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Original Article

Effect of floating toes on knee and trunk acceleration during walking: a preliminary study

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Abstract. [Purpose] This study investigated the effect of floating toes on knee and trunk acceleration during walking in experimental setting. [Subjects and Methods] Twelve healthy volunteers walked barefoot at a preferred speed along a linear pathway under 2 conditions: normal gait (control) condition and floating toes (FT) condition. In the latter, weight bearing by the toes was avoided using kinesiology tape applied along the toe extensors. Accelerations of the knee (Kn) and lumbar spine (Lx) were assessed using triaxial accelerometers mounted on the right fibular head and the spinous process of L3. Acceleration vectors were oriented such that the anterior, right, and cranial deviations were positive along the anteroposterior, lateral, and vertical axes, respectively. The root mean squares (RMSs; anteroposterior, RMSap; lateral, RMSl; vertical, RMSv) were calculated, and the mean values of 3 trials in each condition were determined. Differences between the conditions were assessed using the Wilcoxon signed-rank test. [Results] LxRMSap and LxRMSv were larger in the FT condition than in the control condition. KnRMSv tended to be higher in the FT condition than in the control condition. [Conclusion] Floating toes increase acceleration and might create mechanical stress on the lower back and knee during walking.
Key words: Floating toes, Walking pattern, Triaxial acceleration

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INTRODUCTION

The foot is the foundation of the human body, as it is the first part of the body that contacts the ground during gait. Hence, toe flexor function is essential for balancing[1)] and walking[2)]. However, in clinical practice, patients often present with lower extremity or lower-back dysfunction and unable to touch the ground with their toes—that is, floating toes[3)]—during walking and standing. Floating toe syndrome is the condition in which one or more toes fail to purchase the weight bearing surface in stance and walking[3)]: elevation of the metatarsal ray prevents it from being loaded under the weight-bearing condition. Floating toe has been reported to be an aftereffect of foot surgery[4, 5)], and decrease in toe grip strength may be one of the factors causing floating toes in adult[6)].

In Japan, floating toe has recently been focused on as a malalignment of the foot both in adults[6, 7)] and children[8, 9)]. Because these studies are epidemiological studies, the association between floating toe and physical function has remained unclear. Biomechanical change in one joint can influence the kinetics or kinematics of proximal or distal joints during weight bearing; hence, floating toe may also affect the kinetics or kinematics of proximal joints. Therefore, floating toe may influence gait pattern. Faulty foot biomechanics can adversely affect all supporting joints above the foot, including the lower back[10)]. Toe flexor function is essential for producing the propulsive force at the toe, which is essential for walking; floating toe-induced insufficient toe flexor function may have a negative influence on the knee, hip, and lower back. For example, Dananberg and Guiliano[11)] stated that appropriate treatment to correct gait style by using custom-made foot orthoses was

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effective in improving the symptoms of lower-back pain; in other words, altering the gait pattern influences lower-back pain.

In assessing gait patterns, accelerometers are advantageous over traditional gait analysis instruments, such as three-dimensional motion analyzer and force plates, because of their low cost, compact size, and ability to be used outside of a laboratory environment[12, 13]. Therefore, because walking is a relatively unrestricted motion, it is ideal for quantifying gait abnormalities, for determining how individual adapts to functional disturbances, and for evaluating changes in gaitpatterns[12].

Therefore, this preliminary study investigated the effect of floating toes on knee and trunk acceleration during walking by using accelerometers. We hypothesized that floating toes during walking might affect the normal gait pattern and thus have an effect on knee and trunk acceleration.

SUBJECTS AND METHODS

This study was approved by the Research Ethics Committee of Kio University (H23-35). All participants provided written informed consent prior to participating in the study.

Twelve healthy volunteers (9 males, 3 females; age, 21.2 ± 0.7 years; height, 165.8 ± 8.0 cm; weight, 59.3 ± 7.9 kg) were asked to walk barefoot at a preferred but constant speed along a linear pathway under 2 conditions: with normal gait (control condition) and with inhibited toe flexion to prevent weight bearing on the toes (floating toe (FT) condition). The test order of the two conditions was randomized. Participants' 10-m walking speed was measured using a stopwatch. Accelerations of the knee (Kn) and lumbar spine (Lx) were measured using triaxial accelerometers (MVP-RF-8-GC-500, Microstone Corporation, Nagano, Japan) mounted on the right fibular head[14]and the spinous process of L3[12, 13, 15]. Acceleration vectors were oriented such that the anterior, right, and cranial deviations were positive along the anteroposterior, lateral, and vertical axes, respectively, on the basis of the local coordinate axis on the accelerometers (6 degrees of freedom). Heel strike was confirmed using pressure sensors placed under both heels. In the FT condition, toe flexion was inhibited using kinesiology tape (NKH-25, Nitto Denko Corporation, Osaka, Japan) applied along the toe extensors at the maximal extension position. Reduced weight bearing on the toes was confirmed using a force platform (WinFDM; Zebris, Isny im Allgäu, Germany). The participants were instructed to initiate walking with the left foot, and data from the sixth and eighth steps, both of which were in the stance phase on the right side, were recorded. The same protocol was repeated 3 times in each condition at a sampling rate of 1 kHz. The root mean squares (RMSs) (anteroposterior, RMSap; lateral, RMSl; vertical, RMSv) were calculated, and the means of 3 trials in each condition were determined.

Differences between the two conditions were assessed using the Wilcoxon signed-rank test. All statistical analyses were performed using SPSS version 22.0 (IBM, Tokyo, Japan), with the level of significance set at 5%.

RESULTS

Participants' walking speeds in the control and FT conditions were 4.33 km/h ± 2.71% and 4.29 km/h ± 2.65%, respectively. LxRMSap and LxRMSv were higher in the FT condition than in the control condition (p=0.013 and 0.046, respectively). Similarly, KnRMSv tended to be higher in the FT condition than in the control condition (p=0.055) (Table 1).

DISCUSSION

This study demonstrated that floating toes during walking increased anteroposterior and vertical accelerations of the lower back and tended to increase vertical acceleration of the knee. Hessert et al.[16] identified a difference in the foot-pressure distribution in the hallux region of healthy young and elderly groups during walking. A factor related to age-related changes in walking patterns might be a change in the toe contact area. Floating toe–induced insufficient toe contact with the ground—that is, reduction in the toe contact area—means a smaller support base, which might influence postural control during the

Table 1. Root mean square of acceleration of the knee and lumber spine (L3)

		Control condition	Floating toe condition
Lx	RMSap	0.635 (0.471–1.041)	0.720* (0.497–1.146)
	RMSl	0.821 (0.646–1.166)	0.854 (0.729–1.196)
	RMSv	0.858 (0.644–1.438)	1.038* (0.674–1.766)
Kn	RMSap	2.176 (1.527–3.345)	2.142 (1.603–3.659)
	RMSl	1.337 (0.826–2.552)	1.452 (0.940–2.718)
	RMSv	2.051 (1.471–3.568)	2.127 (1.707–3.931)

Lx: lumber spine, Kn: knee, RMS: root mean square, ap: anteroposterior, l: lateral, v: vertical
Data are expressed as median (range) m/s^2.
Differences were compared using the Wilcoxon signed-rank test. *$p<0.05$

single-leg stance phase during walking. Elis et al.[17] reported that reduced plantar sensation causes a cautious walking pattern. Tanaka et al.[18] highlighted the importance of toe strength and somatosensory feedback from the sole during dynamic single-leg balancing. Floating toe–induced reduction in the support base might result in decreased sensory input from the plantar surface, which might lead to changes in the walking pattern.

Typically, weight-bearing during walking proceeds from the heel to the toe, which enables the generation of the propulsive force. However, floating toe–induced insufficient toe contact prevents normal weight-shift from the posterior to the anterior during walking; hence, vertical acceleration of the knee and trunk might increase. Menz et al.[19] reported that head acceleration to stabilize its position was not affected even if pelvic acceleration increased. They demonstrated that in order to stabilize head position during walking, trunk acceleration might compensate for the change in postural control strategy caused by insufficient toe contact with the ground.

An abnormal gait eventually interferes with spinal segmental movements[20], which could lead to serial postural distortions, muscular imbalances, and spinal joint dysfunction. Some researchers have demonstrated changes in the motor control of the trunk during walking in patients with chronic lower-back pain[21, 22]. Therefore, increased anteroposterior and vertical accelerations of the lower back might induce increased mechanical stress on the discs, facet joints, and muscles, which in turn might cause degenerative changes of the lumbar structures and/or lower-back pain. Electromyography and three-dimensional motion analysis studies can further clarify the influence of floating toes on muscle activity and movement of the trunk.

In this study, floating toes during walking tended to increase vertical acceleration of the knee. This change might result in increased mechanical stress, which could affect the articular cartilage of the knee. In their case–control cohort study, Segal et al.[23] reported that maximum articular contact stress was higher in incident cases with osteoarthritis (OA) of the knee compared with normal control knees. Gross et al.[24] reported that planus foot morphology was associated with frequent knee pain and medial tibiofemoral cartilage damage in older adults. Moreover, an association between the hallux and knee OA[25], including that between low pressure on the hallux during walking and medial knee OA[26], has been reported. Therefore, insufficient floating toe–induced toe contact caused might be associated with development of knee OA. In future studies, the relationships of toe contact with knee motion and muscle activity should be investigated in a clinical setting in patients with knee OA.

This study has several limitations. First, the sample was small and had more males than females. Second, this study did not consider the differences in the functions of the hallux and lesser toes because experimental floating toes included all toes. In addition we did not measure foot pressure in the toe region, although we could confirm that toe region did not contact during walking in the FT condition. Future studies are required to examine such multidimensional aspects as ground reaction force, muscle activity, and three-dimensional motion, although the associations between insufficient toe contact with the ground and accelerations of the knee and trunk were investigated in this study. Furthermore, because this was an experimental study, additional studies are needed to clarify the influence of toe function during walking in patients with lower-back pain or knee dysfunction in a clinical setting. These studies might elucidate the unknown cause of musculoskeletal dysfunction and can lead to the development of a novel physical therapy. In conclusion, floating toes increase anteroposterior and vertical accelerations of the lower back and tend to increase vertical acceleration of the knee during walking. Therefore, insufficient toe contact might increase mechanical stress on the lower back and knee, which might cause musculoskeletal dysfunction.

Conflict of interest

The authors have no conflicts of interest to declare.

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