The effect of sex and fatigue on lower limb during unanticipated side-step cutting

Abstract

Purpose: To determine how sex and fatigue affect lower limb kinematics, kinetics, and muscle activity during unanticipated side-step cutting.

Methods: Twenty-three physically active subjects (men: 11, women: 12) performed 10 successful trials of cutting maneuvers each to either side under unanticipated conditions in response to 2 light emitting diodes before and after fatigue conditions. Data were analyzed and compared regarding sex and fatigue conditions using 2-way repeated measures analysis of variance.

Results: After fatigue-inducing exercise, women demonstrated larger impulses of ground reaction force (IGRF) during the first 50 ms (2.4 ± 0.8 vs. 2.1± 0.9, $P < 0.05$) than did men. Significant primary effects of sex indicated that women showed a smaller hip flexion angle at initial contact (40.4 ± 6.9° vs. 49.7 ± 9.1°, $P < 0.05$) and at maximum flexion angle (41.3 ± 7.7° vs. 51.4 ± 9.0°, $P < 0.05$) compared with men. Significant primary effects of fatigue were observed in the gluteus maximus muscle during 50 ms before initial contact (+21.5 ± 48.3%, $P < 0.05$) and in the semimembranosus muscle during 50 ms before initial contact (-6.2 ± 20.1%, $P < 0.05$) and the first 50 ms of side-step cutting (-7.9 ± 26.6%, $P < 0.05$).

Conclusions: Our results suggest that sex differences, especially larger IGRF in a fatigue state combined with less hip flexion angle, leads to women having a higher risk for ACL injury. These findings may contribute to understanding the underlying mechanism of injury and development of preventive exercises against ACL injury.

Level of evidence: Prospective comparative study, Level II.

Key words: Non-contact anterior cruciate ligament injury, Unanticipated condition, Fatigue, Sex difference.

Introduction

Between 80,000 and 250,000 anterior cruciate ligament (ACL) injuries annually occur in the United States and it is one of the most common knee injuries related to sports activities [14, 25]. In addition to the high cost of surgery and rehabilitation [13], athletes undergoing surgery for ACL are likely to suffer additional difficulties, such as missing the sports season or a sports scholarship, and a higher risk of osteoarthritis and other pathological conditions [11, 36]. According to the National Collegiate Athletics Association (NCAA) based on a 16-year report (1988–2003) [34], although the ACL injury rate for men’s spring football and women’s gymnastics was ranked first, the percentage of ACL injuries for female sports (e.g., soccer, lacrosse, and basketball) was higher than that for male counterparts.

Researchers [5] have reported that 72% of ACL injuries are due to a noncontact mechanism and 28% are due to a contact mechanism. Furthermore, one of the common non-contact mechanisms of ACL injuries is described as decelerating, just before or in the middle of a change in direction [7]. Based on these previous findings, many studies using cutting [1, 3, 4, 10, 19, 24, 26, 27, 33, 37], landing [2, 6, 12, 28, 43], and other jump tasks [7,31] have found some deleterious changes, such as greater knee valgus moment, quadriceps electromyogram (EMG) intensity, and knee valgus angle, which are possibly linked to non-contact ACL injury.

Young and Farrow [40] stated that sports activity, such as a planned change in direction (e.g., going around the bases in baseball), is rare. Therefore, it can be assumed that performance requiring decision-making (e.g., change in direction) under unanticipated conditions reflects most sports activities. Subsequently, some previous studies [3, 10] have indicated that unanticipated conditions may increase the risk for non-contact knee ligament injuries. Another predisposing factor for non-contact ACL injury is fatigue. Epidemiological studies have shown that a larger number of sports-related injuries occur in the later stages of practices and games [18, 32]. Laboratory-based studies show that fatigue has deleterious effects on the human body, such as increased ligamentous laxity [38] and decreased sensitivity of mechanoreceptors, resulting in impaired proprioceptive information [23, 30].

Based on the findings described above, it is predictable that playing sports under unanticipated conditions, combined with fatigue, predisposes athletes to be at higher risk for non-contact knee ligament injury, such as an ACL rupture, especially in the later stage of practices and games [6]. Some studies [6, 24, 33] have examined how unanticipated conditions and fatigue affect landing and side-step cutting for female athletes and have indicated that there are some negative changes (e.g., lower hip and knee flexion angles) after fatigue protocols, which may potentially be linked to a higher risk of non-contact ACL injury in women. However, to date, there are no studies of how unanticipated conditions and fatigue affect side-step cutting movement in relation to sex. Therefore, there is a need for a comprehensive approach, including both biomechanical and neuromuscular control factors during side-step cutting, to obtain a greater understanding of these sex differences.

Therefore, the purpose of this study was to evaluate the effect of fatigue under unanticipated conditions on hip and knee kinematics, kinetics, and EMG parameters in the sagittal plane during side-step cutting, focusing on sex differences. We hypothesized that women exhibit lower hip and knee flexion angles and less hamstring activation than men during side-step cutting.

Materials and methods

Previous studies for the mechanism of non-contact ACL injuries including various activity levels [2, 12, 24] (e.g., NCAA Division 1 level or physically active level) have been performed. A review of recent studies for non-contact ACL injuries [34] reported that there is lack of information on how differences in skill level or athleticism affect ACL injuries. ACL injury is likely to occur in athletes, as well as general, physically active people. Therefore, 12 physically active women (age, 21.9 ± 1.2 [SD] years) and 11 physically active men (age, 22.9 ± 1.0 years) with no known history of knee pathology (N=23) were recruited for the current study. We defined “physically active” as individuals performing aerobic exercises (e.g., walking or jogging), 3 days per week [2]. Subjects’ physical characteristics are shown in Table 1. This study was approved by the Institutional Review Board of Kyoto University. Informed consent was obtained from each subject before participating in this study.

Procedures

The tasks chosen for this experiment included 60° side-step cutting and 30°crossover cutting [3].Based on previous findings, limb dominance does not appear to affect side-step cutting [26]. Therefore, in this study, the right leg was chosen to step on the force plate. To create an unanticipated environment, subjects were required to cut to either side in response to 2 light emitting diodes embedded in a board that were turned on when the subjects reached a point 2 m before the force plate [1]. When the right-side light was illuminated, the subject was required to turn right (crossover cutting) and when the left-side light was illuminated, the subject was required to turn left (side-step cutting) (Figure 1). The illumination pattern of the lights was randomized. Light gates were integrated with a Racetime 2 system (Microgate S.r.L, Bolzano-Bozen, Italy) and monitored the approach running speed over a 3-m distance, which was delimited to 3.0 m/s [3]. Subjects wore tight-fitting black clothing, a white t-shirt, and no footwear during the experiment. After a 10-min jog on the treadmill at a self-selected speed, the subjects were familiarized with the cutting task, and performed this 5 times each to either side under anticipated conditions. A total of 10 successful trials under pre- and post-fatigue conditions were measured following the familiarization period. The corresponding data were averaged and then analyzed under pre- and post-fatigue conditions. Only data from the side-step cutting are reported in the current study. To maintain measurement accuracy, all data regarding kinematic, kinetic, and EMG values were rounded to one decimal place. P values and Cohen’s d values were rounded to two decimal places.

Fatigue protocol

Fatigue was induced by having the subjects perform successive counter-movement jumps (CMJs) with maximal effort in the same place [35]. First, subjects were requested to jump as high as possible with his or her own jump style 3 times after the warm-up phase, and then the height of the highest of the 3 jumps was recorded. Following the pre-fatigue session, subjects were asked to perform successive CMJs until they were unable to jump as high as 70% of the highest recorded jump for 2 consecutive trials. To maintain the fatigue state during the post-fatigue session, the subjects were asked to perform an additional 5 consecutive maximal CMJs after every 5 trials [7], and the maximum jump height of those jumps by each jump trial was recorded and represented as a percentage of the maximum jump height at the pre-fatigue state by sex (Figures 2). All jump heights were measured with an electric mat device (DKH, Inc., Tokyo, Japan) that can calculate the jump height from the flight time. Figure 2 shows that all mean post-fatigue maximum jump heights for each trial by sex fell within ±1 SD of the mean post-fatigue jump height at the first trial, and the percentage of the mean post-fatigue jump height was similar to that of previous studies [24, 33].

Data collection

EMG data were recorded on an 8-channel telemetry EMG system (Nraxon Telemyo Inc, model 2400 TV2, Scottsdale, AZ, USA) with a sampling rate of 1000 Hz. Bipolar surface electrodes (Ambu Blue Sensor, Ballerup, Denmark) were placed approximately halfway between the knee joint and the ischial tuberosity over the muscle bellies of the semimembranosus (SM) and biceps femoris, and halfway to the anterior superior iliac spine over the muscle bellies of the rectus femoris. Other electrodes were placed approximately 5 cm from the patellar at 45°over the muscle bellies of the vastus medialis (VM) and approximately halfway from the greater trochanter to the sacrum over the muscle bellies of the gluteus maximus (GM). All electrodes were placed on the right leg. The subject’s skin was shaved and cleaned with alcohol before electrode application.

Integrated EMG (iEMG) was recorded during 50 ms before initial contact and the first 50 ms of the cutting phase. We chose these 2 time intervals for the following reasons. (1) We chose 50 ms before initial contact because evidence suggests that this is appropriate for individual pre-planned muscle recruitment strategy [31]. (2) We chose the first 50 ms of the stance phase for side-step cutting to assess muscle activation immediately after initial contact because previous studies have shown that ACL injuries occur immediately following initial contact [5, 20, 22]. In previous studies of side-step cutting [4], researchers normalized EMG to the cutting task instead of a maximum voluntary contraction to reduce inter-subject variability. However, for our study, we recorded the iEMG for each muscle over 5 anticipated side-cutting tasks and then averaged the iEMG records.

Kinetics were recorded with a multiple component force plate (Kistler Instruments, Inc., model 9286A,Winterthur, Switzerland) with a sampling rate of 1000 Hz, which measured vertical ground reaction force (vGRF). The impulses of ground reaction force during the first 50 ms ($IGRF_{50ms}$) and the subsequent 50 ms ($IGRF_{100ms}$) were determined. Initial contact was defined as the instant when the vGRF first exceeded 10 N, and $IGRF_{50ms}$ and $IGRF_{100ms}$ of the initial contact were determined [12].The three-dimensional analysis system (VICON, Oxford, UK) with a sampling rate of 200 Hz, included 7 high-speed cameras that measured the 35 retro-reflective markers (14 mm) placed on the subjects' bodies according to Plug In Gait Full Body Model instructions (VICON). The hip and knee flexion/extension angles at initial contact and the maximal flexion angle of the hip and knee joints during cutting were measured.

Data analysis

All raw EMG data were low-pass filtered at 250 Hz, high-pass filtered at 20 Hz, rectified, and smoothed by a zero-lag 4th-order Butterworth low-pass filter with a cut-off frequency of 30 Hz. Integrated EMG data under unanticipated conditions were divided by the averaged anticipated iEMG records for each muscle.

Vicon Clinical Manager (VCM) software (Oxford Metrics Ltd., UK) was used to quantify hip and knee motion in the sagittal plane. The raw kinematic data were filtered with a Woltering quintic spline filter with a predicted mean square error of 10 mm. Based on a frequency content analysis of the digitized coordinate data, marker trajectories were filtered at 7 Hz using a 4th-order Butterworth filter. The average angular velocities of knee joint flexion during the first 50 ms and subsequent 50 ms were then calculated to quantify knee joint movement in the sagittal plane during the corresponding time intervals [12]. Kinetic data were normalized to body weight. Details of the calculations for $IGRF_{50ms}$ and $IGRF_{100ms}$ of the initial contact have been described previously [12].

Statistical analysis

Results are presented as mean ± standard deviation (SD). Knee and hip flexion angles, knee flexion velocity, IGRF, and iEMG data were analyzed using repeated 2-way ANOVA with sex as a between-subject factor and fatigue as a within-subject factor. Tukey's post-hoc analyses were performed for each sex if a significant difference was observed. Statistical significance was set at $P<0.05$. All statistical analyses were performed using the IBM SPSS statistical package (Japanese version 20.0; IBM, Inc., New York, NY, USA). Previous studies [27, 8] similar to the current study showed that a minimum of 11 (same-sex) subjects are required to achieve 80% statistical power with an exploratory alpha level of 0.05.

Results

There was a significant sex-by-fatigue difference for $IGRF_{50ms}$. Specifically, women had a significantly higher $IGRF_{50ms}$ than did men after fatigue protocols (P=0.04; Figure 3). No significant sex-by-fatigue difference was observed after analysis of all kinematic data. Analysis of the hip flexion angle at initial contact and the maximum flexion angle showed significant primary effects for sex. Specifically, women showed a significantly smaller hip angle than did men at initial contact and the maximum hip flexion angle (P=0.03, P=0.02, respectively; Table 2). Although there was no significant sex-by-fatigue difference with analysis of iEMG data, there was a significant main effect of fatigue for some muscles during 50 ms before initial contact and the first 50 ms of side-step cutting (Figures 4 and 5). Specifically, the iEMG of GM during 50 ms before initial contact was significantly increased under fatigue conditions compared with that under non-fatigue conditions (P=0.03, *d*= 0.49; Figure 4). Integrated EMGs of SM during 50 ms before initial contact and the first 50 ms of side-step cutting were significantly decreased under fatigue conditions compared with those under non-fatigue conditions (P=0.03, P=0.01; *d*=0.51, *d*=0.58, respectively; Figures 4 and 5).

Discussion

The most important finding of the present study was a significant difference between the effect of sex and fatigue on $IGRF_{50ms}$ during side-step cutting in this study. $IGRF_{50ms}$ in women was increased, whereas $IGRF_{50ms}$ in men was decreased following the fatigue protocol. Krosshaug et al. [22] reported that non-contact ACL injuries are most likely to occur within 50 ms after initial contact. Moreover, Hewett et al. [16] conducted a prospective study in which a total of 205 high school female athletes were asked to perform a landing task before the start of the sports season. They recorded the number of ACL injuries in the course of the season and their results showed that the injured athletes had a higher peak vertical ground reaction force than that in uninjured athletes. Meyer and Haut [29] showed that increased tibiofemoral joint compression combined with a posteriorly sloped tibia causes posterior femur displacement, leading to increased ACL strain. Although the difference in vGRF and $IGRF_{50ms}$ should account for the inconsistencies between Hewett et al.'s study [16] and the current study, both of them are highly likely to be factors involved in increasing tibiofemoral joint compression. Consequently, higher IGRF during the first 50 ms of side-step cutting after the fatigue protocol executed by female subjects in this study is likely to be a potentially hazardous factor related to non-contact ACL injury.

Related to the finding of increased IGRF during the first 50 ms of side-step cutting, it was observed that the hip flexion angle at initial contact and the maximum hip flexion angle for women were significantly smaller than those for men. This finding partially supports our hypothesis that women have smaller hip flexion angles than men. Zhang et al. [43] reported that hip flexion angles play an important role in energy dissipation. Furthermore, Tsai and Powers [39] reported that the peak tibiofemoral compression force is significantly decreased for landing after training, emphasizing a soft landing with increased hip and knee flexion angle. Taking these findings into account, small angles of the hip joints may explain an increased $IGRF_{50ms}$, especially after fatigue. Therefore, the smaller hip flexion angle displayed by the female subjects of our study could have been a predisposing factor for non-contact knee ligament injury

In the present study, no significant primary effect or interaction on knee kinematic values with regard to sex or fatigue was observed. This may be due to differences in athletic or skill level, or fatigue protocol between the current study and previous studies with various outcomes [10, 12, 33]. Future studies should take into consideration various factors related to the mechanism of non-contact ACL injury, by combining factors, such as hormonal [42], neuromuscular [21], or anatomical differences [9] for a higher ACL injury risk with the current perspectives (e.g., biomechanical differences; during the preovulatory phase vs. the postovulatory phase).

In our study, some significant differences were found between pre- and post-fatigue conditions in iEMG data during side-step cutting. Specifically, GM muscle activation was significantly increased after fatigue during the 50-ms phase before initial contact compared with that before fatigue. Zhang et al. [43] found that hip and knee extensors are more likely to be involved in energy dissipation with increased mechanical demand. Fatigue-inducing exercise in our study consisted of repetitive jumping. It is plausible that fatigue-inducing exercise using jumps, which we asked our subjects to perform even during the trials, led to increased GM muscle activation.

Another finding related to muscle activation in this study is that SM muscle activity was significantly decreased after fatigue during 50 ms before initial contact and in the first 50 ms of the stance phase compared with those at pre-fatigue conditions. This decreased hamstring activity is consistent with previous studies on landing [12, 31].More importantly, hamstring muscles are widely believed to reduce anterior shear force and protect the ACL [41]. Based on these findings, unanticipated conditions combined with fatigue are associated with a potentially hazardous neuromuscular pattern for non-contact knee ligament injury. Furthermore, a recent study [15] reported that patients who had undergone an ACL reconstruction surgery with a hamstring graft had a significantly lower knee flexion torque than did patients with a patellar tendon graft. Although a hamstring graft has recently prevailed for ACL reconstruction rather than a patellar tendon [15], our finding may be also beneficial to orthopedic surgeons who favor a patellar tendon graft over a hamstring graft.

A number of study limitations must be taken into consideration. First, generally, women become less fatigued and recover faster than men at the same intensity of muscle contraction [17]. Although our results showed that the level of fatigue for both sexes showed a similar tendency, we referred to only jump heights for the scale of fatigue, and therefore, more precise tracking tools from both subjective (e.g., Borg scale) and objective aspects (e.g., lactate threshold) are required for future studies. Furthermore, we chose repetitive jumps as our fatigue protocol. As Lucci et al. [24] pointed out, there appears to be two main types of fatigue protocols in previous studies: one protocol is a short-term protocol (e.g., repetitive jumps) [6, 7, 35]; and the second protocol is a long-term protocol (e.g., shuttle running) [24, 33, 37]. Caution is needed in interpreting results from the current study, which used a type of short-term protocol according to the classification described above. A second limitation is the athletic level. In the present study, subjects were composed of physically active subjects. To date, previous studies analyzing the mechanism of non-contact ACL injuries and the current study used isolated athletic level. Our results should be interpreted with caution for whether the subjects from the current study can be generalized to men and women at other athletic levels, or for other age groups. Therefore, future studies need to combine different athletic levels (e.g., NCAA level vs. recreational athlete) to examine how athletic levels affect sport-specific tasks. A third limitation is that, in addition to the relatively small sample size, we performed ANOVA many times, which may have caused a type 1 error. Therefore, a future study is required with more subjects to decrease the probability of type 1 errors. The fourth limitation is the method of stimulation for cutting direction. We used light stimulations with 2 options (side step or crossover step). However, some previous studies used light stimulations, but with more options (e.g., cutting, running straight forward, or stopping) [1, 4] or visualized sports-specific tasks [24, 33]. The fifth limitation is that, although previous studies used various approaching speeds from 3.0 to 5.0 m/s [1, 3], the approaching speed was delimited to 3.0 m/s in the present study. Lastly, we analyzed only the sagittal plane biomechanics of side-step cutting. More investigation is required including the frontal and transverse plane, commonly linked to non-contact ACL injury [10, 12, 20, 37].

From a clinical standpoint, it is worth noting that some significant differences were found between the pre- and post-fatigue state, despite relatively small Cohen’s d values. This suggests that some changes, such as a small hip flexion angle, as well as increased IGRF during the first 50 ms of side-step cutting, which are possibly related to ACL injury, are likely to occur in the physically active population, even with a small effect of fatigue. Therefore, our findings can be considered as clinically relevant. More importantly, our study indicates that a smaller hip flexion angle during the unanticipated cutting task combined with fatigue may potentially be linked to the increased tibiofemoral compression force, resulting in increased ACL loading. Based on this finding, effective injury screening by using cutting or landing, especially for the physically active female population, can be implemented to find risk factors related to ACL injury for lower limb biomechanics in a fatigue state. Subsequently, individuals at higher risk for ACL injury should participate in preventive programs focusing on an increased hip flexion angle during sports-related activities.

Conclusion

In the current study, there were some sex differences in kinetic and kinematic parameters, such as hip angle and $IGRF_{50ms}$ during unanticipated side-step cutting. Our results suggest that a smaller hip angle and increased $IGRF_{50ms}$ lead to a movement pattern, which is possibly related to non-contact ACL injury in women. This movement could potentially be due to an unanticipated condition, especially when combined with fatigue. Another important finding from iEMG data is that fatigue changes some muscle activation levels. Especially in the SM muscle, one of the hamstrings believed to protect the ACL, the activation level is decreased before initial contact and during side-step cutting. This neuromuscular pattern is also a predisposing factor for non-contact ACL injuries. These findings may contribute to a better understanding of the underlying mechanism of injury, effective injury screening and prevention exercises for non-contact ACL injuries.

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Figure legends

Fig. 1 Experimental setup

S60° = 60° side-step cut angle, XOS30° = 30°crossover cut angle

Fig. 2 Comparison of mean post-fatigue maximum jump height with mean pre-fatigue maximum jump height for each jump trial for women and men. The area between the dotted lines represents ±1 SD of the mean post-fatigue jump height at the 1sttrial

Fig. 3 Interaction of sex and fatigue conditions for $IGRF_{50ms}$. $IGRF_{50ms}$ was significantly increased in women compared with that in men after fatigue-inducing exercise ($P<0.05$). "BW" means body weight

Fig. 4 Integrated EMG percentage changes between pre- (white bars) and post-fatigue (grey bars) conditions during 50_{ms} before initial contact under unanticipated conditions. Mean values ± SD are shown. These values were normalized by the mean iEMG recorded in the pre-fatigue condition under anticipated conditions. *Denotes a significant difference between pre- and post-fatigue conditions ($P<0.05$)

Fig. 5 Integrated EMG percentage changes between pre- (white bars) and post-fatigue (grey bars) conditions during 50_{ms} after initial contact under unanticipated conditions. Mean values ± SD are shown. These values were normalized by the mean iEMG recorded in the pre-fatigue condition under anticipated conditions. *Denotes a significant difference between pre- and post-fatigue conditions ($P<0.05$)

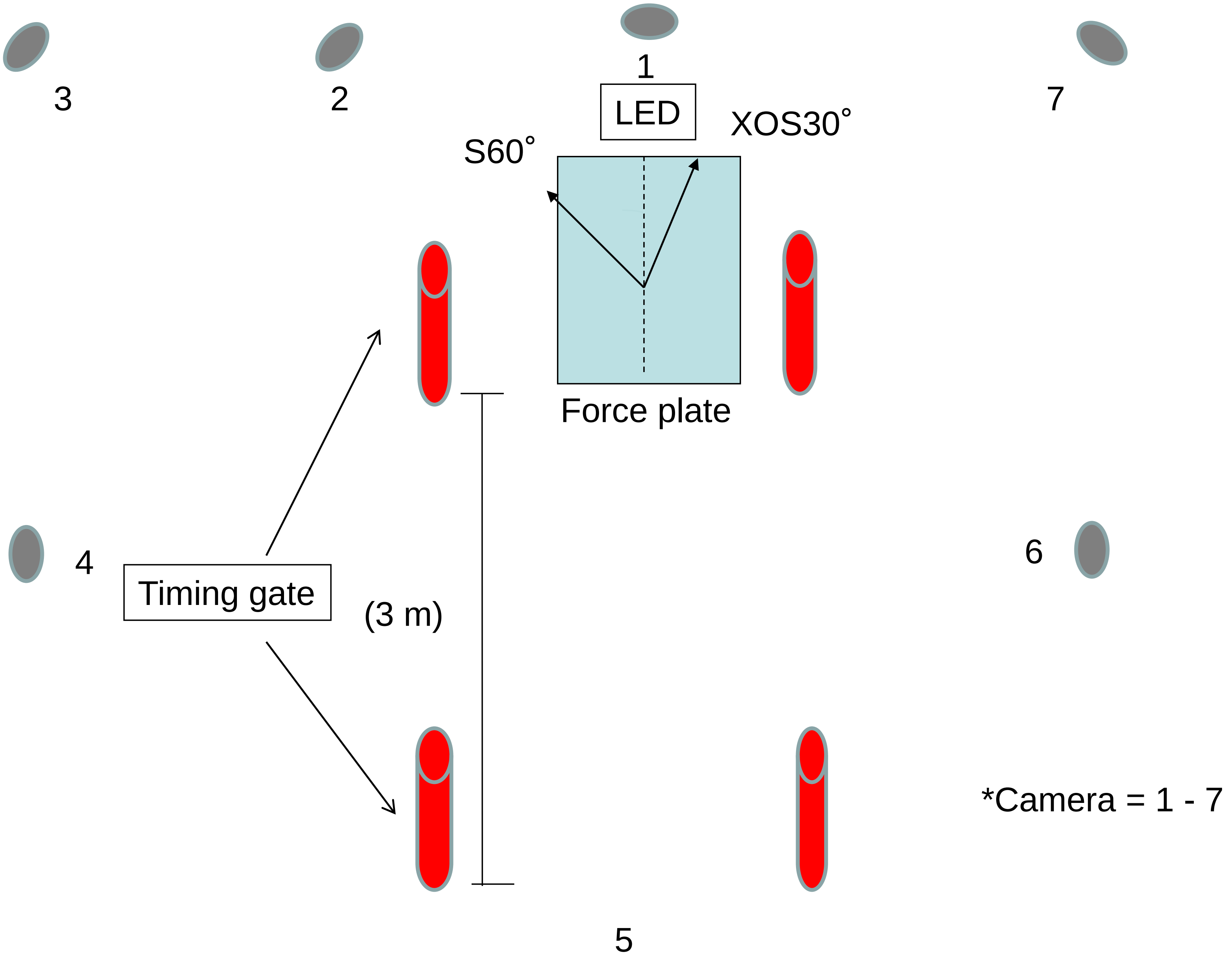
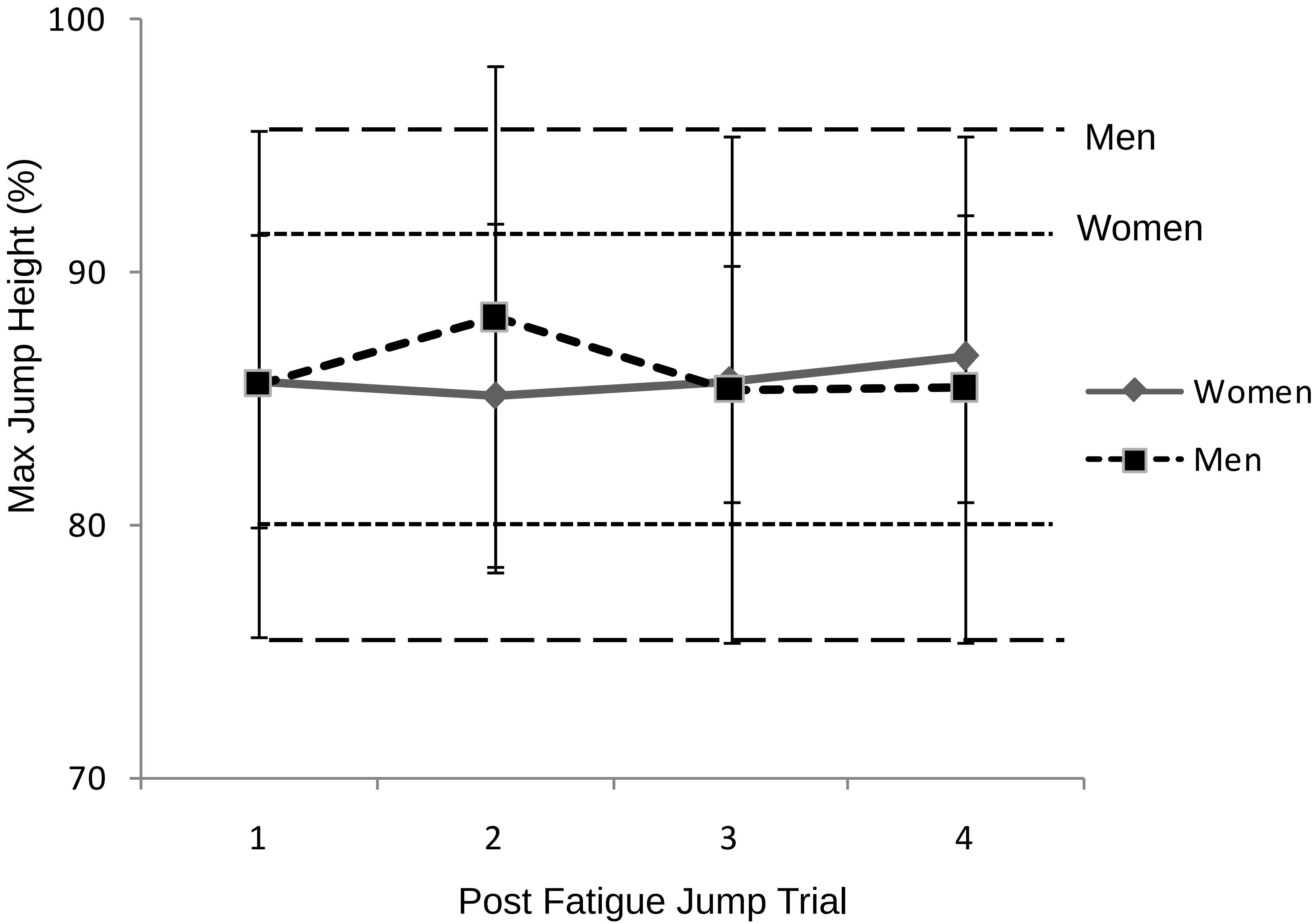


Figure 1

Figure 2



100
90
80
70
Max Jump Height (%)
Men
Women
Women
Men
1
2
3
4
Post Fatigue Jump Trial

Figure 3

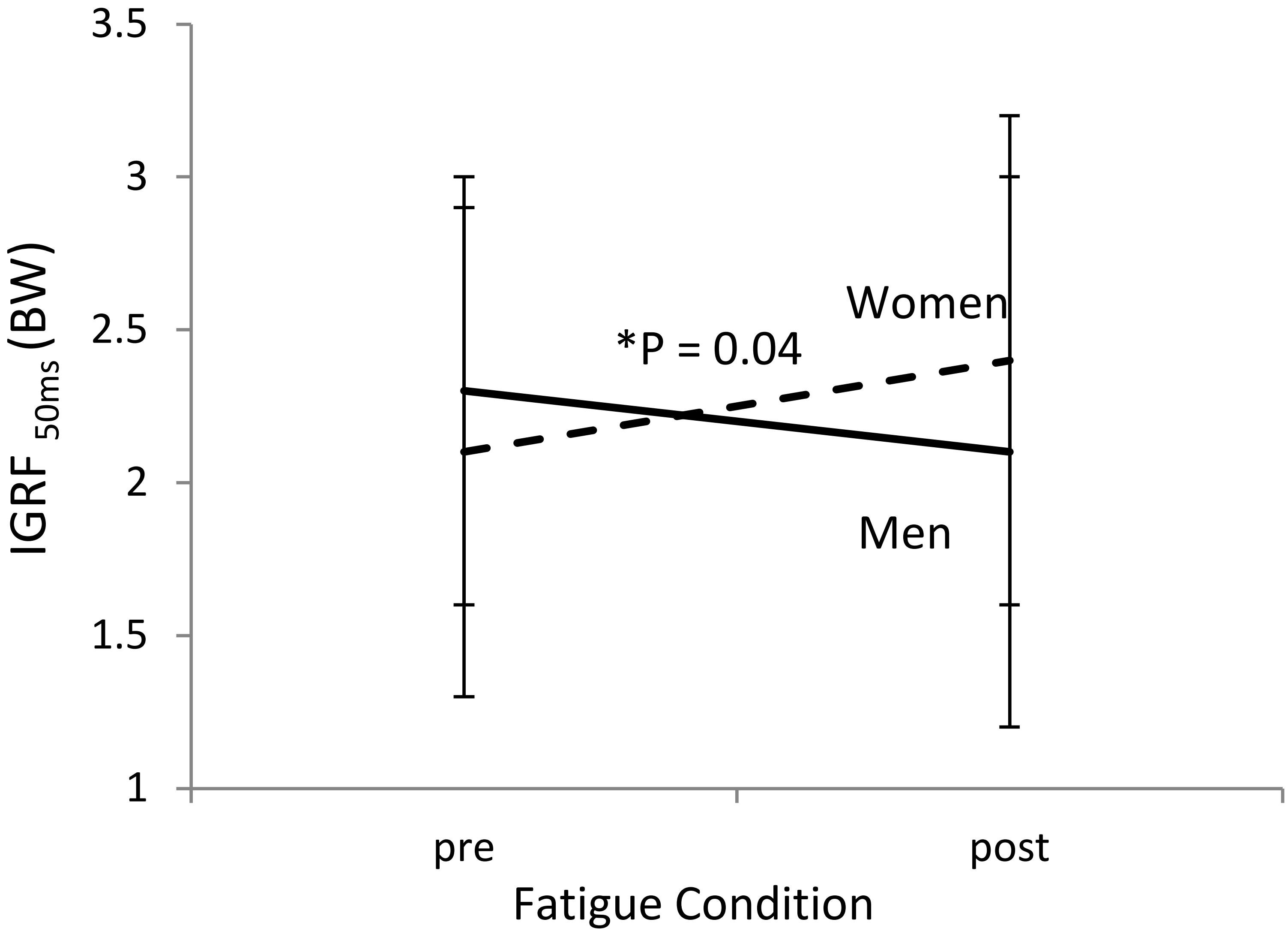
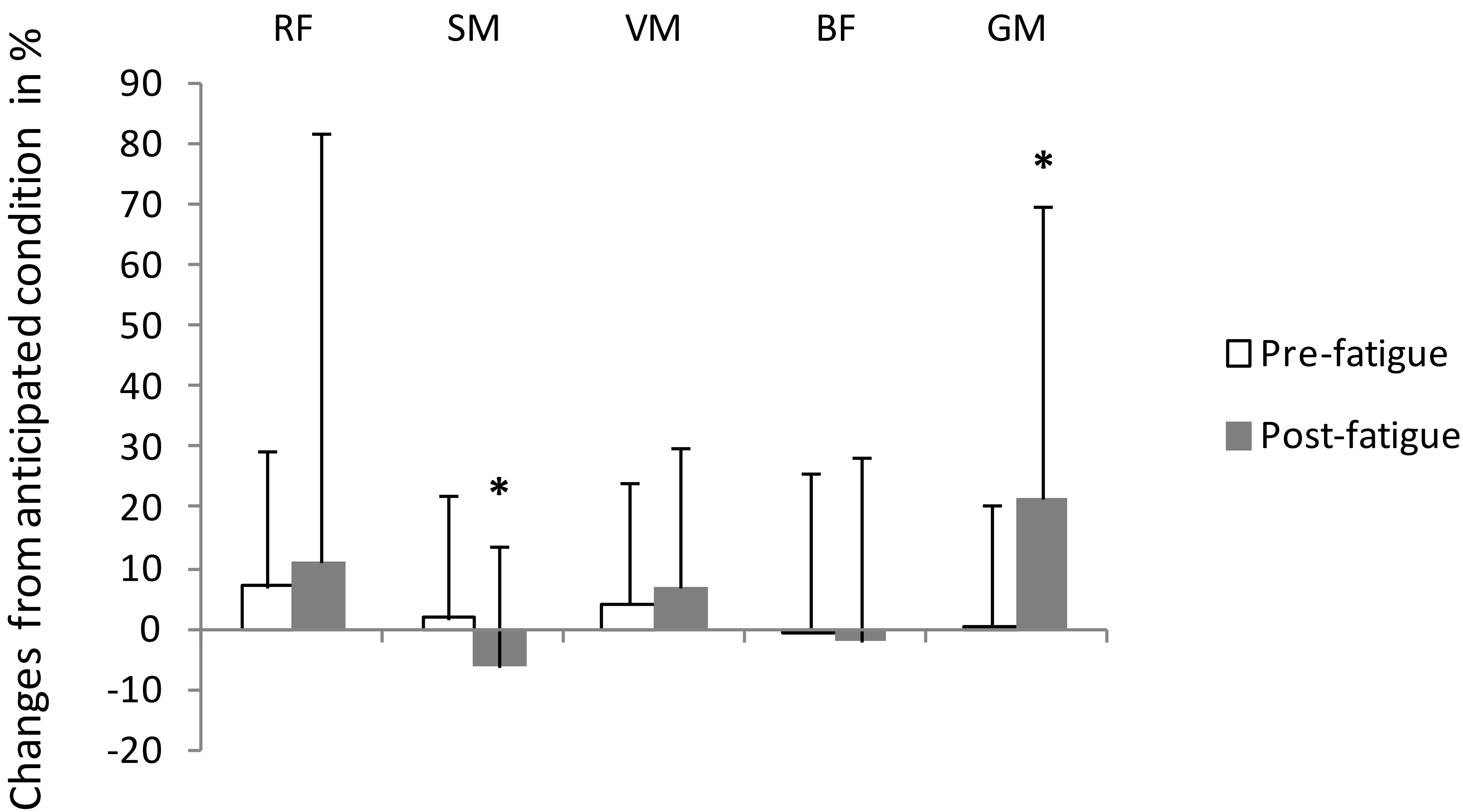

3.5
3
2.5
2
1.5
1
IGRF 50ms (BW)
Women
*P = 0.04
Men
pre
post
Fatigue Condition

Figure 4



RF
SM
VM
BF
GM
90
80
70
60
50
40
30
20
10
0
-10
-20
Changes from anticipated condition in %
*
*
Pre-fatigue
Post-fatigue

Figure 5

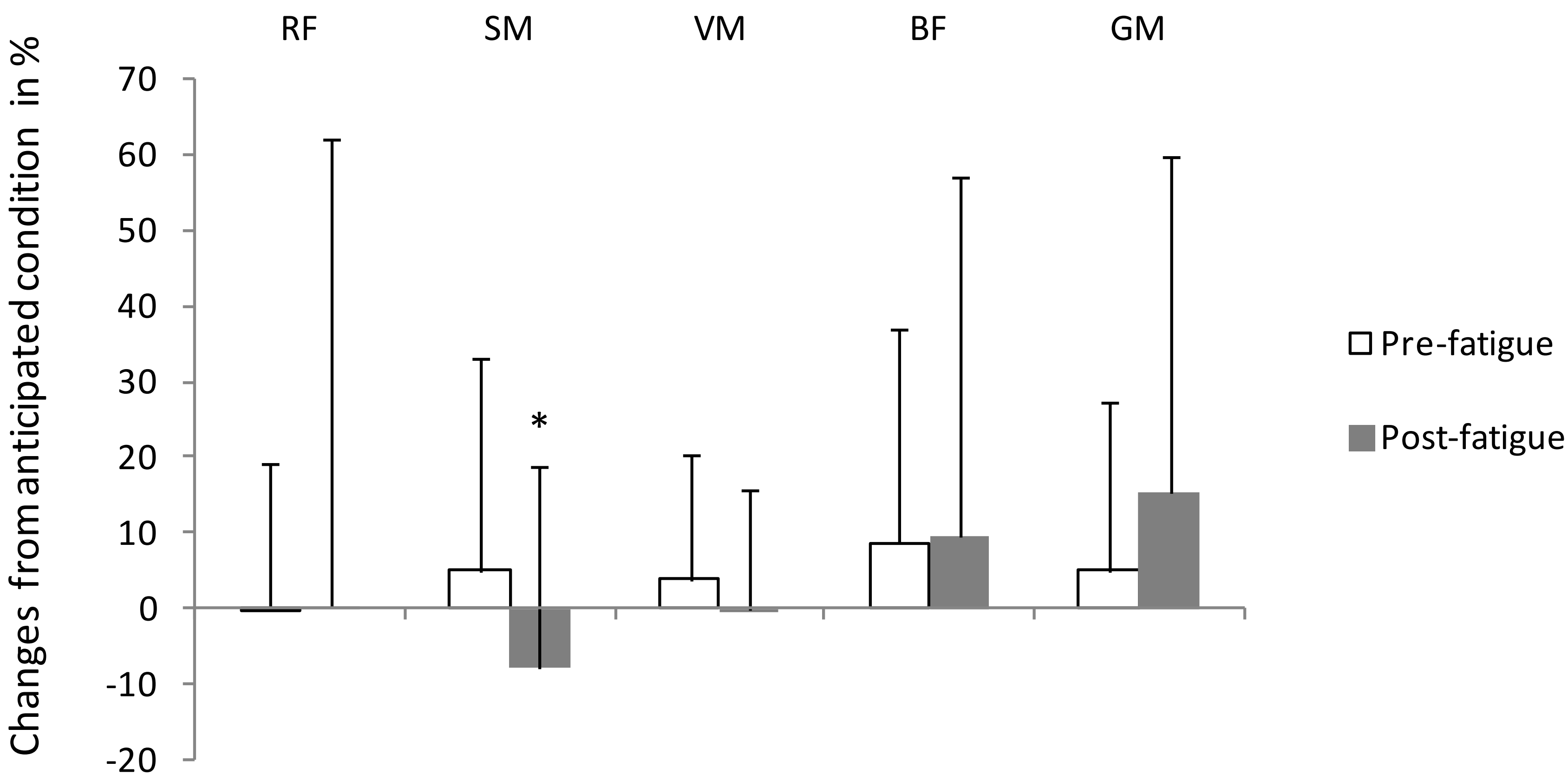

RF
SM
VM
BF
GM
70
60
50
40
30
20
10
0
-10
-20
Changes from anticipated condition in %
*
Pre-fatigue
Post-fatigue

Table 1. Mean subject characteristics by sex

Characteristic	Sex: Male ± SD (N = 11)	Sex: Female ± SD (N = 12)
Age (y)	22.9 ± 1.0	21.9 ± 1.2
Height (cm)	170.9 ± 4.5	160.6 ± 5.0
Weight (kg)	64.2 ± 7.6	55.0 ± 5.2

Table 2. Descriptive statics (mean, standard deviation) for kinematic and kinetic variables between pre- and post-fatigue by sex

	Women			Men			p value of two-way ANOVA		
	Pre-fatigue	Post-fatigue	Cohen's *d*	Pre-fatigue	Post-fatigue	Cohen's *d*	Sex	Fatigue	Sex x fatigue
Kinematics									
Onset knee flexion angle (°)	26.4 (6.9)	24.2 (6.2)	0.58	26.1 (10.4)	26.0 (10.8)	0.04	n.s.	n.s.	n.s.
Maximum knee flexion angle (°)	54.8 (6.4)	54.5 (6.5)	0.09	58.4 (6.0)	58.5 (5.8)	0.02	n.s.	n.s.	n.s.
Onset hip flexion angle (°)*	42.4 (8.6)	40.4 (6.9)	0.41	48.5 (9.4)	49.7 (9.1)	0.21	0.03	n.s.	n.s.
Maximum hip flexion angle (°)*	43.0 (8.4)	41.3 (7.7)	0.32	50.2 (10.0)	51.4 (9.0)	0.17	0.02	n.s.	n.s.
Knee flexion velocity 0-50 ms (°/s)	211.2 (32.3)	216.2 (27.6)	0.29	237.8 (64.6)	243.6 (63.2)	0.17	n.s.	n.s.	n.s.
Knee flexion velocity 50-100 ms (°/s)	44.0 (65.2)	55.5 (68.5)	0.52	61.6 (25.7)	62.3 (35.0)	0.02	n.s.	n.s.	n.s.
Kinetics									
$IGRF_{50\ ms}$ (BW)†	2.1 (0.8)	2.4 (0.8)	0.52	2.3 (0.7)	2.1 (0.9)	0.37	n.s.	n.s.	0.04
$IGRF_{100\ ms}$ (BW)	3.5 (0.5)	3.5 (0.6)	0.08	3.4 (0.6)	3.1 (1.1)	0.48	n.s.	n.s.	n.s.

* Denotes a significant difference between sex. † Denotes a significant interaction between the effect of sex and fatigue.
"Onset" means initial contact. "BW" means body weight.