Effects of prophylactic ankle and knee braces on leg stiffness during hopping

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Abstract: During human movement, the leg can be represented as a mechanical spring, with its stiffness potentially contributing to sports performance and injury prevention. Although many individuals perform athletic activities with joint stabilizers, little is known about the effects of prophylactic lower extremity braces on leg stiffness. The objective of this study was to investigate the effect of ankle and/or knee braces on leg stiffness measured during one-legged hopping at a range of frequencies. Thirteen male participants performed one-legged hopping with their dominant leg at frequencies of 2.2, 2.6, and 3.0 Hz. All participants were randomly tested under the following four brace conditions: 1) no brace (control), 2) prophylactic ankle brace, 3) prophylactic knee brace, and 4) prophylactic ankle and knee braces. Based on a spring–mass model, leg stiffness was calculated using data from an accelerometer. It was found that leg stiffness increased with increasing hopping frequency for each brace condition. However, there were no significant differences in leg stiffness among the four brace conditions at the three hopping frequencies. Since some level of leg stiffness is needed for optimal athletic performance and training, these results suggest that ankle and knee braces do not significantly interfere with dynamic hopping activities.

Keywords: spring–mass model, injury prevention, compensatory strategy

Introduction

Since many individuals perform athletic activities with joint stabilizers, prophylactic ankle and knee braces are required to prevent lower extremity injury without interfering athletic performance in sport activities. Previous studies have reported that semirigid or soft ankle braces do not significantly affect a person’s jumping performance.\(^1\,^2\) Furthermore, several studies have demonstrated that prophylactic knee braces do not significantly inhibit athletic performance during a stop–jump task,\(^3\) cross-over hop, or one-legged vertical jump.\(^4\,^5\) However, little is known about the effects of prophylactic lower extremity braces on one-legged hopping, which involves typical spring-like behavior of the legs.

During hopping and jumping activities, the legs of a human exhibit characteristics similar to those of a spring. The leg spring is compressed during the first half of the stance phase and rebounds during the second half. Leg stiffness (\(K_{leg}\)), which is defined as the ratio of the peak ground reaction force to the maximum center of mass vertical displacement at the middle of the stance phase,\(^6\) has been shown to increase with increasing hopping height.\(^7\,^9\) \(K_{leg}\) is also correlated to agility and speed during sprint running.\(^10\,^14\) Previous studies have suggested that endurance training enhances \(K_{leg}\),\(^15\,^16\) but that plyometrics training has a greater influence on \(K_{leg}\) than
endurance training. Therefore, a better understanding of \( K_{\text{leg}} \) regulation would provide us with a basis for better evaluation of the changes in stiffness that accompany training regimes and would allow for the development of more effective training methods.

A previous study has shown that neither prophylactic ankle taping nor bracing affects \( K_{\text{leg}} \) during hopping at frequencies of 2.3–3.0 Hz. However, in that study, the authors only investigated the effects of an ankle stabilizer on \( K_{\text{leg}} \) during hopping. Therefore, it remains unclear whether \( K_{\text{leg}} \) during hopping is affected by knee braces or by a combination of ankle and knee braces during hopping. The objective of this study was to investigate the effect of ankle and/or knee braces on leg stiffness measured during one-legged hopping at a range of frequencies. We hypothesized that \( K_{\text{leg}} \) would not vary during hopping with ankle and/or knee bracing over a wide range of hopping frequencies.

**Methods**

**Participants**

Thirteen healthy male subjects with no known neuromuscular disorders or lower-limb functional limitations participated in this study. The physical characteristics of the participants were as follows: age, 26.5±5.2 years; height, 1.75±0.06 m; and body mass, 66.08±8.43 kg (mean ± standard deviation). We only included subjects on whose legs currently available prophylactic joint braces fitted. All participants were either sedentary or mildly active; none had been involved in any type of regular exercise or training for at least 1 year prior to the test. All participants provided written informed consent prior to the study, which had in turn received institutional ethical approval (Environment and Safety Headquarters, Safety Management Division, AIST).

**Ankle and knee braces**

In our study, commercially available ankle braces (Ankle Guard-Soft; ALCARE, Tokyo, Japan) and knee braces (Knee Guard-Ligament 3; ALCARE) were used to stabilize the ankle and knee joints, respectively (Figure 1). The Ankle Guard-Soft provides medial support of the ankle via a half figure-eight lift, horseshoe, and stirrup straps that encompass the ankle to prevent inversion and joint laxity. The Knee Guard-Ligament 3 provides anterior support to the knee joint via interconnected anchor straps on the thigh and shank with medial plastic stays, which constrain anterior perturbation and joint laxity. To minimize within-subject and between-subject variations, the ankle and knee braces were fitted and checked by a single tester.

**Task and procedure**

Prior to the experiment, limb dominance was determined by asking the participants which leg they preferred to use when kicking a ball, and the limb reported by the participant was identified as the dominant leg. After being fitted with the braces, the participants immediately moved to the experiment area. Each participant completed the testing by performing one-legged hopping under the following four brace conditions: 1) no braces (NBR), 2) prophylactic ankle brace (ANK), 3) prophylactic knee brace (KNE), and 4) prophylactic ankle and knee braces (A&K). The brace conditions and hopping frequencies were randomized.

The participants were instructed to perform one-legged hopping in place on their dominant leg with their arms akimbo. During each trial, a hopping frequency of 2.2, 2.6, or 3.0 Hz was maintained using a digital metronome. We chose these frequencies because a range of 2.2–3.0 Hz was the broadest possible metronome beat frequency range that the subjects could follow and because we considered a spring–mass model to be appropriate for modeling the activity in this range. Because different contact time instructions can affect stiffness regulation during hopping at a given hopping frequency, the participants were asked to hop for as short a contact time as possible. Before data were collected, all participants were instructed to practice for as long as necessary until they felt comfortable with the task. All participants practiced for 3–4 min and reported that the practice session had sufficiently prepared them.

**Data collection and analysis**

Data collected during 10 consecutive hops per brace condition were used in the analyses. According to a previous
study.\(^4\) \(K_{\text{leg}}\) can be calculated using a spring–mass model (Figure 2). We used an accelerometer (Myotest\(^8\); Myotest SA, Sion, Switzerland) to estimate \(K_{\text{leg}}\) during hopping for each subject and brace condition. The Myotest device (dimensions: 5.4x10.2x11.1 cm; weight: 58 g) contains a three-dimensional inertial accelerometer (68 g) that allows vertical acceleration to be recorded at a sampling frequency of 500 Hz. The acceleration data obtained were used to estimate the contact and flight times. The \(K_{\text{leg}}\) during hopping can be indirectly calculated by an estimation equation.\(^{23}\) In the equation, \(K_{\text{leg}}\) was calculated by modeling the ground reaction force as a sine wave as it is expected from oscillation of pure spring–mass model. Therefore, \(K_{\text{leg}}\) during hopping was calculated as follows:

\[
K_{\text{leg}} = \frac{m\pi(t_c + t_f)}{\left[ t_c^2 + (t_c + t_f)^2 / \pi - t_c / 4 \right]}
\]

where \(m\) is the total body mass, \(t_c\) is the ground contact time, and \(t_f\) is the flight time.\(^{21}\) The device was attached so that it was perpendicular to a large (8.5 cm) Velcro elastic belt. The device was fixed at the hip level on the left side of the body, as recommended by the manufacturer.\(^{24}\) The reliability and validity of the device were examined in previous studies.\(^{24–26}\)

### Statistics

A two-way (frequency \(\times\) braces) repeated-measures analysis of variance (ANOVA) was performed to compare \(K_{\text{leg}}\) for the four brace conditions. To assess the validity of the assumptions inherent in the ANOVA, Mauchly’s test of sphericity was performed using all of the ANOVA results. The Greenhouse–Geisser correction was used to adjust the number of degrees of freedom if an assumption was violated, and Bonferroni’s post hoc test for multiple comparisons was used if a significant main effect was observed. Statistical significance was set at \(P<0.05\). We calculated the effect sizes (ES) for each ANOVA. SPSS for Windows, version 19 (SPSS Inc., Chicago, IL, USA) was used for all of the statistical analyses.

### Results

The statistical analyses revealed the existence of a significant main effect of the hopping frequency on \(K_{\text{leg}}\) \((F_{(1.17, 14.01)} = 55.03, P<0.01, \text{ES}=0.82)\). \(K_{\text{leg}}\) was greatest at a frequency of 3.0 Hz, followed by 2.6 and 2.0 Hz \((P<0.01\) for all frequencies; Figure 3). However, there was no significant main effect of the brace condition on \(K_{\text{leg}}\) \((F_{(3.00, 36.00)} = 0.23, P=0.87, \text{ES}=0.02)\), nor was there a significant interaction effect between the hopping frequency and the brace condition \((F_{(6.00, 72.00)} = 0.49, P=0.82, \text{ES}=0.04)\).

### Discussion

The objective of this study was to investigate the effect of ankle and/or knee braces on leg stiffness measured during one-legged hopping at a range of frequencies. We found that \(K_{\text{leg}}\) increased with increasing hopping frequency for each brace condition, but there were no significant differences in \(K_{\text{leg}}\) among the different brace conditions (Figure 3). The results support our initial hypothesis, which was that for a wide range of hopping frequencies, \(K_{\text{leg}}\) would be

![Figure 2](image2.png)  
**Figure 2** Spring–mass model for hopping.  
**Notes:** This model consists of a body mass and a massless linear spring that supports the body mass. The mass is equivalent to the body mass. The model is shown at the beginning of the ground contact phase (left), the middle of the ground contact phase (middle), and the end of the ground contact phase (right).

![Figure 3](image3.png)  
**Figure 3** Comparison of leg stiffness among the four brace conditions at three hopping frequencies.  
**Note:** The symbol \(***\) denotes significant differences between adjacent frequencies for each brace condition \((P<0.01)\).  
**Abbreviations:** NBR, no braces; ANK, prophylactic ankle brace; KNE, prophylactic knee brace; A&K, prophylactic ankle and knee braces.
invariant when ankle and/or knee braces were worn. Given that prophylactic braces are used extensively for prevention and treatment of soft tissue injuries of the lower extremities, it is interesting to discover that wearing prophylactic lower-extremity braces does not impede $K_{\text{leg}}$ during dynamic tasks.

One possible explanation for the invariance of $K_{\text{leg}}$ when prophylactic braces are worn is that the braces used in this study did not restrict hopping movement in the sagittal plane. According to a previous study, the biomechanical characteristics of a hopping movement can be described in the sagittal plane. However, the ankle (Ankle Guard-Soft) and knee braces (Knee Guard-Ligament 3) used in this study provide medial support to the ankle and anterior support to the knee joint. Hence, the results of this study could be attributable to the fact that the braces used did not influence the joint motion in the sagittal plane.

A third possible explanation for the invariance of $K_{\text{leg}}$ with ankle and/or knee braces is that the braces used in this study did not restrict hopping movement in the sagittal plane. According to a previous study, the biomechanical characteristics of a hopping movement can be described in the sagittal plane. However, the ankle (Ankle Guard-Soft) and knee braces (Knee Guard-Ligament 3) used in this study provide medial support to the ankle and anterior support to the knee joint. Hence, the results of this study could be attributable to the fact that the braces used did not influence the joint motion in the sagittal plane.

In summary, our results suggest that during a one-legged hopping task, neither prophylactic ankle nor knee bracing affects $K_{\text{leg}}$ over a range of hopping frequencies. Evidently, additional research is necessary to determine the mechanisms responsible for the invariance of $K_{\text{leg}}$ when ankle, knee braces, and combination of both ankle and knee braces are worn.
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Disclosure
The authors report no conflicts of interest in this work.

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