POTENTIATING RESPONSE TO DROP-JUMP PROTOCOLS ON SPRINT ACCELERATION: DROP-JUMP VOLUME AND INTRAREPETITION RECOVERY DURATION

PAUL J. BYRNE,1,2 JEREMY A. MOODY,2 STEPHEN-MARK COOPER,2 DANIELLE CALLANAN,1 AND SHARON KINSELLA1

1Department of Science and Health, Institute of Technology Carlow, Carlow, Ireland; and 2Cardiff School of Sport and Health Sciences (Sport), Cardiff Metropolitan University, Cardiff, Wales, United Kingdom

ABSTRACT

Byrne, PJ, Moody, JA, Cooper, SM, Callanan, D, and Kinsella, S. Potentiating response to drop-jump protocols on sprint acceleration: drop-jump volume and intrarepetition recovery duration. J Strength Cond Res 34(3): 717–727, 2020—The purpose of this study was to investigate the postactivation potentiation response first to bounce drop jump (BDJ) volume; second, BDJ intrarepetition recovery duration and recovery duration between BDJs and 20-meter (including 5- and 10-m split times) sprint performance. The study was undertaken in 2 parts, the first part compared different volumes of BDJs and the second part compared different BDJ intrarepetition recovery periods. The effect of recovery periods between the BDJs and the subsequent 20-m sprints was examined in both parts 1 and 2 (15 seconds, 4, 8, and 12 minutes). Fourteen (mean ± SD: age = 20.83 ± 1.26 years; height = 1.77 ± 0.04 m; and mass = 74.89 ± 6.07 kg) (part 1) and 15 (mean ± SD: age = 20.64 ± 1.00 years; height = 1.78 ± 0.06 m; and mass = 75.67 ± 6.28 kg) (part 2) male collegiate and club hurling players volunteered to participate. A randomized cross-over design was used to compare BDJ volumes (1, 2, and 3 sets of 3 repetitions) and BDJ intrarepetition recovery time (15 vs. 60 seconds) after a warm-up followed by 2 baseline 20-m sprints. The results in part 1 reported a significant improvement in 5- and 10-m sprint time for 1 set of 3 BDJs between baseline and 4 minutes (5 m: −2.34%, 𝑝 = 0.04, effect size [ES] = −0.043; 10 m: −1.42%, 𝑝 = 0.03, ES = −0.35), and baseline and 12 minutes (5 m: −3.33%, 𝑝 = 0.03, ES = −0.57; 10 m: −2.13%, 𝑝 = 0.01, ES = −0.52). Part 2 reported a significant improvement in 5-m sprint time between baseline and 15 seconds (5 m: −3.38%, 𝑝 = 0.01, ES = −0.83; 10 m: −2.07%, 𝑝 = 0.02, ES = −0.58) after the BDJs. The findings support the use of 1 set of 3 BDJs using a 15-second intrarepetition recovery period to maximize 5-, 10-, and 20-m sprint performance after 15 seconds of recovery after the final BDJ in hurling players. The acute response to this BDJ protocol proves to be time efficient and effective in acutely improving sprint acceleration.

KEY WORDS bounce drop jump, intrarepetition rest, postactivation potentiation, sprinting, hurling

INTRODUCTION

The ability to perform sprint accelerations over distances from 5 to approximately 20 m is an important requirement to be successful in many field sports such as hurling, Gaelic football, and soccer (16,22,42). Consequently, there is a requirement in preparing players of these respective field sports pre-match to develop a means to enhance acceleration over these distances and the use of a conditioning activity to express postactivation potentiation (PAP) has been shown to be effective acutely. Postactivation potentiation is a phenomenon whereby muscular performance is acutely enhanced based on a muscles’ contractile history (32,43). Three mechanisms have been proposed as to how PAP may lead to the enhanced ability to accelerate. The mechanisms include the phosphorylation of myosin regulatory light chains, the recruitment of higher-order motor units, and the change in pennation angle (32,43) (for more detail on PAP mechanisms, readers are directed to these reviews (32,43)). Previous work has shown contradictory findings in terms of enhancing sprint and jump performance depending on the protocol used to stimulate a PAP response (5,9,12–14,19,28,34,49,51,55).

Heavy loading protocols using weight training exercises (deadlifts, power cleans; front and back squats) have reported contradictory findings to date (5,12,19,30,49,55). Several studies that used heavy loading protocols reported no significant changes in 5-, 10-, 20-, and 40-m sprint performance when using a volume of a single set of 3–5 repetitions (19,30,49). However, Bevan et al. (5) reported a significant improvement in the best time in comparison.
with the baseline time for 5 and 10 m when using back squats. An earlier study by Chatzopoulos et al. (12) reported significant improvements in 10- and 30-m sprint performance after a 5-minute recovery using 10 repetitions using a heavy loaded protocol. Furthermore, significant improvements in average speed have been shown for 10–20 m and 30–40 m splits during a 40-m sprint (55). However, plyometric exercises (9,13,34,51), except for tuck jumps, have been found to lead to a positive expression of PAP (49). Till and Cooke (49) used 5 tuck jumps and found no significant improvement in 10- and 20-m sprint performance after rest periods of 4, 5, and 6 minutes. Plyometrics in the form of bounce drop jumps (BDJs) have been found to be effective at expressing PAP by using the fast stretch-shortening cycle (SSC), which is underpinned by reactive strength (9,13,21,34). The fast SSC is used when the athlete steps from a height (individualized or predetermined), lands, and immediately performs a rebound jump seeking to minimize ground contact time and maximize jump height (56). Bounce DJs can exploit PAP as a means to enhance the ability of field sport players to accelerate over distances of 20 m acutely (9).

Previous studies have examined different forms of plyometric activity to induce PAP and have also considered the recovery time required for the maximum effect to occur (9,13,21,51). A recent study (51) reported 3 sets of 10 leg bounds led to a significant improvement in 10-m sprint performance after 4 minutes of recovery. The same study also found that the same volume of alternate leg bounds, but with a 10% weighted vest, led to a significant improvement in 10- and 20-m sprint velocity after 4 and 8 minutes of recovery, respectively. Several studies (9,13,34) found that BDJs were effective at significantly improving countermovement jump (CMJ) and sprint performance using a 15-second BDJ intrarepetition recovery period. Two studies (9,13) have used BDJs with an individualized drop height causing significant improvements in CMJ and sprint performance. Countermovement jump height increased significantly after a single set of BDJs was performed after a 2-minute recovery period (13). For 20-m sprint performance, an improvement was reported after performing 3 BDJs as part of a warm-up including dynamic stretches using a 1-minute recovery period (9). However, 2 studies (21,34) that used multiple sets of BDJs from predetermined heights reported significant increases in CMJ height. Furthermore, a significant improvement occurred in 50-m sprint performance after 10 and 15 minutes of recovery (34) and a nonsignificant improvement in 10-m sprint time after an 8-minute recovery (21). Despite these studies reporting significant improvements in sprint performance with varied volumes and recovery periods between the plyometrics and the subsequent sprint, no research to date has compared various volumes of plyometrics and their modulating effect on a PAP response in sprint acceleration performance.

Another important programming variable is recovery time between repetitions of a conditioning activity used to cause a PAP response. This intrarepetition recovery period may affect the ability of the working muscle to regenerate adenosine triphosphate because of the depletion of creatine phosphate. Depletion of creatine phosphate stores has been suggested to occur during power exercises lasting up to 7 seconds (52). When performing BDJs in a set, each maximal repetition lasts approximately for 1 second and may not deplete phosphagen stores. Because of the brief nature of a single BDJ, the depletion of creatine phosphate to regenerate ATP may not be a limiting factor in terms of fatigue. To date, one study has compared 3 different DJ intrarepetition recovery periods (15, 30, and 60 seconds) (41). They...
reported that a 15-second recovery period was suitable, as there were no significant differences for jump height and ground reaction force during take-off between the 3 recovery periods. To date, no study has investigated the optimum intrarepetition recovery period for conditioning activities to cause a PAP response.

A lack of guidelines exists for sport science and strength and conditioning practitioners to use for plyometrics, specifically BDJs. This study was undertaken to develop a PAP protocol with respect to BDJ intensity, volume, BDJ intrarepetition rest periods, and a rest period between the conditioning activity (BDJs) and the subsequent sprint for acute and short-term treatments. Therefore, the purpose of this study was to examine the PAP response to (a) different volumes of BDJs, (b) different BDJ intrarepetition recovery periods, and (c) various recovery periods (15 seconds, 4, 8, and 12 minutes) between the BDJs and subsequent 5-, 10-, and 20-m sprint performance in male hurling players.

METHODS

Experimental Approach to the Problem
The aim of this study was to acutely compare volumes and interrepetition recovery periods of BDJs in their ability to express a PAP response by improving sprint acceleration performance over 20 m (including 5- and 10-m splits) at 15 seconds, 4, 8, and 12 minutes’ post-BDJ performance in male hurling players. Part 1 of the study compared the response with 1, 2, and 3 sets of 3 BDJs and part 2 compared BDJ interrepetition recovery periods of 15 and 60 seconds. By achieving the aims of the study, an acute protocol was developed to improve sprint performance over these distances in male hurling players competing at the collegiate and club level.

A randomized cross-over design with repeated measures was used to compare the response of the different volumes and intrarepetition recovery periods (Figure 1). The outcomes of this study were used to develop a “composite” training protocol (BDJs in conjunction with a 20-m sprint) with respect to programming guidelines of intensity, volume, BDJ intrarepetition recovery time, and intra-“composite” (a recovery period between BDJs and subsequent sprint) recovery time.

Subjects
Fifteen and 14 male college students (mean ± SD; part 1: age = 20.83 ± 1.26 years, height = 1.77 ± 0.04 m, and mass = 74.89 ± 6.07 kg; part 2: age = 20.64 ± 1.00 years; height = 1.78 ± 0.06 m; and mass = 75.67 ± 6.28 kg; range for both parts 19–23 years old) competing in the Irish collegiate hurling league season and at club level volunteered to participate in part 1 and part 2 of this study, respectively. Part 1 took place during the hurling pre-season and part 2 in the in-season. All subjects were encouraged to undertake their normal training during the study. For parts 1 and 2, subjects were hurling training on average 3 and 2 times per week, respectively, whereas weight training twice per week and playing 1 match once per week. Subjects had, on average, 4 years of weight training experience and had been playing hurling on average for 12 years (Table 1 for additional performance measures). No orthopedic or musculoskeletal injuries to the lower extremities in the previous 6 months were reported during medical screening for both parts of the study. Written consent was obtained from all subjects. Ethical approval was provided by ITCarlow and School of Sport and Health Sciences (Sport), Cardiff Metropolitan University.

Procedures
Subjects were familiarized with the testing and training procedures during 1 familiarization session. Subjects were tested at the same time of day to account for diurnal variations (1,400–1,600 hours) and testing took place indoors in the human performance laboratory. Subjects were required to wear the same footwear for all tests. For parts 1 and 2, a dynamic warm-up was at the beginning of each test session. The warm-up comprised 5 minutes of self-paced low-intensity jogging followed by a protocol of 5 dynamic stretches over a 10-m distance (50). The warm-up was followed 2 and 4 minutes later by baseline measures of 20-m (including split times at 5 and 10 m) sprints using Kit Race time 2 Light Radio Photo Cells to record times (Microgate, Bolzano, Italy). A 10-minute recovery period was used between the second baseline sprint measure and the subsequent BDJ protocols in both parts of the study. The repeated sprint measures were performed approximately 15 seconds, 4, 8, and 12 minutes after BDJ protocols throughout the study.

| TABLE 1. Additional performance measures (mean ± SD) and median BDJ drop height for parts 1 and 2 of the study.* |
|---------------------------------------------------------------|
| Measures                         | Part 1         | Part 2         |
| CMJ height (cm)                  | 36.18 ± 5.75  | 36.93 ± 3.81  |
| RSI (m·s⁻¹)                      | 1.50 ± 0.36   | 1.54 ± 0.31   |
| Drop height (cm)                 | 42.14 ± 12.51 | 35.62 ± 12.63 |
| Median drop height (cm)          | 40            | 30            |
| 3RM (kg)                         | 105.71 ± 15.22| 108.15 ± 13.35|
| 1RM (kg)                         | 112.0 ± 16.96 | 116.15 ± 14.88|
| 1RM/BM                           | 1.50 ± 0.22   | 1.56 ± 0.21   |

*BDJ = bounce drop jump; CMJ = countermovement jump; RSI = reactive strength index; 3RM = absolute 3 repetition maximum back squat strength; 1RM = absolute 1 repetition maximum back squat strength; 1RM/BM = relative 1 repetition maximum back squat strength.
Bounce Drop-Jump Protocols. For parts 1 and 2, test sessions were performed 1 week apart at the same time of day. Part 1 compared 1, 2, and 3 sets of 3 repetitions of BDJs. The intensity of the BDJs was determined from reactive strength index (RSI) testing described later in the methods to identify each player’s individualized drop height. A 15-second rest (41) was used between the 3 BDJ repetitions with a 2-minute recovery period between sets (13). Three repetitions of the BDJs were chosen, as it has been previously shown in our laboratory to produce a positive PAP response when sprinting over 20 m (9).

Part 2 used the results of part 1 with respect to volume to compare 2 different intrarpetition BDJ recovery periods of 15 and 60 seconds. These 2 time frames were chosen, as previous work has shown that 15 seconds is as effective as a recovery period between DJS as is 30 and 60 seconds. A 60-second intrarpetition rest has been used previously to assess PAP protocols on CMJ and squat jump performance (28,46). A review by Willardson (54) has suggested that rest intervals of 1–2 minutes may be sufficient between single maximal effort movements because of the phosphagen system being primarily involved (53).

Sprint Performance Testing. Sprint testing was performed over a 20-m distance, including split times at 5 and 10 m. Subjects performed a single trial over the distance for the 2 baseline measures and for the subsequent recordings at 15 seconds, 4, 8, and 12-minutes after BDJ protocols throughout the study. Each 20 m sprint began in a static upright position 0.5 m behind the first photocell (Microgate) and was started by the lead author through the instruction, “3, 2, 1, go.”

Countermovement Jump Testing. Subjects performed 3 CMJs by squatting to a self-selected depth and jumped upward for maximum height. Take-off and landing during the jumps were performed on a portable force plate (Type 92886AA; Kistler Instruments Ltd., Hook, United Kingdom). Hands were placed on the hips for the entire jump movement. A 15-second recovery period was provided between jumps (41). The best trial from the 3 trials was used for analysis. Scores were recorded as the trial that produced the greatest height in meter.

Reactive Strength Index Testing and Drop Height Determination. Subjects performed RSI testing within 2–7 days of the commencement of the treatment trials. Subjects performed a BDJ test to determine their highest RSI, which was then used to identify drop height for bounce drop-jumping. Two practice jumps from each drop height before 2 jumps for measurement were provided. Two BDJs from 5 different drop heights were performed (0.20, 0.30, 0.40, 0.50, and 0.60 m) using an incremental protocol. An incremental protocol was used so that the stretch load (intensity) would be progressively increased. The potential for an order effect was deemed to be nonsignificant because of familiarization of the BDJs provided and 2 minutes of rest given between drop heights to minimize fatigue (57). The recovery period used between CMJs (15 seconds) was also used between BDJs across all the heights with a 2-minute recovery period used between each group of jumps (practice jumps, test jumps, and between drop heights). The best RSI of 2 jumps for each drop height was used for analysis. Drop height was determined by using the RSI method (11). The RSI method identifies the drop height to be used as the height that produces the maximum RSI. Objectively, the ground contact time for each DJ has to be less than 0.250 seconds (45).

Data Analysis for Countermovement Jump, Reactive Strength Testing, and Drop Height Determination. A portable

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**Table 2.** Effect sizes and classifications for the 5-, 10-, and 20-m sprint times for parts 1 and 2 of the study according to Cohen (15).

|          | 15 s | 4 min | 8 min | 12 min |
|----------|------|-------|-------|--------|
| **Part 1** |      |       |       |        |
| 5 m      |      |       |       |        |
| 1        | 0.37; trivial | -0.43; small | 0.22; small | -0.57; medium |
| 2        | 0.43; small | -0.15; trivial | 0.17; trivial | 0.10; trivial |
| 3        | 0.04; trivial | 0.09; trivial | -0.16; trivial | 0.14; trivial |
| 10 m     |      |       |       |        |
| 1        | 0.49; medium | -0.35; small | 0.28; small | -0.52; medium |
| 2        | 0.45; medium | 0.03; trivial | 0.15; trivial | 0.21; small |
| 3        | 0.35; small | 0.32; small | -0.08; trivial | 0.29; small |
| 20 m     |      |       |       |        |
| 1        | 0.55; medium | -0.11; trivial | 0.29; small | -0.24; small |
| 2        | 0.40; small | 0.18; trivial | 0.20; small | 0.25; small |
| 3        | 0.37; small | 0.19; trivial | -0.06; trivial | 0.08; trivial |
| **Part 2** |      |       |       |        |
| 5 m      |      |       |       |        |
| 15 s     | -0.83; large | -0.58; small | -0.60; medium | -0.30; small |
| 60 s     | 0.60; medium | -0.27; small | -0.21; medium | 0.04; trivial |
| 10 m     |      |       |       |        |
| 15 s     | -0.58; medium | -0.47; small | -0.39; small | -0.35; small |
| 60 s     | 0.80; large | -0.22; small | -0.17; small | 0.08; trivial |
| 20 m     |      |       |       |        |
| 15 s     | -0.34; small | -0.28; small | -0.21; small | -0.14; trivial |
| 60 s     | 0.71; medium | -0.10; trivial | -0.13; trivial | 0.12; trivial |
multicomponent force plate with a built-in charge amplifier (Type 92886AA; Kistler Instruments Ltd.) was used to measure force-time measures at a sampling frequency of 1,000 Hz, and data were saved and analyzed using BTS-SMART software, using a tailor-made protocol (BTS Spa, Milan, Italy). Jump height for the CMJs and BDJs was calculated from flight time using the following equation (7):

\[ H = \frac{g \times t^2}{2} \]

where \( H \) = jump height (m); \( g \) = gravity (9.81 m s\(^{-2}\)); and \( t \) = flight time (s).

Ground contact time during the amortization phase (the time frame when a subject is in contact with the ground before the subsequent jump) was calculated as the time between initial foot contact and take-off (26). The RSI was calculated based on the equation:

\[ RSI = \frac{\text{jump height (m)}}{\text{contact time (s)}} \]

Three-Repetition Maximum Back Squat Strength Testing. Three-repetition maximum (3RM) testing was performed on the same day as CMJ testing, RSI testing, and identification of drop height. Subjects completed the 3RM back squat strength test after a 5-minute recovery period placed between the end of RSI testing and the start of the 3RM back squat strength. Subjects performed a modified form of a 3RM protocol as used by Cunningham et al. (20). Warm-up sets comprising 2 sets of 8 repetitions of 50% of their predicted 1RM followed by 4 repetitions at 70% 1RM. After completing the 4 repetitions, attempts at performing 3 repetitions at a 3RM load commenced. A 2-minute recovery period and a 5-minute recovery were used between warm-up sets and 3RM attempts, respectively. The 3RM trials continued until the subject was unable to complete the lift through the designated range of movement. Subjects were required to squat down until their thighs were parallel with the ground. This position was set by a bench placed behind the subject. The orientation of the bench was tailored for each subject. One RM was estimated using a chart published by Baechle and Earle (4). Relative strength was calculated from the following equation: relative strength = 1RM (kg)/body mass (kg).

Statistical Analyses
Descriptive statistics were reported as mean values and SDs. Data were found to be normally distributed from the Shapiro-Wilk test. Two-way within-within repeated-measures analyses of variance were performed to determine where significant differences existed for part 1 of the study examining the acute effect of the 3 different volumes of BDJs and part 2, where 2 different BDJ intrarepetition recovery periods were investigated for significant differences for 5-, 10-, and 20-m sprint times. Furthermore, the recovery periods of 15 seconds, 4, 8, and 12 minutes after the BDJ protocols for part 1 and part 2 were also assessed. Where multiple pair-wise mean comparisons were analyzed,
a Dunn-Sidak adjustment was used. Paired t-tests were used in part 1 to show where significant improvements occurred between baseline times and 4 minutes, and baseline times and 12 minutes for the 5 and 10 m distances, respectively. In part 2, a paired t-test was used to show a significant improvement in performance from baseline to 15 seconds after the BDJ protocol for 10 m. Effect size (ES) was calculated using Cohen’s d where the mean of the baseline sprint time was subtracted from the best sprint time for 5, 10, and 20 m and divided by the respective pooled SD. Effect size was interpreted as 0.5–0.8 to be a moderate ES and 0.8 and above as a large ES (15). The sprint and 3RM back squat strength measures were found to be reliable using an intraclass correlation coefficient (5 m: ICC = 0.90; 10 m: ICC = 0.95; 20 m: ICC = 0.96; absolute and relative 3RM: ICC = 0.99). The reliability of the CMJ and DJ measures has been previously established (10). Statistical significance was set at \( p < 0.05 \). All statistical analyses were computed using the Statistics Package for Social Sciences (Version 23.0).

**RESULTS**

Table 2 displays Cohen’s d ESs for 5-, 10-, and 20-m sprint times for parts 1 (\( n = 14 \)) and 2 (\( n = 15 \)) of the current study at baseline and the 4 subsequent recovery times (15 seconds, 4, 8, and 12 minutes).

**Part 1**

No significant (\( p > 0.05 \)) change for sets was evident for 5, 10, and 20 m sprint times when comparing 1, 2, and 3 sets of 3 BDJ repetitions.

**5-m Sprint Time.** A significant change for time (\( F = 3.86, \ p = 0.008, \ \text{partial eta squared} = 0.22, \ \text{power} = 0.86 \)) and for sets by time interaction was evident (\( F = 2.76, \ p = 0.01, \ \text{partial eta squared} = 0.17, \ \text{power} = 0.92 \)). A significant (\( p = 0.05 \)) decrease in 5-m time from 15 seconds to 4 minutes and 15 seconds to 12 minutes occurred after 1 set of BDJs (Figure 2). However, paired samples t-tests showed that 1 set of 3 BDJs caused a significant decrease from baseline time to the time at 4 minutes (\(-2.34\%; \ t = 2.22; \ p = 0.04\)) and 12 minutes (\(-3.33\%; \ t = 2.35; \ p = 0.03\)).

**10-m Sprint Time.** A significant change for time (\( F = 6.28, \ p = 0.0001, \ \text{partial eta squared} = 0.32, \ \text{power} = 0.98 \)) and for sets by time interaction was evident (\( F = 3.40, \ p = 0.002, \ \text{partial eta squared} = 0.20, \ \text{power} = 0.97 \)). One set of 3 BDJs led to a significant (\( p = 0.04 \) and \( p = 0.02 \), respectively) decrease in time between 15 seconds and 4 minutes and 15 seconds and 12 minutes (Figure 2). However, paired samples t-tests showed that 1 set of 3 BDJs caused a significant decrease from baseline time to the time at 4 minutes (\(-1.42\%; \ t = 2.24; \ p = 0.04\)) and 12 minutes (\(-2.13\%; \ t = 2.80; \ p = 0.01\)).

**20-m Sprint Time.** A significant change for time (\( F = 10.93, \ p = 0.0001, \ \text{partial eta squared} = 0.45, \ \text{power} = 0.99 \)) and for sets by time interaction was evident (\( F = 2.69, \ p = 0.01, \ \text{partial eta squared} = 0.17, \ \text{power} = 0.92 \)). A significant increase in 20-m time was found from baseline to 15 seconds after 1 and 2 sets of 3 BDJs (\( p = 0.05 \) and \( p = 0.007 \), respectively). One set of 3 BDJs led to a significant decrease in 20-
m time between 15 seconds and 4 minutes and 15 seconds and 12 minutes ($\rho = 0.03$ and $\rho = 0.02$, respectively) (Figure 2). Three sets of 3 BDJs led to a significant decrease in 20-m time from 15 seconds to 8 minutes ($\rho = 0.02$). One set of 3 BDJs resulted in a nonsignificant improvement of −1% from baseline to 12 minutes (3.16 ± 0.11 vs. 3.13 ± 0.13 seconds).

**Part 2**
No significant ($\rho > 0.05$) changes were evident for the recovery period by time interaction (10- and 20-m sprint times), recovery periods, and time (5-, 10-, and 20-m sprint times).

**5-m Sprint Time.** A significant change for the recovery period by time interaction was evident ($F = 3.90$, $\rho = 0.007$, partial eta squared = 0.21, power = 0.87). A significant ($F = 3.69$, $\rho = 0.01$, partial eta squared = 0.20, power = 0.85) improvement in 5-m time of −3.38% from baseline to 15 seconds after 1 set of BDJs with a 15-second intrarepetition was found (1.16 ± 0.06 vs. 1.11 ± 0.06 seconds). One set of 3 BDJs with a 15-second intrarepetition recovery period resulted in a nonsignificant improvement of −3.06, −2.75, and −1.00% from baseline to 4 minutes, baseline to 8 minutes, and baseline to 12 minutes, respectively (Figure 3).

**10-m Sprint Time.** A paired samples $t$-test found that 1 set of 3 BDJs with a 15-second intrarepetition recovery period led to a significant decrease from baseline time to 15 seconds (−2.07%; $t = 2.55$; $\rho = 0.02$). One set of 3 BDJs with a 15-second intrarepetition recovery period resulted in a nonsignificant improvement of −1.95, −1.44, and −1.36% from baseline to 4 minutes, baseline to 8 minutes, and baseline to 12 minutes, respectively (Figure 3).

**20-m Sprint Time.** One set of 3 BDJs using a 15-second intrarepetition recovery period led to a nonsignificant improvement of −0.94% (3.17 ± 0.09 vs. 3.14 ± 0.07 seconds) in 20-m time from baseline to 15 seconds (Figure 3).

**DISCUSSION**
This is the first study to have investigated the potentiating response to different BDJ volumes and different BDJ intrarepetition recovery periods on sprint acceleration over 5, 10, and 20 m. The findings of this study have shown that in part 1, 1 set of 3 BDJs led to an improvement in 5- and 10-m sprint performance between baseline and 4 minutes and baseline and 12 minutes. In part 2, an improvement in 5-, 10-, and 20-m sprint performance was found between baseline and sprint performance (5, 10, and 20 m) at the subsequent recovery time points of 15 seconds, 4, 8, and 12 minutes. Based on these findings, a DJ protocol using 1 set of 3 repetitions of individualized BDJs with a 15-second intrarepetition recovery period is effective in enhancing sprint performance over 5, 10, and 20 m from 15 seconds to at least 12 minutes. In part 1, 1 set of 3 BDJs led to significant increases in sprint performance over 5 and 10 m between baseline and 4 minutes (5 m: −2.34%, $ES = −0.43$; 10 m: −1.42%; $ES = −0.35$) and baseline and 12 minutes (5 m: −3.33%, $ES = −0.57$; 10 m: −2.13%, $ES = −0.52$). In part 2, a 15-second BDJ intrarepetition recovery period caused a significant increase in sprint performance between baseline and 15 seconds for the 5 and 10 m distances (5 m: −3.38%, $ES = −0.83$; 10 m: −2.07%, $ES = −0.58$).

Our study shows contrasting findings to previous studies (5,19,30,49) that used heavy loading protocols (back squats, power cleans, and deadlifts) and reported no significant changes in 5-, 10-, 20-, and 40-m sprint performance when using a volume of a single set of 3–5 repetitions. Till and Cooke (49) reported no significant improvement in 10- and 20-m sprint performance after either using heavy deadlifts, an isometric maximum voluntary contraction, or 5 tuck jumps. However, our study supports the significant improvements in sprint performance when using similar recovery times (4 minutes in part 1), despite our study using a BDJ protocol. The BDJ protocol used a high-velocity power-based fast SSC exercise compared with heavy loading protocols that used slow velocity strength-based resistance exercises such as back squats and deadlifts. Bevan et al. (5) reported a significant improvement in the best time in comparison with the baseline time for 5 and 10 m using back squats. An earlier study reported significant improvements in 10- and 30-m sprint performance after a 5-minute recovery using 10 repetitions using a heavy loaded protocol (back squats) (12). Furthermore, significant improvements in average speed have been shown from 10 to 20 and 30 to 40 m splits during a 40-m sprint in male strength trained athletes using a loading protocol (front and back squats) for 30–70% 11RM for a total of 12 repetitions after a 4-minute recovery period (55). When considering previous research using plyometric exercises, one study to date has reported no significant effect when using 5 tuck jumps (49). Despite this finding regarding tuck jumps, the current study supports the use of plyometric exercises and in particular, BDJs to cause a potentiating response in terms of augmented sprint performance. Previous work (9) in our laboratory provided evidence that 3 BDJs can improve 20-m sprint performance after a 1-minute recovery period. Further research using BDJs has shown that male professional sprinters significantly improved their 50-m sprint and CMJ performance after a 10- and 15-minute recovery period when using 2 sets of 5 repetitions with a 15-second BDJ intrarepetition recovery period from non-individualized drop height (34). Turner et al. (51) provided evidence that leg bounds and weighted leg bounds (plus 10% of body mass) are effective in improving 20- and 10-m sprint performance after 4-minute recovery and after 4 and 8 minutes, respectively, with a volume of 3 sets of 10. When considering the use of BDJs to enhance CMJ performance, Chen et al. (13) used 1 and 2 sets of 5 BDJs and found a significant improvement in CMJ performance for both volumes within 2 minutes of their BDJ protocol. A second study (21) reported that 3 sets of 5 alternate single-leg BDJs...
with a 10-second intrarepetition recovery period caused a significant increase in CMJ height and a nonsignificant improvement in 10-m sprint time after an 8-minute recovery period. These studies have a number of differences in terms of their potentiation protocols. Studies that used a DJ protocol with individualized drop height with 1 or 2 sets of 3–5 repetitions showed significant improvements in the performance measure after 1–2 minutes (9,13). Part 2 of the current study showed the best and most significant improvement in 5- and 10-m sprint performance occurred after a 15-second recovery period. Three studies (21,34,51) that used multiple sets of alternate leg bounds and double-footed and single-legged DJs from predetermined drop heights found that sprint and CMJ performance improvements occurred 4, 8, 10, and 15 minutes later. It seems that when designing a "composite" repetition (plyometric exercise combined with a sprint) to enable a PAP response, too high a volume or intensity or both of the plyometric exercise can lead to a delay and dampening of the potentiating response concerning sprint acceleration over distances ranging from 5 to 20 m based on the findings of the current study. In terms of using a BDJ, the RSI method seems critical to determine the individualized drop height. Individualizing drop height aims to prevent excessive eccentric overloading, which can cause muscular inhibition through the activation of the Golgi tendon organ that monitors muscle force (29).

In part 1, the single set of the BDJ protocol led to improvements in 5-, 10-, and 20-m sprint performance at 4 minutes with the best performances occurring at 12 minutes. Two and 3 sets led to an improvement for 5 m at 4 minutes and for 5 and 10 m at 8 minutes, respectively. However, at 15 seconds after the BDJ protocol for all sets used, a decrease in performance occurred across all sprint distances. We suggest that the decrease in performance at 15 seconds and 8 minutes was because subjects did not perform the sprint with maximum effort, despite being provided with motivation by the lead author after completing 1 set. In addition, 2 and 3 sets of the BDJ protocol seems to have caused a dampening in the expression of PAP. In support of our 1-set argument, research has suggested that fatigue and potentiation can coexist and performance of the subsequent activity, a sprint in our case, increases if potentiation offsets the fatigue that results from the BDJs (40). When considering the impact of multiple sets in the current study, Sale (44) has suggested that the time course to display PAP after a conditioning activity can be influenced by the amount of fatigue produced during the conditioning activity with greater work volumes increasing the delay before performance gain occurs. Therefore, as time extends from the completion of the conditioning activity, fatigue is dissipated and the ability to express PAP responses increases. If, however, the time between the conditioning activity and the subsequent performance is extended for too long, the ability to express PAP will decrease (46). A review and meta-analysis (47) focusing on factors modulating PAP performance suggested that
generation and shorter ground contact time in a CMJ after completing an alternate single-leg DJ protocol. The DJ protocol caused increases in RSI and leg-spring stiffness indicating that the SSC behavior was enhanced during the CMJ. These responses led to a significant improvement in CMJ height and a nonsignificant improvement in 10-m sprint performance. Although no physiological mechanisms were recorded in the current study, improved sprint acceleration performance following the BDJ protocols may have occurred from various neuromuscular responses such as increased neural drive to the agonist muscles through the H-reflex and from the cortical level (48), increasing the activation level of active type 2 motor units (31), adjustments in the muscle-tendon unit (MTU) stiffness characteristics (33), adjustments in pennation angle (27), and adjustments in single-fiber mechanics (35,36). The H-reflex response has been found to be present during fast concentric muscle actions at high stimulation frequencies (1). This generation of greater concentric force in a short time interval can enhance the ability of the athlete to accelerate at the initiation of a sprint and overcome the body weight resistance (38). The increase in concentric force during sprint running is probably due to an increase in MTU stiffness, which can be attributed to an increase in a reflex response (3), such as the H-reflex. This increase in MTU stiffness enables elastic energy storage in the series elastic component, especially the tendon (6). The efficient use of stored elastic energy in the MTU that occurs during the prestretch phase of the SSC is enabled by some level of leg stiffness, which is required for optimal use of the SSC (8). Optimal use of a fast SSC requires landing with a stiff leg action in conjunction with minimizing ground contact time (18). An increase in leg stiffness can be connected to increased leg cadence during sprinting that uses a fast SSC (2,24). Furthermore, previous work has demonstrated that stretch and shortening occurred in the quadriceps tendon with little change in muscle length during the concentric phase of a DJ (25). At very high speeds, energy stored in the tendon is used during tendon recoil and with a large restoring force to amplify power output (6). When considering adjustments in single-fiber mechanics, increased force generation during eccentric muscle actions may be due to a function of mechanical detachment of cross-bridges suspended in an active bound state as well as the activation of a second myosin head to act, thereby increasing the number of active cross-bridges (35,36). Furthermore, titin stiffness can be increased due to the binding of calcium to titin causing enhanced force generation during eccentric muscle actions (23). Our findings seem to confirm that the maximal activation of the lower limbs and the use of eccentric muscle actions by means of BDJs are critical in stimulating a PAP response in hurling players. The explosiveness of the BDJs used in our protocols that recruit type 2 motor units seem to be a highly effective conditioning activity for a positive PAP response.

Despite the enhanced explosive performance of our subjects due to the BDJ protocols used, a number of limitations were present in the current study. Players were requested not to perform any strenuous exercise for 24 hours before testing. This was a limitation during part 1 of the study because of the lack of control we had over external commitments of the players and relied on their honesty. Based on the data from part 1, we believe that this lack of recovery during the 24-hour period before testing led to the delay in enhancement in acceleration in comparison with the data from part 2. Subject motivation may have been somewhat reduced due to their college coursework and training regime. The deceleration distance after the 20-m sprint in our laboratory is restricted to 10 m and may have caused players to not maintain maximum acceleration to the 20-m mark. Furthermore, some players seemed to focus their attention on certain distances such as 5 and 10 m, despite the lead author providing instruction and encouragement to accelerate through the 20 m finish. For future studies, researchers may consider investigating the acute response to different recovery periods between the BDJ protocol and a 20-m sprint. Furthermore, the desired number of these repetitions needs to be examined to determine the response to this type of training in a single session as well as in the short and long term.

In conclusion, this study has shown that 1 set of 3 BDJs with a 15-second intrarepetition rest period is effective at improving sprint acceleration over 5, 10, and 20 m after 15 seconds of recovery in hurling players. Furthermore, it seems that there is a strong link between intensity and volume. By individualizing BDJ drop height using the RSI method, volume may be kept to a minimum to maximize the eccentric loading of the musculature and the subsequent response on leg-spring stiffness. Individualizing drop height should reduce the incidence of injury.

**Practical Applications**

This study has produced a protocol that can acutely improve sprint acceleration performance over 5, 10, and 20 m in male hurling players competing at college and club level. The protocol may be used for other field sports that would have similar physiological demands to hurling, namely Gaelic football, soccer, rugby union, and field hockey. This BDJ protocol comprises 1 set of 3 BDJs using RSI to determine individualized drop height with a 15-second intrarepetition recovery and a 15-second recovery between the BDJ and the subsequent 20-m sprint. Hurling coaches and strength and conditioning practitioners need to be aware that the individualized drop height for their players needs to be predetermined during a separate test day to ensure appropriate loading of the lower limb musculature to optimize the PAP response on sprint acceleration performance over these distances repeatedly performed during a hurling match. Furthermore, it is recommended that coaches and practitioners identify the recovery time between BDJs and...
subsequent sprint performance, as this may need to be individualized to the athlete. This study has developed a protocol where the appropriate DJ volume, drop height, and recovery time are identified. Coaches, hurling players, and other field sport players similar to that of hurling and playing at a similar competition level may maximize sprint performance when using this form of combination training, which the authors are referring to as "composite training."

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