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Ankle Taping and Vertical Drop Landing

Yi Chung-hwi, Ph.D., P.T.
Dept. of Rehabilitation Therapy, College of Health Science
Institute of Health Science, Yonsei University

국문 요약

발목관절의 테이핑과 수직 착지동작

이충휘
연세대학교 보건과학대학 재활학과 및 보건과학연구소

발목에 대한 유착성 테이핑의 적용은 물리치료 분야와 운동 트레이닝 분야에서의 일반적인 치료 접근 방법이라 할 수 있다. 즉 발목 염좌 같은 손상을 예방하기 위한 방법과 재활의 부가적인 치료 형태로 이용될 수 있는 것이다. 본 연구는 발목의 테이핑과 트레드밀에서의 30분간 보행이 수직 착지 동작 동안 하지의 운동 역학적 요소들에 어떠한 영향을 주는지 알아보기 위해 시행되었다. 14명의 신체 건강한 대상자들 (남:10, 여:4)이 본 연구에 참여하였다. 한발로 서있는 동안 40 ㎝의 높이로 뛰게 하였다. 가자미근, 전경골근, 안쪽넓은근, 넙다리 두갈래근에 근전도 전극이 부착되었다. 테이핑된 신체 부위로 착지하는 동안 근전도와 힘판(force plate) 자료가 500 ㎐의 주파수로 수집되었다. 대상자들의 우세쪽 하지 발목에 테이핑을 하였고, 대상자는 한발로 뛰어 내리는 동작을 반복하였다. 트레드밀에서 30분 동안 발목에 테이핑을 한 채로 보행하였고 이후 한발로 뛰어 내리는 동작을 반복하여 수행하였다. 테이핑을 적용한 상태와 테이핑한 채로 30분 동안 트레드밀에서 걷기 운동을 한 조건에서 수직 지면 반발력의 통계학적으로 유의미한 증가가 있었다. 착지 동안에 네 가지 상황에서의 최대 내측 가속도의 유의한 차이가 있었고, 그 차이는 테이핑 전과 테이핑을 한 채로의 운동 조건에서 유의한 차이가 있었다. 테이핑한 상태에서 가자미근은 접촉되는 착지 순간부터 최대 수직 지면 반발력이 나타나는 동안의 평균 근전도의 수치에 있어서 유의한 감소가 있었다. 반면에 다른 근육들에서는 아무런 변화를 보이지 않았다. 비록 발목 테이핑이 발목 손상의 위험을 줄이는데 효과적이라고 일반적으로 인식되고 있으나 이번 실험의 결과는 30분 동안의 트레드밀에서의 보행 후 테이핑은 발목의 움직임을 제한하는 효과는 있지만 한편으로는 가자미근의 활동을 감소시키는 것을 보여주었다. 따라서 이 연구의 결과는 테이핑을 하면 점프와 착지로 이어지는 동작 중에 발목관절 손상 위험을 증가시킬 가능성이 있음을 보여주었다.

핵심단어: 발목 테이핑; 운동역학적 분석; 착지.

Introduction

Athletic participation results in a relatively high risk of injury to the ankle joint. Ankle sprains are the most frequently reported injury in sport. The sport with the highest prevalence of ankle injuries is basketball, with over 50% of players having ankle joint problems that have resulted from ligament injuries (Brynnon and

Renstrom, 1991). Lateral ligaments of the ankle are the most common site of injury in netball (Hopper, 1986; Hopper et al, 1999). A study has shown that 90 95% are inversion injuries causing partial or complete rupture of the anterior talofibular ligament and occasionally the calcaneofibular ligament (Garrack and Requa, 1988). Due to the high incidence of acute ankle sprain and sprain reoccurrence, many physicians, physical therapists, and athletic trainers attempt to prevent ankle injuries through the use of various taping/strapping techniques or ankle orthoses. Several studies have examined the effects of prophylactic bracing/taping on the incidence of ankle sprains in basketball (Garrick, 1977; MacKean et al, 1995; Miller and Hergenroeder, 1990). To decrease the risk of an inversion sprain, traditional ankle taping or various commercially available ankle stabilizers have been used to provide functional stabilization to the joint. Ankle taping has become the principal means of preventing ankle sprains in sport (Bullard et al, 1989). Whereas taping was once thought to stabilize the ankle mechanically, this seems unlikely considering reports that show no measurable stabilizing effect of tape after as little as 20 minutes of exercise (Perlman et al, 1987). Accordingly, ankle taping is now thought to prevent ankle injury mainly through improving the user's judgment of position and orientation of the plantar surface with respect to the leg. This foot position awareness, in the domain of proprioception, is usually referred to as kinaesthetic sense (Karlsson and Andreasson, 1992). Presumably humans use kinaesthetic sense information in anticipation of foot contact with a surface either to position the plantar surface before the support phase to attenuate forces causing inversion, or to command muscle support to sustain these forces, thereby preventing ligament loading, or both. By this reasoning, ankle sprains are caused by impaired foot position awareness resulting in inadequate use of these anticipatory maneuvers under conditions such as sports, when there is insufficient time to respond to the actual loading event (Robbins et al, 1995).

Ankle taping is commonly used by athletic trainers or sports physical therapists to protect the ankle and to maximize its function during sporting activities (Cerney, 1972; Firer, 1990). Nevertheless, recommendations for or against the use of taping are sometimes confusing and not so clear, ranging from prophylactic external stabilization of both ankle joints during all exercise, to refusal due to the assumed risk or adverse effect of ankle injury caused by restriction of joint movement (Hume and Gerrard, 1998). The positive effect of taping, therefore, is not so conclusive and the effect on lower limb kinetics and kinematics after exercise with ankle taping has not been widely studied (Heit et al, 1996; Shapiro et al, 1994).

A vertical or vertical-horizontal fall and the collision of the human body with ground is a frequent occurrence in human locomotion (Kovacs et al, 1999). Landing from a jump is a task that is important to many sports. Previous studies have examined the effects of landing surfaces (Gross and Bunch, 1989), the manipulation of stiffness (DeVita and Skelly, 1992; Dufek and Bates, 1990; Gross and Nelson, 1988; Mizarahi and Susak, 1982), or elastic energy storage and utilization and coordination (Dufek and Bates, 1990) on lower extremity joint kinetics. Bobbert et al (1986, 1987) reported ground reaction force data and lower extremity joint movements and powers by applying countermovement and bounce type drop jumps falling from several heights. They observed ankle joint dominance in power production for bounce drop jump in contrast with countermovement drop jump where knee joint dominance was observed. These studies showed that all lower extremity joints participated in energy absorption and generation in landings and jumps using forefoot landing strategy, and as landing height increased the role of the ankle musculature increased (Kovacs et al, 1999).

The purpose of this study, therefore, was to determine the effect of ankle taping and the combined effect of ankle taping plus 30 minutes of a treadmill walking on ankle stabilization during landing from a jump. Such information is of interest not only for athletes to improve training exercises but also for clinicians including physical therapists because of the wide application of ankle taping in different types of sports and the dearth of study on landing impact to ankle with taping. The results of this study will provide useful information for physical therapists, athletic trainers, and other professionals related to sports to judge the injury prevention effect of ankle taping.

Methods

Subjects

Fourteen healthy adults (10 female, 4 male) volunteered for this study. All subjects signed informed consent forms approved by the University Institutional Review Board prior to their participation.

Instrumentation

Materials utilized for the taping were one and one half inch tape[1)], foam prewrap[2)], and adherent spray[3)].

Surface electrodes were applied to the center of the muscle bellies of the tibialis anterior, soleus, vastus medialis and biceps femoris muscles of the dominant limb. Conductive paste was first applied to the electrodes, which were held in place by adhesive tape. Each recording electrode consisted of two silver-silver chloride 1-㎝ diameter electrodes embedded in an epoxy-mounted preamplifier system (x35) whose centers were spaced 2 ㎝ apart. A reference electrode was attached to the medial aspect of the tibia on the non-dominant side. The EMG signals are band-pass filtered (20 ㎐ to 4 ㎑) (Therapeutics Unlimited, Iowa City, Iowa) and full-wave rectified on-line. Final amplification was 2 k. One force plate, embedded in a level walkway (10 in length and 1.22 m in width), measured ground reaction forces. Processed EMG and amplified force platform signals were sampled on-

1. Johnson & Johnson Products, Inc.
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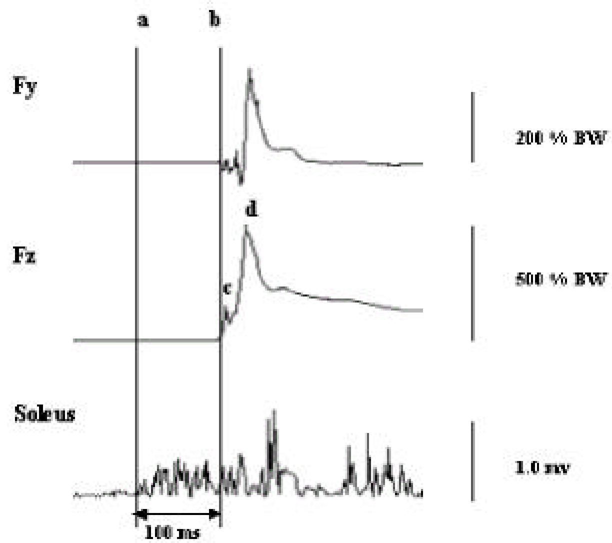

Fig 1. Forceplate record and EMG of Soleus. Fy: mediolateral acceleration, Fz: vertical ground reaction force, a: 100 ㎳ prior to landing, b: landing, c: peak Fz on toe impact, d: peak ㎐ on heel impact.

line at a rate of 500 ㎐ for 5 seconds[4]. All ground reaction forces were normalized to body weight.

Procedures

Subjects were asked to complete four tasks on one occasion. First, subjects stood on their dominant limb on a 40 ㎝ high platform that was placed 20 ㎝ from the edge of the force plate. The force plate to measure ground reaction forces was situated where the subject would land from a hop. Subjects were asked to hop down such that they landed safely without the need to readjust the landing leg. Subjects completed 3 practice trials followed by 3 experimental trials (PT: Pretape trials). The arms were not constrained during the landings and were generally held up and in front of the subjects for balance. The ankle of the dominant limb was then taped by a certified athletic trainer. The taping configuration involved two circumferential anchor strips of tape applied at the fore-foot region and proximally at the lower 1/3 part of tibia. Three stirrups were applied in a basketweave configuration. Circulars were applied to fill in gaps, followed by two heel locks. The taping methods were applied with the ankle in neutral inversion-eversion and dorsiflexion. The subject repeated 3 hopping trials (T: Taped trials). The subject then walked for 30 minutes on a treadmill at comfortable self-selected speed. Following a 5 minute rest, the subject again repeated the 3 hopping trials (TW: Tape and walk trials). After removal

4. BIOPAC Systems, Goleta, CA

Table 1. Peak vertical ground reaction force (% body weight) across conditions

Conditons	Mean	SD*	p
Pre-taped 1)	503.42	34.23	
Taped 2)	549.51	45.04	.002
Exercise with Taping3)	550.70	47.83	
Untaped 4)	512.41	33.71	

* SD: standard deviation

† There were statistically significant differences in 1) vs 2), 1) vs 3), 2) vs 4), and 3) vs 4).

of ankle taping, 3 hopping trials were performed (RT: Removal of the tape trials).

Data analysis

The EMG dependent variables were average amplitude of iEMG 100 ms prior to landing and average amplitude of four muscles from impact to peak vertical reaction force. Force platform measures include timing and amplitude of the medial-lateral (Fy), and vertical (Fz) ground reaction forces under the dominant limb (Fig 1).

Statistical analysis

One-way analysis of variance (ANOVA) with repeated measures was used to examine the differences between the independent (initial hopping, T, TW, and RT) and the dependent variables of EMG activity and kinetic variables. In cases where the one-way analysis of variance with repeated measures demonstrated a difference ($p<.05$), a post hoc within-subject analysis was performed. A Bonferroni type adjustment was made to account for the possibility of Type I error occurring with multiple comparisons.

Results

Ground reaction forces

Two peaks were observed in the vertical ground reaction force-time curves and showed peak forces at the time of toe touch-down and heel contact in that order (Fig 1). The first peak was always significantly lower compared with the second peak. The vertical force increased sharply from the instant of heel contact and reached above 500% of body weight across 4 conditions (Table 1). There were statistically significant increases in VGRFs for the taped condition and exercise with taping condition compared with that in pretaped and untaped conditions (Table 1).

However, there were no significant differences between the taped condition and the exercise with taping condition. During landing, there was a significant difference in the peak medial acceleration across 4 conditions and there was a statistically significant difference between pretaped and exercise with taping conditions using Bonferroni adjustment. However, in the peak lateral acceleration, no significant difference was found across conditions (Table 2).

Table 2. Peak medial (pronation) and lateral (supination) acceleration forces (% body weight) across conditions

	Medial Acceleration			Lateral Acceleration		
Condition	Mean	SD*	p	Mean	SD	p
Pretaped 1)	201.40	43.33	.048	-40.36	17.54	.588
Taped 2)	218.88	27.61		-44.82	15.74	
Exercise with Taping 3)	228.81	46.54		-43.81	22.32	
Untaped 4)	217.35	41.15		-47.57	26.10	

* SD: standard deviation

† Bonferroni adjustment in medial acceleration showed that there was a significant difference at the .05 in 1) vs 3).

Table 3. Time (ms) to peak vertical ground reaction force of toe and heel across conditions

	Toe			Heel		
Condition	Mean	SD*	p	Mean	SD	p
Pretaped 1)	11.71	2.66	.002	41.57	4.33	.000
Taped 2)	9.76	2.04		36.29	2.96	
Exercise with Taping 3)	10.71	1.72		37.67	2.98	
Untaped 4)	11.94	2.73		40.72	4.24	

* SD: standard deviation

† Bonferroni adjustment in toe showed there were significant differences at the .05 in 1) vs 2), and 2) vs 3).

‡ Bonferroni adjustment in heel showed there were significant differences at the .05 in 1) vs 2), 1) vs 3), 2) vs 4), and 3) vs 4).

At the moment of toe impact, the time to peak ground reaction force was the shortest in the taped condition and at the moment of heel impact, the time to peak ground reaction force of the taped condition was the shortest too (Table 3).

EMG activity

To identify the muscle preparation during landing, 100 ms integral EMG data prior to impact were analyzed. There was no significant difference across conditions (Table 4).

The soleus muscle showed the least activation taken from impact to vertical ground reaction under the taped and exercise with taping condition (Table 5).

Discussion

Jump landing activities can be seen in many sports dealing with a ball or with physical training courses. Two peaks in vertical ground reaction force were shown in the current study (Fig 1 c and d). The first peak was always significantly lower

Table 4. IEMG (㎷) 100 ㎳ pre-impact across muscles and conditions

	Pre-taped		Taped		Exercise with Taping		Untaped		
Muscles	Mean	SD*	Mean	SD	Mean	SD	Mean	SD	p
Soleus	1.32×10^{-2}	0.45×10^{-2}	1.23×10^{-2}	0.55×10^{-2}	1.09×10^{-2}	0.41×10^{-2}	1.12×10^{-2}	0.56×10^{-2}	.063
Tibialis Anterior	1.32×10^{-2}	0.39×10^{-2}	0.69×10^{-2}	0.51×10^{-2}	0.68×10^{-2}	0.48×10^{-2}	0.71×10^{-2}	0.54×10^{-2}	.956
Biceps Femoris	1.32×10^{-2}	0.48×10^{-2}	0.66×10^{-2}	0.45×10^{-2}	0.60×10^{-2}	0.31×10^{-2}	0.62×10^{-2}	0.34×10^{-2}	.253
Vastus Medialis	1.32×10^{-2}	0.49×10^{-2}	1.07×10^{-2}	0.41×10^{-2}	0.96×10^{-2}	0.43×10^{-2}	0.92×10^{-2}	0.38×10^{-2}	.096

*SD: standard deviation

Table 5. IEMG (㎷) from impact to peak vertical ground reaction force (% body weight)

	Pre-taped		Taped		Exercise with Taping		Untaped		
Muscles	Mean	SD*	Mean	SD	Mean	SD	Mean	SD	p
Soleus	0.53×10^{-2}	0.20×10^{-2}	0.37×10^{-2}	0.18×10^{-2}	0.38×10^{-2}	0.14×10^{-2}	0.48×10^{-2}	0.19×10^{-2}	.011
Tibialis Anterior	0.37×10^{-2}	0.22×10^{-2}	0.35×10^{-2}	0.24×10^{-2}	0.34×10^{-2}	0.20×10^{-2}	0.35×10^{-2}	0.22×10^{-2}	.333
Biceps Femoris	0.39×10^{-2}	0.29×10^{-2}	0.34×10^{-2}	0.23×10^{-2}	0.35×10^{-2}	0.32×10^{-2}	0.37×10^{-2}	0.28×10^{-2}	.064
Vastus Medialis	0.77×10^{-2}	0.34×10^{-2}	0.71×10^{-2}	0.36×10^{-2}	0.63×10^{-2}	0.36×10^{-2}	0.71×10^{-2}	0.48×10^{-2}	.265

* SD: standard deviation

† Of the 4 muscles, only soleus muscle showed significant decrease across conditioins.

compared with the second peak which means a toe-heel strategy was used by all subjects at landing.

In this study, after landing, we asked the subjects to keep their position for 2 3 seconds, and not to take even one step conditions, it is no wonder that rapid deceleration of the body must occur. According to Steele and Milburn's report (1989) applied to netball players, VGRFs on landing were 6.8 times body weight. In our study, we had similar results as the peak VGRFs ranged from 503.42% to 550.70% body weight across 4 conditions (Table 1). From previous studies on landing, the magnitude of these VGRFs varied from 3.12 to 3.37 times body weight (Hopper et al, 1999) in single leg forward jump, 4.4

times body weight (Nummela et al, 1994) during fast running, 7 to 12 times body weight (Ramey and Williams, 1985) in a triple jump, to 8.8 to 14.4 times body weight for vault landings in gymnastics (Panzer et al, 1987). Variations in the velocity at which the subject approaches the force plate, the subject's landing technique, the court surface, the position of the foot at the time of landing, the dropping height, and footwear etc. may have been the cardinal factors influencing the magnitude of the VGRFs. We should be especially cautious in interpreting these findings since the court surfaces are different from those of the force plate. These previous studies indicated that if the landing movement happens from a dynamic starting position such as a jog or sprint, VGRFs were higher than those recorded from the stationary starting position as in the present study.

A possible explanation for the increased VGRFs in the tape conditions, is that as taping restricts the amount of motion at the ankle and subtalar joints. The reduced ankle range of motion during landing may result in less energy being absorbed by the soft tissues controlling ankle motion, especially by the eccentric action of the posterior ankle musculature (McCaw and Cerullo, 1999). Lindenberger et al (1985) reported that taping has a significant prophylactic effect against lateral ligament injuries. In addition, taping offered the most support for limiting dorsiflexion range of motion, but it could induce increases in the magnitude of the peak VGRFs in the lower extremity at landing (Cordova et al, 2000). Consequently this finding suggested that the restriction of ankle ROM using ankle taping may be harmful to ankle, knee, and hip joints. Fukuda et al (1987) found that knee and hip joints play an important role in shock attenuation. So there is a possibility that shock on landing might be transferred more to the knee or hip joint than to the ankle in the ankle taped condition than in normal landing. However, the results of this study are not sufficient to prove whether knee and hip joint kinematics are altered when ankle taping is used.

When taping material stretches, or the limb sweats during exercise, taping is known to loosen (Hume and Gerrad, 1998). Exercise periods commonly ranged from 5 to 20 minutes but the amounts of activities with taping is different from each studies (Hume and Gerrard, 1998). Although, in the present study, the ankle ROM before and after 30 minutes of walking on the treadmill with taping was not measured, considering the magnitude of the peak VGRFs in exercise with taping, it is evident that the tape did not lose its restrictive ability to a significant extent even with 30 minutes of walking. It seems that the main reason for this is that the walking exercise was not strenuous enough to cause the tape to lose its tension. The results indicate that ankle taping affects the kinetics of landing, likely through restricting range of motion, and affect the soleus, possibly through the same mechanism. And the changes seen in pre- and post-exercise conditions indicate that 30 minutes of moderate activity does not significantly affect the support provided by the tape.

On the other hand, tape use has been reported to significantly limit inversion before and after exercise but to lose considerable amounts of restriction after exercise compared with the pre-exercise condition (Bauer, 1988). Other studies have reported that although the restriction in ROM was reduced with exercise, the restriction was still significantly greater than without any tape support (Gross et al, 1991). To determine the effect of ankle taping, the type of tape, application technique, and length of time the tape is in use, all need to be considered. In addition, the adherence of tape to the skin, and the tension of the tape strips need to be examined (Hume and Gerrard, 1998).

Peak pronation reaction force increased about 2 times body weight at touch down (Table 2). Glick et al (1976) stated that tape would fail to support the ankle mechanically (ie. as a means of external support) after 20 minutes of exercise, and that an ankle with an increased talar tilt may be more prone to injury than one with a normal talar tilt. The construction style and quality of materials could affect all of the above suggested mechanisms. The tensile strength of tape is lower than the strength of the anterior talofibular ligament (Hume and Gerrard, 1998). If an external support is to provide mechanical support to a ligament it should exceed the strength of the ligament. And Bauer (1988) concluded that athletic tape would fail to support the ankle effectively during and after exercise. In the present study, it seems that the pronation reaction force at landing was stronger than the protection ability of taping in relation to talar movement. The possibility of a canceling out effect, contrary to reports that ankle taping is effective limiting ankle motion, of inversion and eversion must be considered.

With respect to time to peak vertical ground reaction force of the toe, mean differences across conditions were about 2 ㎳ and these differences were statistically significant (Table 3). Although there was a statistically significant difference, we can not exclude the possibility of measurement error. Because we sampled at a rate of 500 ㎐ in the acquisition of EMG signal, a 2 ㎳ difference may have occurred due to measurement error. And although there were significant differences in peak VGRF, these differences were very small and probably not meaningful. For example, there was a 2.18 ㎳ difference between taped and untaped post-exercise which was statistically significant (Table 3).

With regards to time to the peak vertical ground reaction force of heel, significant mean differences across conditions were found. This means that in the taped condition and exercise with taping condition, the ankle joint had the shortest time to absorb the reaction force from the ground. This finding is consistent with the report of Hopper et al (1999) who reported that there was a trend to a shorter time to peak vertical force when subjects were braced, and that may be worthy of further investigation. A reduction in time to peak vertical ground reaction force of heel could reflect a decrease in energy absorption and suggests that this may increase the risk of ankle injury.

To identify the muscle preparation during landing, 100 ms pre-impact iEMG across conditions were analyzed (Table 4). There was no significant difference across conditions in soleus, tibialis anterior, biceps femoris, and vastus medialis. Which means, during landing, there is no muscle preparation in the above mentioned 4 muscles. Surve et al (1994) suggested that the main effect of an orthosis was to improve proprioceptive function of the previously injured, rather than to provide mechanical support alone. Hume and Gerrard (1998) who had reviewed the literature related to muscle activation, reported that the magnitude, duration or timing of muscle activation patterns may or may not change with use of external support such as bracing. Because relatively few studies have investigated muscle preparation of the lower extremity at landing, little information is available on whether the muscle preparation at landing exists or not.

Concerning the iEMG from impact to peak VGRFs (Table 5), when subjects were taped, only soleus iEMG of the 4 lower extremity muscles was decreased. McKanna and Finch (1991) suggested that a decrease in ankle soleus, peroneus longus and anterior tibialis muscle activity may have been due to the restriction of movement by tape application or the muscles relying on the tape for support. Hopper et al (1999) reported that gastrocnemius EMG activity decreased when using a brace or taping. Even though we measured soleus EMG instead of gastrocnemius, significantly decreased soleus iEMG activities were found across conditions. This indicates that the plantar flexors are important in reducing the VGRFs associated with landing (McNitt-Gray, 1991). In this study, it is impossible to explain clearly why the only soleus EMG decreased when subjects were taped. Taping or bracing may diminish muscle activation amplitude and inhibit the natural injury prevention motion of the ankle joint by restricting range of motion (Ferguson, 1973; Hume and Gerrard, 1998).

In this study, to exclude the influence by shoe type, all subjects were instructed to wear low-top sneakers made by the same company when they performed the landing activity. Garrick and Requa (1988) concluded that the use of preventive ankle taping, in addition to decreasing the likelihood of re-injury, offered some protection for the ankles of previously uninjured players although this was only observed for those wearing high-top shoes. The injury rate for the low-top shoes with tape condition was lower than the rate for the high-top shoes and no-tape condition indicating that tape possibly had more of an effect than shoe type.

Limitations of this study were the small subject sample size, and due to using within-subject design, a possible carry-over effect or learning effect occurring during the performance of landing. Additionally, measures to exclude the order effects could not be applied in this study. Thus, claims based on this study should be interpreted with caution.

In conclusion, even though it has been widely believed that the benefits of ankle taping in reducing the risk of ankle injury, our results suggested that tape can provide enough mechanical restriction to ankle motion even after 30 minutes of walking on the treadmill to diminish the magnitude of iEMG of soleus that would result in increasing the risk of an ankle injury at landing from a 40 ㎝ height.

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