

Effects of Prophylactic Lace-Up Ankle Braces on Kinematics of the Lower Extremity During a State of Fatigue

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ABSTRACT

Background: Prophylactic lace-up braces are commonly used in athletics regardless of ankle injury history to reduce lateral ankle sprains (LAS). **Objectives:** The purpose of the study was to assess ankle and knee kinematics associated with chronic knee pathologies during a 90° cutting maneuver before and after a state of fatigue. **Methods:** Using a randomized crossover design, thirteen, active adults (6 males and 7 females) engaged in a 15-m beep test fatigue protocol with a 90° cutting maneuver test before and after the fatigue protocol, both with and without brace. **Results:** Brace condition significantly reduced Ankle Sagittal Displacement (ASD; 52°) compared to no brace condition (62°) ($p < .05$). Peak knee flexion was significantly greater in brace (56°) compared to no brace condition (47°) and, likewise, took longer to reach it (10 ms) ($p < .05$). **Conclusions:** Prophylactic ankle braces limiting ASD can cause the foot to land in a more dorsiflexed position at initial ground contact causing more rearfoot strike, which may contribute to chronic knee pathologies.

Key words: Motion Analysis, Ankle Braces, Kinematics, Fatigue, Knee Flexion, Ankle Dorsiflexion

INTRODUCTION

Prophylactic ankle braces are frequently used by amateur, collegiate, and professional athletes to avoid lateral ankle sprains (LAS). The lower limbs account for more than 50% of injuries sustained during sporting activities, with the ankle and knee suffering the most damage (Schroeder & Weinhandl, 2019). The majority of LAS are brought on by the first foot contact during jogging, cutting, or landing. During cutting, momentum must be swiftly reduced to change direction. An increase in non-contact ankle sprains may result from the body inappropriately attenuating stresses as a result of this abrupt shift (Garrick, 1977). The most common causes of LAS damage are excessive inversion and plantarflexion, which are frequent in sports involving cutting and jumping especially when executed with an abnormal foot placement (Garrick, 1977). These injuries account for 63% of volleyball injuries and 58% of basketball injuries (Shaw et al., 2008). The highest percentages of LAS in NCAA sports are seen in men's basketball (15%), women's basketball (14.5%), women's volleyball (10.7%), and women's lacrosse (10.2%) (Delahunt & Remus, 2019). By limiting the range of motion for ankle inversion and plantarflexion, prophylactic ankle braces are used in conjunction with other preventative and rehabilitation techniques to reduce the incidence of ankle injuries (Dewar et al., 2019).

The most popular preventative ankle braces are elastic/compression braces and semi-rigid braces (lace-up and hinge braces). Both lace-up and hinge ankle braces restrict ankle inversion and eversion in the frontal plane, while lace-up braces also restrict dorsiflexion and plantarflexion in the sagittal plane. In a variety of athletic contexts, external ankle supports have been demonstrated to lower ankle injury rates (Dizon, 2007; Newman et al., 2017; Thacker et al., 1999). The capacity of a lace-up brace to restrict ankle dorsiflexion is not necessary to lower the incidence of ankle sprain injuries, and it may have a detrimental effect on knee kinematics causing knee to flex more such as in landing from a jump. Ankle bracing can further limit all ankle mobility and can reduce ankle frontal plane inversion and eversion by 3.95° and 3.74° in comparison to control conditions (Willeford et al., 2018). Clinicians, teams, and physically active people use lace-up ankle braces regardless of a person's history of ankle injuries because they are frequently used in athletics to prophylactically prevent inversion ankle sprains (McGuine et al., 2011; Pedowitz et al., 2008). However, restrictions in the ankle range of motion during landing and cutting can have an impact on the knee and such altered knee mechanics can lead to chronic knee illnesses (DiStefano et al., 2008; Klem et al., 2017). Recent comprehensive analyses by Mason-MacKay et al. (2016, 2017) discovered

changes in knee kinematics brought on by preventive ankle braces, most notably decreased dorsiflexion. Shorter eccentrically regulated dorsiflexion and knee flexion would boost peak vertical ground reaction forces (VGRF) during landing and cutting (Devita & Skelly, 1992). Therefore, to provide more constant VGRF when ankle sagittal motion is restricted, knee flexion must increase to compensate. The inability to have the ankle more plantarflexed at ground contact to allow greater dorsiflexion will affect the knee similarly because the gastrocnemius and soleus lack the eccentric control necessary to dissipate landing and cutting forces (Devita & Skelly, 1992).

Such eccentric control of knee flexion occurring in more flexed position which then causes greater knee valgus strain during landing tasks are key risk factors for the development of patellar tendinopathy and other chronic knee injuries (West et al., 2014). Patellar tendinopathy is a thickening of the proximal patellar tendon and is associated with decrease in ankle dorsiflexion range of motion of less than 45°. Patellofemoral pain (PFP) is the most common chronic knee pathology in young and physically active females, characterized by anterior knee pain while squatting, leaping, and running, and has a close relationship with greater knee abduction angles (Myer et al., 2015).

Fatigue plays a role in joint stability through altered neuromuscular control causing a reduced preparatory joint motion response and loading to restore joint stability during functional movements (Shaw et al., 2008). Greater knee and ankle flexion angles at initial contact, larger peak ground reaction forces, and a longer stabilization time are all characteristics of participants whose muscles are fatigued (Brazen et al., 2010). Ankle braces have been investigated to determine if they affect performance and ankle range of motion. In preventative rehab programs, braces are contrasted to see whether changes in ankle range of motion can impact the knee or hip joint. It is critical to identify the alterations brought on by wearing preventive ankle braces when engaging in sports motions (such as cutting), as prolonged exposure to these modifications can lead to chronic knee issues. Furthermore, present ankle brace research lacks functional fatigue procedures that would bring participants to exhaustion similar to athletes' physical state during competition. The purpose of this study was to examine how ankle bracing affected knee kinematics during a 90° cutting maneuver before and after fatigue in physically active athletes with no history of ankle injuries. Any changes in knee kinematics associated with chronic knee disorders were specifically examined. We predicted that when individuals were braced, their ankle range of motion would decrease and their peak knee flexion and delay to peak knee flexion would increase. We also hypothesized that the fatigue procedure will modify knee kinematics when compared from pre- to post-fatigue.

METHODS

Design

This study is a randomized crossover design with 2 independent variables of brace and no brace and the order coun-

terbalanced. The dependent variables of the ankle and knee kinematics were Initial Contact Plantarflexion (ICPF), Peak Ankle Dorsiflexion (PDF), Peak Ankle Plantarflexion (PPF), Ankle Sagittal Displacement (ASD), Peak Knee Flexion (PKF), Time to Peak Knee Flexion (T2PKF), and Knee Frontal Displacement (KFD). The dependent variables of the kinetic data were peak vertical ground reaction force (peak F_z), peak moment about vertical axis (peak M_z), and vertical loading rate (VLR) which is an indicator of how fast the vertical GRF rises to its first peak. We assessed these dependent variables during the landing phase of the 90° cutting task.

Participants

Thirteen, physically active young adults (6 males and 7 females, age = 23.5 ± 1.74 yrs, BMI: 22.2 ± 2.25) participated. The participants had an experience in competitive landing and cutting sports (e.g., football, basketball, volleyball, soccer, baseball), performed 150 minutes of moderate to vigorous activity per week, and had never worn an ankle brace or suffered a serious ankle or knee injury. Furthermore, no participants were constrained by their doctors from performing near-heart-rate-maximal activities or had a history of cardiac issues because the fatigue protocol included an estimated VO_2 max. All participants provided written consent, and the study was approved by the Institutional Review Board (protocol #: 1626839-3, approved 08/05/2021, Baylor University).

Instruments

Kinematics and kinetics were measured through motion capture system that utilizes high-speed cameras and force plate. The system comprises of 14 Vicon Vantage motion capture cameras (300 Hz) and 1 AMTI force plate (1,500 Hz, AMTI, Watertown, MA). Markers were placed with double-sided tape based on the lower body using the plug-in-gait model (Vicon, Oxford, UK) which uses 16 markers on various locations on the pelvis, knee, leg, and ankle (Kadaba et al., 1990).

Participants wore a semi-rigid ASO Ankle Stabilizer with Stays (Figure 1, Medical Specialties, NC) and an experimenter tightened both their shoes and the lace-up section of the ankle brace to guarantee comfort and uniform tightness among all participants. All participants' ankle brace had their lace-up portions tightened to 30 lbs of force (measured with a handheld spring scale) and fastened with buckle clamps.

Procedures

The participants attended two sessions on separate days at least 48 hours apart, and they were randomly assigned to either brace or no brace condition at the beginning of their first session. Participants had reflective markers placed on the lower extremities based on the plug-in-gait model (Kadaba et al., 1990). Capillary (fingertip) blood lactate (Nova Biomedical Lactate Plus) and rate of perceived exertion (RPE) on a BORG 6-20 scale were measured before and after the fatigue protocol on both days. Participants performed a structured 10-minute warmup routine followed by the fatigue pro-

TOCOL which was a 15-meter beep test. The 15-meter beep test reliably measures $VO_{2\max}$ and aerobic capacity (McClain & Welk, 2004). Participants must run 15 m between beeps until they cannot continue physically or reach the end before the beep. Immediately after the beep test, participants had their circulating lactate measured, and the BORG scale recorded again. Following the lactate and BORG scale before and after the fatigue protocol, participants completed 5 trials of the 90° cutting task with or without a brace. Participants started their approach 3 meters away from a force plate and were instructed to plant and explode out at a 90° angle with their dominant leg. Motion and GRF were captured during cutting task. Figure 2 shows the timeline of participants' visits.

Statistical Analysis

A 2 (Brace: brace, no brace) x 2 (Test: pre-fatigue, post-fatigue) analysis of variance (ANOVA) with repeated measures on both factors was performed Initial Contact Plantarflexion (ICPF), Peak Ankle Dorsiflexion (PDF), Peak Ankle Plantarflexion (PPF), Ankle Sagittal Displacement (ASD), Peak

Knee Flexion (PKF), Time to Peak Knee Flexion (T2PKF), Knee Frontal Displacement (KFD), peak vertical ground reaction force (peak F_z), peak moment about vertical axis (peak M_z), and vertical loading rate (VLR). The statistical analysis was conducted using SPSS IBM 22. Means were considered significantly different when the probability of a type I error was .05 or less. If the sphericity assumption was violated, Huynh-Feldt corrections for the p -values were reported. Partial eta-squared (η_p^2) values were computed to determine the proportion of total variability attributable to each factor or combination of factors. With a moderate effect size of approximately .5, a probability of type I error value of .05, and 80% power, the recommended sample size is 10.

RESULTS

The 15-m beep test fatigue protocol elicited fatigue in all participants while wearing the ASO ankle brace causing a significant increase in Borg scale results (pre-fatigue = 6.14 ± 0.53, post-fatigue = 15.93 ± 1.49) and lactate (pre-fatigue = 1.81 ± 0.97 mmol/L, post-fatigue = 10.65 ± 2.42 mmol/L). No brace condition showed similar results in Borg scale (pre-fatigue 6.14 ± 0.53, post-fatigue 16.29 ± 1.33), and lactate (pre-fatigue 2.04 ± 1.05, post-fatigue 10.44 ± 1.93). Furthermore, the $VO_{2\max}$ results were not different between brace (41.75 ± 5.03) and no brace (41.75 ± 4.37). There was no significant interaction between brace and test and no significant main effect for test ($p > .05$). However, on the ankle kinematics, results showed statistically significant effect on brace for initial contact plantarflexion (ICPF, $F_{1,12} = 5.69, p = .034, \eta_p^2 = .32$), peak ankle plantarflexion (PPF, $F_{1,12} = 14.4, p = .003, \eta_p^2 = .55$), and ankle sagittal displacement (ASD, $F_{1,12} = 7.80, p = .016, \eta_p^2 = .39$) during the cutting task (Table 1). The participants showed a smaller ICPF in brace (11.5°) compared to no brace (17.3°). Participants also showed a significantly smaller PPF in brace (28.2°) compared to no brace (38.6°), as well as ASD in brace (52.5°) and no brace (62.3°).



Figure 1. Semi-rigid ASO Ankle Stabilizer with Stays

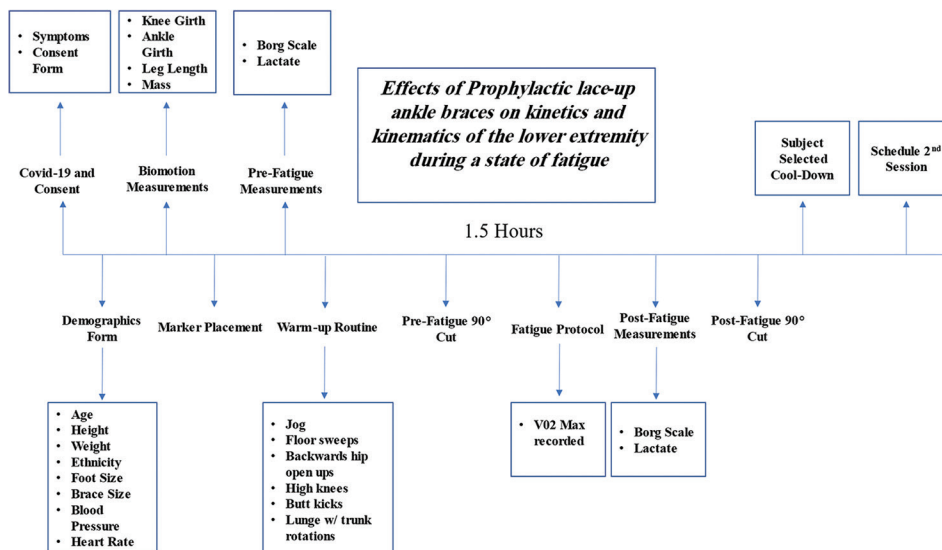


Figure 2. Participant visit timeline

Similarly, for knee kinematics, there was no significant interaction between brace and test and no significant main effect for test ($p > .05$). But, there was a significant main effect for brace relative to peak knee flexion (PKF, $F_{1,12} = 6.23, p = .028, \eta_p^2 = .34$), time to peak knee flexion (T2PKF, $F_{1,12} = 4.9, p = .047, \eta_p^2 = .29$), and knee frontal displacement (KFD, $F_{1,12} = 6.59, p = .025, \eta_p^2 = .35$, Table 2). The restriction of the ankle joint movement with the brace caused the knee joint of the same braced leg compared to the knee joint when the ankle was unbraced a greater PKF (brace = 55.7° , no brace = 47.2°), longer T2PKF (brace = 131 ms, no brace = 124 ms), and smaller KFD (brace = 13.6° , no brace = 18.4°)

Despite ankle and knee kinematics having some effects on brace, kinetic data from the force plate showed no significant interaction or main effects ($p > .05$, Table 3). Regardless of wearing brace and being fatigued, the participants generated consistent peak vertical ground reaction force (F_z), peak vertical moment (M_z), and vertical loading rate (VLR).

DISCUSSION

This study investigated how semi-rigid lace-up ankle braces restrict ankle sagittal plane range of motion and how they influence knee kinematics before and after fatigue. Participants were reasonably fit individuals with previous experience in sports with various types of landing and cutting motions. Previous research has consistently found that preventive ankle braces re-

strict the range of motion in all directions of the ankle (Cordova et al., 2000; Greene et al., 2014; Willeford et al., 2018).

When participants were braced, there were statistically significant decreases in ICPF, PPF, and ASD during the cutting task. The PDF range of motion was also reduced; although, not enough to reach significance. Interestingly, the fatigue protocol had no effect on ankle mechanics, even though fatigue procedures in general, when performed without a brace, have been shown to increase knee flexion and ankle range of motion when compared to non-fatigued settings (Brazen et al., 2010; Haddas et al., 2015; Xia et al., 2017).

Previous research has shown that the difference in the ankle sagittal plane range of motion between brace and no brace conditions is $8.9^\circ \pm 2.4^\circ$ (Greene et al., 2014) which is more than 10% of full range of ankle sagittal motion (70°). The results showed peak dorsiflexion was minimally affected, and knee flexion and frontal displacement changed as a result of insufficient ankle plantarflexion at ground contact which in part corroborates previous finding (e.g., DiStefano et al., 2008). Previously, Gudibanda et al. (Gudibanda & Wang, 2005) discovered similar results in a cutting task, where participants showed smaller plantarflexion angles during touchdown. The ankle kinematic results of the study show that wearing a prophylactic lace-up ankle brace reduces ankle range of motion in the sagittal plane during dynamic tasks. During a cutting movement, this decrease in ASD is due to the ankle retaining more neutral position during contact. Athletic performance is negatively impacted by this

Table 1. Ankle kinematics during 90° cutting task between two sessions

Variable	Brace		No Brace	
	Pre-Fatigue	Post-Fatigue	Pre-Fatigue	Post-Fatigue
ICPF ($^\circ$)*	11.0 ± 7.1	12.1 ± 7.1	17.9 ± 8.1	16.7 ± 8.9
PDF ($^\circ$)	24.0 ± 9.1	24.6 ± 8.7	24.7 ± 7.6	22.8 ± 8.5
PPF ($^\circ$)*	28.6 ± 10.0	27.8 ± 9.2	38.0 ± 9.0	39.2 ± 10.5
ASD ($^\circ$)*	52.5 ± 7.8	52.4 ± 7.3	62.6 ± 12.0	61.9 ± 12.9

*Significant difference between brace and no brace, $p < .05$. ICPF = initial contact plantarflexion, PDF = peak ankle dorsiflexion, PPF = peak ankle plantarflexion, ASD = ankle sagittal displacement.

Table 2. Knee kinematics during 90° cutting task between two sessions

Variable	Brace		No Brace	
	Pre-Fatigue	Post-Fatigue	Pre-Fatigue	Post-Fatigue
PKF ($^\circ$)*	53.9 ± 10.7	57.6 ± 8.4	47.8 ± 11.6	46.7 ± 13.9
T2PKF (ms)*	140 ± 27	128 ± 22	126 ± 22	123 ± 28
KFD ($^\circ$)*	14.6 ± 8.2	12.5 ± 7.5	17.4 ± 8.6	19.4 ± 9.0

*Significant difference between brace and no brace, $p < .05$. PKF = peak knee flexion, T2PKF = time to peak knee flexion, KFD = knee frontal displacement.

Table 3. Kinetic Data During 90° Cutting Task Between Two Sessions

Variable	Brace		No Brace	
	Pre-Fatigue	Post-Fatigue	Pre-Fatigue	Post-Fatigue
Peak F_z (N)	$1,479 \pm 316.8$	$1,494.7 \pm 356.4$	$1,499.5 \pm 260.6$	$1,547.9 \pm 327.1$
Peak M_z (N.m)	91.7 ± 47.2	104.1 ± 63.9	104.2 ± 53.8	103.3 ± 55.1
VLR (BW/s)	44.7 ± 25.7	41.3 ± 19.5	46.8 ± 24.6	46.6 ± 22.4

F_z = vertical ground reaction force, M_z = vertical moment, VLR = vertical loading rate

restricted ankle sagittal plane mobility, which may also contribute to alterations in knee mechanics linked to long-term knee issues.

Knee kinematics when participants were braced showed increases in PKF while simultaneously taking longer to reach PKF and thus necessitating a greater need for eccentric contractions of the quadriceps to maintain joint stability. DiStefano et al. (DiStefano et al., 2008) reported that in depth jumps when ankle joint was restricted, the participants increased knee flexion. The amount of ankle restriction brought on by the brace--which also caused an increase in knee flexion--was minimal (3 degrees). Simpson et al. (Simpson et al., 2013) also showed a similar levels of increased knee flexion during landing positions. However, in the present study, knee flexion in the brace condition compared to no brace condition was almost 10 degrees which coincided with the degree of ankle restriction in sagittal plane with brace.

Although an increase in knee flexion has previously been shown in fatigued participants, our findings revealed only a slight rise in PKF during the brace conditions following the completion of the fatigue treatment. This could be because the fatigue protocol causes individuals to become fatigued aerobically without causing substantial muscle damage to modify muscle spindle discharge patterns, which may results in athletes employing different landing and cutting mechanics. Unexpectedly, bracing the ankle reduced KFD. Excessive valgus and varus displacements are associated with a number of acute and chronic knee disorders in physically active populations because they lead to a less stable knee joint. Overall, the participants' ankle sagittal range of motion was reduced with brace, particularly plantarflexion at ground contact during the deceleration phase of a 90° cutting task. This restriction in return led to the knee flexing more but abducting less to stabilize the knee laterally and reduce knee valgus.

This study used a handheld scale to ensure consistent brace tension among participants so that their ankle joint is equally confined in all planes. This strategy should be used in future investigations to guarantee proper tightness and inter-subject consistency. In groups that are physically active, hinge braces are less common than lace-up braces. However, compared to lace-up braces, hinge braces offer a broader range of motion for the ankle, which makes them less likely to impede athletic performance or change knee mechanics (Schroeder & Weinhandl, 2019). Hinge braces can limit ankle inversion during a 45° cutting motion without changing knee flexion angles,(Schroeder & Weinhandl, 2019) and they can also reduce joint forces at the ankle and knee (Klem et al., 2017). Hinged braces may be a better option than lace-up braces because they allow for higher ankle sagittal range mobility while still limiting the ankle frontal range of motion.

CONCLUSION

According to the findings of this study, prophylactic lace-up ankle braces worn by athletes with no history of ankle injuries reduce ICPF, PPF, and ASD during a 90° cutting task.

The results imply that the knee responded to these changes by increasing PKF and delaying the onset of maximal knee flexion. Additionally, we showed that the fatigue protocol's effects were consistent across conditions and that the fatigue treatment had no discernible impact in either braced or unbraced settings. Before recommending bracing to healthy athletes, clinicians should consider unique impacts of lace-up ankle braces and the athlete's demand for joint stability. Future studies should use a longer dynamic procedure to inflict greater muscle damage while replicating typical athletic performance.

AUTHOR'S CONTRIBUTION

A.H.: Conceptualization, study design and protocol, data collection, data analysis, writing original draft, editing. D. R.: contributed to the conceptualization, study design and protocol, data collection, data analysis. J. S.: contributed to the Conceptualization, study design and protocol, writing original draft, editing. J.R.: contributed to the conceptualization, study design and protocol, editing. D.W.: contributed to the conceptualization, study design and protocol, editing.

DATA AVAILABILITY

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

DECLARATIONS

Ethics approval and consent to participate

The study was approved by Baylor Institutional Review Board (protocol #: 1626839-3, approved 08/05/2021, Baylor University). The details of the study was explained to all the participants prior to study recruitment. A written Informed consent was obtained from all the participants. The procedures of the study were conducted according to the Declaration of Helsinki.

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