Effects of Fatigue on Kinetic and Kinematic Variables During a 60-Second Repeated Jumps Test

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Purpose: The aim of this study was to investigate the effects of a maximal repeated-jumps task on force production, muscle activation and kinematics, and to determine if changes in performance were dependent on gender. Methods: Eleven male and nine female athletes performed continuous countermovement jumps for 60 s on a force platform while muscle activation was assessed using surface electromyography. Performances were videotaped and digitized (60 Hz). Data were averaged across three jumps in 10-s intervals from the initial jump to the final 10 s of the test. Results: No interaction between time and gender was evident for any variable; therefore, all results represent data collapsed across gender. Preactivation magnitude decreased across time periods for anterior tibialis (AT, \( P < .001 \)), gastrocnemius (GAS, \( P < .001 \)) and biceps femoris (BF, \( P = .03 \)), but not for vastus lateralis (VL, \( P = .16 \)). Muscle activation during ground contact did not change across time for BF; however, VL, G, and AT showed significant reductions (all \( P < .001 \)). Peak force was reduced at 40 s compared with the initial jumps, and continued to be reduced at 50 and 60 s (all \( P < .05 \)). The time from peak force to takeoff was greater at 50 and 60 s compared with the initial jumps (\( P < .05 \)). Both knee flexion and ankle dorsiflexion were reduced across time (both \( P < .001 \)), whereas no change in relative hip angle was evident (\( P = .10 \)). Absolute angle of the trunk increased with time (\( P < .001 \)), whereas the absolute angle of the shank decreased (\( P < .001 \)). Conclusions: In response to the fatiguing task, subjects reduced muscle activation and force production and altered jumping technique; however, these changes were not dependent on gender.

Keywords: anaerobic, electromyography, fatigue, force, jumping

The Bosco test is a repeated-jumps protocol in which an athlete performs continuous vertical jumps for a specified duration (typically 60 s). This test evaluates an athlete’s anaerobic power utilizing stretch-shortening cycle actions of the lower extremity. Performance on the Bosco test has been shown to be strongly related to performance on the Wingate test, the most commonly used measure of anaerobic power.
power and capacity.\textsuperscript{2,3} However, the Wingate test is limited to concentric muscle actions and therefore may not reflect anaerobic processes when the predominate motions involve stretch-shortening cycles (SSCs).\textsuperscript{4} Due to the more complex jumping motion involved in the Bosco test it may be a more specific method of assessing some athletes’ lower body power than the Wingate test. In fact, one study has demonstrated that power outputs were not significantly correlated between the Wingate and Bosco test, and suggested that the Bosco test is best used on specific athlete groups.\textsuperscript{5} The Bosco test was shown to be a sensitive measure of anaerobic power and capacity changes during the 7 mo leading to the Women’s Gymnastics Olympic Trials and was a predictive factor in the team that was selected to the Sydney Olympic Games.\textsuperscript{6}

Researchers have examined fatigue effects on neuromuscular system parameters, kinematics and kinetics during various SSC activities, typically utilizing laboratory-based methods to induce fatigue.\textsuperscript{7–14} Performance of maximal SSC activities under fatigue conditions tends to reduce muscle activation immediately preceding contact and during the concentric phase of the movement.\textsuperscript{7,8,12,14–17} Angular displacements and velocities are reduced\textsuperscript{9,18} and force production decreases.\textsuperscript{19}

The Bosco test induces SSC fatigue, and can be performed in the field with a simple timing mat or a portable force platform.\textsuperscript{20,21} However, the performance parameters of the Bosco test remain relatively unexplored. In particular, it is unknown how accumulated fatigue during performance of this test affects certain performance parameters including kinematics, force production, and muscle activation. This study investigated the changes that occur in force production, muscle activation, and kinematics of performance during a 60-s Bosco test, and sought to establish if the effects found differ in timing or magnitude by gender. The results of this study may enhance our understanding of how fatigue affects power production and technique during SSC tasks, in particular while performing the Bosco test.

**Methods**

A total of 11 male (21.4 ± 1.6 y; 1.79 ± .09 m; 78.7 ± 11.0 kg) and 9 female (21.9 ± 3.7 y; 1.72 ± .10 m; 75.9 ± 21.4 kg) athletes participated in this study. All participants provided written informed consent approved by the appropriate University Institutional Review Board. Participants were NCAA Division-I athletes from track and field throws, jumps, and sprints, and soccer. Male participants represented primarily sprinters and middle distance runners while females consisted predominantly of field event jumpers and throwers. The study was conducted while the athletes were in an “off-season” training period.

Due to the training experience of the athletes, warm-up activities were self-selected, but generally consisted of 5 min of easy cycling on an ergometer followed by jogging and jumping activities. Following the warm-up, participants were fitted with surface electrodes and the EMG transmitter. Using a goniometer, participants were positioned in a squat achieving a 90° angle at the knee, and instructed to reproduce this position on each jump during the test. Squat depth during jumping was monitored visually by an investigator. Participants were required to keep their hands on their hips throughout the test protocol to minimize the contribution of the upper body to jumping performance. Participants were instructed to jump as high as possible, and verbal encouragement was provided to the participants throughout
the test to facilitate repeated maximal performance jumps for 60 s. Participants did not receive instruction with regard to ground contact time. Reliability of the Bosco test has been reported to be $r = .95.1$.

Data were analyzed for three consecutive jump series, beginning with the initial three jumps of the 60 s test (control). Thereafter, three consecutive jumps were chosen occurring at approximately 10-s intervals, resulting in seven analysis periods for each 60-s trial. As an example, the jump occurring at 20 s along with the immediately preceding and following jumps would represent the third analysis period. Three consecutive jumps were chosen to assess reliability across trials.

All jumps were performed on a custom built, one-dimensional (Fz) force plate. Vertical ground reaction forces were measured at 500 Hz. The following variables were derived from the force-time records of the jumps of interest: peak force in the eccentric phase (PKF), time to peak force in the eccentric phase (TPF), time from peak force to takeoff from the force plate (PTO), flight time (FT), and ground contact time (GT) from initial landing from the previous jump to takeoff for the next jump.

Muscle EMG activity of the anterior tibialis, gastrocnemius, biceps femoris, and vastus lateralis of the right limb was recorded using surface electrodes (Telemyo System, Noraxon, Scottsdale, AZ) placed in parallel with fiber orientation. Silver/silver chloride pregelled electrodes (10-mm interelectrode distance) were placed over the relevant muscle bellies following appropriate cleaning and debriding of the skin surface. Cabling from the electrodes was secured with athletic tape to minimize interference with the jumping movement and motion artifact. The EMG transmitter was secured in a belt pack worn snuggly around the athlete’s waist. The EMG signal was sampled at 500 Hz. MyoResearch98 software (Noraxon, Scottsdale, AZ) was used for postprocessing of the signal. The raw EMG signal was full-wave rectified and smoothed using the root mean square (RMS) method (5-ms window). Onset of muscle preactivation was assessed for 100 ms before initial contact with the force plate for each jump as indicated by the force-time record. Preactivation onset was considered to occur when the EMG signal achieved a value that represented an increase of 200% above noise. The average RMS EMG over the duration of contact with the force plate was used to assess the magnitude of muscle activation during the jumping task.

The jumping performances were videotaped with a standard camcorder placed perpendicular to the plane of motion of the participant. Performances were digitally captured from videotape and hand digitized (Peak Motus v. 9.0, Peak Performance Technologies, Inc., Englewood, CO). Digitizing began five frames before initial contact with the force plate on the first of three jumps in series, and ended five frames following the peak of flight of the final jump in the series. The body was represented by a five-segment two-dimensional model. Total body center of mass was calculated according to the model by Dempster (as cited in 24). A fourth-order, zero-lag Butterworth filter with an optimized cutoff frequency (Jackson knee point method) was used to smooth the raw kinematic data. Relative angular position of the hip, knee, and ankle, and absolute positions of the trunk, thigh, and shank were calculated (Figure 1) at the lowest position of the squat.

Data were analyzed using SPSS statistical software (version 14.0, SPSS Inc., Chicago, IL). All data were assessed for reliability across the three trials in each time period, and the mean of each three-jump series used for further analyses.
Two-factor analyses of variance (time period × gender) with repeated measures were calculated for each variable. Post hoc pairwise differences were compared using the Bonferroni method. The level of significance for each analysis was set at $P < .05$.

## Results

### Flight and Ground Contact Times.

Figure 2 displays the means and standard deviations for FT and GT, collapsed across gender. Both time period ($P < .001$) and gender ($P < .001$) main effects were significant for FT, but not the interaction of time period × gender ($P = .19$). Post hoc analysis on the main effect of time period showed that there was a significant decrease in FT across each successive time period (all $P < .02$), except from the control jump to the 10-s jump ($P = .21$).

Repeated-measures ANOVA results for GT failed to show a significant interaction of time period × gender ($P = .84$, Greenhouse-Geisser corrected model). The main effect of time, however, was statistically significant ($P < .001$). Post hoc results showed that GT was significantly increased by 50 s into the test, and continued to significantly increase at 60 s.

### Force Variables

Figure 3 displays force-time curves for one representative subject across all seven time periods evaluated. Figure 4a displays the means and standard deviations for PKF across all time periods. Analysis of variance showed that there were significant

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**Figure 1** — Schematic drawing showing relative and absolute angle conventions.
**Figure 2** — Time course of changes in flight time and ground time across 60 s of continuous maximal countermovement jumping. Data are means and SD collapsed across gender. * Significantly different from control.

**Figure 3** — Force-time data across 60 s of continuous countermovement jumping for a representative subject. Data represent a single jump from each 10-s time period.
main effects for time period ($P < .001$) and gender ($P = .03$) but the interaction time period $\times$ gender was not significant ($P = .46$). Post hoc analysis showed that PKF was significantly reduced at 40 s compared with the control jump, and continued to be reduced at 50 and 60 s.

There were no significant main effects for time to peak force (TPF) for time period ($P = .56$, Greenhouse-Geisser corrected model), gender ($P = .996$), or the interaction time period $\times$ gender ($P = .43$). The time from peak force to takeoff (PTO) was significantly greater at 50 and 60 s compared with the control jump ($P < .05$), and this did not differ between gender ($P = .81$) (Figure 4b).

**Muscle Activation**

Average RMS EMG 100 ms before contact decreased across time periods for AT ($P < .001$), GAS ($P < .001$) and BF ($P = .03$, Greenhouse-Geisser corrected); however, the interactions of time and gender were not statistically significant (all $P > .05$) (Figure 5a). No significant difference across time for VL preactivation was found ($P = .16$, Greenhouse-Geisser corrected). AT preactivation was significantly

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**Figure 4** — Time course of changes in (a) peak force and (b) time from peak force to takeoff across 60 s of continuous maximal countermovement jumping. Data are means and SD. *Significantly different from control.
reduced at all time periods compared with the control values (all $P < .05$), while GAS preactivation was significantly reduced at all time periods from 20 s on. Post hoc analysis for BF failed to show any significant pairwise differences.

Repeated-measures ANOVA results showed no significant effect of time period or gender on average RMS EMG during contact for BF. A significant main effect for time was found for VL, G, and AT (all $P < .001$). In addition, AT showed a significant effect of gender ($P = .045$) but the interaction of time and gender was not significant. Figure 5(b) shows the mean RMS EMG for the VL, G, and AT. For AT significant decreases in activation compared with control occurred at 40, 50, and 60 s. The GAS showed an initial nonsignificant increase in activation (10 s), followed by a significant reduction at 40, 50, and 60 s. Finally, the VL showed a significant increase in activation (10 s) followed by a significant reduction by 60 s.

**Figure 5** — Time course of changes in (a) preactivation (100 ms before contact) and (b) average RMS EMG during contact across 60 s of continuous maximal countermovement jumping. Data are means collapsed across gender.
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**Kinematics**

No significant change in hip angle across time was evident \((P = .10)\). Males achieved greater flexion at the hip than females overall \((P < .01)\), but there was no significant interaction of gender and time period. Knee angle increased significantly with time \((P < .001)\) and was greater overall in females compared with males \((P < .01)\). There was no interaction, however, between time and gender \((P = .67)\) for knee angle. Ankle dorsiflexion decreased across the jumps \((P < .001)\), but did not differ by gender \((P = .07)\). No interaction of time and gender was found \((P = .13)\). Post hoc analyses revealed that relative positions of the knee and ankle were significantly different from control at 50 and 60 s.

Absolute angle of the trunk increased with time \((P < .001)\) but did not differ between males and females \((P = .12)\) nor was the interaction of time and gender significant \((P = .07)\). Trunk position was significantly increased compared with control at all time periods from 40 s onward. Absolute angle of the thigh increased significantly with time \((P = .001)\) and was greater in females compared with males overall \((P < .01)\); however, there was no difference between gender across time \((P = .54)\). Post hoc comparisons revealed that absolute angle of the thigh increased significantly compared with control at 50 and 60 s. Absolute angle of the shank decreased across time \((P < .001)\). Overall males and females did not differ in absolute shank angle \((P = .11)\) and no interaction of gender and time was evident \((P = .85)\). Shank angles were decreased at 50 and 60 s compared with control values.

**Discussion**

The results of the current study showed clear fatigue effects on the kinematic and kinetic parameters of performance during a 60-s repeated jumps test, and both males and females appeared to respond to fatigue in a similar fashion. Muscle preactivation was affected earliest in the test, followed closely by flight time. At 40 s into the test, changes to contact phase muscle activation, peak force, ground time and angular positions became evident. The last variable to demonstrate fatigue effects was ground contact time.

Reduced preactivation magnitude was most evident in the AT and GAS muscles, which were affected by 10 and 20 s into the test respectively, and continued to demonstrate reduced preactivation magnitude with each time period as the test progressed. Both BF and VL showed trends toward reduced preactivation early in the jump task, with only BF showing a significant overall time effect. Our results are in line with those of most investigators\(^7,12,14,16\) who showed reduced preactivation magnitude with fatiguing SSC tasks, but differ from others\(^17,26\) who showed increased preactivation magnitude with fatigue. It has been suggested that reduced preactivation with fatigue is specific to maximal SSC tasks, and that with submaximal tasks (such as hurdle jumping\(^17\)) preactivation may actually increase due to reflex potentiation.\(^16\) Our subjects were instructed and verbally encouraged during testing to produce maximal jumps on each effort for the full 60 s. Thus, our changes are more in line with those reported previously for tasks involving maximal effort.

Changes in muscle preactivation magnitude have been shown to be related to joint stiffness by several authors.\(^7,10,12,26\) Kuitunen et al (2002) reported that reduced preactivation magnitude of the triceps surae and knee extensors was positively
related to reductions in ankle and knee joint stiffness in jumps performed immediately after a series of maximal and submaximal jumps on a sledge apparatus until exhaustion. Thus the overall trend toward reduced muscular preactivation magnitude may indicate that fatigue in a jumping task impairs stiffness of the lower extremity, which in turn impairs the transfer of elastic energy from the eccentric phase to the concentric phase of the movement.

An additional explanation for the initial reduced preactivation magnitude might be found in the nature of the SSC task. Contact time for the initial control jumps averaged 659 ms, making the jumps performed by our subjects relatively long SSC actions. Dyhre-Poulson and colleagues (1991) showed that preactivation changes when the task is a land-and-jump vs a rebound, which subsequently affects the storage and utilization of elastic energy in the musculature. Given the relatively long contact time of our subjects, they may have approached this task as a dampening land-and-jump task rather than a rebound task as they became fatigued. Dyhre-Poulson et al also showed that ankle stiffness was negative when the task was landing, but positive when the task was hopping. In the present investigation the duration of contact throughout the jumping series suggests a fairly long coupling time between eccentric and concentric phases, which would reduce the contribution of elasticity to the performance.

Flight time was affected earlier in the jumping series (20 s) than was ground contact time, which was not significantly increased until 50 s. As contact time increases it can be assumed that the coupling between the eccentric and concentric phases of the jump (amortization) is increased, which reduces the efficiency of potentiation in performing the task. Our data also showed that the time from peak force in the jump to takeoff tended to increase with fatigue, while the time to peak force, measured from initial impact from the previous jump to peak force during the countermovement, was not altered with fatigue. Increased contact time was primarily a function of a longer time to perform the concentric, force-producing phase of the jump. This is supported by the results of Viitasalo, who showed that concentric time increased significantly with increased fatigue during submaximal hurdle jumping, but that eccentric-phase kinetic and kinematic parameters did not change. In a study by Rodacki et al (2002), subjects performed single maximal vertical jumps following exercises designed to selectively fatigue either the hamstring or quadriceps muscle groups. It was found that only when the extensor muscles were fatigued was performance reduced. Reduced performance was most evident in the final portion of the movement, as takeoff approached, suggesting that selective fatigue of the knee extensors affected concentric actions more than eccentric actions. It is unclear what the precise source of loss of force-generating capacity is (central/peripheral).

RMS EMG tended to decrease in the VL following an initial nonsignificant potentiation at 10 s, becoming significantly decreased from control only at 60 s. Biceps femoris showed no decrease in activation with fatigue, which supports the data from Rodacki that showed that selective fatigue of BF did not affect jumping ability. In our study it appeared that the most distal muscles, the AT and GAS showed the earliest reduction in muscle activation (significant at 40 s). The changes in GAS may be due to the fiber composition of this muscle being predominately fast twitch. Thus this muscle would be especially sensitive to short-term fatigue and would show reduced activation as the metabolic system favored the glycolytic rather than ATP-PC energy system.
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Pain has also been shown to reduce muscle activation.\textsuperscript{29,30} We did not measure pain but subjectively can report significant discomfort by the subjects as this test progressed. Reduced central command will decrease muscle activation as well. As the subjects became tired they may have consciously or unconsciously reduced muscle activation to preserve performance through the entire 60-s trial.\textsuperscript{31} Unconscious reduced EMG may reflect central fatigue designed to reduce the possibility of continued muscle damage.

Kinematically, significant changes in joint angles and segment positions at the lowest position of the countermovement were first evident at 40 s. Before this, only small changes were observed. Overall, subjects tended to respond to the fatiguing task by reducing dorsiflexion at the ankle, flexion at the knee, and increasing flexion at the hip. The absolute position of the thigh remained relatively unchanged during the jump series, while trunk absolute angle increased significantly. Taken together these changes show that as the subjects fatigued, they used their legs less in the jump, and instead relied more on trunk movement. Maintaining a straighter lower-extremity would serve to reduce the prestretch of the fatigued muscles, which could be protective against continued muscle damage.\textsuperscript{32} The trunk represents the largest moving segment in a countermovement jump, thus it appears that as our subjects fatigued they used the momentum of the trunk to a greater degree to produce force against the ground in action-reaction.

Practical Application and Conclusions

Repeated jumps protocols are becoming more prevalent for assessing athletes’ anaerobic power and capacity due to their specificity and ease of use. However, little information exists regarding how accumulated fatigue is manifest in performance during these protocols. We have shown that performance of the 60-s Bosco repeated jumps test results in decrements in muscle activation, force production, and jumping technique. Reductions in muscle activation and flight time appeared early in the jumping protocol, whereas decrements in force production appeared later. Changes in jumping technique became apparent toward the final time periods of the task, when subjects appeared to minimize lower extremity involvement and favored increasing contribution from trunk motion. Repeated jumps protocols used to assess fatigue during SSC activities should last a minimum of 20 s; however, 40 s was necessary to observe significant changes to all measured parameters. We also demonstrated that the time course and magnitude of changes in these parameters was not gender dependent; therefore, test durations need not be altered based on gender. Future studies should continue to investigate these performance parameters to determine how performers with divergent characteristics (muscle fiber composition, training background, etc) respond to this task, and how this information can be used to direct training.

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References


