AN INVESTIGATION INTO THE RECOVERY PROCESS OF A MAXIMUM STRETCH-SHORTENING CYCLE FATIGUE PROTOCOL ON DROP AND REBOUND JUMPS

THOMAS M. COMYNS, ANDREW J. HARRISON, AND LIAM K. HENNESSY

Abstract
Comyns, TM, Harrison, AJ, and Hennessy, LK. An investigation into the recovery process of a maximum stretch-shortening cycle fatigue protocol on drop and rebound jumps. J Strength Cond Res 25(X): 000–000, 2011—The aim of this study was to investigate the recovery process of a maximal stretch-shortening cycle (SSC) fatigue workout on the biomechanical performance of drop jump (DJ) and rebound jump (RBJ) on a force sledge apparatus. Thirteen elite level rugby players performed sledge DJs and RBJs before and 15, 45, 120, and 300 seconds after a maximum SSC fatigue workout. Flight time, ground contact time (CT), peak force, reactive strength index (RSI), and leg-spring stiffness were the dependent variables. The DJ results showed that after 15 seconds recovery, there was a significant reduction in flight time (FT) (p < 0.01), RSI (p < 0.001), peak force (p < 0.01), and leg stiffness (p < 0.001). Similarly, the results for the RBJ indicated that the fatigue workout significantly reduced FT (p < 0.001), peak force (p < 0.01), RSI (p < 0.01), and significantly increased CT (p < 0.05) at the 15-second interval. The results also indicated a potentiation effect at the 300-second interval because of significant increases in RSI, peak force, and leg stiffness (p < 0.05) for the RBJ and significant increases in RSI (p < 0.05), peak force, and leg stiffness (p < 0.01) and a significant decrease in ground CT (p < 0.05) for the DJ. A maximal SSC fatigue workout had both an inhibiting and potentiating effect on DJ and RBJ performance depending on the recovery interval. The efficiency of the SSC function was reduced immediately after the cessation of the fatigue workout. A potentiation effect was evident for both jumps 300 seconds postfatigue.

Key Words | leg-spring stiffness, plyometric, postactivation potentiation, reactive strength index

Introduction
Muscle fatigue is a multifaceted and very complex phenomenon and is believed to involve physiological, biomechanical, and psychological components. Fatigue can be defined as any reduction in the force-generating capacity of the total neuromuscular system, regardless of the force required in any given situation (7). Although there may be a causal relationship between muscle fatigue and exercise-related musculoskeletal injuries, there is as yet no definitive research to confirm this or describe the exact way in which fatigue may increase susceptibility to injury. It is generally accepted that muscle fatigue produces discomfort and limits force production (19,20,36), but the effects that fatigue and recovery from fatigue have on other aspects of muscle function are not clear.

Complex sports movements are often explosive and powerful in nature and are generally expressed in the form of a stretch-shortening cycle (SSC). The SSC can be defined as an active stretch of a muscle (eccentric contraction), which is immediately followed by a shortening contraction of that same muscle (concentric contraction) thereby causing an enhancement of force development (6). The SSC is crucially important in the performance of many strength, locomotor, and sports activities, and the control of leg-spring and joint stiffness is related to the performance of SSC activities (2,3,22).

It has been proposed that the SSC provides a unique and powerful model to study the effects of neuromuscular fatigue on performance (29). Previous research on the effects of fatigue on SSC function has focussed primarily on longer term effects of fatigue and recovery during several days after exhaustive exercise (3–5,33). These and other research studies examining SSC fatigue in long distance running (29), have indicated that longer duration of fatiguing exercise often results in a reversible muscle damage process, which has considerable influence on muscle mechanisms, stretch reflex sensitivity (29), and joint and muscle stiffness (21). Various studies (19,20,25,27,30) induced fatigue by repeated submaximal SSC movements to exhaustion on a sledge and force platform ergometer and found that fatigue caused immediate reductions in SSC performance or longer term losses because of muscle damage.
In jumping activities, acute fatigue is associated with changes in biomechanical factors such as ground contact time (CT), reactive strength index (RSI), and control of muscle–tendon stiffness. The RSI has been defined as the ability to change quickly from an eccentric to a concentric contraction; it is calculated by dividing the height jumped by the CT (38). The RSI is relatively simple to determine in applied settings and, therefore, has been frequently used by practitioners (18,31) and researchers (38) to monitor an individual's SSC abilities. Recent studies have examined the relationship between SSC performance, muscle stiffness, and the response of these factors to acute bouts of fatiguing exercise. Comyns et al. (13) investigated the optimal resistive loading for complex training in male rugby players and found that heavy resistance exercise resulted in an immediate reduction in jumping performance, but during recovery, the SSC activity was performed with a stiffer leg-spring action and a decreased ground CT. It was concluded that these changes could improve performance in activities such as sprinting where reduced ground CT would be beneficial to performance. Comyns et al. (12,(13) suggested that the changes in the biomechanics of SSC action after heavy resistance exercise could be explained by postactivation potentiation (PAP) (14,23). Postactivation potentiation is a transient increase in muscle contractile performance after previous contractile activity. The theory behind PAP is that the explosive capability of the muscle is enhanced after maximal or near maximal contractions (12,23,34). Research evidence supporting PAP is inconsistent, and some researchers have indicated enhancement in performance during recovery from fatiguing exercise (12,23), whereas others have found no evidence of such enhancement in performance (28).

Moran and Marshall (32) examined the effect of treadmill running induced fatigue on SSC activity by recording tibial impact accelerations during drop jumps (DJs) from heights of 30 and 50 cm. They found that fatigue resulted in a significant increase (24%) in peak accelerations in comparison with the nonfatigued state in DJs from 30 cm but not in DJs from 50 cm. Moran and Marshall (32) concluded that the increased tibial accelerations after fatiguing exercise indicated a state of increased injury risk when performing SSC activities in a fatigued state. It is important to point out, however, that Moran and Marshall (32) did not obtain measures until at least 2 minutes after the completion of the fatigue protocol; therefore, their findings could equally be explained by a PAP response.

Only 1 SSC fatigue study has used a maximal SSC fatigue workout with the aim of investigating possible mechanisms of neuromuscular fatigue (37). The maximal workout involved the subjects completing rebound jumps (RBJs), that is, continuous jumps on the sledge and force platform ergometer, until they were unable to maintain a jumping height >90% of their maximum. Research has not examined the effects of a maximal SSC fatigue workout on the biomechanical performance of DJs or RBJs. This has only been investigated after a submaximal workout. In addition, research has failed to examine the recovery process of SSC function after a maximal SSC fatigue workout. Consequently, the aim of this study was to investigate the recovery process of a maximal SSC fatigue workout on the biomechanical performance of DJs and RBJs in male rugby players. The study sought to investigate this recovery process by requiring the subjects to perform the jumps at various recovery intervals postfatigue. This was conducted to investigate if a PAP effect could be elicited from a maximum SSC fatigue workout. In particular, the effect of the workout on the DJ and RBJ flight time (FT), and the biomechanical factors associated with the SSC, namely, ground CT, RSI, peak vertical ground reaction force (GRF), and leg-spring stiffness ($k_{vert}$), was examined.

**METHODS**

**Experimental Approach to the Problem**

This study involved the subjects performing sets of a 1-legged DJ followed by a one-legged RBJ before (baseline) and at 15, 45, 120, and 300 seconds after a maximal SSC fatigue workout. This testing was completed in 1 experimental session. The dependent variables were FT, CT, RSI, peak GRF, and $k_{vert}$ for both the DJ and RBJ. These were selected to examine the effect of the fatigue protocol on the

| Table 1. Physical characteristics of the subjects (mean ± SD). |
|---------------------------------|----------------|----------------|
| Age (y) | Height (cm) | Mass (kg) |
| 21.4 ± 2.4 | 182.9 ± 5.8 | 88.4 ± 8.1 |

**Figure 1.** Setup of the sledge and force platform apparatus showing a subject about to perform a single-legged drop jump.
performance of the DJ and RBJ. A repeated-measures analysis of variance (ANOVA) was used to analyze the effects of the fatigue protocol on DJ and RBJ performances.

**Subjects**

Thirteen elite male rugby players participated in this study. The physical characteristics of the subjects can be seen in Table 1. The subjects were professional players contracted to the Irish Rugby Football Union. Ten subjects were backs, and the remaining 3 were forwards. All subjects were proficient with the technique of drop and rebound jumping. Approval for the use of human subjects was obtained from the university review board of research compliance. Subjects were informed of the experimental risks and signed an informed consent document before the investigation. In addition, a Physical Activity Readiness Questionnaire was completed by the subjects.

**Instrumentation**

All DJs and RBJs were single-legged jumps, performed on a specially built force sledge apparatus as described by Harrison et al. (22). The apparatus consisted of 3 main components: a sledge frame, a sliding chair, and a force platform (Figure 1). The sledge frame was constructed from box steel with sledge rails inclined at 30°. The chair was mounted on the rails on low-friction steel rollers. The force platform (AMTI OR6-5) was mounted at right angles to the sledge apparatus and sampled at 1,000 Hz to give values for vertical GRF. The subject was secured to the chair with a harness and Velcro straps at the waist and shoulders to prevent any upper body movement during the jumps. All jump trials were recorded on 50-Hz SVHS video cassettes using a Panasonic AGDP800 camera (Panasonic, Osaka, Japan).

The baseline DJ/RBJ jump data were analyzed to establish the test–retest reliability of the various dependent variables, that is, FT, CT, RSI, peak GRF, and $k_{vert}$. Four baseline DJs/RBJs were performed and the intraclass correlation coefficients (ICCs) were obtained for each dependent variable. The reported ICCs for the DJ and RBJ variables are detailed in Table 2. The ICCs indicate high test–retest reliability for each of the dependent variables for both the DJ and RBJ.

**Procedures**

The subjects were instructed to refrain from weight and plyometric training on the day preceding the testing session. A standardized warm-up consisting of both a general and a specific phase was performed by all subjects. The general phase involved performing 3 minutes of low-intensity jogging and static stretching of the major leg muscles, with stretches held for 15 seconds. The specific warm-up consisted of 2 sets of 1 DJ followed immediately by 1 RBJ (DJ/RBJ). Subjects were instructed to minimize their CT on the force platform and to maximize their subsequent jump height for both types of jumps. The drop height used for the DJ/RBJ set was 30 cm, and all subjects were asked to use their preferred hopping leg. After this, the subjects performed the 4 baseline sets of 1 DJ/RBJ with 90 seconds’ rest between each set.

The baseline jump data were then analyzed to determine the jump height for each RBJ. The RBJ with the maximum height was selected, and a reflective marker was fixed on the sledge rails at a point 90% of the maximum jump height above the subject’s seated position in the sledge chair with the leg fully extended. An OMRON Opto-Switch (EE-SY410) was attached to the sledge chair, and when it reached the reflective tape at the 90% level, the light on the Opto-Switch flashed. The mean 90% level was 0.36 ± 0.04 m. For the fatigue workout, the subjects were dropped from a height of 30 cm and performed RBJs until they failed to reach the 90% level for 3 consecutive jumps. The SVHS videotape records were used to determine the duration of the fatigue workout and the number of completed jumps above the 90% level. The

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**Table 2. ICCs for the DJ- and RBJ-dependent variables.***

<table>
<thead>
<tr>
<th></th>
<th>DJ</th>
<th>RBJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>FT</td>
<td>0.940</td>
<td>0.939</td>
</tr>
<tr>
<td>CT</td>
<td>0.902</td>
<td>0.959</td>
</tr>
<tr>
<td>RSI</td>
<td>0.882</td>
<td>0.974</td>
</tr>
<tr>
<td>GRF</td>
<td>0.964</td>
<td>0.977</td>
</tr>
<tr>
<td>$k_{vert}$</td>
<td>0.926</td>
<td>0.989</td>
</tr>
</tbody>
</table>

*DJ = drop jump; RBJ = rebound jump; FT = flight time; CT = ground contact time; RSI = reactive strength index; GRF = vertical ground reaction force; $k_{vert}$ = leg spring stiffness, ICC = intraclass correlation coefficients.

**Table 3. Baseline values for the dependent variables for DJs and RBJs (mean ± SD).**

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Drop jump</th>
<th>Rebound jump</th>
</tr>
</thead>
<tbody>
<tr>
<td>FT (s)</td>
<td>0.788 ± 0.062</td>
<td>0.784 ± 0.044</td>
</tr>
<tr>
<td>CT (s)</td>
<td>0.481 ± 0.097</td>
<td>0.491 ± 0.121</td>
</tr>
<tr>
<td>RSI</td>
<td>0.82 ± 0.17</td>
<td>0.81 ± 0.20</td>
</tr>
<tr>
<td>GRF (N)</td>
<td>1,831.4 ± 344</td>
<td>1,923.9 ± 417.4</td>
</tr>
<tr>
<td>$k_{vert}$ (kN·m⁻¹)</td>
<td>8.9 ± 3.5</td>
<td>7.8 ± 3.3</td>
</tr>
</tbody>
</table>

*DJ = drop jump; RBJ = rebound jump; FT = flight time; CT = ground contact time; RSI = reactive strength index; GRF = vertical ground reaction force; $k_{vert}$ = leg spring stiffness.
mean (±SD) number of RBJs performed during the fatigue workout was 49 ± 20 jumps, and the duration was 62.2 ± 20.9 seconds. After the termination of the fatigue workout, 1 DJ/RBJ set was completed at the 15- and 45-second recovery intervals, and 2 sets were completed at the 120- and 300-second intervals. A cooldown consisting of 3 minutes of light jogging and static stretching of the major leg muscles was completed at the end of the testing session.

Calculation of the Dependent Variables
The dependent variables used were FT, CT, peak GRF, RSI, and $k_{vert}$. The force platform data were used to obtain peak GRF, FT, and CT for each jump. The RSI was calculated by dividing the jump height in meters by the ground CT in seconds. Because of the 30° inclination of the sledge apparatus, jump height was determined from FT using the formula $(\text{gravity} \times FT^2)/16$. 

Figure 2. Mean ± 95% confidence interval flight time difference between the baseline drop jumps (DJs) and rebound jumps (RBJs) and the corresponding jumps done at the different recovery intervals. ***p < 0.001; **p < 0.01.

Figure 3. Mean ± 95% confidence interval contact time difference between the baseline drop jumps (DJs) and rebound jumps (RBJs) and the corresponding jumps done at the different recovery intervals. ***p < 0.001; **p < 0.01; *p < 0.05.

Figure 4. Mean ± 95% confidence interval reactive strength index difference between the baseline drop jumps (DJs) and rebound jumps (RBJs) and the corresponding jumps done at the different recovery intervals. ***p < 0.001; *p < 0.05.

Figure 5. Mean ± 95% confidence interval peak ground reaction force difference between the baseline drop jumps (DJs) and rebound jumps (RBJs) and the corresponding jumps done at the different recovery intervals. **p < 0.01; *p < 0.05.
A spring-mass model was used to analyze the control of vertical leg-spring stiffness, which has been defined as the ratio of the peak force in the spring, to the displacement of the spring at the instant that the leg spring is maximally compressed. Previous studies have shown that the peak GRF and the peak leg-spring displacement both occur simultaneously in the middle of the ground contact phase (17,21). Leg-spring stiffness measures were calculated by dividing the peak force by the displacement of the sledge from initial contact with the force plate to the lowest point of the center of mass during recovery from each DJ. The SVHS video recordings (50 Hz) were digitized using Peak Motus® (Peak Performance Technologies, Colorado Springs, CO, USA) to determine the displacement of the sledge during the jumps.

**Statistical Analyses**

All statistical analyses were conducted using SPSS for Windows, Release 11.0.1. Differences between the baseline scores for each dependent variable and the average scores after each recovery interval for each dependent variable were evaluated using a repeated-measure general linear model (GLM) ANOVA. This ANOVA model had 1 within-subject factor, namely, Condition with 5 levels (baseline, 15, 45, 120, and 300 seconds). This analysis was done for both the DJ and RBJ data. The criterion of significance was set at an alpha level of \( p \leq 0.05 \).

Effect sizes using partial eta squared \( (\eta_p^2) \) were also obtained for each dependent variable using the formula \( \eta_p^2 = \frac{SS_{effect}}{(SS_{effect} + SS_{error})} \), where \( SS_{effect} \) = effect variance and \( SS_{error} \) = error variance. Interpretation of effect size was based on the scale for effect size classification by Hopkins (24). This scale is based on \( f \)-values for effect size, and these were converted to \( \eta_p^2 \) used by the formula \( f = (\eta_p^2 / (1 - \eta_p^2))^{0.5} \). Consequently, the scale for classification of \( \eta_p^2 \) was

- \( \eta_p^2 < 0.04 \) trivial; 0.041–0.249 small; 0.25–0.549 medium; 0.55–0.799 large; and 0.8+ very large.

In addition, a Pearson correlation analysis was done on the dependent variable DJ and RBJ data to assess the relationship of the different variables to each other.

**RESULTS**

The mean baseline scores for each dependent variable (Table 3), were subtracted from their corresponding mean scores for the DJs and RBJs completed after each recovery interval. The results for FT, CT, RSI, peak GRF, and \( k_{vert} \) are presented in Figures 2–6 respectively. In all figures, the x-axis represents the baseline performance. The ANOVA results for the FT showed a significant reduction after the 15-second interval for the DJ \( (p = 0.002) \) (8.2% change) and the RBJ \( (p < 0.001) \) (7.5% change), see Figure 2. It is evident from Figure 3 that there was a significant increase in CT at the 15-second interval for both the DJ \( (p < 0.001) \) (29.5% change) and the RBJ \( (p = 0.007) \) (24.5% change).
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(12.9% change). At the 300-second interval, the ANOVA results report a significant reduction in CT for the DJ ($p = 0.011$) (9.6% change).

The RSI results displayed in Figure 4 reveal a significant reduction in RSI immediately postfatigue at the 15-second interval for both the DJ (32% change) and the RBJ (23.6% change) ($p < 0.001$). In contrast, there was a significant increase in RSI at the 300-second interval for the DJ ($p = 0.033$) (72% change) and the RBJ ($p = 0.027$) (11.2% change). The ANOVA results for peak GRF indicated a significant reduction at the 15-second interval for the DJ ($p = 0.001$) (15.1% change) and the RBJ ($p = 0.021$) (8.7% change), refer to Figure 5. In addition, there was a significant improvement in peak GRF for the DJ at the 120-second interval ($p = 0.049$) (5.9% change) and the 300-second interval ($p = 0.002$) (9.6% change). This significant improvement was also evident for the RBJ at the 300-second interval ($p = 0.031$) (7.6% change). In Figure 6, the results for $k_{vert}$ are illustrated and indicate a significant reduction at the 15-second interval for the DJ ($p < 0.001$) (34.5% change). A significant improvement in $k_{vert}$ is evident at the 300-second interval for both the DJ ($p = 0.004$) (19.4% change) and the RBJ ($p = 0.078$) (12.7% change).

The $\eta_p^2$ values are shown in Table 4 for the DJ and Table 5 for the RBJ. The effect sizes for the variables that were significantly different from the baseline were found to be either large or medium, indicating that the recovery interval results in considerable change in the dependent variable.

The Pearson correlation analysis showed no correlation between jump performance (FT) and any of the other variables. The CT was show to have a strong relationship with RSI (0.882), peak GRF (0.748), and $k_{vert}$ (0.858) for the RBJ data. Similarly, CT had a high correlation with GRF (0.849) and $k_{vert}$ (0.931) for the DJ data.

**Table 5. Values for the RBJ-dependent variables and classification of the magnitude of the effect size according to Hopkins (24).**

<table>
<thead>
<tr>
<th>Variable</th>
<th>15-s Interval</th>
<th>45-s Interval</th>
<th>120-s Interval</th>
<th>300-s Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>FT</td>
<td>0.744; Large</td>
<td>0.155; Small</td>
<td>0.130; Small</td>
<td>0.194; Small</td>
</tr>
<tr>
<td>CT</td>
<td>0.472; Medium</td>
<td>0.004; Trivial</td>
<td>0.105; Small</td>
<td>0.196; Small</td>
</tr>
<tr>
<td>RSI</td>
<td>0.644; Large</td>
<td>0.019; Trivial</td>
<td>0.118; Small</td>
<td>0.345; Medium</td>
</tr>
<tr>
<td>GRF</td>
<td>0.376; Medium</td>
<td>0.019; Trivial</td>
<td>0.201; Small</td>
<td>0.334; Medium</td>
</tr>
<tr>
<td>$k_{vert}$</td>
<td>0.237; Small</td>
<td>0.013; Small</td>
<td>0.116; Small</td>
<td>0.316; Medium</td>
</tr>
</tbody>
</table>

*DJ = drop jump; RBJ = rebound jump; FT = flight time; CT = ground contact time; RSI = reactive strength index; GRF = vertical ground reaction force; $k_{vert}$ = leg-spring stiffness.

**Discussion**

The results provide an insight into the recovery process of a maximal SSC fatigue workout. The fatigue protocol caused an initial reduction in DJ and RBJ performance followed by a subsequent improvement, at later recovery intervals, with evidence of a potentiating effect. At the 15-second interval, for both the DJ and RBJ, there was a dramatic decline in both the jump performance outcome measure (FT) and the biomechanical factors of the jump (process), as evident by the increase in ground CT and the reduction in RSI and leg-spring stiffness. At the 300-second interval, the maximal SSC fatigue protocol resulted in an enhancement in the jumping process because of increases in RSI, GRF, and $k_{vert}$ and a reduction in CT. No significant improvement, however, in jump performance (FT) at this interval was observed. The Pearson correlation analysis showed no relationship between jump process (FT) and the biomechanical factors of the jump (RSI, GRF, $k_{vert}$, CT).

The results for the biomechanical factors, namely, CT, $k_{vert}$, RSI, and GRF, provide an insight into the effect of the fatigue workout on SSC behavior. For effective fast SSC behavior, landing with a stiff leg action and minimizing ground CT is recommended. Butler et al. (10) noted that some level of leg stiffness is required for optimal use of the SSC because it allows for the efficient use of the stored elastic energy in the muscle (MTU) that occurs during the prestretch phase of the SSC. As early as 1965, Cavagna et al. (11) argued that the enhancement during the concentric phase of the SSC is primarily because of this stored elastic energy. Böhme et al. (8) in a study examining the contributory role of muscle series elasticity reported that this elastic energy, stored in the downward phase of drop jumping, provides considerable contribution (32%) to the total muscle energy in the push-off phase. Komi (29) noted that although many additional alternative explanations have been presented, no convincing evidence has been reported that negates the role that elasticity plays in force potentiation during the concentric phase of the SSC. Schmidtbleicher (35) commented that a short amortization phase is required for the subsequent concentric contraction to harness the advantages of this stored elastic energy and the stretch reflex. Specifically, Schmidtbleicher (35) noted that, for a DJ, the effect is doubtful if the ground contact phase lasts too long. It is recommended
that the athlete consciously pretend that he or she will be landing on a hot plate (35). Anderson (1) commented that SSC effectiveness is influenced by the time lag between the eccentric and concentric phases. Consequently, for an effective SSC function, minimizing ground CT is important.

The RSI is another measure that provides information on the jumping process. For efficient SSC behavior, RSI values should show an improvement postfatigue. Leg-spring stiffness like CT and RSI further illustrates how the muscle tendon unit behaves during jumping. An increase in leg stiffness can be associated with increased leg cadence of a fast SSC activity, such as hopping and sprinting (2,15,16). In addition, it has been shown that sprinters have high leg-spring stiffness (9,22). Increases in leg-spring stiffness allow the SSC exercise to be performed with a shorter and stiffer leg-spring action.

Consequently, there was a loss of efficiency of the SSC function at the 15-second interval because of the maximal fatigue workout having a negative effect on the ground CT, RSI, and leg-spring stiffness. The jumps were performed with longer CTs and reduced leg-spring stiffness. This coupled with the reduction in RSI and GRF indicated that the SSC behavior was reduced, as is evident from the deterioration of the performance measure of FT. Similar findings have been reported for fatigue studies that used a submaximal SSC intensity workout. Avela and Komi (4), Gollhoffer et al. (20,19), and Horita et al. (25) reported a reduction in CT postfatigue. Avela and Komi (4), Hortia et al. (26,27), and Nicol and Komi (33) indicated that because of submaximal SSC fatigue, the muscle mechanics and joint and muscle stiffness control are hampered. A reduction in force production has been reported by Gollhoffer et al. (20,19) and Nicol and Komi (33).

Aspects of the bimodal trend for recovery after a fatigue workout, as indicated by Horita et al. (27) and Komi (29), are evident in this study. The initial dramatic decline in DJ and RBJ performances was followed by a gradual improvement in performance at the subsequent recovery intervals up to the point where some variables were enhanced at the 300-second interval. The secondary decline outlined by Komi (29) was not investigated here because postfatigue jump testing did not go beyond a 5-minute recovery.

Uniquely, this study demonstrated that a maximal SSC fatigue workout could have a PAP effect on sledge DJ and RBJ performance after a 300-second recovery. The PAP results in an enhancement in the explosive capability of the muscle owing to prior contractile activity (14,34). Although no performance outcome improvement was seen for the DJ at the 300-second interval, the jumping process was altered resulting in the DJ being performed with a shorter, stiffer, and more elastic leg-spring action. The CT was significantly reduced, and RSI, GRF, and $\Delta k_{\text{ext}}$ showed significant improvements. The maximal fatigue workout altered the way the muscle tendon unit behaved at this recovery interval, resulting in an effective SSC behavior. Similarly, the RBJ results at this interval indicated an enhancement in the jumping process with significant improvements in GRF and leg stiffness. The CT was also reduced, but the mean difference was not significant. Coupled with these changes in the jumping process, the performance outcome measure of FT showed an improvement in mean score, although this improvement was not significant. A similar potentiation effect has been reported when a heavy resistance exercise was used as the contractile activity (13). Both a heavy resistance exercise and a maximum SSC fatigue workout caused a potentiation effect on the DJ jumping process.

This potentiation effect has not been evident in previous research on fatigue processes in jumping. Horita et al. (27) reported an early recovery 2 hours postfatigue, but no potentiation effect was reported for the DJ. Horita et al. (25) again examined the effect of a repeated exhaustive submaximal SSC fatigue protocol on DJs that were performed 20 minutes and 2 and 4 days after the workout. No potentiation effect was reported by the authors. Instead the SSC function was characterized by a delayed depression of jump height, joint power–work delivery and electromyography activity. A possible reason for the lack of a PAP effect in past SSC fatigue studies may be because of a submaximal intensity SSC fatigue workout being used. For example, Horita et al. (25) required subjects to perform repeated RBJs on the sledge and force platform apparatus to a height representing 70% of their predetermined maximum. In contrast, the present fatigue protocol probably provided greater stimulus resulting in a potentiation effect after 300 seconds because of using a 90% level for the repeated RBJs. Future research is needed to clarify the level of fatigue required to induce a potentiation effect. It could be that 90% is the optimal level, but further research should investigate the effect of varying the intensity of the fatigue workout on subsequent fast SSC performance.

**Practical Applications**

This study has shown that a maximal SSC fatigue workout has both an inhibiting and potentiating effect on subsequent sledge DJ and RBJ performances depending on the rest interval. A 15-second rest interval appeared to have an inhibiting effect on jump performance. Uniquely, a PAP effect was evident 300-seconds postfatigue.

From a practical perspective, plyometric type activities should be avoided immediately postfatigue. At least a 300-second recovery is needed before the commencement of plyometric training. At this stage, the results indicate that the DJs will be performed with shorter, stiffer, and a more elastic leg-spring action. This PAP effect results in the jumps being performed with a more effective SSC behavior. Consequently, plyometric activities, such as DJs and RBJs, can be performed 300 seconds postfatigue, and indeed the PAP effect evident at this recovery interval will result in a greater training effect.
Acknowledgments
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