The muscle pre-activity timing of the hamstrings and quadriceps during 180° and 360° rotational jump landings in healthy female subjects

Daisuke Bai a, b, *, Yohei Okada c, Takahiko Fukumoto c, Munehiro Ogawa b, d, Yasuhiro Tanaka b, d

* Department of Rehabilitation, Heisei Memorial Hospital, Nara, Japan
b Graduate School of Medicine, Musculoskeletal Reconstructive Surgery, Nara Medical University, Nara, Japan
c Department of Physical Therapy, Faculty of Health Science, Kio University, Nara, Japan
d Department of Orthopedic Surgery, Nara Medical University, Nara, Japan

A R T I C L E   I N F O

Article history:
Received 20 August 2018
Received in revised form 24 December 2018
Accepted 2 January 2019
Available online 25 January 2019

Abstract

Background/Objective: The muscle activity before the initial contact between during jump landings is referred to as the pre-activity. The muscle pre-activity that occur during jump landing are considered to be an important predictor of non-contact anterior cruciate ligament (ACL) injury risk. ACL injury prevention programs have been widely conducted; these programs are generally focused on increasing the muscle pre-activity and include rotational jump landing. The purpose of this study was to investigate the timing of the muscle pre-activity of the hamstrings and quadriceps during 180° and 360° rotational jump landing.

Methods: The participants were 10 healthy females. Electromyography was conducted on the knee joint muscles of the left leg (the non-dominant leg) during clockwise 180° and 360° rotational jump landings.

Results: The muscle pre-activities during 180° rotational jump landing was VM: 35.68 ± 11.22 msec, RF: 38.05 ± 14.77 msec, VL: 47.10 ± 19.96 msec, BF: 115.63 ± 30.48 msec and SM: 136.45 ± 47.52 msec. And the muscle pre-activities during 360° rotational jump landing was VM: 45.25 ± 17.41 msec, RF: 42.38 ± 13.35 msec, VL: 47.52 ± 19.20 msec, BF: 132.20 ± 46.74 msec and SM: 140.70 ± 40.64 msec. For both the 180° rotational jump landing and the 360° jump landing, the pre-activities of the hamstrings occurred significantly earlier than those of the quadriceps (p < 0.01).

Conclusion: The results of the present study indicate that it may be beneficial for ACL injury prevention programs to include rotational jump landing tasks.

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Introduction

Anterior cruciate ligament (ACL) injury is one of the most common ligament injuries of the knee, especially in female athletes, and mainly occurs through non-contact mechanisms, such as uncontrolled jump landings. To decrease the incidence of non-contact ACL injuries, several ACL injury prevention programs have been developed. ACL injury prevention programs have investigated the biomechanics related to landing techniques. In particular, the knee joint muscle activity before the initial contact in a jump landing (defined as the muscle pre-activity) is considered to play an important role in the dynamic stability of the knee. Previous research has concluded that ACL prevention programs must include increased amounts of knee joint muscle pre-activity.

ACL injury prevention programs often include rotational jump landings (180° and 360° rotational jump landings). Furthermore, rotational jumps are performed in many dynamic-movement sports, including basketball, gymnastics, and martial arts. However, there are no reports about the kinetics and the kinematics of the knee joint during rotational jump landing. According to previous reports regarding the muscle pre-activity during drop or vertical jump landings, hamstring pre-activity occurs significantly earlier compared to that of the quadriceps, with the earlier hamstring pre-activity decreasing the tibial anterior shear and protecting the...
ACL. To prevent ACL injury, the muscle pre-activity must be increased around the knee joint during jump landing; however, no study has investigated the muscle pre-activity during rotational jump landings. Therefore, it is unclear how the muscle pre-activity changes during high-difficulty jump landing. To introduce rotational jump landing into ACL prevention programs, it is necessary to analyse the muscle pre-activity patterns during 180° and 360° rotational jump landings.

The purpose of the present study was to investigate the muscle pre-activity timings of the hamstrings and quadriceps during 180° and 360° rotational jump landings. We hypothesised that the muscle pre-activity timing of the hamstring muscle would occur significantly earlier compared to that of the quadriceps during rotational jump landings.

Materials and methods

Participants

Ten healthy females participated in the present study (mean age, 23.5 ± 2.5 years; weight, 50.3 ± 3.8 kg; height, 158.5 ± 4.8 cm). The non-contact ACL injury rate is two to eight times greater in females than in males; thus, males were excluded. None of the participants had a history of major lower limb injury. The participants were only recreationally active in sports and had no previous experience in rotational jump landings. ‘Recreationally active’ was defined as regularly engaging in running and cutting activities (e.g., soccer, volleyball, tennis, basketball) for a minimum of 30 min at least two or three times per week. The right leg was dominant (for kicking a ball) in all participants. The study protocol received Institutional Review Board approval (H25-20), and written informed consent was obtained from all participants before study commencement.

Tasks

The participants performed clockwise 180° and 360° rotational jumps. The clockwise 180° rotational jumps involved a double-limb take-off with a backward landing; 360° rotational jumps involved a double-limb take-off with a full rotation before landing. After each rotational jump landing task was explained, participants were allowed to adequately practice before the trials. The participants were instructed to fold their arms across their chest and land as naturally as possible with the preceding landing leg on the platform, maintaining the landing posture for approximately 2 seconds. The participants repeated the tasks as many times as necessary to record three successful trials of each rotational jump landing task. All participants performed a single-limb landing for both rotational jump landing tasks, and the results for the left (non-dominant) legs were analysed. Each participant was allowed to rest as much as she wanted to prevent fatigue. All data were acquired on a single day.

Instrumentation

Electromyography (EMG) data were recorded at 1000 Hz using a surface EMG system (SX230, Biometrics Ltd., UK). For all participants, EMG data were collected from the support leg (left leg) muscles, including the vastus medialis (VM), rectus femoris (RF), vastus lateralis (VL), semimembranosus (SM), and biceps femoris (BF). Bipolar surface electrodes (inter-electrode distance, 12 mm) were aligned with the longitudinal axis of the muscle in accordance with the recommendations of the SENIAM project. The ground electrode was placed on the skin over the right styloid process of the ulna. The skin over the belly of these five muscles was shaved.

![Fig. 1. Example of electromyography (EMG) recordings during 360° rotational jump landing. We analysed the data in the rectangle between the time of initial foot-ground contact (IC) and the amplitude for 200 milliseconds before IC. VM: vastus medialis, RF: rectus femoris, VL: vastus lateralis, SM: semimembranosus, BF: biceps femoris.](image-url)
and cleaned with alcohol, reducing the skin impedance to below 5 kΩ. All electrode placements were confirmed with manual muscle testing and were checked for cross-talk. The EMG signal was full-wave rectified and filtered at a bandpass of 10–500 Hz with 130-dB common-mode rejection within the transmitter (Fig. 1). The receiver converted the signal from analogue to digital through an external A/D converter, and the signals were displayed on a computer monitor. The muscle pre-activity was then defined as the timepoint at which the myoelectric activity first exceeded two root mean squares of the average baseline activity in the hamstrings and quadriceps, which was recorded during the quiet period before the rotational jump. The ground reaction forces generated during the rotational jump landings were recorded using a force platform (9281E, Kistler Japan Co., Ltd., Japan) synchronized to the EMG system. These data were measured at the time of the initial foot-ground contact (IC), which was defined as the time at which the ground reaction force exceeded 10 N. The sampling frequency of the force platform was 125 Hz. The area and mean amplitude for 200 milliseconds before the IC were recorded for statistical analysis (Fig. 2).

**Data analysis**

The timing of the pre-activity in each muscle was analysed using a two-way repeated-measures analysis of variance with two muscle levels (quadriceps/hamstrings) and two task levels (180°/360°). Tukey’s post hoc analyses were conducted to identify the muscle pre-activity timing differences among the five assessed muscles. All statistical comparisons were performed with the level of significance set at $p < 0.05$.

**Results**

The muscle pre-activity timing around the knee joint was successfully captured during both the 180° and 360° rotational jump landings in all trials for all participants. In the 180° rotational jump landings, the pre-activity timings of the hamstring muscles (SM and BF) were significantly earlier compared with those of the quadriceps (VM, RF, and VL) ($p < 0.01$, Fig. 3). Similarly, for the 360° landings, the pre-activity timings of the hamstring muscles (SM and BF) were significantly earlier compared with those of the quadriceps (VM, RF, and VL) ($p < 0.01$, Fig. 4). In the five assessed muscles, there were no significant differences in the pre-activity timings between the 180° and 360° rotational jump landings (Table 1).

**Discussion**

The present study examined the muscle pre-activity timing of the hamstrings and quadriceps during rotational jump landings performed by healthy females. The results demonstrated that hamstring pre-activity occurred significantly earlier compared with...
ACL injury prevention programs, we focused only on the muscle pre-activity during rotational jump landings. The differences in muscle pre-activities in 180° and 360° rotational jump landings, which are often included in ACL injury prevention programs. There were no significant differences between 180° and 360° rotational jump landings in the pre-activity timing for each of the five assessed muscles. The 360° rotational jump is more difficult to perform than the 180° rotational jump. Therefore, we predicted that the muscle pre-activities around the knee joint during the 360° rotational jump would be delayed compared with those during the 180° rotational jump. The muscle pre-activities around the knee joint showed a similar pattern in the 180° and 360° rotational jump landing tasks; therefore, in a future study, we will examine the joint angles or the muscle strength of the knee joint in 180° and 360° rotational jump landings, and thus identify the differences between 180° and 360° rotational jump landings. However, regarding the present study, the pre-activity of the hamstrings occurred earlier than that of the quadriceps in both the 180° and 360° rotational jump landing tasks. Cowling et al. reported that the hamstring muscles were activated 200 milliseconds before the IC, while the quadriceps were activated 80 milliseconds before the IC during single-leg jump landings. Therefore, our findings are consistent with those of studies evaluating drop or single-leg jump landings. However, the rotational jump is more difficult than drop or single-leg jump landings. McBride et al. reported that the difficulty of the jump landing task influenced on the muscle pre-activity timing, resulting in a delay in the muscle pre-activity during rotational jump landings compared with that for single-leg jump landings.

Neuromuscular training studies have been conducted in an attempt to reduce the risk of ACL injury. Nagano et al. reported that hamstring pre-activity was significantly increased after jump and balance training. Thus, recent studies have focused on the muscle pre-activity during functional activities, as the muscle pre-activity is important for the dynamic stability of the knee. Studies using video analyses have reported that ACL injuries occur approximately 40 milliseconds after the IC, and that the positive feedback control of muscle activities is too slow to protect against ACL injury. Therefore, as rotational jump training increases hamstring pre-activity, this task may be a necessary part of ACL injury prevention programs, which could be introduced after the participants learn how to correctly perform drop or vertical jump landings.

The present study has some limitations. First, we did not examine the muscle pre-activity level (amplitude), the joint angles or the muscle strength of the knee joint. Although the present results suggest that rotational jump landings may be beneficial for ACL injury prevention programs, we focused only on the muscle pre-activity timings around the knee joint. Therefore, it is necessary to explore the effect of the kinematics of the knee joint on ACL injury prevention. Second, we focused on only female participants, and the sample size was small. The reasons that we only included females were that females reportedly have a high risk of ACL injury during jump landings, and females generally exhibit increased quadriceps activation and decreased hamstrings activation during vertical stop jump landings compared with males. Further large-scale studies are required to clarify these sex differences. Third, the task assessed in the present study was a rotational jump. The rotational jump is more difficult than drop or single-leg jump landings; therefore, in a future study, we will evaluate the muscle pre-activity timing during rotational jump landings compared with that for other types of jump landings, such as single-leg jump landing or drop vertical jump landing.

Conclusion

The present study examined the pre-activity timing of the hamstrings and quadriceps during 180° and 360° rotational jumps performed by healthy females. The hamstring pre-activity occurred earlier than the quadriceps pre-activity during rotational jump landings. Rotational jump landings are often included in ACL injury prevention programs. Therefore, in a future study, we will examine the relationship between the muscle pre-activity and joint kinematics (joint angles and joint moments) and perform an intervention study to assess the effectiveness of ACL injury prevention programs that include rotational jump landing tasks.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Funding/Support Statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors, and no material support of any kind was received.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.asmart.2019.01.001.

References

1. Arendt EA, Agel J, Dick R. Anterior cruciate ligament injury patterns among collegiate men and women. J Athl Train. 1999;34:86–92.
2. Mandelbaum BR, Silvers HJ, Watanabe DS, et al. Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2-year follow-up. Am J Sports Med. 2005;33:1003–1010.
3. Olsen OE, Myklebust G, Engebretsen L, et al. Exercises to prevent lower limb injuries in youth sports: cluster randomized controlled trial. BMJ. 2005;330:449.
4. Omii Y, Sugimoto D, Kuriyama S, et al. Effect of hip-focused injury prevention training for anterior cruciate ligament injury reduction in female basketball players – a 12-year prospective intervention study. Am J Sports Med. 2018;46(4):852–861.
5. Medina JM, McLeod TC, Howell SK, et al. Timing of neuromuscular activation of the quadriceps and hamstrings prior to landing in high school male athletes, female athletes, and female non-athletes. J Electromyogr Kinesiol. 2008;18:591–597.
6. Cowling EJ, Steele JR, McNair PJ. Effect of verbal instructions on muscle activity and risk of injury to the anterior cruciate ligament during landing. Br J Sports Med. 2003;37:126–130.
7. Williams GN, Chmielewski T, Rudolph K, et al. Dynamic knee stability: current theory and implications for clinicians and scientists. J Orthop Sports Phys Ther. 2001;31:546–566.
8. Nagano Y, Ida H, Akai M, et al. Effects of jump and balance training on knee kinematics and electromyography of female basketball athletes during a single limb drop landing: pre-post intervention study. Sports Med Arthrosc Rehabil

Table 1

The differences in muscle pre-activities in 180° versus 360° rotational jump landings.

| Muscle pre-activities (msec) | 180° jump landing | 360° jump landing | p value |
|-----------------------------|-------------------|-------------------|--------|
| VM                          | 35.68 (11.22)     | 45.25 (17.41)     | 0.13   |
| RF                          | 38.05 (14.77)     | 42.38 (13.35)     | 0.60   |
| VL                          | 47.10 (19.96)     | 48.75 (19.20)     | 0.85   |
| BF                          | 115.63 (30.48)    | 132.20 (46.74)    | 0.35   |
| SM                          | 136.45 (47.52)    | 140.79 (40.64)    | 0.82   |

There were no significant differences in the muscle pre-activities between the two tasks.

VM: vastus medialis, RF: rectus femoris, VL: vastus lateralis, SM: semimembranosus, BF: biceps femoris.
9. Otsuki R, Kuramochi R, Fukubayashi T. Effect of injury prevention training on knee mechanics in female adolescents during puberty. *Int J Sports Phys Ther*. 2011;6(1):149–156.

10. Steele JR, Brown JM. Effects of chronic ACL deficiency on muscle activation patterns during an abrupt deceleration task. *Clin Biomech*. 1999;14:247–257.

11. Arendt EA, Dick R. Knee injury patterns among men and women in collegiate basketball and soccer. NCAA data and review of literature. *Am J Sports Med*. 1995;23:694–701.

12. Hermens HJ, Freriks B, Disselhorst-Klug C, et al. Development of recommendation for SEMG sensors and sensor placement procedures. *J Electromyogr Kinesiol*. 2000;10:361–374.

13. Shultz SJ, Perrin DH, Adams JM, et al. Assessment of neuromuscular response characteristics at the knee following a functional perturbation. *J Electromyogr Kinesiol*. 2000;10:159–170.

14. Griffin LY, Albohm MJ, Arendt EA, et al. Understanding and preventing noncontact anterior cruciate ligament injuries: a review of the Hunt Valley II meeting. January 2005. *Am J Sports Med*. 2005;34:121–125.

15. McBride JM, McCaulley GO, Cormie P. Influence of preactivity and eccentric muscle activity on concentric performance during vertical jumping. *J Strength Cond Res*. 2008;22(3):750–757.

16. Hewett TE, Lindenfeld TN, Riccobene JV, et al. The effect of neuromuscular training on the incidence of knee injury in female athletes; a prospective study. *Am J Sports Med*. 1999;27:699–706.

17. Koga H, Nakamae A, Shima Y, et al. Mechanisms for noncontact anterior cruciate ligament injuries: knee joint kinematics in 10 injury situations from female team handball and basketball. *Am J Sports Med*. 2010;38:2218–2225.

18. Krosshaug T, Nakamae A, Boden BP, et al. Mechanisms of anterior cruciate ligament injury in basketball video analysis of 35 cases. *Am J Sports Med*. 2007;35:359–367.

19. Chappell JD, Creighton RA, Giuliani C, et al. Kinematics and electromyography of landing preparation in vertical stop-jump: risk for noncontact anterior cruciate ligament injury. *Am J Sports Med*. 2007;35:235–241.

20. Malinzak RA, Colby SM, Kirckendall DT, et al. A comparison of knee joint motion patterns between men and women in selected athletic maneuvers. *Clin Biomech*. 2001;16(5):438–445.