Biomechanical Correlation Between Trunk and Foot Kinematics During Golf Swing Movement Before and After Fatigue

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Research Article

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Abstract

Background

Kinematic chain of whole body is important during golf swing. Moreover, it was suggested that kinematics of golf swing was affected by fatigue. The purpose of the present study was to investigate the golf swing before and after fatigue of trunk muscles, and to assess the effect of the fatigue on kinematics of trunk as well as lower extremity.

A total of 11 healthy adults participated in the current study. Golf swing motion in each subject was measured with a 7-iron on a grass plate using motion capture system. Three-dimensional kinematics of trunk and lower extremity on the lead side were evaluated.

Results

Sagittal trunk instability was observed after fatigue. Regarding the kinematic chain, range of motion of trunk rotation ($r = -0.76$, $p < 0.01$) and knee rotation ($r = 0.82$, $p < 0.01$) were significantly correlated with the hindfoot rotation before the fatigue task. However, after the fatigue task, the hindfoot rotation was significantly correlated only with the knee rotation ($r = 0.76$, $p < 0.01$).

Conclusions

As fatigue of trunk muscles will alter swing movement and kinematic chain, trunk muscle training can be one of key strategies to maintain swing performance.

Trial registration

Our study was registered to UMIN (No. 000037037, date; 01/07/2019).

Background

Golf is a popular sport for a wide range of age groups and players with various activity level, and thus, musculoskeletal disorders is frequently observed[1, 2]. In particular, low back pain often occurs among professional golfers[3] as well as amateurs[4]. The golf swing is divided into several phases, including backswing, downswing, impact and follow-through phases. According to previous studies, trunk lateral bending at the timing of impact and excessive trunk rotation with extension during follow-through phase can cause excessive mechanical stress on the spine, which will lead to low back pain [5]. In addition, previous studies reported that exacerbation of low back pain during golf swing would be strongly related to the range of motion of trunk rotation[6]. Therefore, control of trunk rotation is a key factor for golfers to avoid low back pain.

Kinematic chain of whole body is extremely important in sport movements. Concerning golf swing, players must activate the limb functions with a fixed position of the trunk[7]. Golf swing begins with a backswing of the upper limb, which is followed by trunk rotation, hip rotation, and knee rotation. Thereafter, a downswing of the upper limb leads to trunk rotation, hip rotation, and knee rotation. Failure of this kinematic chain will deteriorate player's performance as well as musculoskeletal condition. It is well known that fatigue affects various sport performance of athletes. For instance, Wilkins et al. indicated that balance function was notably reduced after fatigue tasks of muscle strength training[8]. Furthermore, postural control was strongly affected by both musculoskeletal and neurogenic factors[9]. In terms of golf, it has been reported that kinematics of putt motion was affected by fatigue such as prolonged putt practice[10]. However, kinematic chain of putt motion is totally different from that of swing motion using one wood driver or other iron clubs. Therefore, the effect of fatigue on golf swing has been unknown, so far.

The purpose of the present study was to investigate the golf swing before and after fatigue of trunk muscles, and to assess the effect of the fatigue on kinematics of trunk as well as lower extremity. It was hypothesized that fatigue of trunk muscles would alter trunk kinematics, which lead to kinematic change of lower extremity.

Methods

Subjects

A total of 11 healthy adults (5 females and 6 males) participated in the current study. Mean age, height, weight and body mass index (BMI) were 20.3 ± 0.8 years, 170.4 ± 6.2 cm, 62.1 ± 9.8 kg, and 21.2 ± 2.0 kg/m^2, respectively. All subjects were right-handed and had at least one year of experience in golf competition. None of the subjects had any history of major injuries of the trunk or lower extremities.

Assessment of golf swing using motion capture system

Golf swing motion in each subject was measured with a 7-iron on a grass plate using motion capture system, which consisted of eight infrared cameras (sampling frequency of 250 Hz, Oqus, Qualisys, Sweden) and two force plates (frequency 600 Hz; AM6110, Bertec, Columbus, OH, USA). A total of 73 reflective markers were placed on standardized bony landmarks, and in addition, Oxford foot model, which is one of the marker set for detailed analysis of foot kinematics, including hind-, mid- and fore-foot, was used in the present study, (Fig. 1)[11]. The motion of markers was recorded by Qualisys Track Manager Software (version 2.7). To calculate kinematics and swing speed, Visual 3D (C-motion Company, Rockville, MD, USA) was used. After performing the golf swing several times as warm-ups, two trials were recorded for all subjects.

Fatigue task

Plank training was chosen for the fatigue task in the present study (Fig. 2). Plank training is widely used as a whole-body training exercise involving the trunk, and is considered as a high-intensity exercise [12, 13]. In the present study, each subject continued plank training based on the modified Borg scale [14]. The goal of the scale was set at greater than 17 in which subjects felt very hard. After the fatigue protocol, subjects performed the golf swing 30 seconds from the fatigue task, and this swing trial was also recorded using three-dimensional motion capture system.

Evaluations

Three-dimensional kinematics of trunk and lower extremity on the lead side were evaluated for each subject. In addition, range of motion during golf swing was assessed for trunk, hip, knee, ankle, hind-, mid- and fore-foot. Range of motion of the trunk was determined as relative value with respect to pelvis. Moreover, swing speed was measured based on markers put on 7-iron (Fig. 3).

Statistical Analysis

After confirming normality assumption using the Shapiro-wilk test, range of motion was compared between before and after the fatigue task using paired t-test or Wilcoxon t-test. Furthermore, to examine the kinematic chain during golf swing, the relationship of the motility between trunk and lower extremity was assessed using Pearson or Spearman's rank correlation coefficient based on normality assumption. All statistical analyses were done with SPSS® Version 26 for Mac (Chicago, IL, USA). The significance level was set at less than 5%. The sample size for the current investigation was determined to be 10 subjects in each group with 80% power (GraphPad Statmate 2, San Diego, CA, USA). This calculation was performed using trunk bending angle in the sagittal plane during golf swing, with defined significant differences of 2.0° between before and after the fatigue task.

Results

Swing speed was not significantly different between pre- and post-fatigue (21.53±4.26m/s vs 21.40±3.41m/s). Excursion of trunk sagittal bending during swing movements after the fatigue task significantly increased compared to before the task (47.9 ± 14.3°vs 43.4 ± 12.9°, $p<0.01$, Fig.4. a. □). Moreover, sagittal excursion of ankle on the lead leg after the fatigue task significantly decreased compared to before the task (30.0 ± 6.9° vs 34.5 ± 8.0°, $p<0.05$, Fig.5. a. □). Similarly, excursion of ankle rotation significantly decreased after fatigue task (12.3 ± 3.7° vs 15. 8 ± 3.9°, $p<0.01$, Fig.5. b. □), whereas there were no significant differences in range of motion at other joints between before and after the fatigue task.

Regarding the kinematic chain, no significant correlations were detected in coronal and sagittal planes before the fatigue task as well as after the task. In the transverse plane, the mobility of trunk rotation ($r = -0.76$, $p < 0.01$) and knee joint rotation ($r = 0.82$, $p < 0.01$) were significantly correlated with the hindfoot rotation before the fatigue task (Table 1). However, after the fatigue task, the hindfoot rotation was not significantly correlated with the trunk rotation ($r = -0.37$, $p = 0.25$), though the hindfoot rotation was significantly correlated with the knee joint rotation ($r = 0.76$, $p <0.01$). The other joints showed no association with hindfoot movement both before and after the fatigue task (Table 2).

Discussion

The results of the present study supported the hypothesis that fatigue of trunk muscles would alter trunk kinematics, which lead to kinematic change of lower extremity. The most important finding in the current investigation was that kinematic chain during golf swing might change after the fatigue task compared to before the task.

From the present study, excursion of trunk sagittal bending significantly increased, and simultaneously, excursion of ankle movement in the sagittal plane significantly decreased during golf swing after the fatigue task. According to previous research, the swing performance would depend on trunk stability[15]. Specifically, smaller sagittal movement of trunk should be favorable in golf swing movements. Another study reported that increased swing speed was strongly associated with sagittal bending and axial rotation of the trunk relative to the pelvis[16]. In the present study, sagittal trunk instability did not result in deterioration of swing performance as swing speed was similar between pre- and post-fatigue. Instead, the mobility of the sagittal and transverse movements at ankle joint decreased after fatigue based on results of the current study. Faux et al suggested that the foot center of pressure was central to the base of support and in-line with the center of mass (CoM), indicating significantly increased stability when the CoM was near maximal acceleration [17]. Therefore, smaller movements at ankle joint seemed to be compensatory mechanics after fatigue to maintain postural control. The results of this study examined joint mobility in a series of movements from the address to the follow-through phase of the swing motion. Difference between before and after fatigue became pronounced from the impact phase to the follow-through phase (60%-100% of the swing motion cycle, Fig. 4). This result suggested that it could be difficult to maintain posture after fatigue especially in the follow-through phase, as increased rigidity of the lower limbs was observed after fatigue (Fig. 6). Furthermore, Lim et al., suggested that lumbar spine loading at the L4-L5 level significantly increased during the follow-through phase based on electromyography [18]. In conjunction with the results of their study, trunk muscle fatigue might lead to relative increase of erector spinae activity, as instability of trunk sagittal bending was observed after fatigue in the present study.

In terms of alteration of kinematic chain, the hindfoot rotation of the lead leg was associated with the range of motion of knee and trunk rotations before the fatigue task. However, after the fatigue task, the hindfoot rotation of the lead leg was associated with knee rotation, though it was not associated with trunk rotation. These results suggested that the kinematic chain from the foot was derived to the trunk before the fatigue task, while the chain remained to the knee joint after the fatigue task. It has also been reported that the muscle output of the lower extremity on the lead leg is strongly exerted from impact to follow-through [19]. The fatigue task used in the present study was plank training. This training is widely used for athletes as a task for the core muscles of the trunk and is designed to stabilize the pelvis and posture during training [20]. During plank training, not only trunk muscle power but also thigh muscle power is exerted to stabilize the pelvis and posture[21]. All of the subjects in the current study continued to perform plank training until Borg scale 17 (very hard). It has been reported that the muscle activity in the golf swing movement greatly increases the muscle activity attached to the thigh such as the gluteus maximus, external oblique abdominis, internal oblique abdominis, pectoralis major, psoas major, and quadratus lumborum muscles, compared to the simple rotational movement of trunk [22]. Plank training has known to be an exercise that increases muscle activity in the oblique abdominal muscles, rectus abdominis, and rectus femoris rather than the erector spinae[23]. Besides, it has also been reported that the erector spinae muscles' activity was not changed by fatigue with repetitive golf swing movements [24]. As fatigue in the present study was appropriate for subjects, it was possibly difficult for them to exert thigh muscle contraction, which is essential for pelvic stabilization. Therefore, their swing movements were affected by the fatigue task.

Several limitations of the present study should be noted. First, the direction and distance of the ball after the swing motion were not evaluated. Therefore, golf swing performance was unknown even if swing speed was assessed. Second, player's experience or competition level was relatively different. Lastly, plank training was simulation of fatigue, and thus, fatigue caused by actual golf competition seemed to be different. Nonetheless, the present results provide important information regarding the effect of the fatigue task on biomechanical change of lower limbs and trunk during golf swing.

Conclusion

From the present study, subjects could not maintain trunk stability due to fatigue as the range of motion of the trunk in sagittal plane increased after the fatigue task. In addition, correlations between the hindfoot rotation and the trunk and knee rotation were found before the fatigue while the hindfoot rotation was correlated only with the knee rotation after the fatigue. The results suggest that the kinematic chain from the lead leg to trunk did not work after fatigue. As fatigue of trunk muscles will deteriorate swing movement, trunk muscle training can be one of key strategies to maintain swing performance.

Abbreviations

BMI; Body Mass Index, CoM; Center of Mass

Declarations

Ethics approval and consent to participate

Each subject provided a written informed consent, and the study protocol was approved by our ethical committee (No. 2019-0116).

Consent for publication

Written informed consent was obtained from the patient for publication of this case report and accompanying images.

Availability of data and materials

The data that support the findings of this study are available from the corresponding author, [author initials], upon reasonable request.

Competing interests

The authors declare that there is no conflict of interest.

Funding

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Authors' contributions

Satoshi Hakukawa; Writing (Original Draft Preparation), Methodology, Programming, Validation,

Formal analysis, Investigation, Visualization

Kengo Harato; Writing (Original Draft Preparation), Methodology, Conceptualization,

Project administration

Erika Morita; Methodology, Validation, Investigation, Resources

Kohei Nishizawa; Programming, Methodology, Validation, Investigation, Resources

Shu Kobayashi; Writing (Review and Editing), Supervision

Yasuo Niki; Writing (Review and Editing), Supervision

Morio Matsumoto; Writing (Review and Editing), Supervision

Masaya Nakamura; Writing (Review and Editing), Supervision

Takeo Nagura; Writing (Review and Editing), Project administration

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Tables

Table 01

	Hindfoot Dorsiflexion and Plantarflexion	Hindfoot Inversion and Eversion	Hindfoot Rotation
Trunk Rotation	-0.19 (0.55)	-0.11 (0.74)	-0.76(0.006) *
Hip Rotation	-0.48 (0.12)	-0.56 (0.06)	0.05(0.86)
Knee Rotation	-0.02 (0.93)	0.11 (0.73)	0.82(0.002) *
Ankle Rotation	-0.27 (0.41)	0.42(0.19)	0.36(0.27)

Data are presented as correlation coefficients (p value).

* Indicates significance at p < 0.05

Table 02

Data are presented as correlation coefficients (p value).

	Hindfoot Dorsiflexion and Plantarflexion	Hindfoot Inversion and Eversion	Hindfoot Rotation *
Trunk Rotation	0.05 (0.87)	-0.04 (0.89)	-0.37 (0.25)
Hip Rotation	0.37 (0.26)	-0.46 (0.15)	-0.10 (0.76)
Knee Rotation	0.146 (0.668)	0.63 (0.03) *	0.76 (0.006) *
Ankle Rotation	-0.10 (0.76)	0.28 (0.40)	0.16 (0.63)

Indicates significance at $p < 0.05$

Figures

Figure 1

Golf swing motion in each subject was measured with a 7-iron on a grass plate using motion capture system, which consisted of eight infrared cameras (sampling frequency of 250 Hz, Oqus, Qualisys, Sweden) and two force plates (frequency 600 Hz; AM6110, Bertec, Columbus, OH, USA). A total of 73 reflective markers were placed on standardized bony landmarks, and in addition, Oxford foot model, which is one of the marker set for detailed analysis of foot kinematics, including hind-, mid- and fore-foot, was used in the present study, (Fig.1)[11].

Figure 2

Plank training was chosen for the fatigue task in the present study (Fig. 2).

Figure 3

Range of motion of the trunk was determined as relative value with respect to pelvis. Moreover, swing speed was measured based on markers put on 7-iron (Fig.3).

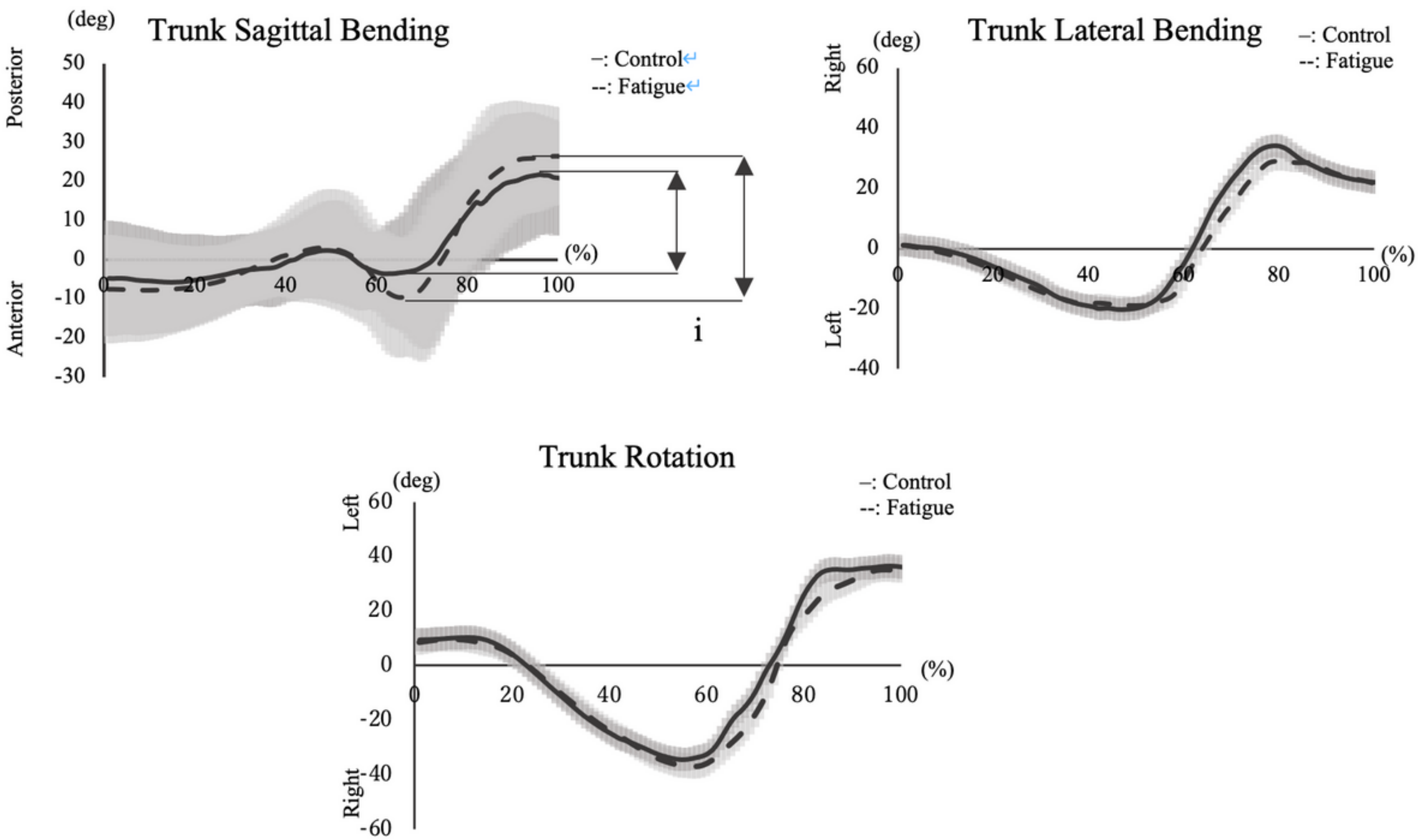

Figure 4

Excursion of trunk sagittal bending during swing movements after the fatigue task significantly increased compared to before the task (47.9 ± 14.3°vs 43.4 ± 12.9°, $p<0.01$, Fig.4. a. i).

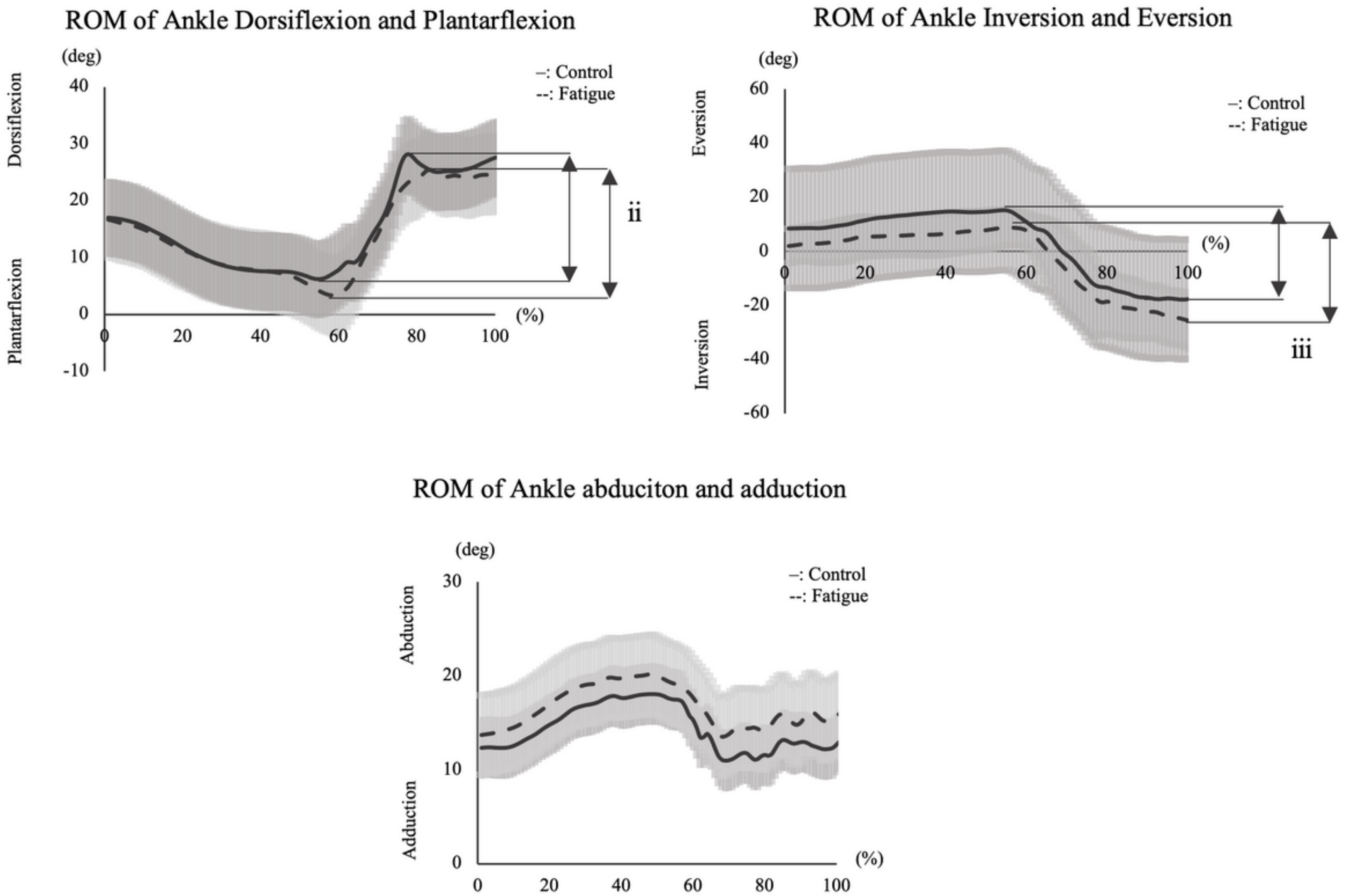

Figure 5

Moreover, sagittal excursion of ankle on the lead leg after the fatigue task significantly decreased compared to before the task (30.0 ± 6.9° vs 34.5 ± 8.0°, p<0.05, Fig.5. a.). Similarly, excursion of ankle rotation significantly decreased after fatigue task (12.3 ± 3.7° vs 15. 8 ± 3.9°, p<0.01, Fig.5. b.), whereas there were no significant differences in range of motion at other joints between before and after the fatigue task.

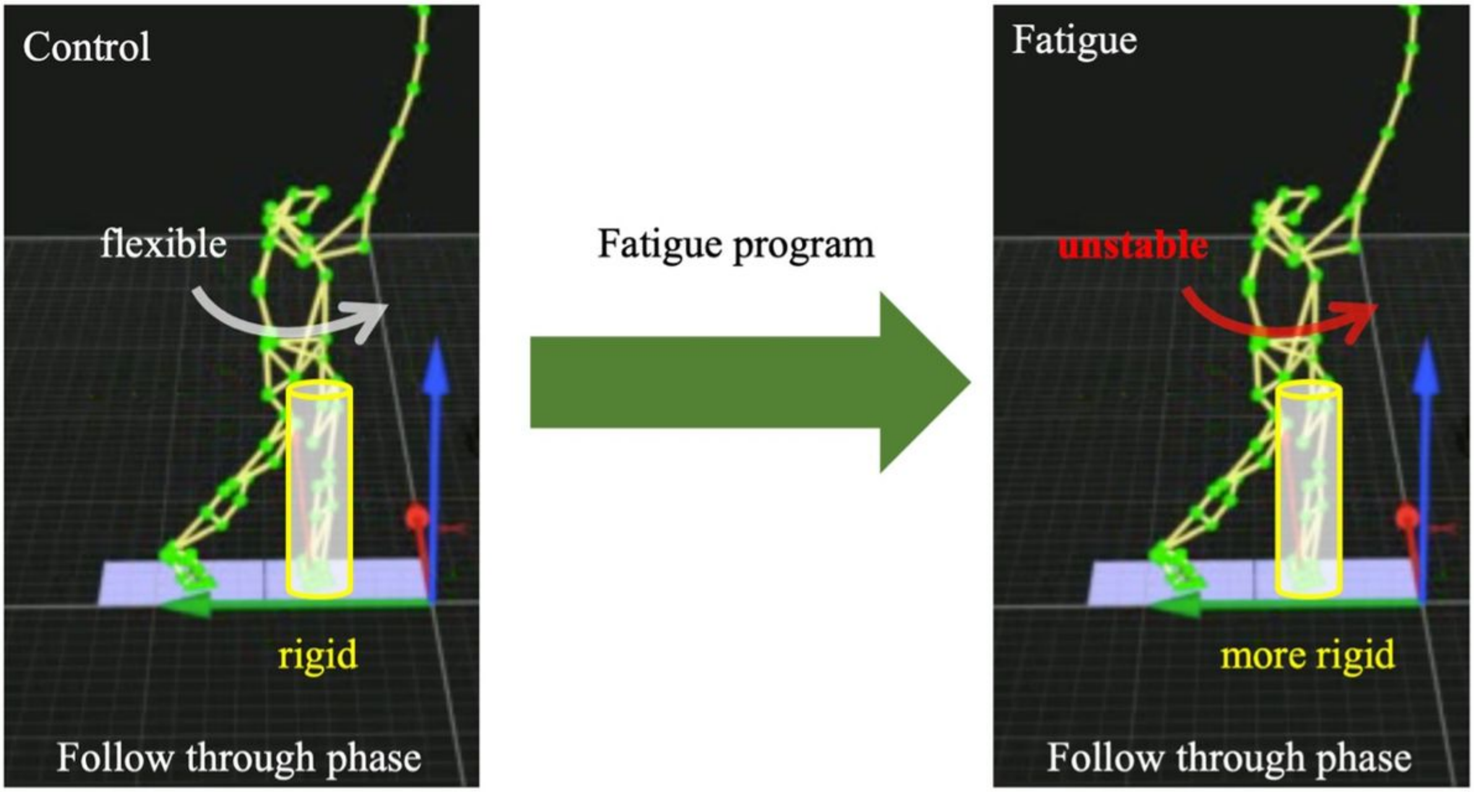

Figure 6

This result suggested that it could be difficult to maintain posture after fatigue especially in the follow-through phase, as increased rigidity of the lower limbs was observed after fatigue (Fig.6).