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Campbell, B., Cipriani, D., & Yaggie, J. (2007). Influence of a functional knee brace and exercise on lower extremity kinematics during jogging. *Clinical Kinesiology, 61*(2), 7-13.

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Influence of a Functional Knee Brace and Exercise on Lower Extremity Kinematics During Jogging

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ABSTRACT

Context: Functional knee braces (FKB) are used prophylactically and in rehabilitation to aide in the functional stability of the knee joint. *Objective*: To determine if alterations in sagittal plane lower extremity kinematics remain evident throughout a one hour period in healthy individuals.
Design: 2X5 repeated measures design. *Setting*: Biomechanics Laboratory. *Subjects*: Twenty subjects (14 male and 6 female, mean age 26.5±7 yrs; height 172.4±13 cm; weight 78.6±9 kg), separated into braced (B) and no brace (NB) groups. *Intervention*: A one-hour exercise program divided into three 20 minute increments. *Main Outcome Measures*: Synchronized three-dimensional kinematic data were collected at 20-minute increments to assess the effect of the FKB on select lower extremity joint kinematics. *Results*: Hip, knee and ankle joint position were not significantly affected by time (exercise). However significant decreases in hip ($p = .05$) and knee flexion ($p < .05$) were noted in the B group compared to the NB group regardless of time while ankle joint position was unaffected. *Conclusions*: Hip and knee flexion angles were reduced in the B group compared to the NB group, while ankle joint position was not affected. Wearing a knee brace appears to not only influence knee joint position but also hip joint position. It is possible that repetitive changes to hip joint kinematics may be detrimental to hip and low back function and thus lead to injury.

Key Words: bracing, joint position, exercise

INTRODUCTION

Functional knee braces (FKB) are often used in the prevention and rehabilitation of anterior cruciate ligament (ACL) injuries and have been shown to have a potential protective effect on the ACL immediately after donning the brace (6, 8, 9, 12, 13). Previous research has demonstrated that, in part, this may be due to decreases in knee joint torques that are shifted to the hip and possibly the ankle (8). It may be that these alterations in torque are a product of altered lower extremity kinematics. However, limited research exists regarding the documentation of changes in lower extremity kinematics, associated with the use of an FKB during locomotor activities (9, 13, 18).

Osternig and Robertson (13) investigated the effects of non-prescription prophylactic knee bracing on lower extremity joint position and muscle activation during running. They found that there were significant changes in knee joint position between the braced versus nonbraced conditions. They further stated that 83%-89% of the braced and nonbraced comparisons generated significant differences in knee joint position while significant hip and ankle joint position changes occurred in 50%-58% of the comparisons.

DeVita et al. (9) observed kinematic changes in the ACL reconstructed population. They found that while walking with a knee brace, the patients demonstrated significantly less (19%) knee flexion during the stance phase. Although not statistically significant, the results also revealed that the patients elicited 26% less hip flexion while walking with the brace. The results of this study suggest that individuals who had undergone an ACL reconstruction walked with a stiffer/straighter lower extremity while wearing a brace.

Additionally, it has been shown that exercise, and the associated fatigue from exercise, has the potential to alter lower extremity locomotor kinematics (7). Derrick et al. (7) investigated the changes in lower extremity kinematics at the beginning, middle and end of an exhaustive run. They found that knee flexion angle and subtalar joint angle significantly increased over time. The authors suggest that these kinematic changes could have been a result of a strategy to shift the optimizing criteria from performance to injury prevention or possibly a failure of the system to maintain optimal behavior. They also suggest the possibility that the altered kinematics acted to prevent decrements in performance that would have taken place if the kinematic changes had not occurred.

Typically, those who use FKB's tend to also participate in some form of exercise which leads to fatigue. Thus, it is logical to investigate interactions between the effects of FKB use and exercise that may uniquely influence lower extremity kinematics. To date no research is available that has investigated the possible interaction between exercise duration and FKB influence on lower extremity joint kinematics. The previously cited research investigated the immediate effects of wearing a knee brace, without considering the additional impact of prolonged exercise. Given that exercise and bracing independently influence joint kinematics, it is likely that the combination may result in observable joint changes.

Functional knee braces are widely used in the prevention and rehabilitation of ACL injuries and have been shown to have a protective effect on the anterior cruciate ligament immediately after brace application. A comprehensive understanding of the means by which FKB's provide such protection, as well as factors such as exercise/fatigue that may influence this protective function, may enhance the ability of clinicians to optimize the use of FKB.

Thus, the purpose of this study was to examine the effect of a FKB on lower extremity sagittal plane hip, knee and ankle joint angles during jogging throughout a one hour bout of exercise.

METHODS

Design. A 2X5 factorial design with repeated measures (brace X time) was utilized. Subject sample size was estimated *a priori* by calculating effect size of the previous literature.

Subjects. Approval for this investigation was granted by the university's human subjects review board.

Twenty healthy volunteers (14 male and 6 female, mean age = 26.5 ± 7 yrs, ht = 172.4 ± 13 cm and wt = 78.6 ± 9 kg) were screened to assure age appropriateness, health status and freedom from lower extremity pathologies within two years prior to the investigation. Participants reviewed and completed a health history questionnaire and all informed consent documents prior to inception of the protocol. Subjects were then randomly assigned into a braced (B; n = 10) or no braced group (NB; n = 10).

Instrumentation and Equipment. The DonJoy Legend™ FKB (dj Orthopedic, Vista, CA) (Figure 1) was selected due to its popularity in the marketplace and its use in recent, relevant literature (10, 14, 15, 17). Multiple left limb braces were procured to assure proper fit as indicated by manufacturer's guidelines.

Two photocells (Micro Switch, Freeport, Ill) were used to monitor the subject's jogging velocity during each of the gait trials. Each subject self selected their own comfortable jogging pace. Once that comfortable pace was achieved the photocells were used to monitor that speed and make sure that each jogging trial fell within a 5% window on either side of their self selected pace.

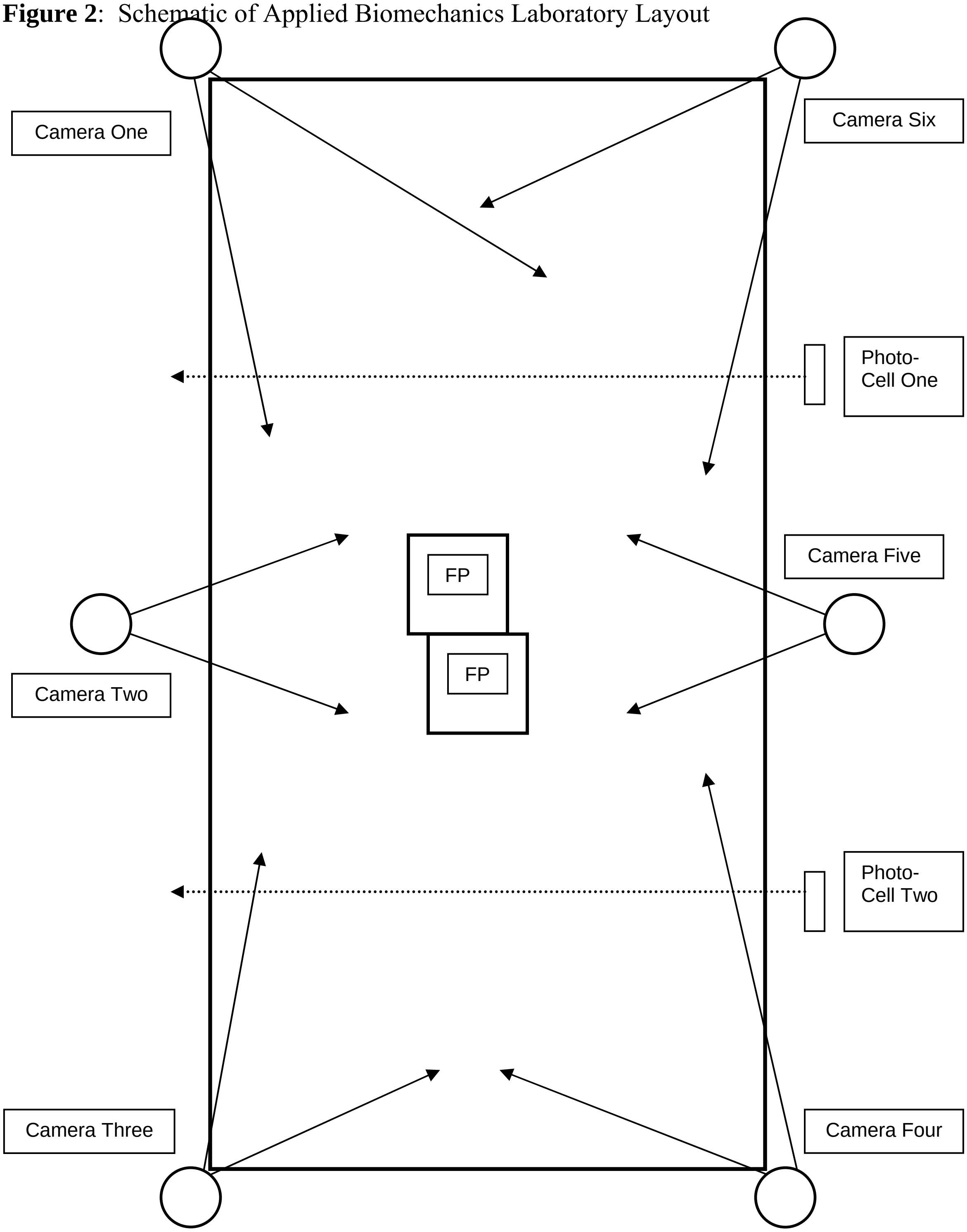
Figure 1: Photographs of the DonJoy Legend FKB

Six Falcon Motion Analysis cameras (Santa Rosa, CA), sampling at 60Hz, were integrated with Eva Hi-RES software to obtain the kinematic data during the multiple gait cycles. A Helen Hayes lower body marker set was used to assist in the acquisition of the kinematic data. The left lateral knee marker was fixed to the lateral aspect of the FKB which aligned to the lateral femoral condyle. This marker placement was monitored throughout the jogging trials to check for the FKB migrating distally which would have altered the marker placement. The markers were removed to allow the subject perform the bouts of exercise comfortably. Therefore, a permanent marking pen was used to mark each of the retroflective marker sites on their skin. This was to ensure that the markers were placed in the precise location throughout the study. Orthotrak 4.2 (Santa Rosa, CA) was used to calculate the kinematic values generated by the subjects during the jogging gait trials. All data were time matched using an external trigger (Motion Analysis Corporation, Santa Rosa, CA).

Force plate (AMTI, Watertown, MA) data were collected to determine the point of mid-stance during the gait cycle. Force plate data were sampled at 960 Hz. Figure 2 provides an illustrated of the Biomechanics lab layout used for this investigation.

Protocol. Prior to the testing, the subjects performed five practice jogging trials to determine a comfortable jogging pace. A 5% window above and below their self selected jogging pace was calculated. Acceptable jogging trials needed to fall within the defined window to be considered for data analysis. Each subject performed a multi-trial jogging gait analysis, consisting of 7-10 bouts/jogging trials, to establish a baseline for force plate and kinematic measures. The subjects in the B group were then fit with a FKB with the factory installed extension stop

Figure 2: Schematic of Applied Biomechanics Laboratory Layout



set at 10° of flexion. All braces were fit by the principal investigator according to the manufacturer's guidelines. After fitting, each subject completed a series of jogging trials to establish immediate post brace measures. Subjects from both groups then performed five minutes of lower extremity stretching followed by a one hour exercise protocol. The exercise protocol consisted of various multidirectional activities that would be included in a typical athletic workout regimen (Table 1).

The exercise protocol was subdivided in three 20-minute bouts made up of exercise and rest. At each 20-minute increment, additional jogging gait trials were performed in order to obtain kinematic

TABLE 1: **Exercise Protocol.** All activities were performed at a self selected pace. Lower extremity stretching consisted of various self selected lower extremity stretches. With the exception of the jog around the track and the stationary bike all other activities were performed on a 20 m marked course within an indoor gymnasium.

Activity	Time (min)
Jog around 175 m indoor track	2
Stationary Bike	2
Rest	1
Backward Running	1
High Knee Running	1
Rest	2
Figure Eight Running	1
High Knee Running	1
Rest	1
Backward Running	1
Ladder Runs	1
Rest	1
Carioca to the Right	1
Carioca to the Left	1
Rest	1
Jog around 175 m indoor track	2
Total	**20**

measures of the lower extremity. The NB group performed the identical protocol, with the exception of the application of the brace.

Data Analysis. Successful trials were averaged in the *Multiple Trial Module* of Orthotrak and then exported to a spreadsheet to obtain the desired mid-stance numerical values. Mid-stance was identified at the point at which the anterior/posterior ground reaction force curve was equal to zero. This was repeated for each subject at each time point (T). Five time points (T1 – T5) were identified in this investigation for both groups. Time point one (T1) was the baseline measure prior to brace application for the B group. Time point two (T2) was identified as the measure immediately after the brace was applied to the B group. Time point 2 for the NB groups consisted of sitting in a chair and waiting a similar amount of time that the B group did during initial FKB application. Time points three - five (T3 – T5) were measures after subsequent 20-minute bouts of exercise. Previous research (8, 9) identified torque, work and power alterations as they occurred specifically at mid-stance. It is possible that the significant changes in kinetic data found at mid-stance may be caused by similar significant changes in the kinematic data. Therefore, this investigation focused on the occurrence of kinematic changes specifically at mid-stance. The kinematic values at mid-stance were then extracted for further analysis. Intraclass correlation coefficients ($ICC_{2,3}$) for the kinematic values for the B and NB conditions were 0.85 and 0.95, respectively.

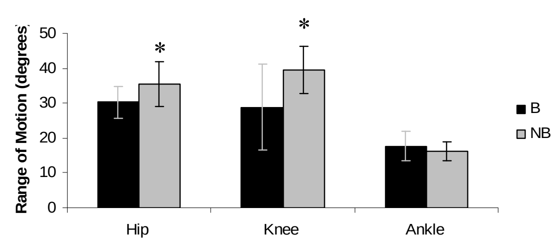
In order to test for the initial effects of wearing the brace on hip, knee and ankle joint angle at midstance, a two factor analysis of variance was run. This was done specifically to compare the two groups on the kinematic variables at the ankle, knee, and hip from T1 to T2. In the event of a significant interaction between brace and time, independent t-tests were run to compare the brace and non-brace conditions at T1 and T2 on each of the dependent variables. In order to test for the possible interaction effect of exercise and knee brace on the joint angle at mid-stance, two-way ANOVA with repeated measures for each dependent variable was run. Level of statistical significance was set at $p \leq .05$ for all comparisons. The statistical analysis was performed using the SPSS 11.0 for Windows package (SPSS Inc., Chicago, Ill).

RESULTS

Joint Range of Motion at Mid-Stance. The two-factor ANOVA revealed a significant interaction ($p < .05$) between brace and time, when testing the B and NB conditions from T1 to T2. While there were no differences at the hip, knee or ankle joint angle at T1 between the two groups ($p > .05$), hip and knee joint angle decreased significantly at T2, when comparing the B and NB groups ($p < .05$).

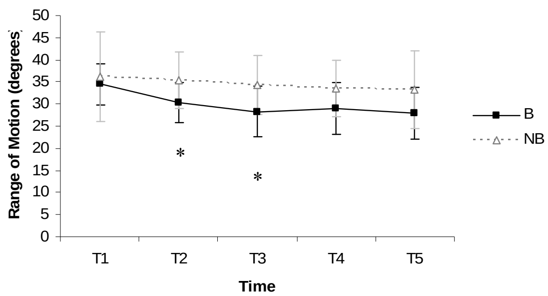
Figure 3 illustrates the means and standard deviations for the hip, knee and ankle joint position values at T2 for the B (Hip = 30.28 ± 4.57, Knee = 28.85 ± 12.39, Ankle = 17.67 ± 4.15) and the NB (H = 35.35 ± 6.43, K = 39.51 ± 6.83, A = 16.19 ± 2.76) groups, respectively. Post hoc Independent samples t-tests revealed that there was significantly less hip flexion ($p < .05$) and knee flexion ($p < .05$) immediately following brace application (T2) while the ankle joint angle was unaffected ($p > .05$).

Figure 3: Means (± SD) of Hip, Knee and Ankle Joint Position immediately following brace application (T2). Hip and knee flexion significantly reduced in the B group. ($p \leq .05$)



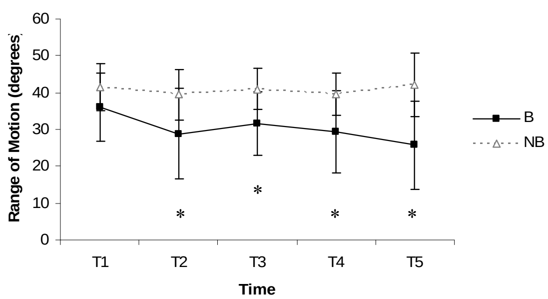
* indicates significant difference between groups ($p \leq .05$)

Figure 4: **Means (± SD) of Hip Joint Position at T1 - T5.** Hip flexion significantly reduced in the B group at T2 and T3. ($p \leq .05$)



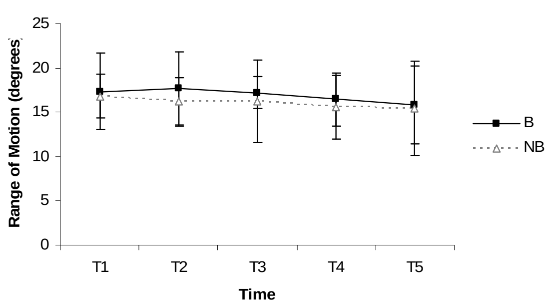
* indicates significant difference between groups ($p \leq .05$)

Figure 5: Means (± SD) of Knee Joint Position at T1 - T5. Knee flexion significantly reduced in the B group at T2 – T5. ($p \leq .05$)



* indicates significant difference between groups ($p \leq .05$)

Figure 6: **Means (± SD) of Ankle Joint Position at T1 - T5.** No significant differences observed over time or between groups. ($p \leq .05$)



Hip. Figure 4 illustrates the means and standard deviations for the hip joint angle values of the B (T1 = 34.47 ± 4.57, T2 = 30.29 ± 4.57, T3 = 28.19 ± 5.72, T4 = 29.07 ± 5.86, T5 = 27.97 ± 5.78) and the NB (T1 = 36.18 ± 10.18, T2 = 35.35 ± 6.43, T3 = 34.41 ± 6.68, T4 = 33.39 ± 6.38, T5 = 33.13 ± 8.77) group across time points 1-5. There was no significant interaction between time period and brace condition ($p > .05$). There was no significant main effect for time ($p > .05$); hip joint angle was not influenced by exercise. There was, however, a main effect for condition ($p = .05$) revealing that the B group experienced significantly less hip flexion than the NB. Independent samples T-test revealed the differences between groups at T2 and T3.

Insert Figure 4 Here

Knee. Figure 5 illustrates the means and standard deviations for the knee joint angle values for the B (T1 = 35.97 ± 9.19, T2 = 28.84 ± 12.39, T3 = 31.60 ± 8.71, T4 = 29.44 ± 11.10, T5 = 25.73 ± 11.85) and the NB (T1 = 41.52 ± 6.31, T2 = 39.51 ± 6.83, T3 = 40.98 ± 5.49, T4 = 39.64 ± 5.82, T5 = 42.11 ± 8.56) group across time points 1-5. There was no significant interaction between time period and brace condition. There was no significant main effect for time ($p > .05$); knee joint angle did not change over time as a result of the exercise protocol. There was, however, a main effect for condition ($p < .05$) revealing that the B group experienced significantly less knee flexion than the NB. Independent samples T-test revealed the differences between groups for T2 – T5.

Ankle. Figure 6 illustrates the means and standard deviations for the ankle joint angle values for the B (T1 = 17.34 ± 4.29, T2 = 17.67 ± 4.15, T3 = 17.21 ± 1.77, T4 = 16.43 ± 3.01, T5 = 15.87 ± 4.40) and the NB (T1 = 16.79 ± 2.48, T2 = 16.19 ± 2.76, T3 = 16.18 ± 4.65, T4 = 15.51 ± 3.59, T5 = 15.46 ± 5.32) group across time points 1-5. There was no significant interaction between time period and brace condition. There was no significant main effect for time ($p > .05$); exercise did not affect ankle joint angle. There was also no main effect for condition ($p > .05$) revealing that the ankle joint angle was not affected by the brace.

DISCUSSION

The purpose of this study was to examine the effect of a FKB on lower extremity sagittal plane joint angles during jogging throughout a one hour bout of exercise. The design of this investigation was limited to the kinematic observations of the braced limb.

There was a significant decrease in hip and knee flexion during the stance phase of the jogging trials in the B group immediately after the FKB was applied at T2 while ankle joint angle was not affected. This suggests that the addition of the FKB caused the subjects in the B group to jog with more stiff or straight lower extremity. These kinematic changes in the gait pattern have been associated with a “quadriceps avoidance” gait pattern (1-3, 11, 16). This more erect posture via reduced hip and knee flexion during the stance phase while wearing the FKB, potentially reduces the need for quadriceps muscle activity. This reduction has been suggested by multiple authors (1-3, 11, 16), as possibly causing a reduction of anterior shear force experienced by the knee joint during the gait pattern.

Furthermore, an overall decrease in knee joint angle was observed across all time points (T2-T5) in the braced group when compared with the NB group. This indicates that the FKB had an affect on knee joint angle from the time the brace was applied throughout the entire bout of exercise. Although not tested in the current investigation, this change is possibly due to the altered muscle firing patterns caused by the application of the brace. These findings are unique, in that there have been no studies investigating the persistence of these changes in gait while wearing a FKB. It is apparent from the current study that the FKB appears to be altering the knee joint angle throughout a bout of exercise.

The current findings are contrary to the significant increases in knee joint angle that Derrick et al. (7) found during an exhaustive run. It is possible that the exercise protocol that was used was not at an intensity level required to elicit such changes in knee joint angle. It is also possible that the FKB provided a protective mechanism against the effects of exercise. However, this does not explain the lack of change in the NB group as well.

Hip joint angle was not affected over time, which implies that the bouts of exercise had no affect on the hip joint position during the stance phase. However, differences in hip joint angle were noted between groups, particularly at T2 and T3. This finding may indicate that the addition of an FKB may lead to a straighter lower extremity, specifically during mid-stance. It is noted that there was no significant difference in hip joint angle between groups at T4 and T5 while there was a difference at T2, immediate post brace application, and T3 after the first 20-minute bout of exercise. The authors suggest that following the first bout of exercise, subjects may became more accustomed to the brace and although the differences in knee joint angle were maintained throughout the exercise, subjects reorganized their gait pattern and the compensated with the trunk and or non-braced leg.

There were no significant findings relative to ankle joint angle, neither the exercise nor the addition of a FKB had an impact on ankle joint position. It is possible that the FKB does not effect joints that are distal to the braced joint. Therefore any changes in the kinematics of the gait cycle may occur at joints proximal to the braced joint namely, the hip and pelvis. These findings are consistent with those of Osternig and Robertson (13) who indicated that the effects of knee bracing on the hip and ankle were less than those for the knee. They suggested that accommodations to bracing in joints proximal and distal to the knee brace may be common.

In a recent study, Campbell, Yaggie and Cipriani (5) investigated the changes in lower extremity kinetics throughout a one hour period of exercise between a braced and no-braced group. Peak GRF values were similar for the B and NB groups across trials and conditions. These GRF findings indicate that the rate of the jogging trials, and the subsequent acceleration of body mass, were also similar. In addition, Campbell (4) observed a reduction in step length and an increase in the percent of stance throughout the cycle, when wearing a FKB, indicative of a restricted posture of the braced limb. These restrictions may elicit kinematic changes in the remainder of the kinetic chain, potentially through the pelvis and or un-braced limb, in order to sustain the reaction force of each successive step. Given the restrictions on joint position of the braced limb, a compensatory action may exist in the opposite limb or by the rotary action of the pelvis. This compensation was not assessed in the current investigation and represents a limitation of these data, as well as the design of the existing relevant literature. Further investigation is required to evaluate a comprehensive bilateral comparison of lower extremity kinematics, pelvic and trunk rotation, and the temporal displacement of the COM in the braced and unbraced conditions.

CLINICAL IMPLICATIONS

These results indicate that the application of a FKB causes joint position changes to the braced joint and may elicit compensations from other joints during the jogging gait cycle throughout a one hour bout of exercise. Although the current investigation was limited to quantifying these changes in the braced leg, it is important to understand that the application of a brace may be causing changes to more proximal joints and possibly the pelvis and unbraced limb. Clinicians who apply braces to their patients should be aware of these potential changes and the potential risks that may be introduced to the unbraced limb as a result of the brace application.

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