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Kinematics and Muscle Activities of the Lower Limb during a Side-Cutting Task in Subjects with Chronic Ankle Instability

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Abstract

Purpose: The purpose of the present study was to evaluate lower limb kinematics and muscular activities during walking, side-turning while walking, and side-cutting movement in athletes with chronic ankle instability and compare the results to those of athletes without chronic ankle instability.

Methods: Lower limb kinematics and muscular activities were evaluated in 10 athletes with chronic ankle instability and 10 healthy control athletes using a three-dimensional motion analysis system and surface electromyography during the 200-ms pre-initial contact (IC) and stance phases while walking, side-turning while walking, and side-cutting.

Results: During walking or side-turning while walking, there were no significant differences in kinematics or muscle activities between the subjects with and without chronic ankle instability. For the side-cutting task, however, ankle inversion angles during the 200-ms pre-IC and late stance phases [effect sizes (ESs) = 0.95–1.43], the hip flexion angle (ESs = 0.94–0.96), and muscular activities of the gastrocnemius medialis (ESs = 1.04–1.73) during the early stance phase were significantly greater in the athletes with chronic ankle instability than in the healthy control athletes.

Conclusions: Alterations of kinematics in athletes with chronic ankle instability were found not only at the ankle but also at hip joints during the side-cutting movement. These alterations were not detected during walking or side-turning while walking. The findings of the present study indicate that clinicians should take into account the motion of the hip joint during the side-cutting movement in persons with chronic ankle instability.

Level of Evidence: Level III.

Key Words: Ankle sprain; Neuromuscular control; Ankle biomechanics; Motion analysis; turn

Introduction

Chronic ankle instability is a common sequela of a lateral ankle sprain [1, 29]. It has been defined as recurrent ankle sprain, episodes of "giving way," or subjective instability. Several causative factors relating to chronic ankle instability has been proposed, including impaired neuromuscular control, proprioception, and postural control [6, 17]. Chronic ankle instability has also been linked to an increased risk of ankle osteoarthritis [27]. Determining the pathology of chronic ankle instability is important for preventing recurrent ankle sprain.

Previous studies reported that subjects with chronic ankle instability had altered kinematics during dynamic activities in the ankle [7-9, 22], knee [5, 15, 26], and hip joint [3, 9]. Altered muscle activities during dynamic tasks were observed around the ankle joint, such as in the peroneus longus, gastrocnemius, and tibialis anterior muscles [7-9, 25]. In addition, muscular activity patterns of the entire lower limb for chronic ankle instability subjects, including proximal muscles around the hip joint, are different from those in subjects without chronic ankle instability during transition from double-leg to single-leg stance [28], during a single-leg rotational squat [30] and during sudden ankle inversion [2]. However, activity patterns of the proximal muscles are commonly investigated under limited conditions. It is important to identify muscular and kinematic changes of the entire lower limb in subjects with chronic ankle instability during actual dynamic activities of daily living or sports-related tasks.

Brown et al. [4] examined lower limb kinematics during a variety of movement tasks (walk, run, step down, drop jump, stop jump) and suggested that deceleration and rapid directional change during movement may reveal kinematic changes related to ankle instability. To the best of our knowledge, however, no study has examined the kinematics and muscular activities of the entire lower limb in subjects with chronic ankle instability during a change-of-direction task, such as a side-cutting movement, despite the fact that this movement has a high risk of causing a lateral ankle sprain [23, 31]. Identifying the changes in the kinematics and muscular activities in subjects with chronic ankle instability during a variety of movement tasks, including turning or cutting movements, may help to develop a rehabilitation program for patients with a lateral ankle sprain. The purpose of the present study was to compare the kinematics and muscular activities of the lower limb during walking, a side-turn while walking, and a side-cutting movement between chronic ankle instability athletes and healthy control athletes. The hypothesis of the present study was that differences in kinematics and myoelectrical activities between the two groups would be observed more often during the side-cutting task than during the other two tasks.

Materials and Methods

Ten athletes with chronic ankle instability (9 men, 1 woman; age 21.0 ± 0.9 years; height 1.74 ± 0.08 m; weight 65.9 ± 7.2 kg) and 10 age- and sex-matched healthy athletes without chronic ankle instability (9 men, 1 woman; age 20.8 ± 1.8 years; height 1.74 ± 0.07 m; weight 66.5 ± 8.3 kg) were recruited from the university. All subjects were instructed about the experimental procedure and were required to sign informed consent forms before participating.

The inclusion criteria for the chronic ankle instability group were partially based on the recommendations of the International Ankle Consortium [16]: (1) at least one significant lateral ankle sprain that resulted in protected weight bearing and/or immobilization; (2) a history of two or more lateral sprains to the same ankle; (3) multiple episodes of the ankle “giving way”; (4) based on the study of Wright et al. [32], a Cumberland Ankle Instability Tool (CAIT) score of ≤ 25. No one was undergoing rehabilitation at the time of testing. Inclusion criteria for the control group were no history of lower limb injuries, ankle joint instability, and/or an episode of “giving way.” An inclusion criterion for all subjects was participating in sports activities at least twice a week. The exclusion criteria for all subjects were: (1) a history of fracture and surgery in the lower limb and major musculoskeletal injuries (other than a history of lateral ankle sprain in the chronic ankle instability group); (2) inflammation and swelling of the ankle at the time of testing; (3) a history of acute injuries to other joints of the lower limb within the past 3 months [16]. If the subjects with chronic ankle instability had bilateral unstable ankles, the more affected side (determined by the CAIT score) was studied. The chronic ankle instability and control groups were matched on test limb dominance, which was defined as the side used for kicking a stationary ball (9 dominant legs and 1 nondominant leg).

Procedure

A static trial was performed with the subject standing. The subjects then performed three movement tasks: normal walking, side-turn during normal walking, and side-cutting movement. For the walking task, the subjects walked straight on a walkway at their natural speed while looking straight ahead (Fig. 1a). For the side-turn during walking, the subjects walked straight on a walkway at their natural speed, then planted their test limb on the force plate and changed direction to the medial side at 45°, then continued walking for approximately 2.5 m (Fig. 1b). For the side-cutting task, the subjects were positioned in a crouched position with their knee flexed at approximately 45° in front of the force plate (0.4 m) [14]. When an audio cue was played by the examiner, the subject performed a forward jump, with the test limb being required to contact the force plate. The subject then performed a sidestep cut at 45° and ran approximately 2.5 m as rapidly as possible (Fig. 1c).

Before the tasks were recorded, the subjects were allowed to practice until they could successfully perform them. The three tasks were performed in random order. The subjects were allowed to rest for approximately 1 minute between trials and 5 minutes between tasks.

Kinematic, ground reaction force (GRF), and electromyography (EMG) data from three valid trials were collected for each task. Trials were excluded if the entire foot did not make contact with the force plate or if any markers were lost during testing. No subject complained of any discomfort or pain during the testing.

After recording all movement trials, 5-second maximum voluntary isometric contractions (MVICs) were recorded to normalize the EMG amplitude during all movement trials. Other than for the gastrocnemius medialis, the MVICs were performed against manual resistance [18]. For recording the MVIC of the gastrocnemius medialis, subjects maintained a single-leg heel-raised position.

Data collection and reduction

Kinematic data were recorded using EvaRT software (Motion Analysis Corporation, Santa Rosa, CA, USA) with six digital cameras (Hawk cameras; Motion Analysis Corporation) and a force plate (Type 9286; Kistler AG, Winterthur, Switzerland) that were sampled at 200 Hz and 1000 Hz, respectively. Modified Helen Hays marker sets with 25 retroreflective markers were attached to the skin of the lower limbs of each subject. All subjects wore the same type of shoes in appropriate sizes (Artic Mesh M; Adidas, Herzogenaurach, Germany). Holes were cut in the shoes so the markers could be attached directly to the skin. The joint angles were calculated with SIMM 4.2.1 software (MusculoGraphics Inc., Santa Rosa, CA, USA) [10]. All joint angles in the static standing position were set at 0° for each subject.

Activities of the gluteus maximum, gluteus medius, rectus femoris, semitendinosus, peroneus longus, tibialis anterior, and gastrocnemius medialis muscles were recorded using a wireless surface EMG system (WEB-1000; Nihon Kohden Corporation, Tokyo, Japan) with surface-type electrode telemeters that sampled at 1000 Hz. The maximum amplitudes during the MVICs were used to normalize the EMG data during all movement trials (%MVIC).

The coefficient of multiple correlation (CMC) was calculated to evaluate the within-day repeatability of all kinematic and EMG waveform data [21]. The repeatability was good to excellent in both groups for all kinematic waveform data (walking CMC = 0.92–0.99, side-turn CMC = 0.73–0.99, side-cutting CMC = 0.75–0.99), and for all EMG waveform data (walking CMC = 0.77–0.92, side-turn CMC = 0.73–0.92, side-cutting CMC = 0.71–0.97).

The institutional review board of the Faculty of Health Sciences, Hokkaido University approved this study (Approval number: 11-57).

Statistical analysis

All tasks were divided into a pre-initial contact (IC) phase (200 ms before IC) and a stance phase (time-normalized to 100%, from IC to toe-off). IC was defined as the instant the vertical GRF first exceeded 10 N. Toe-off was defined as the first time it fell below 10 N after IC. Mean values of the normalized EMG data were calculated by averaging the pre-IC phase and every 10% windows of stance phase, respectively. The independent *t* test or Mann–Whitney test was used to detect group differences in the kinematic and EMG data. In addition, the effects of the groups and tasks on the maximum vertical GRF were determined by two-way analysis of variance and the post hoc Sidak test. All significance levels were set at $P < 0.05$. Statistical analyses were performed using IBM SPSS Statistics version 17 (IBM Corporation, Armonk, NY, USA). In addition, effect sizes (ESs) were calculated to indicate the magnitude of the differences using G*Power 3.1. The sample size was calculated using the *t* test model of G*Power 3.1 based on our pilot study comprising seven subjects (four healthy subjects and three chronic ankle instability subjects). More than eight subjects per group were required to detect a group difference in the ankle inversion angle during the side-cutting task (80% power, $\alpha = 0.05$). Ten subjects per group were included to compensate for possible defective data.

Results

There were no significant differences between the two groups regarding age, height, or body weight (n.s.). The CAIT score of the chronic ankle instability group (19.6 ± 3.6) was significantly lower than that of the control group (29.8 ± 0.6, $P < 0.001$). There were 7.9 ± 4.0 previous lateral ankle sprains in the chronic ankle instability group and none in the control group.

For walking and side-turn tasks, there were no significant differences between the groups at any of the joint angles (n.s.) (Figs. 2 and 3). For side-cutting movement, the chronic ankle instability group exhibited significantly greater hip flexion than the control group from 11% to 18% of the stance phase ($P < 0.05$, ESs = 0.94–0.96) (Fig. 4). The mean group difference was 5.2°. The chronic ankle instability group also exhibited significantly greater ankle inversion than the control group during the two time periods: from pre-IC 200 ms to pre-IC 165 ms ($P < 0.05$, ESs = 0.99–1.25), and from 78% to 100% of the stance phase ($P < 0.05$, ESs = 0.95–1.43) (Fig. 4). The mean group differences were 7.7° and 6.4°, respectively. No group differences were found for the other angles (n.s.) (Fig. 4).

For walking and side-turn tasks, there were no significant group differences in the mean EMG activities for any of the muscles (n.s.) (Figs. 5 and 6). For the side-cutting movement (Fig. 7), the chronic ankle instability group exhibited significantly higher mean activity of the gastrocnemius medialis than the control group during 10–30% of the stance phase ($P < 0.05$, ESs = 1.04–1.73). No group differences were found in the other muscles' activities (n.s.) (Fig. 7).

For the maximum vertical GRF (Table 1), there were no significant group effects during any of the tasks (n.s.), although a significant task effect was found ($P < 0.001$). The maximum vertical GRF in the side-cutting task was significantly greater than that in the walking and side-turn movement ($P < 0.001$ for each). There was no significant difference in the maximum vertical GRF between walking and the side-turn movement (n.s.).

Discussion

The principal finding of this study was that the subjects with chronic ankle instability exhibited altered kinematic patterns of the hip and ankle joints compared with the healthy controls during the side-cutting movement. The patterns during the normal walking and side-turn while walking, however, were not different between the two groups. These results supported our hypothesis that the group differences in the kinematics would be observed more frequently during the side-cutting task. These findings are also partially consistent with previous findings, which indicated that kinematic differences between mechanical ankle instability, functional ankle instability, and “coper” (having a history of ankle sprain but did not develop chronic ankle instability) groups were detected more often in the progression of movement tasks [4]. In the present study, the side-cutting movement showed greater impact force than walking or the side-turn movement. The subjects were required to perform impact absorption, a rapid change of direction, and deceleration for the side-cut movement. This movement is common in court sports and presents a potential risk of lateral ankle sprain [23, 31]. Sports-related movements require more complex joint control for the lower limb than movements that occur during activities of daily living (i.e., walking, turning), as was demonstrated by the changes in the kinematics of the chronic ankle instability subjects. The changes related to chronic ankle instability may be associated with the difficulty of the movement tasks and may be task-dependent.

Compared with the control subjects, the chronic ankle instability subjects exhibited greater hip joint flexion and ankle inversion during the side-cutting movement. Brown et al.

[3] reported increased hip flexion and external rotation in mechanical ankle instability subjects during a stop-jump task. Previous studies reported that subjects with ankle instability showed an increased inversion angle during sports-related tasks [8, 9, 22]. To the best of our knowledge, this is the first study to show that the chronic ankle instability subjects exhibited significantly greater hip flexion and ankle inversion than the controls during the side-cut movement. The altered ankle kinematics could help explain why they are susceptible to their ankles giving way or to lateral ankle sprains during the side-cut movement. Also, the chronic ankle instability subjects might have attempted to adjust their bodies so the center of mass was lower, thereby gaining dynamic stability using mainly hip flexion. In addition, the kinematic changes may be the result of compensatory movement strategies used during the acute phase of a lateral ankle sprain [11, 12].

The hypothesis of the present study that differences in myoelectrical activity between the two groups would be observed more frequently during the side-cutting task was not supported. Feger et al. [13] reported that there were no differences in muscle activity, but that the onset time and activation time of lower limb muscles were altered in chronic ankle instability subjects during walking. The analysis of muscle activity pattern that includes a temporal element, rather than a simple quantitative assessment of muscle activity, may reveal the neuromuscular changes associated with chronic ankle instability. The chronic ankle instability subjects in the present study, however, exhibited increased mean activity of the gastrocnemius medialis during the early-stance phase of the side-cutting task. Gastrocnemius activity has important roles in absorbing impact and increasing ankle stiffness to protect the ankle joint [20]. Our subjects with chronic ankle instability might have increased their gastrocnemius medialis activity to stabilize their ankle joints or reduce the ankle load immediately after ground contact.

Concerning the study’s clinical relevance, it is important that clinicians observe the movements of lower limb joints during sports-related tasks to assess adequately whether their movement patterns render the patient vulnerable to lateral ankle sprain. Training for dynamic activities, including rapid direction change and deceleration, should be incorporated into any rehabilitation program after lateral ankle sprain. Clinicians should also assess hip function, such as muscle strength and/or range of motion for rehabilitation after a lateral ankle sprain. The clinician should educate the patient about vulnerable ankle positions. It is also important to correct any ankle malpositioning observed during the side-cutting movement by using an external ankle support to prevent recurrent ankle sprains or their “giving way.”

Several limitations associated with this study should be acknowledged. First, the side-cutting movement was an anticipated condition. Side-cutting movements during sports activities are commonly unanticipated. Identifying the kinematics and neuromuscular control during an unanticipated side-cutting movement might be helpful for subjects with chronic ankle instability [19, 24]. Second, we could not determine whether the observed changes in the chronic ankle instability subjects were present before or after injury. A longitudinal follow-up study should be conducted to clarify this issue. Third, we did not evaluate any methods for correcting the observed changes in the chronic ankle instability subjects. A future study should examine the effect of braces on the hip and ankle during the side-cutting movement in subjects with chronic ankle instability.

Conclusions

Kinematics and muscular activities of the hip, knee, and ankle during walking, side-turning while walking, and side-cutting movement were evaluated in athletes with chronic ankle instability and healthy athletes (controls). Compared with the controls, the chronic ankle instability subjects exhibited increased hip flexion and ankle inversion and greater gastrocnemius medialis activity during the side-cutting movement.

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Figure captions

Fig. 1 Illustrations of the tasks: walking (a), side-turn while walking (b), and side-cutting movement (c).

Fig. 2 Average joint angles (mean ± SEM) during walking. Horizontal axes indicate the pre-initial contact (pre-IC) phase and 100% stance phase.

Fig. 3 Average joint angles (mean ± SEM) during the side-turn while walking. Horizontal axes indicate the pre-IC phase and 100% stance phase.

Fig. 4 Average joint angles (mean ± SEM) during the side-cutting movement. Horizontal axes indicate the pre-IC phase and 100% stance phase. Gray box areas indicate the periods of significant differences between the chronic ankle instability and control groups ($P < 0.05$).

Fig. 5 Average muscle activities (mean ± SEM) during walking. Horizontal axes indicate the pre-IC phase and 100% stance phase.

Fig. 6 Average muscle activities (mean ± SEM) during the side-turn while walking. Horizontal axes indicate the pre-IC phase and 100% stance phase.

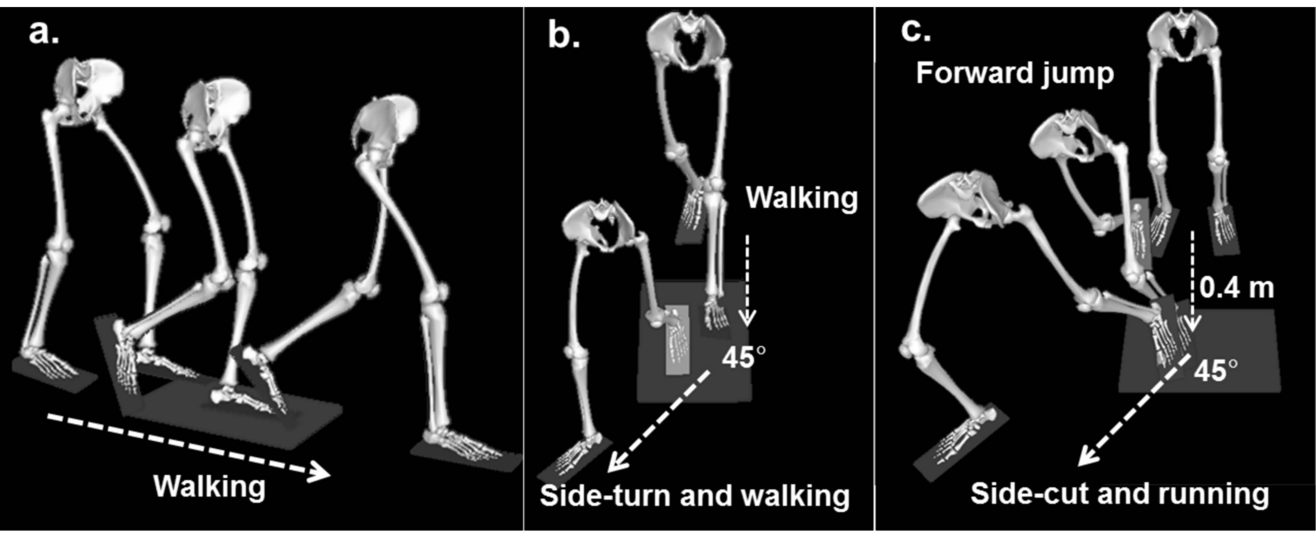
Fig. 7 Average muscle activities (mean ± SEM) during the side-cutting movement. Horizontal axes indicate the pre-IC phase and 100% stance phase. A gray box area indicates the period of significant differences between the chronic ankle instability and control groups ($P < 0.05$).

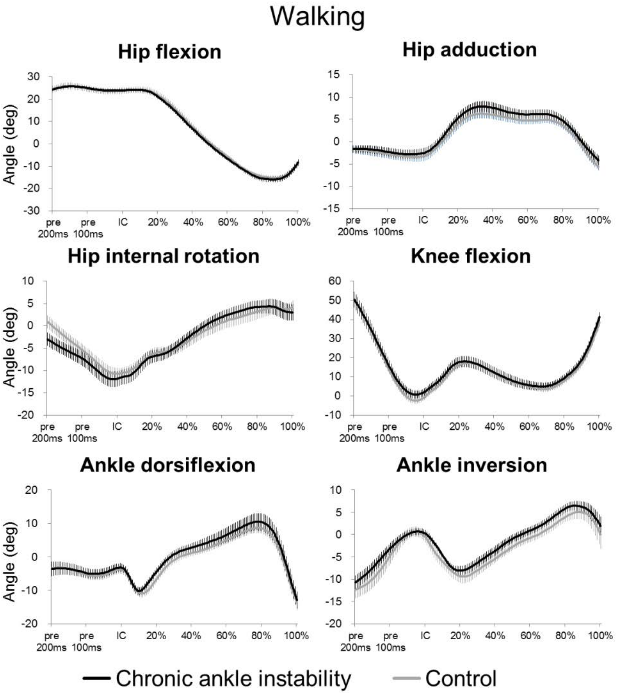
Table 1. Maximum vertical ground reaction forces (N/kg) of the chronic ankle instability and control groups during all movement tasks

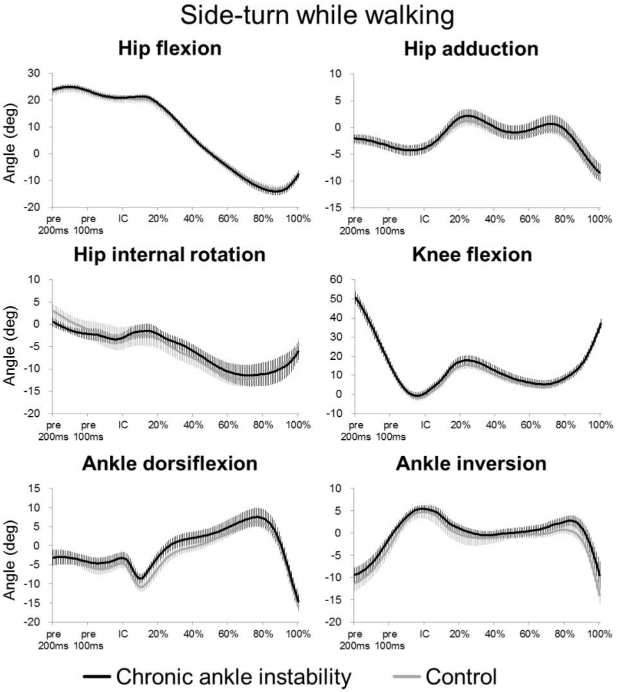
	Walking	Side-turn	Side-cutting[a]
Chronic ankle instability	11.2 (1.0)	11.6 (0.8)	19.4 (2.1)
Control	11.5 (0.5)	11.5 (0.5)	19.5 (2.0)

All values are mean (SD)

[a] indicates significantly greater than the walking and side-turn tasks ($P < 0.001$)


a.
Walking
b.
Walking
45°
Side-turn and walking
c.
Forward jump
0.4 m
45°
Side-cut and running


Walking
Hip flexion
Angle (deg)
30
20
10
0
-10
-20
-30
pre 200ms
pre 100ms
IC
20%
40%
60%
80%
100%
Hip adduction
15
10
5
0
-5
-10
-15
pre 200ms
pre 100ms
IC
20%
40%
60%
80%
100%
Hip internal rotation
Angle (deg)
10
5
0
-5
-10
-15
-20
pre 200ms
pre 100ms
IC
20%
40%
60%
80%
100%
Knee flexion
60
50
40
30
20
10
0
-10
pre 200ms
pre 100ms
IC
20%
40%
60%
80%
100%
Ankle dorsiflexion
Angle (deg)
20
10
0
-10
-20
pre 200ms
pre 100ms
IC
20%
40%
60%
80%
100%
Ankle inversion
10
5
0
-5
-10
-15
-20
pre 200ms
pre 100ms
IC
20%
40%
60%
80%
100%
Chronic ankle instability
Control


Side-turn while walking
Hip flexion
Hip adduction
Hip internal rotation
Knee flexion
Ankle dorsiflexion
Ankle inversion
Angle (deg)
30
20
10
0
-10
-20
15
5
-5
-15
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40
pre 200ms
pre 100ms
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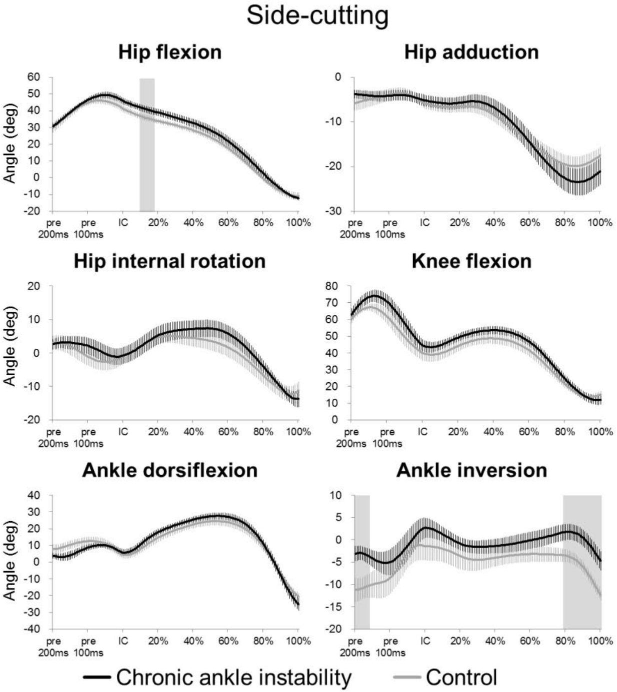
80%
100%
Chronic ankle instability
Control


Side-cutting
Hip flexion
Hip adduction
Hip internal rotation
Knee flexion
Ankle dorsiflexion
Ankle inversion
Angle (deg)
60
50
40
30
20
10
0
-10
-20
-30
-40
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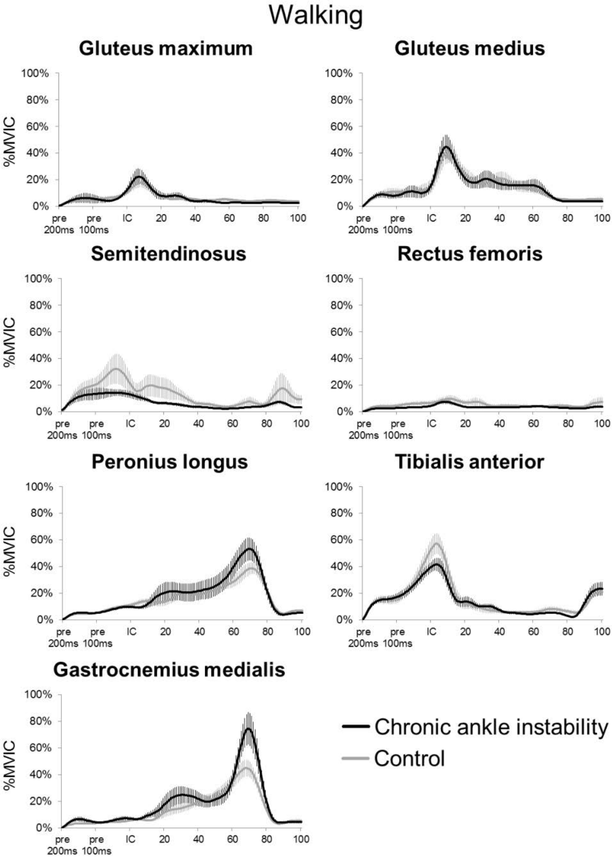
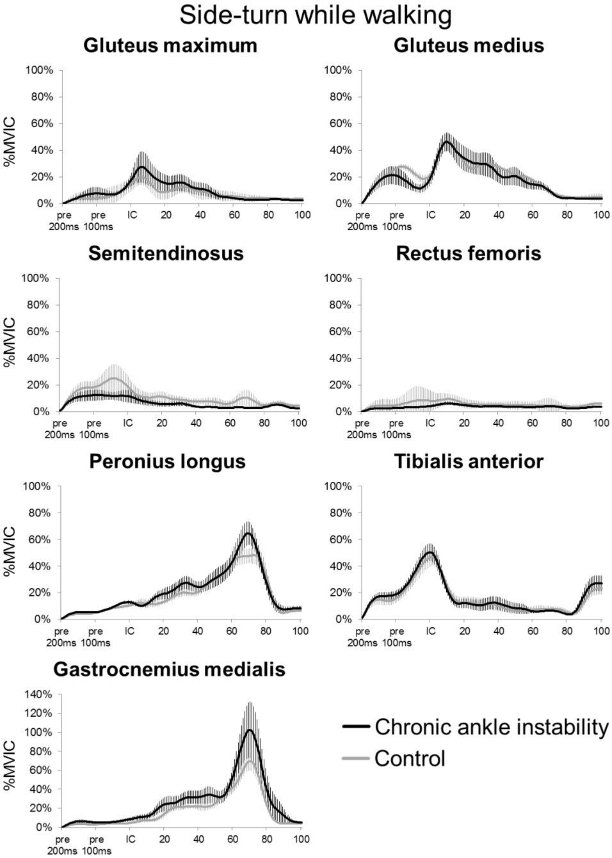
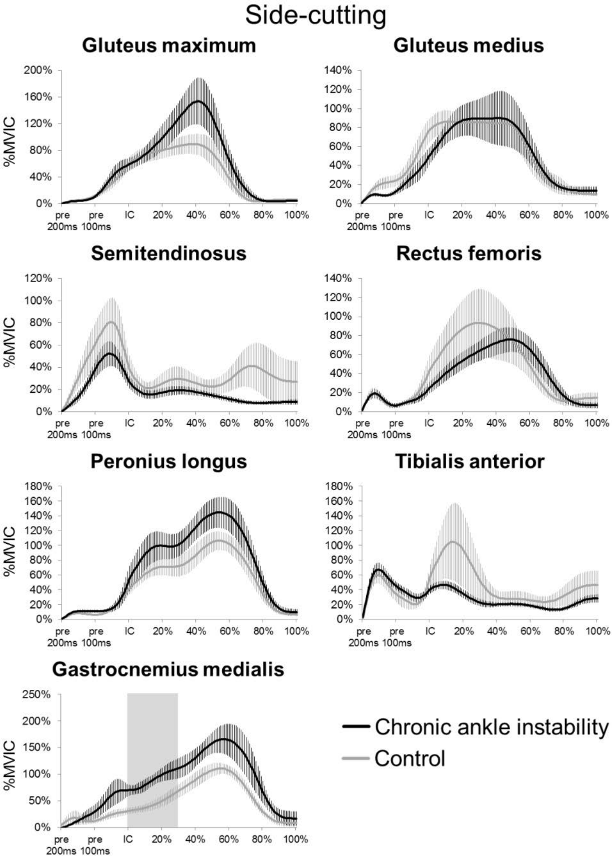
60%
80%
100%
Chronic ankle instability
Control


Walking
Gluteus maximum
Gluteus medius
Semitendinosus
Rectus femoris
Peronius longus
Tibialis anterior
Gastrocnemius medialis
%MVIC
100%
80%
60%
40%
20%
0%
pre 200ms
pre 100ms
IC
20
40
60
80
100
Chronic ankle instability
Control


Side-turn while walking
Gluteus maximum
Gluteus medius
Semitendinosus
Rectus femoris
Peronius longus
Tibialis anterior
Gastrocnemius medialis
%MVIC
0%
20%
40%
60%
80%
100%
120%
140%
pre 200ms
pre 100ms
IC
20
40
60
80
100
Chronic ankle instability
Control


Side-cutting
Gluteus maximum
200%
160%
120%
80%
40%
0%
%MVIC
pre 200ms
pre 100ms
IC
20%
40%
60%
80%
100%
Gluteus medius
140%
120%
100%
80%
60%
40%
20%
0%
Semitendinosus
120%
100%
80%
60%
40%
20%
0%
Rectus femoris
Peronius longus
180%
160%
140%
120%
100%
80%
60%
40%
20%
0%
Tibialis anterior
Gastrocnemius medialis
250%
200%
150%
100%
50%
0%
Chronic ankle instability
Control