higher during CS than when walking or performing SS. However, there no research concerning gender difference during a change in direction. It is important to identify gender differences during changes in direction, because cases of hip joint disease and total hip arthroplasty (THA) are more frequent in females. In general, hip external and internal rotation torques might show a gender-related difference in pelvic width because pelvic width (distance between tops of the iliac crest) tend to be wider in female. Moreover, the more wide pelvis has, the more pelvic rotation torque increases. Moreover, there has been no research into the relationship between horizontal pelvic rotation and hip external and internal rotation torques during changes in direction. The hip external and internal rotation torques were necessary movement for pelvic rotation because on the stance, horizontal pelvic rotation was described as horizontal hip rotation. The hip external and internal rotation torques control the horizontal pelvic rotation during walking and changes in direction, and its magnitude might therefore be influenced by pelvic width.

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Consequently, we hypothesized that the hip external and internal rotation torque is greater in females during changes in direction because the pelvic shape shows a gender difference. The purpose of this study was to examine lower extremity joint torque during a change in direction while walking and to investigate gender differences based on pelvic shape.

SUBJECTS AND METHODS

The subjects were healthy, defined as having no orthopedic or neurological disorders, and comprised ten males (age: 21.6 ± 0.52 years, height: 171.1 ± 4.9 cm, body mass: 65.5 ± 12.4 kg) and ten females (age: 21.5 ± 0.52 years, height: 159.1 ± 4.9 cm, body mass: 52.7 ± 5.75 kg) The muscle strength of the lower extremities was confirmed in each participant using Daniels and Worthingham’s Muscle Testing manual; hip extension, flexion, abduction, external and internal rotation, knee extension, flexion, ankle dorsal flexion and plantar flexion were tested and there was no severe muscle weakness in any subject in any test. In addition, these subjects had no severe restriction of range of motion. The study procedures, risks, and benefits were explained both verbally and in writing to all participants. All participants provided their written informed consent prior to their participation. This study was approved by the ethical committee of Kansai University of Health Sciences (approval number: 16-39).

Walking, SS and CS were performed by each subject and data were recorded in the same way as in a previous study. Subjects walked naturally along an 8-m walkway at a self-selected pace in their bare feet. Then, subjects were asked to stand on a pair of embedded series 2 force platforms (BP400600, 400 × 600 mm, AMTI, Inc., Watertown, MA, USA) in the middle of the walkway; the left leg was positioned on the first force platform, and the right leg was positioned on the second force platform. The ground reaction forces of both legs were collected at a 180 Hz frequency.

SS was defined as switching to a new direction by planting the right foot in the opposite direction and CS was defined as switching to a new direction by planting the right foot on the same side while crossing the left leg in front of the right leg. The angle of the change in direction was 45° from the walkway. These motions were recorded using four infrared cameras (UM-CAT, UNIMEC, Co. Ltd., Aichi, Japan) at a frequency of 180 Hz. Reflective markers (20 mm) were placed on the top of the iliac crest, the greater trochanter, the lateral epicondyle of the femur, the lateral malleolus, and the head of the fifth metatarsal bone on each leg.

Subjects practiced each motion sufficiently before measurement, and, in particular, were asked not to stand unnaturally on the force platform. All data were smoothed using a Butterworth filter (with a 6 Hz cut-off frequency). During the trials, a metronome was used to reproduce each participant’s pace during each motion (metronome sound pace was 100, 104 or 108 per minute). In addition, a set walking velocity was used based on the velocity of the center of the mass (COM) of the lower extremities; the velocity was calculated from 0.1 second before right heel contact. A trial with a velocity less than 10 cm per second based on walking speed was chosen for assessment of SS and CS. To confirm the velocity of each motion until right heel contact, each subject’s waveform of left horizontal ground reaction forces was checked.

Then, the lower extremity joint torque in stance phase were computed for both lower extremities from the result of a three-dimensional analysis system (CAT Analysis, UNIMEC, Co. Ltd.) based on an inverse dynamic technique using these data of motions and ground reaction forces. The joint torque curves were smoothed using a Savitzky-Golay filter configured with a five-point moving average method and were confirmed by comparison with previously-reported torque curves. These torque curves were calculated in the local coordinate system and the pattern of torque curves were similar to those observed in our study. Then, each joint peak torque normalized to each subject’s body mass was compared among motions. Hip extension, abduction, external rotation and knee extension and ankle dorsiflexion were measured with torque in deceleration phase (the period between heel contact on one side and mid-stance on the same side). Hip flexion, abduction, internal rotation and knee flexion and ankle plantar flexion were measured with torque in the acceleration phase (the period between mid stance on one side and toe off on the same side).

To examine gender difference, we focused on pelvic shape because the pelvis exhibits a gender difference in transverse diameter. However, the taller a person is, the wider the pelvis is. In walking, pelvis and upper-body momentums in the horizontal plane canceled each other out. Therefore, breadth of shoulders (between posterolateral tops of the acromion) were recoded using three-dimensional analysis system as put makers each subjects after trials and width of pelvis (between the tops of the iliac crest) and breadth of shoulders were used as gender differences. These values were calculated using a three-dimensional analysis system based on standing which was recorded after three trials, and were used for examining correlation between torques showing gender differences.

Analyses were performed as follows: (1) A two-way factorial analysis of variance was used to examine whether each joint peak torque in both legs among walking, SS and CS interacts with gender. Then, each joint peak torque which showed an interaction was evaluated by Bonferroni’s method. (2) To compare each peak joint torque in both legs, each motion in each gender using non-paired t-test was examined for gender difference in each motion. (3) To correlate width of pelvis with the joint torque which showed a gender difference, and to correlate width of pelvis divided by breadth of shoulders (P/S ratio) with the joint torque which showed a gender difference, Pearson’s product–moment correlation coefficient was used. The significance level was set at p<0.05 and IBM SPSS Statistical software ver.24 (SPSS Inc., a subsidiary of IBM Corp., Armonk, NY, USA) was used for statistical analyses.
RESULTS

Table 1 shows the difference in each joint peak torque by gender during the left stance phase. The mean value of three trials is shown. In the left stance phase in males during CS, ankle plantar flexion torque showed a significant interaction effect and was significantly decreased compared with walking and SS phases. Table 2 shows the difference in each joint peak torque by gender during the right stance phase, with the mean of three trials shown. In the right stance phase during CS, hip extension, external and internal rotation torque, and ankle plantar flexion torque all showed a main effect in both males and females, and were significantly increased compared to the values during walking and SS.

Tables 3 and 4 show the gender difference during each motion in left and right stance phases. There were significant gender differences in joint torque during CS, although there were no significant gender differences in joint torque during walking or SS. Left and right ankle plantar flexion torque during CS in males was significantly higher than in females. In contrast, right hip external and internal rotation torques during CS in females were significantly higher than in males.

The width of the pelvis in females was significantly greater than in males (male: $33.3 \pm 1.82$, female: $35.2 \pm 1.70$; $p<0.05$), as was the P/S ratio (male: $0.75 \pm 0.03$, female: $0.87 \pm 0.04$; $p<0.05$). There was no significant correlation between the width of the pelvis and each torque. However, the P/S ratio correlated with gender differences in torque as follows. The right hip external and internal torques during CS had significant positive moderate correlation (external rotation: $r=0.56$; $p<0.05$, internal rotation: $r=0.53$; $p<0.05$). The left and right ankle plantar flexion torques during CS had significant negative moderate correlation (left: $r=-0.59$; $p<0.05$, right: $r=-0.52$; $p<0.05$).

Table 1. Mean and SD of the joint peak torque of the left lower extremity during each motion (Nm/kg)

|       | Male                  |          |          | Female               |          |          |
|-------|-----------------------|----------|----------|----------------------|----------|----------|
|       |                       | Walking  | SS       | CS                   | Walking  | SS       | CS       |
| Hip   | Extension             | 0.34 ± 0.14 | 0.32 ± 0.07 | 0.33 ± 0.10          | 0.33 ± 0.10 | 0.33 ± 0.09 | 0.34 ± 0.13 |
|       | Flexion               | 0.22 ± 0.08 | 0.21 ± 0.04 | 0.22 ± 0.05          | 0.25 ± 0.07 | 0.23 ± 0.06 | 0.24 ± 0.07 |
|       | Abduction (deceleration) | 0.57 ± 0.09 | 0.58 ± 0.14 | 0.57 ± 0.12          | 0.55 ± 0.12 | 0.57 ± 0.11 | 0.56 ± 0.08 |
|       | Abduction (acceleration) | 0.58 ± 0.07 | 0.59 ± 0.09 | 0.57 ± 0.13          | 0.57 ± 0.09 | 0.58 ± 0.09 | 0.57 ± 0.12 |
|       | External rotation     | 0.14 ± 0.04 | 0.15 ± 0.05 | 0.15 ± 0.07          | 0.15 ± 0.06 | 0.15 ± 0.03 | 0.16 ± 0.08 |
|       | Internal rotation     | 0.16 ± 0.02 | 0.16 ± 0.03 | 0.11 ± 0.05          | 0.17 ± 0.03 | 0.16 ± 0.03 | 0.11 ± 0.02 |
| Knee  | Extension             | 0.54 ± 0.09 | 0.56 ± 0.15 | 0.58 ± 0.12          | 0.53 ± 0.08 | 0.54 ± 0.11 | 0.57 ± 0.09 |
|       | Flexion               | 0.33 ± 0.08 | 0.35 ± 0.11 | 0.36 ± 0.04          | 0.35 ± 0.07 | 0.33 ± 0.07 | 0.37 ± 0.08 |
| Ankle | Dorsiflexion          | 0.26 ± 0.05 | 0.27 ± 0.02 | 0.26 ± 0.08          | 0.26 ± 0.03 | 0.26 ± 0.03 | 0.27 ± 0.05 |
|       | Plantar flexion       | 0.99 ± 0.15 | 0.99 ± 0.13 | 1.09 ± 0.15*         | 0.95 ± 0.16 | 0.96 ± 0.15 | 0.98 ± 0.11 |

* $p<0.05$ compared with each joint torque using Bonferroni’s method after examined interaction by a two-way factorial analysis of variance.

Table 2. Mean and SD of the joint peak torque of the right lower extremity during each motion (Nm/kg)

|       | Male                  |          |          | Female               |          |          |
|-------|-----------------------|----------|----------|----------------------|----------|----------|
|       |                       | Walking  | SS       | CS                   | Walking  | SS       | CS       |
| Hip   | Extension             | 0.33 ± 0.15 | 0.36 ± 0.11 | 0.41 ± 0.13          | 0.34 ± 0.10 | 0.36 ± 0.09 | 0.43 ± 0.12 |
|       | Flexion               | 0.23 ± 0.06 | 0.21 ± 0.06 | 0.29 ± 0.09          | 0.27 ± 0.09 | 0.22 ± 0.05 | 0.23 ± 0.04 |
|       | Abduction (deceleration) | 0.59 ± 0.08 | 0.57 ± 0.11 | 0.55 ± 0.08          | 0.57 ± 0.13 | 0.57 ± 0.09 | 0.59 ± 0.07 |
|       | Abduction (acceleration) | 0.59 ± 0.02 | 0.58 ± 0.11 | 0.57 ± 0.12          | 0.58 ± 0.09 | 0.59 ± 0.10 | 0.59 ± 0.07 |
|       | External rotation     | 0.14 ± 0.02 | 0.16 ± 0.03 | 0.22 ± 0.07*         | 0.15 ± 0.03 | 0.15 ± 0.02 | 0.28 ± 0.05* |
|       | Internal rotation     | 0.15 ± 0.03 | 0.14 ± 0.02 | 0.23 ± 0.04*         | 0.15 ± 0.03 | 0.15 ± 0.03 | 0.28 ± 0.06* |
| Knee  | Extension             | 0.53 ± 0.14 | 0.55 ± 0.11 | 0.56 ± 0.11          | 0.52 ± 0.13 | 0.53 ± 0.13 | 0.56 ± 0.12 |
|       | Flexion               | 0.36 ± 0.12 | 0.32 ± 0.07 | 0.37 ± 0.05          | 0.40 ± 0.08 | 0.33 ± 0.06 | 0.40 ± 0.08 |
| Ankle | Dorsiflexion          | 0.26 ± 0.06 | 0.29 ± 0.05 | 0.27 ± 0.06          | 0.27 ± 0.06 | 0.27 ± 0.04 | 0.26 ± 0.04 |
|       | Plantar flexion       | 1.01 ± 0.15 | 0.98 ± 0.16 | 1.11 ± 0.14*         | 0.94 ± 0.12 | 0.93 ± 0.11 | 0.99 ± 0.12* |

* $p<0.05$ compared with each joint torque using Bonferroni’s method after examined interaction by a two-way factorial analysis of variance.
DISCUSSION

Walking, SS and CS were compared in a previous study\(^6\) and conclusions were drawn as follows; because walking and SS can be considered as similar motions with regard to the pattern of variation in angle and joint torque. And there were no differences in peak torques between walking and SS in previous study\(^6\) and this study. In addition, hip extension and external rotation torque acted in deceleration body forward while hip internal rotation torque acted in acceleration body forward in pivoting the leg during CS. The same reasons were identified in this study with regard to significant difference in CS compared with walking and SS in both females and males.

In females, because the width of the pelvis is greater than in males, greater hip external and internal rotation torque is necessary to control pelvic rotation\(^11\) which is determined by the lever arm on hip rotation. However, only the P/F ratio correlated with hip external and internal rotation torques. The pelvic horizontal rotational angular momentum was influenced by the angular momentum of the upper-body\(^12\) and lower extremity angular momentum was balanced by pelvic and upper-body angular momenta\(^10\). We might consider that hip external and internal rotation torque was influenced by P/F ratio. However, although the rotation angular momentum of the upper body was not measured in this study, we believe that breadth of shoulders influences the rotation angular momentum of the horizontal upper body. Therefore, the horizontal pelvic rotation might be greatly decelerated by hip external rotation torque because the initial process of decelerating gait speed for turning is similar to rapid stopping\(^13\). In addition, it is considered that exerting hip internal rotation torque acts more in acceleration than in pelvic rotation of the same side than in males.

The ankle plantar flexion torque has two roles in walking, as follows: (1) To decelerate forward movement of the body by working the COM upward\(^14\). In particular, the deceleration mechanism involving ankle plantar flexion acts in a spin turn, Table 3. Mean and SD of joint peak torque of the left lower extremity during each motion analysed separately in each gender (Nm/kg)

|          | Male     | Female   | Male     | Female   | Male     | Female   |
|----------|----------|----------|----------|----------|----------|----------|
| Hip      |          |          |          |          |          |          |
| Extension| 0.34 ± 0.14 | 0.33 ± 0.10 | 0.32 ± 0.07 | 0.33 ± 0.09 | 0.33 ± 0.10 | 0.34 ± 0.13 |
| Flexion  | 0.22 ± 0.08 | 0.25 ± 0.07 | 0.21 ± 0.04 | 0.23 ± 0.06 | 0.22 ± 0.05 | 0.24 ± 0.07 |
| Abduction (deceleration) | 0.57 ± 0.09 | 0.55 ± 0.12 | 0.58 ± 0.14 | 0.57 ± 0.11 | 0.57 ± 0.12 | 0.56 ± 0.08 |
| Abduction (acceleration) | 0.58 ± 0.07 | 0.57 ± 0.09 | 0.59 ± 0.09 | 0.58 ± 0.09 | 0.57 ± 0.13 | 0.57 ± 0.12 |
| External rotation | 0.14 ± 0.04 | 0.15 ± 0.06 | 0.15 ± 0.05 | 0.15 ± 0.03 | 0.15 ± 0.07 | 0.16 ± 0.08 |
| Internal rotation | 0.16 ± 0.02 | 0.17 ± 0.03 | 0.16 ± 0.03 | 0.16 ± 0.03 | 0.11 ± 0.05 | 0.11 ± 0.02 |
| Knee     |          |          |          |          |          |          |
| Extension| 0.54 ± 0.09 | 0.53 ± 0.08 | 0.56 ± 0.15 | 0.54 ± 0.11 | 0.58 ± 0.12 | 0.57 ± 0.09 |
| Flexion  | 0.33 ± 0.08 | 0.35 ± 0.07 | 0.35 ± 0.11 | 0.33 ± 0.07 | 0.36 ± 0.04 | 0.37 ± 0.08 |
| Ankle    |          |          |          |          |          |          |
| Dorsiflexion | 0.26 ± 0.05 | 0.26 ± 0.03 | 0.27 ± 0.02 | 0.26 ± 0.03 | 0.26 ± 0.08 | 0.27 ± 0.05 |
| Plantar flexion | 0.99 ± 0.15 | 0.95 ± 0.16 | 0.99 ± 0.13 | 0.96 ± 0.15 | 1.09 ± 0.15* | 0.98 ± 0.11 |

*p<0.05 in gender difference compared with male and female using non-paired t-test.

|          | Male     | Female   | Male     | Female   | Male     | Female   |
|----------|----------|----------|----------|----------|----------|----------|
| Hip      |          |          |          |          |          |          |
| Extension| 0.33 ± 0.15 | 0.34 ± 0.10 | 0.36 ± 0.11 | 0.36 ± 0.09 | 0.41 ± 0.13 | 0.43 ± 0.12 |
| Flexion  | 0.23 ± 0.06 | 0.27 ± 0.09 | 0.21 ± 0.06 | 0.22 ± 0.05 | 0.29 ± 0.09 | 0.23 ± 0.04 |
| Abduction (deceleration) | 0.59 ± 0.08 | 0.57 ± 0.13 | 0.57 ± 0.11 | 0.57 ± 0.09 | 0.55 ± 0.08 | 0.59 ± 0.07 |
| Abduction (acceleration) | 0.59 ± 0.02 | 0.58 ± 0.09 | 0.58 ± 0.11 | 0.59 ± 0.10 | 0.57 ± 0.12 | 0.59 ± 0.07 |
| External rotation | 0.14 ± 0.02 | 0.15 ± 0.03 | 0.16 ± 0.03 | 0.15 ± 0.02 | 0.22 ± 0.07 | 0.28 ± 0.05* |
| Internal rotation | 0.15 ± 0.03 | 0.15 ± 0.03 | 0.14 ± 0.02 | 0.15 ± 0.03 | 0.23 ± 0.04 | 0.28 ± 0.06* |
| Knee     |          |          |          |          |          |          |
| Extension| 0.53 ± 0.14 | 0.52 ± 0.13 | 0.55 ± 0.11 | 0.53 ± 0.13 | 0.56 ± 0.11 | 0.56 ± 0.12 |
| Flexion  | 0.36 ± 0.12 | 0.40 ± 0.08 | 0.32 ± 0.07 | 0.33 ± 0.06 | 0.37 ± 0.05 | 0.40 ± 0.08 |
| Ankle    |          |          |          |          |          |          |
| Dorsiflexion | 0.26 ± 0.06 | 0.27 ± 0.06 | 0.29 ± 0.05 | 0.27 ± 0.04 | 0.27 ± 0.06 | 0.26 ± 0.04 |
| Plantar flexion | 1.01 ± 0.15 | 0.94 ± 0.12 | 0.98 ± 0.16 | 0.93 ± 0.11 | 1.11 ± 0.14* | 0.99 ± 0.12 |

*p<0.05 in gender difference compared with male and female using non-paired t-test.
similar to CS\textsuperscript{13}. (2) To progress the body and to swing the leg forward\textsuperscript{15, 16}. It has been considered that left ankle plantar flexion torque acted more on horizontal pelvic rotation as a result of progression of the body and swinging the leg forward in males during CS. As a variation of step length, walking step length subtracted from CS (period between right heel off and left heel contact, distance between left lateral malleolus and right head of fifth metatarsal bone) was evaluated, and revealed a tendency for the values in males to be wider than in females (male: 0.06 ± 0.03 × 10\textsuperscript{-1}, female: 0.03 ± 0.04 × 10\textsuperscript{-1} divided by each height). Meanwhile, it was considered that right ankle plantar flexion torque may be more active in deceleration in males during CS. The result of correlation between P/S ratio and right plantar flexion torque, there was tendency which the less P/S ratio was, the more right ankle plantar flexion torque exert. In females, less right plantar flexion torque is exerted because females have a higher P/S ratio and greater exertion of higher hip external rotation torque. Therefore, both ankle plantar flexion torques in males during CS might act more on the horizontal pelvic rotation and deceleration with less influence on hip external and internal rotation torque than in females.

Limitations of this study are as follows: upper-body momentum was not calculated and the relationship between upper-body rotation and pelvic rotation in the horizontal plane was not clarified. Consequently, we investigated these points after this study. However, since there is little research into hip external and internal rotation in walking and changing direction, we believe this study reports the importance of the hip external and internal rotator. The results of this study will provide data which will help with the design of physical therapy for patients who are older, those with osteoarthritis of the lower limbs and after orthopedic surgery.

In conclusion, the difference in joint torque among the separate trials was the same result as was previously reported in males alone\textsuperscript{6}; additionally, walking and SS showed no gender differences in joint torque. However, there were gender differences in joint torque during CS. Therefore, we are of the opinion that the hip external and internal rotator is necessary to perform CS smoothly in females.

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