Journal of Athletic Training 2011:46(4):395–402

www.nata.org/jat

original research

Performance of Healthy Braced Participants During Aerobic and Anaerobic Capacity Tasks

Neetu Rishiraj, PhD, ATC*; Jack E. Taunton, MD, MSc†; Brian Niven, MSc‡; Robert Lloyd-Smith, MD†; William Regan, MD†; Robert Woollard, MD§

*ACTIN Health & Rehabilitation, Inc, Vancouver, BC, Canada; †Allan McGavin Sports Medicine Centre, University of British Columbia, Vancouver, Canada; ‡Department of Mathematics & Statistics, University of Otago, Dunedin, New Zealand; §Department of Family Practice, University of British Columbia, Vancouver, Canada

Context: Knee braces were introduced in sports approximately 30 years ago. However, the effects of a functional knee brace (FKB) on aerobic and anaerobic performance after fatigue are unknown.

Objective: To investigate whether FKB use in noninjured participants hindered performance during aerobic (Léger beep test) and anaerobic (repeated high-intensity shuttle test [RHIST]) tasks.

Design: Crossover study.

Setting: Laboratory.

Patients or Other Participants: Twenty-seven healthy male provincial and national basketball and field hockey athletes (age = 19.4 ± 3.0 years, range, 17–26 years; height = 182.6 ± 6.8 cm, range, 168–196 cm; mass = 80.0 ± 9.1 kg, range, 66–108 kg).

Intervention(s): Each participant was provided a custom-fitted FKB and performed 5 nonbraced (NBR) testing sessions over 3 days, followed by 5 braced (BR) testing sessions over 3 days, for a total of 17.5 hours of testing per condition. During each testing session, participants performed 1 trial of the Léger beep test and 1 trial of the RHIST in each condition.

Main Outcome Measure(s): Predicted maximal oxygen consumption ($\dot{V}O_2max$) and time performance measures were recorded for each NBR and BR trial.

Results: Initial performance levels were lower for BR than NBR for both the Léger beep test (BR = 44.3 mL/kg/min, NBR = 47.3 mL/kg/min; $F_{1,26} = 8.726$; $P = .007$) and the RHIST (BR = 16.5 seconds, NBR = 16.2 seconds; $F_{1,26} = 13.98$, $P = .001$). However, with continued FKB use, the aerobic performance measure remained higher for only the first 2 BR testing sessions (NBR = 46.9 mL/kg/min, BR = 42.4 mL/kg/min; $F_{3.0,79.8} = 4.95$, $P = .003$). For the anaerobic test, no performance difference was noted between the testing conditions (NBR = 16.2 seconds, BR = 16.4 seconds; $P = .7$), whereas fatigue levels were lower during BR testing sessions (NBR = 33%, BR = 31%). After 14.0 hours of FKB use, performance levels were almost equal between the testing conditions (NBR = 47.6 mL/kg/min, BR = 46.1 mL/kg/min).

Conclusions: We found an initial decrement in performance when the FKB was used during an aerobic or anaerobic task. However, after 14.0 hours of FKB use, accommodation to the FKB was possible.

Key Words: anterior cruciate ligament, accommodation, functional knee braces

Key Points

- Performance levels in aerobic and anaerobic tasks were hindered initially by use of a functional knee brace.
- After 14.0 hours of brace use, no differences in performance or fatigue levels existed between noninjured participants in the braced and nonbraced conditions.
- Functional knee brace users should be provided with an adaptation or accommodation phase before engaging in full sport participation.

Knee injuries are particularly common in collision sports, such as ice hockey and North American football.[1–3] In the United States, the estimated total cost for operative treatment and rehabilitation of anterior cruciate ligament (ACL) injuries has reached $2.0 billion per annum.[4,5] This amount does not include the cost of initial evaluation and treatment of injured people who receive nonoperative care and does not include the potential expenses related to future medical treatment.[6,7] Researchers have provided evidence about the long-term risk of developing osteoarthritis associated with an ACL knee injury in soccer for both sexes 12 to 14 years after injury.[8,9]

Investigators have addressed numerous risk factors associated with ACL injury.[5,10–23] Although prevention programs have shown some promise, no conclusive evidence has been presented, and widespread disagreement about the effectiveness of these programs remains.[24–27]

Present knowledge about the effect of functional knee braces (FKBs) has resulted from studies performed on ACL-deficient knees in cadaver and surrogate models[28–36] and in humans.[37,38] These studies showed that FKBs reduce pathologic anterior-posterior laxity associated with the ACL-deficient knee.[39–41] According to a 2004 American Academy of Orthopaedic Surgeons[42] position statement, "studies designed to test whether functional knee braces protect against the knee 'giving way' have demonstrated some beneficial effect of the brace." Despite the apparent preventive role, players and many authors have perceived knee braces as being cumbersome and hindering athletes' performance,[6,42] especially for highly skilled playing positions.[43,44] The American Academy of Orthopaedic Surgeons[42] concurred with these concerns: "On the negative side, braces might slow an athlete's straight-ahead speed and cause early fatigue to its wearer." However, several researchers[22,43,45–48] have provided limited evidence that FKB use by noninjured athletes might not hinder performance. Nevertheless, researchers have not investigated how FKB use in noninjured athletes restricts performance levels or, if there is hindrance, whether wearers need a period of familiarization or learning. We refer to this relearning process as the adaptation or accommodation phase.

Therefore, the primary purpose of our study was to ascertain whether performance of noninjured participants was hindered while they wore FKBs during aerobic and anaerobic capacity running tests. The secondary purpose was to ascertain whether continued FKB use allowed accommodation to the FKB, thus potentially minimizing concerns about performance hindrance during these tasks.

METHODS

Study Design

Our goal was to ascertain whether accommodation to the FKB was possible. The repeated-measures design allowed potential participants (control and experimental groups) to be matched for performance ability and physiologic performance levels (energy systems) for all tests conducted during all testing sessions (Table 1). If 1 or more participants had inferior or superior performance or functional ability or had greater or lesser developed energy systems, then the results might have been biased. If participants were prescreened for functional or physiologic performance levels (ie, muscle biopsies), then the results might have been prejudiced. In addition, because the FKBs were purchased to eliminate product testing bias, the repeated-measures design allowed cost efficiency; a counterbalanced, randomized study design would have required twice the number of participants and FKBs to ensure adequate study power.

Our independent variables were testing sessions, FKB use, and the accommodation to using an FKB over the testing period. The dependent variable was performance measure: predicted maximal oxygen consumption ($\dot{V}o_2$max) for the aerobic capacity test and time for the anaerobic test.

Participants

A total of 375 noninjured potential participants were contacted through their national or provincial sport, university, or high school athletic directors to volunteer for the study. Participants were excluded if they had sustained a knee ligament or meniscus injury 6 months before testing (n = 51) or had any other lower extremity injury that might hinder performance

Table 1. Testing Schedule and Duration of Bracing

Session[a]	Time of Day	Condition	Time Accumulated in Brace, h
1	Morning	Nonbraced	NA
2	Afternoon	Nonbraced	NA
3	Morning	Nonbraced	NA
4	Afternoon	Nonbraced	NA
5	Morning	Nonbraced	NA
6	Afternoon	Rest	NA
7	Morning	Braced	0.0–3.5
8	Afternoon	Braced	3.5–7.0
9	Morning	Braced	7.0–10.5
10	Afternoon	Braced	10.5–14.0
11	Morning	Braced	14.0–17.5

Abbreviation: NA, not applicable.

[a] Participants performed the drop jump, vertical jump, sprint, repeated high-intensity shuttle test, agility test, and Léger beep test during each testing session. However, only the data from the repeated high-intensity shuttle test and the Léger beep test are presented in this article.

(n = 114), had reconstructive ligament surgery to either lower extremity (n = 18), or had any identified potential medical conditions or risk factors likely to be exacerbated by exercise (n = 25). All information was verified in consultation with the respective team physician. Of those contacted, 140 were unavailable or did not respond.

Twenty-seven male athletes (age = 19.4 ± 3.0 years, range, 17–26 years; height = 182.6 ± 6.8 cm, range, 168–196 cm; mass = 80.0 ± 9.1 kg, range, 66–108 kg) started and completed the study. All participants provided written informed consent, and the study was approved by the University of Otago Human Ethics Committee and the University of British Columbia Clinical Research Ethics Board.

Casting for Custom Functional Knee Brace

Each participant was custom fitted with an FKB (mass = 0.76 ± 0.10 kg, range, 0.65–0.95 kg; Extreme; Össur, Richmond, BC) on his dominant leg. The participant's *dominant leg* was defined as the stance or push-off leg during a running jump. Only the dominant leg was braced because Matava et al[49] suggested that no correlation exists between dominant or nondominant limb and injury rate.

All participants had their dominant legs casted using Techform I casting tape (Össur) while seated with their knees in approximately 10° of flexion. A protective elastic compression sock was applied to the participant's leg for easier removal of the solidified cast. Casting tape was applied approximately 15 cm proximal and distal from the superior and inferior aspects of the patella, respectively, and was allowed to set for 5 to 7 minutes to ensure that the cast solidified. Two layers of casting tape were applied to preserve the integrity of the solidified cast after removal from the participant's limb. When the cast had solidified, a cut was made on its medial side, allowing for optimal cast integrity on the lateral side for accurate brace hinge placement. The cast was numbered and forwarded to the brace manufacturer.

Testing Procedures

Before the first day of testing, floor markers were placed using temporary colored floor tape (model 2070; 3M Canada, London, ON). Participants were divided randomly into 4 groups of 6 or 7 individuals, and the groups were scheduled to start testing at 2-hour intervals. Each group rotated through 6 testing stations during each testing session, and data were collected at each station over the 6 days (11 sessions) of testing (Table 1). To allow for and then evaluate potential accommodation to FKB use, each participant performed 2 testing sessions (total duration = 6.0 to 7.0 h) on days 1 and 2 and 1 session on day 3 for the NBR condition (sessions 1–5) and performed 2 testing sessions on days 4 and 5 and 1 session on day 6 for the BR condition (sessions 7–11). Testing session 6 on day 3 was a rest session for all participants. To ensure that all testing sessions were completed at the same time each day, 5 different gymnasiums with wood playing surfaces were used. In this study, we concentrated on the results from the repeated high-intensity shuttle test (RHIST; fourth testing station) and the Léger beep/multistage test (beep test; last testing station); the results from the remaining tests will be presented in subsequent studies.

Brace Use and Accommodation

After completing the 5 NBR testing sessions (days 1–3) and before the first BR testing session (day 4, session 7), participants were provided their FKBs and brace application guidelines. These guidelines included anatomic landmarks for brace positioning and included tension requirements and application sequence for the brace straps. Participants were given 3 brace application trials with feedback on bracing procedure after each trial. After these 3 trials, participants wore the braces for a 20-minute warmup period and then proceeded to the first test. No additional time was permitted for brace use and accommodation. Participants were instructed not to remove the brace for the entire warmup and testing duration but were allowed to readjust the strap for tension and brace repositioning as needed. After each morning's BR testing session (sessions 7, 9, and 11), participants removed their braces during the 30-minute rest period and reapplied the braces for the afternoon testing session (sessions 8 and 10) according to the morning brace application protocol. Participants then followed the morning 20-minute warmup protocol. At the end of the afternoon sessions, all braces were collected, cleaned, and left to air dry overnight.

Data Collection

Anaerobic Capacity. The RHIST was designed to measure anaerobic capacity and endurance or the ability to recover from high-intensity work bouts.[50] It has been validated as an accurate measure of anaerobic capacity and has been used to evaluate anaerobic endurance in high-caliber athletes.[51] Data were collected using an electronic timing light system with an accuracy of 0.01 second (Brower ID XS Training System; Brower Timing Systems, Draper, UT) at the end of each 70-m run. The RHIST was the fourth test performed through all testing sessions.

The RHIST consisted of running 6 sprints for a total of 70 m. Participants sprinted to a marker and then back to the start line before sprinting to the next marker. Markers were placed at distances of 5 m, 10 m, and 20 m. A 60-second rest period was provided between sprints. The electronic lights used to collect data at the end of each 70-m run were set at a height of 75 cm. All floor markings remained in place for the entire testing duration, were remeasured before each testing day, and were re-marked when necessary.

Aerobic Capacity. The beep test has been found to be an accurate estimate of aerobic capacity (predicted $\dot{V}o_2$max).[52,53] In addition, the testing activity is similar to that of many team sports with respect to the stop, start, and change-of-direction movement patterns. In our study, it was the last test performed during each testing session. Predicted $\dot{V}o_2$max was calculated with the following regression equation: $y = 5.857x - 19.458$, where x is the maximal level attained.[53]

During the beep test, participants ran continuously between 2 lines that were 20 m apart in time to recorded beeps. The time between recorded beeps decreased each minute (level), and participants exercised at increasing intensities until volitional fatigue occurred. The athletes' scores were the levels and numbers of shuttles reached before they were unable to keep up with the recorded beeps. These data were used to calculate the predicted maximal oxygen consumption. All floor markings remained in place for the entire testing duration, were remeasured before each testing day, and were re-marked when necessary.

Statistical Analysis

A power analysis on the pilot study data (5 participants: 3 women, 2 men) demonstrated that a minimum of 20 participants would be needed for both tests and that the power of the study would be increased in both tests if only 1 sex was tested (Table 2). The statistical power was set to 0.80, and the α level was set at .05.

This study was a 2×5 factorial design with repeated-measures analysis of variance (ANOVA) completed on the testing conditions (NBR, BR) and testing sessions (NBR, 1–5; BR, 7–11). The 2×5 study design allowed potential participants to be their own controls and, therefore, they were matched for performance ability and physiologic performance levels (energy systems) for the 6 tests conducted during all testing sessions. All 27 participants were familiar with the beep test and the RHIST because their coaches used these tests for team preseason and in-season physiologic evaluations. The study design and previous familiarization with the tests reduced the performance effect and allowed evaluation for an accommodation effect over the testing sessions. In addition, the test order (NBR

Table 2. Power Analysis Data From the Pilot Study[a]

Test	Difference[b]	SD	n[c]	Power[d]
Repeated high-intensity shuttle, s	0.02	±0.53	25	0.65
Treadmill run at submaximal oxygen consumption, mL/kg[e]	17.8	±0.84	25	1.00

[a] The α level was set at .05.
[b] Difference between nonbraced and braced performance measures.
[c] The minimum number of participants needed to achieve adequate power.
[d] The statistical power was set at 0.80.
[e] Treadmill run was replaced by Léger beep test in the final study because of financial and facility constraints.

followed by BR) allowed continual accommodation to FKB use because an interruption in FKB use could have hindered accommodation progression.

The main outcome measures were predicted $\dot{V}O_2max$ (beep test) and time in seconds (RHIST). Participants performed 1890 sprints/trials (beep test, 1 trial × 10 sessions × 27 participants; RHIST, 6 sprints/trials × 10 sessions × 27 participants) over 10 testing sessions in 2 conditions (NBR, BR) while we collected predicted $\dot{V}O_2max$ and performance times. When we found a difference, we conducted a post hoc Tukey test to ascertain where changes might have occurred over the respective condition and test sessions. For the RHIST, percentage of fatigue ([slowest time – fastest time]/fastest time × 100) was determined.[54] The α level for all tests was .05. Percentage difference analysis was conducted between NBR and BR conditions. Data were analyzed using SPSS (version 13.0 for Windows; SPSS Inc, Chicago, IL).

RESULTS

Group Mean Performance Levels Between Conditions

The group mean performance level is an average of all test sessions within each group (NBR, NR) of the respective outcome measure. The group mean performance measures of BR participants were lower than the mean NBR performance levels for the beep test ($F_{1,26}=8.726$, $P=.007$) and the RHIST ($F_{1,26}=13.98$, $P=.001$), respectively (Table 3). However, the fatigue levels during the RHIST were lower during the BR than the NBR conditions (Table 3).

Mean Performance Levels Over Days (Accommodation) Between Conditions

Beep Test. Fatigue levels were consistent during the 5 NBR testing sessions (SD ± 2.3 mL/kg). Conversely, a steady improvement was noted during BR testing conditions, and by testing sessions 10 and 11 (approximately 14.0 hours of brace use), a 1.5-kg/mL/min predicted $\dot{V}O_2max$ difference remained between the NBR and BR conditions (Figure 1). In considering the mean SD of ±1.4 kg/mL over the 5 BR testing sessions, the performance measures between the NBR and BR testing conditions were comparable during testing sessions 4 and 10 and sessions 5 and 11, respectively. This similar performance measure during the 2 testing conditions was illustrated further by the post hoc Tukey test results (Table 4); after the first 2 testing sessions, no differences were noted between the NBR and BR testing conditions.

Repeated High-Intensity Shuttle Test. Running speed during NBR conditions was constant over the 5 testing sessions, with the best performance time recorded in session 3. During BR testing conditions, performance levels showed an initial decrease (session 8) followed by improved performance measures (sessions 9 and 10); by testing session 10, a 0.20-second difference remained between the testing conditions (Figure 2). A post hoc analysis was not conducted because the mean performance measures over the 5 testing sessions between the conditions were not different ($F_{4,104}=0.556$, $P=.7$).

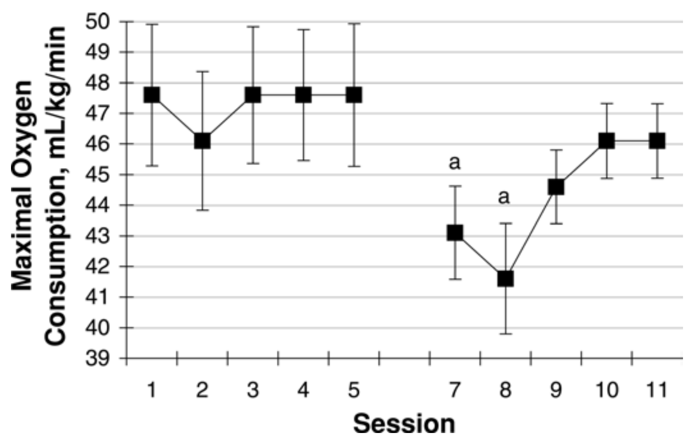

Figure 1. Léger beep test (aerobic capacity–predicted maximal oxygen consumption). Accommodation over days for nonbraced sessions 1 through 5 versus braced sessions 7 through 11. [a]Indicates difference between conditions ($P<.05$).

Table 3. Aerobic and Anaerobic Performance Levels Between Nonbraced and Braced Conditions After Initial Test

			Condition, Mean ± SD		
Variable	Test Performed	N	Nonbraced	Braced	*P* Value
Aerobic capacity, mL/kg/min[a]	Léger beep	27	47.3 ± 2.3	44.3 ± 1.4	.007[b]
Anaerobic capacity, s (% fatigue)[c]	Repeated high-intensity shuttle	27	16.2 ± 1.2 (39)	16.5 ± 1.1 (33)	.001[b]

[a]Indicates predicted maximal oxygen consumption.
[b]Indicates difference ($P<.05$).
[c]Percentage fatigue = (slowest time – fastest time)/fastest time × 100.[54]

Table 4. Performance Difference Percentage Change by Nonbraced and Braced Participants[a] Over Sessions for the Léger Beep Test and the Repeated High-Intensity Shuttle Test

	Performance Difference, %				
Test	Sessions 1 and 7	Sessions 2 and 8	Sessions 3 and 9	Sessions 4 and 10	Sessions 5 and 11
Léger beep	12.0[b]	10.0[b]	5.1	0.9	1.3
Repeated high-intensity shuttle	2.1	2.5	2.8	1.3	2.4

[a]Participants were nonbraced for sessions 1 through 5 and were braced for sessions 7 through 11.
[b]Indicates difference ($P<.05$).

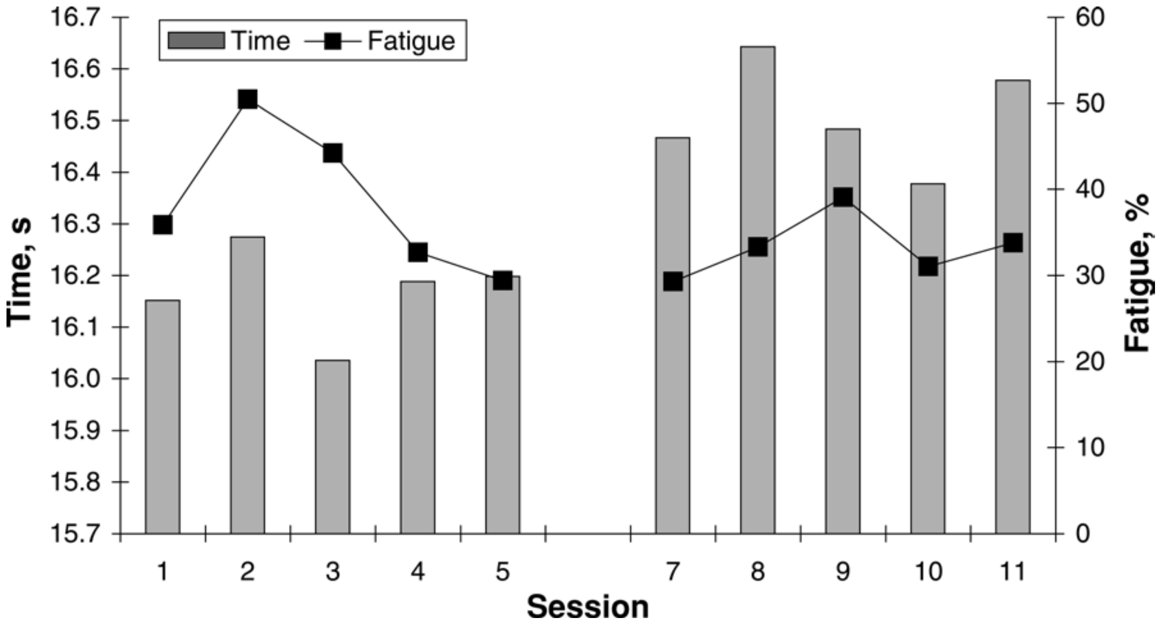

Figure 2. Repeated high-intensity shuttle test (anaerobic capacity). Accommodation over days for nonbraced sessions 1 through 5 versus braced sessions 7 through 11.

Performance Percentage Difference. Performance improvement tendency was further illustrated in the performance measure percentage differences between NBR and BR conditions over the 5 NBR (sessions 1–5) and 5 BR (sessions 7–11) testing sessions. For the beep test, BR performance measures improved 11.1% between testing sessions 7 and 10 (Table 4). Although BR performance measures improved by session 10 in the RHIST, performance levels were 1.3% lower than for the NBR group in session 4 (Table 4).

DISCUSSION

In our study, oxygen consumption during the beep test for the NBR participants was lower than published standards for similar-caliber Australian[52] and for Canadian athletes.[55] The lower results (10.6 mL/kg/min, range, 10.7–11.1 mL/kg/min) in our study probably can be attributed to the training periodization cycle because all athletes were completing their "active rest" periods and starting their competitive training cycles. The "average normative" results recorded in our study should not be a factor; as Highgenboten et al[56] stated, "individuals of average and above-average fitness levels will respond similarly to the effect of brace wear." For the anaerobic capacity test, data obtained for NBR participants were also similar to available standards.[57]

We found a 12% higher fatigue level in the first 7.0 hours of FKB use during the beep test. However, with 14.0 hours of brace use, brace accommodation seemed to occur as fatigue levels declined, so that only a 0.9% difference remained between the NBR and BR testing conditions. A post hoc analysis of the aerobic capacity test further illustrated that familiarization with FKBs did take place during this test, as the elevated metabolic cost was noted only during the initial 7.0 hours (sessions 1 and 2) of brace use.

These results are similar to the findings of Highgenboten et al,[56] who tested asymptomatic BR participants and reported a 3% to 8% increase in oxygen consumption. Although Highgenboten et al[56] provided a 3-week "adjustment period with the braces" and then completed treadmill testing over a 2-week period, no specific data about the duration of accommodation to the knee brace were provided. Veldhuizen et al[58] reported a 6% lower $\dot{V}O_2$max on day 1 of testing for NBR participants than for BR participants. After 28 days of brace use, they reported, "the performance results were practically identical to their base value."[58] However, as with the Highgenboten et al[56] study, specific knee brace accommodation data were not provided.

Performance in the anaerobic capacity test (RHIST) also was hindered substantially while participants were wearing an FKB over the first 11.0 hours. However, after they used a brace for 12.0 to 14.0 hours (session 4), no difference in performance levels between noninjured BR and NBR participants was found. This lack of difference in performance levels is of interest because the RHIST involves challenging the anaerobic metabolic system and involves the turning and pivoting skills observed in most team sports. Our data could not be compared with previous research because we were the first to test healthy BR participants completing a high-intensity anaerobic capacity task. The percentage of fatigue levels of the BR participants were lower than those of the NBR participants.

These findings are important for many team sports in which the energy produced by the aerobic and anaerobic metabolic systems can be overtaxed.[52,59] Furthermore, fatigue has been shown to negatively influence dynamic muscle control of the lower extremities and potentially contribute to ACL injury.[60,61] Fatigue and the initial use of the FKB could have been factors during the first 2 BR testing sessions (sessions 7 and 8) because performance levels decreased while participants performed both tests. However, if fatigue had contributed to the lower performance measures during testing sessions 7 and 8, then oxygen consumption levels (beep test) and performance times and fatigue levels (RHIST) should have decreased further (increased fatigue) during BR testing sessions 9 and 10. In fact, the opposite results were recorded for both tests. Furthermore, because no differences were found between the 2 testing conditions after 14.0 hours of brace use, our results suggested that fatigue and hindered performance should not be concerns during the beep test or RHIST capacity activity while participants use an FKB.

The lack of difference in performance results recorded between the 2 testing conditions after accommodation could be attributed to the proprioceptive effect of wearing a knee brace. Several authors suggested that participants with ACL-deficient or ACL-reconstructed knee joints lack a certain amount of proprioceptive input to the central nervous system.[62] Researchers[62–64] also have illustrated that alterations in proprioceptive feedback (in participants with ACL-deficient and ACL-reconstructed knees) as a result of bracing might be partly responsible for performance improvement. Given this central nervous system relearning philosophy, if we apply this concept to a noninjured ("normal" proprioceptive) knee joint, perhaps the noninjured BR participants experienced altered proprioceptive feedback and therefore were able to perform with greater perceived knee joint stability and confidence with continued brace use. This notion is supported by the data reported by Herrington et al.[63] They reported that the application of a knee sleeve on noninjured participants increased active tracking accuracy by 28% ($P = .004$), the angle reproduction test showed a 23% increase in accuracy ($P = .03$), and the accuracy of the perceived angle test improved by 27% ($P = .04$).[63]

Our study design could have included rest periods between testing sessions within each condition; however, because our goal was to measure possible accommodation to FKB use, successive testing sessions were needed. Furthermore, the chosen study design allowed an assessment of muscular fatigue during FKB use because researchers[6,61] have suggested that fatigue is a negative factor in dynamic muscle control that can lead to a knee ligament injury. Concern also might be raised about a learning effect due to the study design. However, both tests in this study have been used consistently by researchers and physiologists to evaluate athletes' training progression.[52,54,57] Therefore, all athletes participating in our study should have been familiar with the testing procedures, which should have minimized a learning effect. Although ideally desired, a counterbalanced study design for brace condition (NBR, BR), in which a comparison of the ordering effect was needed would have necessitated additional participants (and increased cost to purchase the braces) to maintain the desired power levels because each testing group would have included half the number of participants. Furthermore, because one objective of the study was to evaluate accommodation to FKB use, potential learning progression was an essential aspect of the study.

This information might assist physicians and athletic trainers and therapists in discussing potential concerns of athletes regarding FKB use, specifically increased fatigue levels, importance of an adaptation or accommodation phase, and the duration of the phase that is needed before performance levels are not hindered.

In future studies of measures to prevent knee ligament injury, researchers should investigate the potential role of the FKB during practice and games, especially in collision and contact sports. Authors need to conduct competition-related studies because research performed in laboratory settings might exclude important components of actual game play that contribute directly to the chosen movement response and resultant risk.[23,26] Furthermore, a game-based setting assessment involving sports in which participants are at high risk for ACL injury might provide strategies for more reliable neuromuscular injury screening and prevention compared with a laboratory setting.

Our study might be limited by the performance ability of each athlete. Although each athlete was screened to be competitive and to be of provincial or national caliber, athletes differ in their individual intensity and motivation levels. The competitive nature of these participants also might cause peer competition, leading to increased motivation and possibly enhanced performance. Because the FKBs were purchased, finances limited the study design (counterbalanced, randomized control study) and limited the duration of the adaptation or accommodation phase. A longer-duration use of braces might lead to greater accommodation, which might further improve performance measures. Time and financial constraints also did not allow for in-depth evaluation of brace migration concerns. In addition, no clinical laboratory test can replicate game conditions.

CONCLUSIONS

Despite extensive research, the risk of injury to a knee ligament during a sporting activity continues to be of concern. Our data illustrated that performance levels in aerobic and anaerobic tasks were hindered when the FKB initially was used. However, after 14.0 hours of brace use, no differences in performance or fatigue levels were recorded between noninjured NBR and BR participants. Therefore, all FKB users should complete an adaptation or accommodation phase before engaging in full sport participation.

ACKNOWLEDGMENTS

We thank the Kitsilano Senior Boys (AAA) High School Basketball Team and the Men's National Field Hockey Team for volunteering for this study. We also thank R. Cohee, H. Lin, and C. Munro for allowing access to gymnasiums; M. Gibson for assisting with room bookings on the University of British Columbia campus; I. Arthur (ORFU), J. LaBreche (Pacific Sport), and G. Sleivert (Pacific Sport) for providing the testing apparatus; and T. Prior (Össur, Richmond, BC) for coordinating the functional knee brace payment plan. Finally, we thank P. Chhanabhai, J. B. Dobson, R. E. Forbes, A. John, and T. Lorenz for assisting with the testing.

REFERENCES

1. Rishiraj N, Lloyd-Smith R, Lorenz T, Niven B, Michel M. University men's ice hockey: rates and risk of injuries over 6 years. *J Sports Med Phys Fitness*. 2009;49(2):159–166.
2. Agel J, Dompier TP, Dick R, Marshall SW. Descriptive epidemiology of collegiate men's ice hockey injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 through 2003–2004. *J Athl Train*. 2007;42(2):241–248.
3. Dick R, Ferrara MS, Agel J, et al. Descriptive epidemiology of collegiate men's football injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 through 2003–2004. *J Athl Train*. 2007;42(2):221–233.
4. Yu B, Garrett WE. Mechanisms of non-contact ACL injuries. *Br J Sports Med*. 2007;41(suppl 1):i47–i51.
5. Griffin LY, Agel J, Albohm MJ, et al. Noncontact anterior cruciate ligament injuries: risk factors and prevention strategies. *J Am Acad Orthop Surg*. 2000;8(3):141–150.

6. Hewett TE, Myer GD, Ford KR. Anterior cruciate ligament injuries in female athletes, part I: mechanisms and risk factors. *Am J Sports Med*. 2006;34(2):299–311.
7. Kao JT, Giangarra CE, Singer G, Martin S. A comparison of outpatient and inpatient anterior cruciate ligament reconstruction surgery. *Arthroscopy*. 1995;11(2):151–156.
8. Roos EM. Joint injury causes knee osteoarthritis in young adults. *Curr Opin Rheumatol*. 2005;17(2):195–200.
9. Chaudhari AM, Briant PL, Bevill SL, Koo S, Andriacchi TP. Knee kinematics, cartilage morphology, and osteoarthritis after ACL injury. *Med Sci Sports Exerc*. 2008;40(2):215–222.
10. Bahr R, Krosshaug T. Understanding the injury mechanisms: a key component of preventing injuries in sports. *Br J Sports Med*. 2005;39(6):324–329.
11. McIntosh AS. Risk compensation, motivation, injuries, and biomechanics in competitive sport. *Br J Sports Med*. 2005;39(1):2–3.
12. Meeuwisse WH. Assessing causation in sport injury: a multifactorial model. *Clin J Sport Med*. 1994;4(3):166–170.
13. Albright JP, Powell JW, Smith W, et al. Medial collateral ligament knee sprains in college football: brace wear preference and injury risk. *Am J Sports Med*. 1994;22(1):2–11.
14. Besier TF, Lloyd DG, Ackland TR. Muscle activation strategies at the knee during running and cutting maneuvers. *Med Sci Sports Exerc*. 2003;35(1):119–127.
15. de Loës M, Dahlstedt LJ, Thomee R. A 7-year study on risk and costs of knee injuries in male and female youth participants in 12 sports. *Scand J Med Sci Sports*. 2000;10(2):90–97.
16. Griffin LY, Albohm MJ, Arendt EA, et al. Understanding and preventing noncontact anterior cruciate ligament injuries: a review of the Hunt Valley II meeting, January 2005. *Am J Sports Med*. 2006;34(9):1512–1532.
17. Hewett TE, Ford KR, Myer GD. Anterior cruciate ligament injuries in female athletes, part 2: a meta-analysis of neuromuscular interventions aimed at injury prevention. *Am J Sports Med*. 2006;34(3):490–498.
18. Mandelbaum BR, Silvers HJ, Watanabe DS, et al. Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2-year follow-up. *Am J Sports Med*. 2005;33(7):1003–1010.
19. Miura K, Ishibashi Y, Tsuda E, Okamura Y, Otsuka H, Toh S. The effect of local and general fatigue on knee proprioception. *Arthroscopy*. 2004;20(4):414–418.
20. Myklebust G, Engebretsen L, Braekken IH, Skølberg A, Olsen OE, Bahr RB. Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. *Clin J Sport Med*. 2003;13(2):71–78.
21. Otago L, Saunders N, McLean S. Case report: can neuromuscular measures predict ACL injury [abstract]? *J Orthop Sports Phys Ther*. 2007;37(2):A22.
22. Rishiraj N, Taunton JE, Clement DB, Lloyd-Smith R, Regan W, Woollard R. The role of functional knee bracing in a dynamic setting. *N Z J Sports Med*. 2000;28(3):54–61.
23. Seegmiller JG, McCaw ST. Ground reaction forces among gymnasts and recreational athletes in drop landings. *J Athl Train*. 2003;38(4):311–314.
24. Shultz SJ, Schmitz RJ, Nguyen AD. Research retreat IV: ACL injuries—the gender bias, April 3–5, 2008, Greensboro, NC. *J Athl Train*. 2008;43(5):530–531.
25. Renstrom P, Ljungqvist A, Arendt E, et al. Non-contact ACL injuries in female athletes: an International Olympic Committee current concepts statement. *Br J Sports Med*. 2008;42(6):394–412.
26. Chappell JD, Limpisvasti O. Effect of a neuromuscular training program on the kinetics and kinematics of jumping tasks. *Am J Sports Med*. 2008;36(6):1081–1086.
27. Myer GD, Chu DA, Brent JL, Hewett TE. Trunk and hip control neuromuscular training for the prevention of knee joint injury. *Clin Sports Med*. 2008;27(3):425–448.
28. Wojtys EM, Kothari SU, Huston LJ. Anterior cruciate ligament functional brace use in sports. *Am J Sports Med*. 1996;24(4):539–546.
29. Jonsson H, Kärrholm J. Brace effects on the unstable knee in 21 cases: a roentgen stereophotogrammetric comparison of three designs. *Acta Orthop Scand*. 1990;61(4):313–318.
30. Jonsson H, Kärrholm J. The stabilizing effect of the knee braces after anterior cruciate ligament rupture. *Acta Orthop Scand*. 1989;60(suppl 231):29.
31. Mishra DK, Daniel DM, Stone ML. The use of functional knee braces in the control of pathologic anterior knee laxity. *Clin Orthop Relat Res*. 1989;241:213–220.
32. Rink PC, Scott RA, Lupo RL, Guest SJ. Team physician #7: a comparative study of functional bracing in the anterior cruciate deficient knee. *Orthop Rev*. 1989;18(6):719–727.
33. Beck C, Drez DJ, Young J, Cannon WD Jr, Stone ML. Instrumented testing of functional knee braces. *Am J Sports Med*. 1986;14(4):253–256.
34. Colville MR, Lee CL, Ciullo JV. The Lenox Hill brace: an evaluation of effectiveness in treating knee instability. *Am J Sports Med*. 1986;14(4):257–261.
35. Bassett GS, Fleming BW. The Lenox Hill brace in anterolateral rotatory stability. *Am J Sports Med*. 1983;11(5):345–348.
36. Nicholas JA. The five-one reconstruction of anteromedial instability of the knee: indications, technique, and the results in fifty-two patients. *J Bone Joint Surg Am*. 1973;55(5):899–922.
37. Beynnon BD, Pope MH, Wertheimer CM, et al. The effect of functional knee braces on strain on the anterior cruciate ligament in vivo. *J Bone Joint Surg Am*. 1992;74(9):1298–1312.
38. Branch TP, Hunter RF, Reynolds P. Controlling anterior tibial displacement under static load: a comparison of two braces. *Orthopedics*. 1988;11(9):1249–1252.
39. Najibi S, Albright JP. The use of knee braces, part I: prophylactic knee braces in contact sports. *Am J Sports Med*. 2005;33(4):602–611.
40. Liu SH, Mirzayan R. Current review: functional knee bracing. *Clin Orthop Relat Res*. 1995;317:273–381.
41. Decoster LC, Vailas JC. Functional anterior cruciate ligament bracing: a survey of current brace prescriptions patterns. *Orthopedics*. 2003;26(7):701–706.
42. American Academy of Orthopaedic Surgeons. *AAOS Position Statement: The Use of Knee Braces* [retired December 2008]. Rosemont, IL: American Academy of Orthopaedic Surgeons; 2004. Document no. 1124.
43. Greene DL, Hamson KR, Bay RC, Bryce CD. Effects of protective knee bracing on speed and agility. *Am J Sports Med*. 2000;28(4):453–459.
44. Albright JP, Powell JW, Smith W, et al. Medial collateral ligament knee sprains in college football: effectiveness of preventive braces. *Am J Sports Med*. 1994;22(1):12–18.
45. Yu B, Herman D, Preston J, Lu W, Kirkendall DT, Garrett WE. Immediate effects of a knee brace with a constraint to knee extension on knee kinematics and ground reaction forces in a stop-jump task. *Am J Sports Med*. 2004;32(5):1136–1143.
46. Rishiraj N, Taunton JE, Lloyd-Smith R, Regan W, Woollard R, Niven B. Is adaptation to functional knee brace use in non-injured subjects during aerobic activity possible? A possible first step in preventing knee ligament injuries (pilot study). *Minerva Orthop Traumatol*. 2009;59(6):313–320.
47. Rishiraj N, Taunton JE, Lloyd-Smith R, Niven B, Regan W, Woollard R. Drop and hop jump GRFs and joint kinematics of braced non-injured subjects: preliminary study. *Minerva Orthop Traumatol*. 2009;60(3):193–204.
48. Rishiraj N, Taunton JE, Lloyd-Smith R, Regan W, Woollard R, Clement D. The potential role of prophylactic/functional knee bracing in preventing knee ligament injury. *Sports Med*. 2009;39(11):937–960.
49. Matava MJ, Freehill AK, Grutzner S, Shannon W. Limb dominance as a potential etiologic factor in noncontact anterior cruciate ligament tears. *J Knee Surg*. 2002;15(1):11–16.
50. Smith DJ. *Physiological and Performance Components of Endurance* [dissertation]. Edmonton: University of Alberta; 1981.
51. Quarrie KL, Handcock P, Toomey MJ, Waller AE. The New Zealand Rugby Injury and Performance Project: IV, anthropometric and physical performance comparisons between positional categories of senior A rugby players. *Br J Sports Med*. 1996;30(1):53–56.
52. Gore CJ, ed; for Australian Sports Commission. *Physiological Tests for Elite Athletes*. Lower Mitcham, Australia: Human Kinetics; 2000.
53. Léger LA, Lambert J. A maximal multistage 20-m shuttle run test to predict $\dot{V}o_2$max. *Eur J Appl Physiol Occup Physiol*. 1982;49(1):1–12.
54. Anthony M; New Zealand Rugby Union. *Guidelines for Athlete Assessment in New Zealand Sport*. Auckland, New Zealand: New Zealand Rugby Union; 2003:1–8.

55. Canadian Society for Exercise Physiology. *Certified Fitness Appraiser Resource Manual*. Ottawa, ON: Canadian Society for Exercise Physiology; 1995.
56. Highgenboten CL, Jackson A, Meske N, Smith J. The effects of knee brace on perceptual and metabolic variables during horizontal treadmill running. *Am J Sports Med*. 1991;19(6):639–643.
57. Bailey C; New Zealand Hockey Federation Inc. *Guidelines for Athlete Assessment in New Zealand Sport*. Auckland, New Zealand: New Zealand Hockey Federation Inc; 2002:1–8.
58. Veldhuizen JW, Koene FM, Oostvogel HJ, von Thiel TP, Verstappen FT. The effects of supportive knee brace on leg performance in healthy subjects. *Int J Sports Med*. 1991;12(6):577–580.
59. Baechle TR, Earle RW, eds; and National Strength and Conditioning Association. *Essentials of Strength Training and Conditioning*. 2nd ed. Champaign, IL: Human Kinetics; 2000.
60. Wojtys EM, Huston LJ, Schock HJ, Boylan JP, Ashton-Miller JA. Gender differences in muscular protection on the knee in torsion in size-matched athletes. *J Bone Joint Surg Am*. 2003;85(5):782–789.
61. Lephart SM, Abt JP, Ferris CM. Neuromuscular contributions of anterior cruciate ligament injuries in females. *Curr Opin Rheumatol*. 2002;14(2):168–173.
62. Reed-Jones RJ, Vallis LA. Proprioceptive deficits of the lower limb following anterior cruciate ligament deficiency affect whole body steering control. *Exp Brain Res*. 2007;182(2):249–260.
63. Herrington L, Simmonds C, Hatcher J. The effect of a neoprene sleeve on knee joint position sense. *Res Sports Med*. 2005;13(1):37–46.
64. McNair PJ, Stanley SN, Strauss GR. Knee bracing: effects of proprioception. *Arch Phys Med Rehabil*. 1996;77(3):287–289.

Address correspondence to Neetu Rishiraj, PhD, ATC, ACTIN Health & Rehabilitation, Inc, 5767 Oak Street, Vancouver, BC, Canada V6M 2V7. Address e-mail to nrishiraj@actinhealth.com.