J. Phys. Ther. Sci. 29: 2147–2150, 2017

The Journal of Physical Therapy Science

Original Article

Does trampoline or hard surface jumping influence lower extremity alignment?

Kiyokazu Akasaka, RPT, PhD[1, 2)*], Akihiro Tamura, RPT, MS[1, 3)], Aoi Katsuta, RPT[4)], Ayako Sagawa, RPT[5)], Takahiro Otsudo, RPT, PhD[1, 2)], Yu Okubo, RPT, PhD[1, 2)], Yutaka Sawada, RPT, MS[2)], Toby Hall, RPT, PhD[6)]

[1)] *Saitama Medical University Graduate School of Medicine: 981 Kawakado, Moroyama, Iruma-gun, Saitama 350-0496, Japan*
[2)] *School of Physical Therapy, Saitama Medical University, Japan*
[3)] *Department of Physical Therapy, Sekishindo Hospital, Japan*
[4)] *Department of Physical Therapy, Saitama Sekishinkai Hospital, Japan*
[5)] *Department of Physical Therapy, Mito Kyodo General Hospital, Japan*
[6)] *School of Physiotherapy and Exercise Science, Curtin University, Australia*

Abstract. [Purpose] To determine whether repetitive trampoline or hard surface jumping affects lower extremity alignment on jump landing. [Subjects and Methods] Twenty healthy females participated in this study. All subjects performed a drop vertical jump before and after repeated maximum effort trampoline or hard surface jumping. A three-dimensional motion analysis system and two force plates were used to record lower extremity angles, moments, and vertical ground reaction force during drop vertical jumps. [Results] Knee extensor moment after trampoline jumping was greater than that after hard surface jumping. There were no significant differences between trials in vertical ground reaction force and lower extremity joint angles following each form of exercise. Repeated jumping on a trampoline increased peak vertical ground reaction force, hip extensor, knee extensor moments, and hip adduction angle, while decreasing hip flexion angle during drop vertical jumps. In contrast, repeated jumping on a hard surface increased peak vertical ground reaction force, ankle dorsiflexion angle, and hip extensor moment during drop vertical jumps. [Conclusion] Repeated jumping on the trampoline compared to jumping on a hard surface has different effects on lower limb kinetics and kinematics. Knowledge of these effects may be useful in designing exercise programs for different clinical presentations.

Key words: Repetitive jump landing, Trampoline, Drop vertical jump

(This article was submitted Aug. 6, 2017, and was accepted Sep. 20, 2017)

INTRODUCTION

Exercise to facilitate improved biomechanical alignment in standing or walking has been investigated. Such training includes standing on one leg, forward lunge, and different trunk exercises[1–3)]. It is thought that altering biomechanical alignment might be useful in the management of people with musculoskeletal disorders such as low back pain, as well as people who are frail[5, 6)].

Previous studies have reported on the effect of different exercise such as jumping or plyometrics to improve landing biomechanics and performance[7–10)]. Lephart et al. reported that initial and peak knee and hip flexion angles, and time to peak knee flexion during jump landing increased after repetitive jump landing exercise[9)]. Hewett et al. reported that plyometric exercise decreased the impact force during jump landing as well as increasing hamstring muscle power[7)]. In addition, they

*Corresponding author. Kiyokazu Akasaka (E-mail: akasaka-smc@umin.ac.jp)

concluded that plyometric exercise might have a significant effect on knee stabilization and the prevention of knee injury, as well as improvement in vertical jump height[11]. These reports indicate that jumping or plyometric exercise training may alter lower extremity alignment during jump landing as well as enhance jumping performance.

In recent years, trampoline exercise has been investigated as a means of preventing lower extremity injuries[12], as well as effects on gait in cerebral palsy infants[13]. In generally, it has been known that the change of surface stiffness influences the stiffness of the leg spring during ground contact in hopping and running[14–16]. Ferris et al. reported that lower surface stiffness increased the leg stiffness during ground contact in running[14]. A trampoline has specifically a characteristic of the elastic surface as contrasted with the ground. Therefore, landings on a trampoline may effect to the change of lower extremity alignment by decreasing the leg stiffness. However, few studies have focused on the effects of trampoline jumping on lower extremity alignment. We evaluated the effect of repeated jumping landing, either on the ground or on a trampoline, on lower extremity biomechanics during vertical drop jump landing.

SUBJECTS AND METHODS

Twenty healthy females (age; 21.0 ± 0.9 years old, height; 160.4 ± 3.9 cm, weight; 53.6 ± 6.3 kg) participated in this cross-over designed study. A washout period of one week was set between each experiment. Subjects were randomly assigned to one of two groups. Group A (n=12, 21.2 ± 0.8 years old, 160.5 ± 4.3 cm, 52.6 ± 7.4 kg), undertook trampoline jumping (Shinewood, OSJ, Tokyo, Japan) in the first phase, followed by a second phase of jumping on the ground. Group B (n=8, 20.8 ± 0.9 years old, 160.2 ± 3.4 cm, 55 ± 4.3 kg), undertook jumping on the ground in the first phase and trampoline jumping in the second phase. Subjects were instructed to perform their maximum jump on each occasion, 10 times repeatedly for 3 sets. A 30-seconds rest period was given between sets. All subjects performed a drop vertical jump (DVJ) before and after the repeated jump exercise. This consists of first landing after dropping down from a 40 cm box and then a second landing after a maximum vertical jump rebounding from the drop. They were instructed only to perform their maximum jumps after first landings and then keep their balance after second landings. Several practice trials were conducted to enable the participants to perform the DVJ in the correct fashion. Subsequent trials were repeated until data from 5 successful trials was achieved. Trials were excluded if the participant lost balance during the landing process. A 3-D motion analysis system (Vicon MX, Vicon's Motion Systems) and two force plates (AMTI MSA-6, Mass.) were used to record lower extremity angles, moments, and vertical ground reaction force (vGRF) during the first landing of DVJ. Mean angles, moments, and vGRF during landings of the middle 3 successful DVJs were adopted as representative data for this study.

Thirty-five reflective markers were placed on specific anatomical landmarks (left and right anterior and posterior aspect of the head, 7th cervical vertebrae, 10th thoracic vertebrae, clavicle, sternum, right back, shoulders, lateral epicondyles of the elbows, medial wrists, lateral wrists, second metacarpal heads, anterior superior iliac spines, posterior superior iliac spines, lateral thighs, lateral epicondyles of the knee, lateral tibias, lateral malleoli, second metatarsal heads, and heels). The Vicon Plug-in-Gait model was used to drive lower extremity kinematic data. The sampling rate for kinematic data was set at 240 Hz, and 1,200 Hz for the ground reaction forces. The landing phase of the first landing was set as the time when the vGRF exceeded more than 10 N until the time when the vGRF fell below 10 N. Peak angles and moments of lower extremity joints and vGRF were recorded at the moment respective maximum values were recorded during the first landing of DVJ.

Mean vGRF, joint angles, and moments of the lower extremity joints during the first landing of DVJ were compared using unpaired t-tests with trials prior to each exercise to make sure of adequate group allocation. In addition, unpaired t-tests were also used to compare differences between variables during the first landing of DVJ at the completion of each exercises. Paired t-tests were used to evaluate differences before and after each exercise. Significant differences were set at $p<0.05$. Data collection for this study was conducted according to the Declaration of Helsinki and was approved by the ethics committees of the Saitama Medical University (M-65).

RESULTS

The results for vGRF, angles, and moments of the lower extremity measured during DVJ landing before and after repeated jumping on a trampoline or on the ground are shown in Table 1. There were no significant differences in the vGRF, angles, and moments of the lower extremity joints between pre-trials ($p>0.05$).

Regarding comparisons between trials after repeated jumping on a trampoline or on the ground (Table 1), knee extensor moment after jumping on a trampoline was greater than that after jumping on the ground (trampoline; 1.67 ± 0.72 Nm/kg, ground; 1.53 ± 0.43 Nm/kg, p=0.02). There were no significant differences in vGRF and lower extremity joint angles between trials after each type of jump ($p>0.05$). The results for change associated with repeated jumping, showed that trampoline jumping increased peak vGRF (pre; 2.40 ± 0.68 N/kg, post; 2.77 ± 0.87 N/kg, p=0.001), hip extensor moment (pre; 2.63 ± 2.55 Nm/kg, post; 3.16 ± 3.07 Nm/kg, p=0.02), knee extensor moment (pre; 1.51 ± 0.60 Nm/kg, post; 1.67 ± 0.72 Nm/kg, p=0.02), and hip adduction angle (pre; −1.1 ± 6.4°, post; 0.7 ± 6.4°, p=0.005), while it decreased hip flexion angle (pre; 54.2 ± 12.2°, post; 51.2 ± 13.2 °, p=0.03) during DVJ landing. In addition, repeated jumping on the ground increased peak vGRF (pre; 2.21 ± 0.52 N/kg, post; 2.61 ± 0.61 N/kg, p=0.004), ankle dorsiflexion angle (pre; 33.2 ± 6.6°, post; 35.0 ± 5.9°, p=0.002), and hip extensor moment (pre; 2.08 ± 0.74 Nm/kg, post; 2.74 ± 0.94 Nm/kg, p=0.02) during DVJ landing.

Table 1. Peak vGRF, angles, and moments of the lower extremity measured during drop vertical jumps before and after repeated jumping exercise on a trampoline or on the ground

	Trampoline		Ground	
	Pre-trial	Post-trial	Pre-trial	Post-trial
vGRF (N/kg)	2.40 ± 0.68	2.77 ± 0.87 [a]	2.21 ± 0.52	2.61 ± 0.61 [c]
Angles (°)				
Hip flexion angle	54.2 ± 12.2	51.2 ± 13.2 [b]	56.7 ± 12.4	55.0 ± 10.8
Hip adduction angle	−1.1 ± 6.4	0.7 ± 6.4 [a]	1.8 ± 6.3	1.0 ± 4.8
Knee flexion angle	70.7 ± 14.8	67.5 ± 13.2	72.0 ± 10.3	74.8 ± 10.0
Knee abduction angle	6.1 ± 8.0	6.4 ± 8.8	3.2 ± 3.5	3.3 ± 4.4
Ankle dorsiflexion angle	35.9 ± 7.1	34.5 ± 6.8	33.2 ± 6.6	35.0 ± 5.9 [c]
Joint moments (Nm/kg)				
Hip extensor moment	2.63 ± 2.55	3.16 ± 3.07 [b]	2.08 ± 0.74	2.74 ± 0.94 [c]
Hip abductor moment	1.15 ± 1.00	1.05 ± 0.89	0.84 ± 0.41	1.00 ± 0.53
Knee extensor moment *	1.51 ± 0.60	1.67 ± 0.72 [b]	1.43 ± 0.48	1.53 ± 0.43
Knee adductor moment	0.61 ± 0.34	0.70 ± 0.40	0.56 ± 0.29	0.62 ± 0.30
Ankle plantar flexor moment	2.06 ± 0.50	2.03 ± 0.51	2.03 ± 0.62	2.01 ± 0.39

vGRF: vertical ground reaction force.
[*] Significant difference at $p<0.05$ comparing trials post repeated jumping exercise on a trampoline and on the ground.
[a] Significant difference at $p<0.01$ comparing trials before and after repeated jumping exercise on a trampoline.
[b] Significant difference at $p<0.05$ comparing trials before and after repeated jumping exercise on a trampoline.
[c] Significant difference at $p<0.01$ comparing trials before and after the repeated jumping exercise on the ground.

DISCUSSION

Knee extensor moments are primarily a result of quadriceps muscular activity[17], and in jumping are in response to knee flexion that occurs during landing. This indicates that DVJ landing induces an eccentric contraction of knee extensor muscles, including the quadriceps. The results from this study indicate that DVJ landing after repeated trampoline jumping increased knee extensor moments more than when jumping on the ground. Increased knee extensor moments, associated with trampoline jumping, may be the result of an attempt to increase stability of the knee joint to compensate for the unstable surface on the trampoline. This result indicates that repeated trampoline jumping could have a negative effect of increasing the knee joint stress during landing compared with repeated jumping on the ground.

Other researchers have also investigated the kinematic and kinetic effects of exercising on a trampoline. Aragão et al. reported that 14 weeks of training on a trampoline increased the ability for elderly people to recover balance when falling[18]. They concluded that the improvement seen was attributed to a higher rate of hip moment generation. On the other hand, there is also evidence of negative effects of trampoline exercise. For example, Márquez et al. reported that jumping on an elastic surface such as a trampoline increased leg stiffness, decreased jump height, and generated less stored and returned energy[12, 19]. In particular, Ferris et al. has claimed that landings on an elastic surface might increase the leg stiffness[14]. Furthermore, Butler et al. have reported that greater leg stiffness might be associated with bony injuries[20]. These reports indicate that exercise on a trampoline have wide-ranging effects on lower extremity function and increased risk of bony injuries. In addition to these previous findings, the results from our study indicate the need to consider the potential for increased stress on the knee joint as a result of trampoline jumping.

Jumping on a trampoline reduced the hip flexion angle while increasing the hip adduction angle. This could be explained by the flexibility characteristics of the trampoline surface. These characteristics may cause stiffening of lower extremity joints to compensate for the unstable soft surface. Despite the effect on the hip joints, trampoline exercise did not change the knee and ankle joint angles. It has been reported that the hip joint is important for energy absorption during jump landing[21]. Hence, trampoline jumping might reduce the role of the hip joint in terms of the shock attenuation mechanism during jump landing. On the other hand, hip extensor and knee extensor moments and vGRF increased after trampoline jumping. These effects may be due to the results of increased hip and knee extensor muscle activity during landing, in preparation for the next jump take-off. During a DVJ, it is necessary to prepare for re-bound after the initial drop from the box. Repeated trampoline jumping may teach the subjects to be able to learn optimum jumping methods which alter DVJ landing characteristics. From these reasons, repeated trampoline jumps might promote a learned improvement in jump take-off.

Repeated jumping on a hard surface increased ankle dorsiflexion angle, which was not the case after jumping on the trampoline. The increase in inclination of the lower leg relative to the foot is probably a compensatory shock absorption mechanism during landing. Hip extension moments were also increased, probably for the same reasons, after repeated jumping on the trampoline. These finding suggest that changing the ground conditions during a repeated jumping task may be a suitable way of changing lower limb kinetics and kinematics, depending on which characteristic is required.

Jump landing on an elastic surface such as a trampoline tended to decrease the knee motion as a result of attenuation by the surface, while a smaller hip flexion angle occurred. Repeated jumping on a trampoline may be useful if the goal is to reduce hip motion during landing and induce upright lower extremity alignment. These results may be useful for those who tend to flex their hips during jump landing, such as athletes as well as the disabled with weak extremities. Further studies are required to investigate lower extremity alignment as well as other body parts such as the trunk in terms of the effects of repeated jump landing.

This study has some potential limitations. The long-term influence of trampoline and hard surface jumping were not evaluated, hence long-term changes in lower limb biomechanics following these exercises are not known. In addition, only young females were investigated and evaluated the influence of jump exercises on trampoline. Females had an increased risk of knee injuries including anterior cruciate ligament injuries during sports activities[22]. Furthermore, landing alignment in females seems to be causative factors of some knee injuries according to previous reports[23]. Future studies are needed to evaluate long-term effects of jump exercises on a trampoline and investigate the effects in a wider range of age and the difference between genders.

REFERENCES

1) Harrison EL, Duenkel N, Dunlop R, et al.: Evaluation of single-leg standing following anterior cruciate ligament surgery and rehabilitation. Phys Ther, 1994, 74: 245–252. [Medline] [CrossRef]
2) Hides J, Stanton W, Freke M, et al.: MRI study of the size, symmetry and function of the trunk muscles among elite cricketers with and without low back pain. Br J Sports Med, 2008, 42: 809–813. [Medline] [CrossRef]
3) Paz GA, Maia MF, Farias D, et al.: Kinematic analysis of knee valgus during drop vertical jump and forward step-up in young basketball players. Int J Sports Phys Ther, 2016, 11: 212–219. [Medline]
4) Karthikbabu S, Nayak A, Vijayakumar K, et al.: Comparison of physio ball and plinth trunk exercises regimens on trunk control and functional balance in patients with acute stroke: a pilot randomized controlled trial. Clin Rehabil, 2011, 25: 709–719. [Medline] [CrossRef]
5) Knutson GA: Incidence of foot rotation, pelvic crest unleveling, and supine leg length alignment asymmetry and their relationship to self-reported back pain. J Manipulative Physiol Ther, 2002, 25: 110E. [Medline] [CrossRef]
6) Binder EF, Schechtman KB, Ehsani AA, et al.: Effects of exercise training on frailty in community-dwelling older adults: results of a randomized, controlled trial. J Am Geriatr Soc, 2002, 50: 1921–1928. [Medline] [CrossRef]
7) Hewett TE, Stroupe AL, Nance TA, et al.: Plyometric training in female athletes. Decreased impact forces and increased hamstring torques. Am J Sports Med, 1996, 24: 765–773. [Medline] [CrossRef]
8) Chimera NJ, Swanik KA, Swanik CB, et al.: Effects of plyometric training on muscle-activation strategies and performance in female athletes. J Athl Train, 2004, 39: 24–31. [Medline]
9) Lephart SM, Abt JP, Ferris CM, et al.: Neuromuscular and biomechanical characteristic changes in high school athletes: a plyometric versus basic resistance program. Br J Sports Med, 2005, 39: 932–938. [Medline] [CrossRef]
10) Makaruk H, Sacewicz T: The effect of drop height and body mass on drop jump intensity. Biol Sport, 2011, 28: 63–67. [CrossRef]
11) Markovic G: Does plyometric training improve vertical jump height? A meta-analytical review. Br J Sports Med, 2007, 41: 349–355. [Medline] [CrossRef]
12) Márquez G, Aguado X, Alegre LM, et al.: The trampoline aftereffect: the motor and sensory modulations associated with jumping on an elastic surface. Exp Brain Res, 2010, 204: 575–584. [Medline] [CrossRef]
13) Pahwa P: Multi-disciplinary therapeutic intervention programs for athetoid cerebral palsy child in clinical settings: a case report. Int J Ther Rehabil Res, 2012, 1: 10–14.
14) Ferris DP, Louie M, Farley CT: Running in the real world: adjusting leg stiffness for different surfaces. Proc Biol Sci, 1998, 265: 989–994. [Medline] [CrossRef]
15) Farley CT, Morgenroth DC: Leg stiffness primarily depends on ankle stiffness during human hopping. J Biomech, 1999, 32: 267–273. [Medline] [CrossRef]
16) Márquez G, Morenilla L, Taube W, et al.: Effect of surface stiffness on the neural control of stretch-shortening cycle movements. Acta Physiol (Oxf), 2014, 212: 214–225. [Medline] [CrossRef]
17) Rao G, Amarantini D, Berton E: Influence of additional load on the moments of the agonist and antagonist muscle groups at the knee joint during closed chain exercise. J Electromyogr Kinesiol, 2009, 19: 459–466. [Medline] [CrossRef]
18) Aragão FA, Karamanidis K, Vaz MA, et al.: Mini-trampoline exercise related to mechanisms of dynamic stability improves the ability to regain balance in elderly. J Electromyogr Kinesiol, 2011, 21: 512–518. [Medline] [CrossRef]
19) Márquez G, Aguado X, Alegre LM, et al.: Neuromechanical adaptation induced by jumping on an elastic surface. J Electromyogr Kinesiol, 2013, 23: 62–69. [Medline] [CrossRef]
20) Butler RJ, Crowell HP 3rd, Davis IM: Lower extremity stiffness: implications for performance and injury. Clin Biomech (Bristol, Avon), 2003, 18: 511–517. [Medline] [CrossRef]
21) Devita P, Skelly WA: Effect of landing stiffness on joint kinetics and energetics in the lower extremity. Med Sci Sports Exerc, 1992, 24: 108–115. [Medline] [CrossRef]
22) Hewett TE, Myer GD, Ford KR, et al.: Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. Am J Sports Med, 2005, 33: 492–501. [Medline] [CrossRef]
23) Hewett TE, Torg JS, Boden BP: Video analysis of trunk and knee motion during non-contact anterior cruciate ligament injury in female athletes: lateral trunk and knee abduction motion are combined components of the injury mechanism. Br J Sports Med, 2009, 43: 417–422. [Medline] [CrossRef]