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Lower Extremity Function in Terms of Shock Absorption when Landing with Unsynchronized Feet

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Abstract The purpose of this study was to clarify the lower extremity function in terms of the shock absorption during unsynchronized-foot landings. The characteristics of the supination and pronation in the ankle joint at landing were investigated, assuming that the measurements of the impact force on the body could be demonstrated by the changes that occurred during 3 different landing motions: — unsynchronized-foot landings, synchronized-foot landings, and one-foot landings. Subjects jumped to the floor from 10-cm footstools 3 times for each type of landing. For the synchronized-foot landing, the rear foot angle was 92.2° at the start of landing and did not change significantly from landing start to 100 msec. For the one-foot landing, rear foot angle was 95.1° at the start of landing and decreased rapidly to 87.1° by 75 msec, and then increased rapidly to 90.8° by 140 msec. For the unsynchronized-foot landing, the rear foot angle was 93.8° at the start of the landing, decreased rapidly to 88.0° by 75 msec, and then increased rapidly to 89.9° by 115 msec.

It was clarified that the lower extremity function for the shock attenuation during landing with the unsynchronized-foot was similar to that with one-foot landings, and the lower extremity function for supporting the body after another foot landing was similar to that after the synchronized-foot landings in this study. *J Physiol Anthropol Appl Human Sci 22 (6): 279–283, 2003* http://www.jstage.jst.go.jp/en/

Keywords: landing, unsynchronized feet, shock absorption, rearfoot angle

Introduction

When a person jumps down from an elevated position, the body reaches the floor at a certain velocity. Generally, the momentum is described as the product of velocity and mass, which means that the force of impact increases in proportion to a body weight. However, in the case of a person jumping down from an elevated position, the momentum is equivalent to impact the velocity because the body weight remains constant. (Maeda et al., 1990, Bobbert et al., 1991, Chapman and Caldwel, 1993; Komi et al., 1987; Maeda et al., 1993b). Because the changes in the momentum are equal to the impulse, the height of the jump is an important factor in terms of the force of impact.

In a study of factors influencing landing motions in runners, Nigg et al. (1986) observed an important consideration in terms of the external forces, that is, the forces produced by the supination and pronation of the ankle (Nigg, 1986; Bahlsen and Nigg, 1987; Nigg et al., 1988). According to their observations, the impact force at floor contact was attenuated by the good cushioning during the supination and pronation of the ankle joint. These authors stressed that at the moment of the floor contact, the ankle joints were in a state of the supination, with the position rapidly shifting to the pronation (Bahlsen and Nigg, 1987; Nigg et al., 1987; Bobbert et al., 1992).

The landing motions of athletes in sports activities consist of the landing with synchronized feet (SF), unsynchronized feet (USF), and with only one foot (OF). Maeda et al (1994) reported on a lower extremity function in terms of the shock absorption during one-foot landings. They found that the maximum pronation angle of the ankle joint for one-foot landings at the moment of the floor contact was significantly larger than that required for the synchronized-foot landings. However, there are no studies about the lower extremity function in terms of the shock absorption during the unsynchronized-foot landings.

The purpose of this study was to clarify the lower extremity function in terms of the shock absorption during the unsynchronized-foot landings. The characteristics of the supination and pronation in the ankle joint at landing were investigated, assuming that the measurements of the impact force on the body could be demonstrated by the changes that occurred during 3 different landing motions—unsynchronized-foot landings (USF), synchronized-foot landings (SF), and one-foot landings (OF).

Method

Subjects included 10 Japanese males who make a habit of exercising for their health. The characteristics of the subjects were (mean±SD) 24.9±1.8 years old, weighed 72.2±7.1 kg, and were 172.5±3.8 cm tall. All subjects participated voluntarily after providing an informed consent.

The subjects jumped to the floor from 10-cm footstools 5 times for each type of landing. During the first jump, they landed without the synchronized feet (USF); for the second jump, they landed with the synchronized feet (SF), and for the third jump, they landed with only the left foot (one-foot landing; OF). The supination and pronation of the ankle joints were observed at each landing.

To ensure a consistent jumping action, the subjects were instructed to stand on the footstool, the subjects stick their left feet horizontally out to the side, then put their right feet beside the left, and landed on a force platform marked with a footprint. During the landing with the USF, at first they landed with only left foot, soon their right foot landed. They were instructed to land at the interval time between left and right feet were voluntary on the USF. They were instructed not to jump up from the footstools and also to maintain an upright position with both knees as straight as possible on landing. The landing action was defined as the time from the floor contact to the time when the center of body gravity reached its lowest position. The joints of all the lower extremities were sufficiently bent during floor contact.

The main external forces acting on the body during jumping were the ground reaction forces encountered by the subjects during contact with the ground. These forces could be measured with the force platform (Kistler Inc.). The platform allowed the quantification of the ground reaction force and its vertical, anterior-posterior, and mediolateral components.

Two electrically synchronized high-speed video cameras (NAC Inc. Tokyo, Japan) were used to sample the landing motion at 200 frames/sec (shatter speed was 1/2000 sec) positioned at near the force platform, with one camera located on the left side of the subjects to the analyze the angle of knee, ankle, and forefoot joints, while the other was located behind the subjects to analyze the supination and pronation of the ankle joints. The markers to calculate the angle of knee, ankle, and forefoot joints were located as follows: A: Toe of 5^{th} metatarsal; B: Forefoot at the head of the 5^{th} metatarsal; C: Heel undernerth the calcaneus; D: Lateral maleous; E: Head of the fibula; F: Located above the knee joint (tibio-femoral joint on a middle line for lateral view in the standing position); and G: Same as F but 2/3 of the distance between the tibio-femoral and the hip joint. Using these markers, the following variables can be defined. The definition of knee angle was angle between DE and FG on the posterior side of the knee joint. The definition of ankle angle was angle between BC and DF on the anterior side of the ankle joint. The definition of forefoot angle was angle between AB and CD on the anterior side of the forefoot joint. Fig. 1 shows the positions of the landmarks

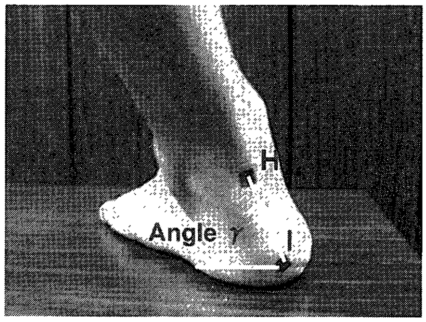

Fig. 1 The markers for measurement of the supination and pronation angles in the ankle joints. H: On the horizontal level of the sphyrion and located so that the line between the HI and horizontal forms an angle of 90° in the unloaded ankle joint. I: In the center of the pternion (posterior view).

Table 1 Comparison of peak force/body weight and time to peak of vertical force during landing among three landing conditions

	Peak force/body weight	Time to peak (msec)
Unsynchronized feet (USF)	2.80±0.28	74.1±12.8
Synchronized feet (SF)	2.77±0.19	75.0±10.2
One foot (OF)	2.82±0.38	74.0±11.1

determined by the method of Nigg et al., 1986. The displacement of the angle γ, which are formed by the rear parts of the leg and the horizontal line make centering around the ankle joints, were filmed and used in the kinematic analysis.

One-way analysis of variance (ANOVA) was used to validate statistical differences between three experimental conditions. Multiple comparisons by the Welch method were used to compare differences between each group means. P-value less than or equal to 0.05 was considered to be statistically significant in this study. SPSS for Windows Release 7.5.1J (SPSS Inc., Chicago, IL) statistical package was used for statistical analysis.

Results

Comparison of the impact forces and time to peak at landing among three landing conditions

Table 1 shows the peak force/body weight at impact and the time to peak force during the 3 landing conditions. The peak force/body weight at impact varied from 2.77 to 2.82 and there were no significant differences among the 3 landing conditions. The time to peak force varied from 74.0 to 75.0 with no significant differences among the 3 landing conditions.

Changes in the angles of the knee, ankle, and forefoot joints at the landing.

To observe the role of the lower limbs as a shock absorber, changes in the angle of knee, ankle, and forefoot joints were

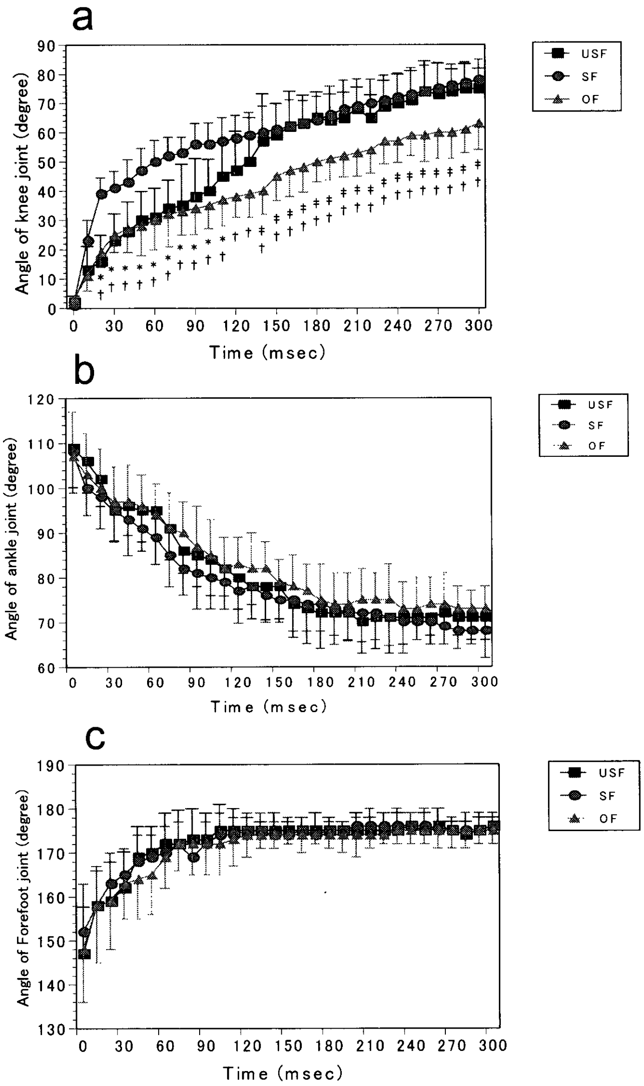

Fig. 2 The changes in angle of the knee joint (a), ankle joint (b), and forefoot joint (c) during landing motion

The average and standard deviation (n=10 landings) of each angle are shown. *p<0.05, the difference between the USF and SF. †p<0.05, the difference between the OF and SF. ‡p<0.05, the difference between the USF and OF.

measured. Figure 2-a shows the changes in angle of the knee joint during landing. The angle of knee joint increased rapidly from the start of landing to 300 msec after landing, with some significant differences among the 3 landing conditions. The largest angle of the knee joint occurred during the synchronized-foot landing (SF), the second-largest angle occurred during the unsynchronized-foot landing (USF), and the smallest angle occurred during the one-foot landing (OF). There was a significant difference in the angle of knee joint between the USF and SF from the start of landing to 100 msec after landing ($p<0.05$). However there was no significant difference in the angle of the knee joint between the USF and SF landing from 100 msec to 300 msec. There was no difference in the angle of the knee joint between the USF and OF from the start of landing to 100 msec after landing. However, there was a significant difference in the angle of knee joint between the USF and OF from 100 msec to 300 msec ($p<0.05$). There was also a significant difference in angle of the knee joint between the SF and OF from the start of landing to 300 msec. ($p<0.05$).

Figure 2-b shows the changes in angle of the ankle joint during landing. The angle of the ankle joint decreased rapidly from the start of landing to 300 msec in all 3 landing conditions, with no significant differences among the 3 landing conditions.

Figure 2-c shows the changes in the angle of the forefoot joint during landing. The angle of forefoot joint increased rapidly from the start of landing to 100 msec, and was maintained at a large angle to 300 msec. There were no significant differences among the 3 landing conditions.

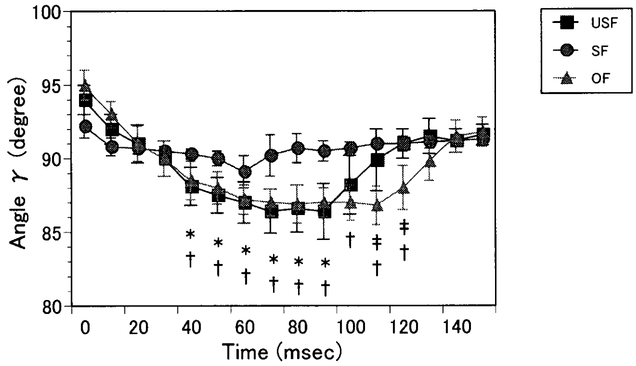

Fig. 3 The change of the angle γ (rearfoot angle) during landing motions

The average and standard deviation (n=10 landings) of the angle γ are shown. *p<0.05, the difference between the USF and SF. †p<0.05, the difference between the OF and SF. ‡p<0.05, the difference between the USF and OF.

Changes in the supination and pronation of the ankle joint at the landing.

To observe the role of the foot as a shock absorber, changes in the rear foot angle at landing were measured (Figure 3). For the SF, the rear foot angle was 92.2° at the start of landing and did not change significantly from landing start to 100 msec. For OF, rear foot angle was 95.1° at the start of landing and decreased rapidly to 87.1° by 75 msec, and then increased rapidly to 90.8° by 140 msec. For the unsynchronized-foot landing, the rear foot angle was 93.8° at the start of the landing, decreased rapidly to 88.0° by 75 msec, and then increased rapidly to 89.9° by 115 msec.

Discussion

The principal findings of this study were that the lower extremity function for shock attenuation during landing with unsynchronized feet was clarified. These data represent important findings relating to the increase of the landing performance so as to prevent the ankle injury.

There were many reports to measure the magnitude of vertical impact force peak during walking and running. Using force platform, Cavanagh et al. (1981) reported that the magnitude of vertical impact force peak/body weight was 0.6 during 1.3 msec walking by barefoot. Frederick et al. (1986) reported that the magnitude of vertical impact force peak/body weight was 2.9 during 4.5 msec running by barefoot. Furthermore, Nigg (1986) reported that the magnitude of vertical impact force peak/body weight was 3.6 during 5.5 msec running with shoes. In this study, an equation of motion can be adopted for calculating the landing velocity: 0.8 msec for a 10 cm height in this study, and the magnitude of vertical impact force peaks/body weight in three landing conditions were about 2.8. This magnitude was near that of 4.5 msec running. To quantify the impact force of jumping down and running on the kinematics of the lower extremities, the forces exerted during the ground contact have two differences: (1) The impact force in jumping down was concentrated on the vertical direction, whereas that in running appeared in many directions, with an especially high loading rate in the anterior-posterior direction (Robertson, 1980; Hamill et al., 1987; Komi, et al., 1987); and (2) Jumping down had no takeoff action after the landing, whereas running repeated a kicking-off action for taking off immediately after the landing. The difference of the impact forces in the two kinds of landing actions resulted in the variability of force curve measurements with different ground contacts.

No significant differences were found among three groups in the magnitude of impact force peak/body weight. Namely, the shock attenuation of the USF was same level of the other conditions. Many previous studies reported that the knee flexion was most important factor for shock attenuation during landing (Maeda et al., 1994, Maeda et al., 1998). The maximum angular velocity of knee flexion in the USF was significantly smaller than that of SF during landing. On the early period of the USF, the subjects could not flex fully their knee joint, because the landing motion was supported by one leg. It was difficult to keep their stability on the landing with one leg. On later period of the USF, the subjects could flex fully their knee joints after another foot landing. However, the knee flexion after 100 msec have no effect of the shock attenuation, because the time to peaks of ground reaction forces were about 75 msec. The other factor is needed to help the shock attenuation of the knee flexion in the USF. The supination and pronation of ankle were an important factor to help the shock attenuation of the knee flexion in the USF. The maximum angular velocities of angle γ were (mean$\pm$SD) 6.9$\pm$1.2 degree/sec in the USF, 7.2$\pm$1.4 degree/sec in OF, and 1.2$\pm$0.3 degree/sec in SF. The large supination and pronation rise to the injury of ankle, because the range of motion in ankle is smaller than the other joints. Thus, the supination and pronation of ankle were not added to the shock attenuation. The subjects could not help adding to the supination and pronation of ankle in the shock attenuation of the USF and OF in this study.

The subjects landed in a position with supination, and, there is no doubt that a rapid pronation must be made from landing at 100 msec. The angle γ of the USF at the landing start was about 96 degree. Thus, it was prepared for the rapid pronation after toe contact. There were some studies about the ankle and knee movement prior to landing in jumping down and running. Caulfield and Garret (2002) investigated the ankle and knee angular displacement pre and post landing in single leg jumping down from height of 40 cm. They reported that the angular displacement of the ankle flexion in the healthy subjects at the 20 msec prior to impact was -17.5 degree (planter flexion), and the angular displacement of the knee flexion in the healthy subjects at 20 msec prior to impact was 13.3 degree. Evidence for an important CNS (Central nervous system) role in controlling ankle stability is available from Reber et al. (1993) who demonstrated activation of ankle musculature prior to ground contact running. The pre-activation of the ankle musculature has also been demonstrated prior to ground contact during landing from a jump (Duncan and McDonagh 1997, Dyhre-Puulsen et al. 1991). In this study, the pre-activation of ankle appeared not only at the planter flexion but also at the supination in the USF and OF. The results of Nigg's experiments showed that the initial supination becomes significantly dominant in running, and there is typically pronation at the time of the ground contact. The supination and pronation patterns of the ankle joints in this study were similar to the results of Nigg in running motion. It is likely that the interplay between the central programming and peripheral feedback is responsible for the control of the ankle stability during functional activities (Konradsen et al. 1997). Ligament receptors may, through the gamma motoneuron system, participate in the regulation and preparatory adjustment of the stiffness of muscles around the ankle joint (Johansson 1991). Thus the sensory system of the ankle ligaments can contribute significantly to the functional stability of the ankle joint.

It was clarified that the lower extremity function for the shock attenuation during landing with the USF was similar to that of the OF, and the lower extremity function for supporting the body after another foot landing was similar to that of the SF in this study. Jumping down had no takeoff actions after the landing, whereas the running and many other support activities are needed to repeat a kicking-off action for taking off immediately after the landing. Thus, the stability of body after the motion for the shock attenuation was very important. The findings of this study highlight the need for further investigations into the motor control following the acute ankle sprain in order to explain the increase of the landing motion and preventing injury of the lower extremity during landing with the unsynchronized feet.

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