The potentiating response to drop jump protocols on sprint acceleration: Drop jump volume and intra-repetition recovery duration.

Running head: PAP and drop jumps

Original Investigation

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Abstract

The purpose of this study was to investigate the postactivation potentiation (PAP) response firstly to bounce drop jump (BDJ) volume; secondly, BDJ intra-repetition recovery duration and recovery duration between BDJs and 20 meter (including 5 and 10 meter split times) sprint performance. The study was undertaken in two parts, the first part compared different volumes of BDJs and the second part compared different BDJ intra-repetition recovery periods. The effect of recovery periods between the BDJs and the subsequent 20 m sprints were examined in both part 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; mass = 74.89 ± 6.07 kg) (part 1) and fifteen (mean ± SD: age = 20.64 ± 1.00 years; height = 1.78 ± 0.06 m; mass = 75.67 ± 6.28 kg) (part 2) male collegiate and club hurling players volunteered to participate. A randomized cross-over design was employed to compare BDJ volumes (one, two and three sets of three repetitions) and BDJ intra-repetition recovery time (15 seconds versus 60 seconds) after a warm-up followed by two baseline 20 m sprints. The results in part one reported a significant improvement in 5 and 10 m sprint time for one set of three BDJ between baseline and 4minutes (5 m: -2.34%, P = 0.04, ES = -.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 two 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) post the BDJs. The findings support the use of 1 set of three BDJs using a 15 sec intra-repetition recovery period to maximize 5, 10 and 20 m sprint performance after 15 seconds of recovery post 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.

Keywords: Bounce drop jump, volume, intra-repetition rest, post activation potentiation.

Introduction

The ability to perform sprint accelerations over distances from five to approximately twenty meters 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. PAP is a phenomenon whereby muscular performance is acutely enhanced based upon 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 (RLC), 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 employed to stimulate a PAP response (5, 9, 12, 13, 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 employed 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 three to five repetitions

(19, 30, 49). However, Bevan et al. (5) reported a significant improvement in the best time in comparison to the baseline time for 5 and 10 m when using back squats. An earlier study by Chatzopoulus 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 to 20 m and 30 to 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) employed five 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 depth jumps (BDJs) have been found to be effective at expressing PAP by utilizing 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 pre-determined), lands and immediately performs a rebound jump seeking to minimize ground contact time and maximize jump height (56). BDJs can exploit post activation potentiation (PAP) as a means to enhance the ability of field sport players to accelerate over distances of 20 meters 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 three sets of ten 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 CMJ and sprint performance using a 15-second BDJ intra-repetition recovery period. Two studies (9, 13) have employed BDJs with an individualized drop height causing significant improvements in CMJ and sprint performance. CMJ 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 three BDJs as part of a warm-up including dynamic stretches using a 1-min recovery period (9). However, two studies (21, 34) that employed multiple sets of BDJs from pre-determined heights, reported significant increases in CMJ height. Furthermore, a significant improvement occurred in 50 m sprint performance after 10 and 15 minutes recovery (34) and a non-significant 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 intra-repetition recovery period may affect the ability of the working muscle to regenerate ATP 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 one second and may not deplete phosphagen stores. Due to 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 three different drop-jump intra-repetition 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 three recovery time periods. To date, no study has investigated the optimum intra-repetition 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 intra-repetition 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 i) different volumes of BDJs, ii) different BDJ intra-repetition recovery periods and iii) various recovery periods (15 s, 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 inter-repetition 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 one of the study compared the response to 1, 2 and 3 sets of three BDJs and part two compared BDJ inter-repetition 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 intra-repetition recovery periods (see 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 intra-repetition recovery time and intra - 'composite' (recovery period between BDJs and subsequent sprint) recovery time.

Subjects

Fifteen and fourteen male college students (mean ± SD: Part 1: age = 20.83 ± 1.26 years, height = 1.77 ± 0.04 m, mass = 74.89 ± 6.07 kg; Part 2: age = 20.64 ± 1.00 years; height = 1.78 ± 0.06 m; mass = 75.67 ± 6.28 kg) 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 three and two times per week, respectively, while weight training twice per week and playing **one** match once per week. Subjects had, on average, four years of weight training experience and had been playing hurling on average for twelve years (see Table 1 for additional performance measures). No orthopedic or musculoskeletal injuries to the lower extremities in the previous six months were reported during medical screening for both parts of the study. Written consent was obtained from all subjects. Ethical approval was provided by the institutional ethics committee.

Procedures

Subjects were familiarized with the testing and training procedures during one familiarization session. Subjects were tested at the same time of day to account for diurnal variations (1400 – 1600 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 five minutes of self-paced low intensity jogging followed by a protocol of five dynamic stretches over a 10 m distance (50). The warm-up was followed two and four minutes later by baseline measures of 20 m (including split times at 5 and 10 meters) 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 post-BDJ protocols throughout the study.

Bounce drop-jump (BDJ) protocols

For parts 1 and 2, test sessions were performed one week apart at the same time of day. Part one compared one, two and three sets of three repetitions of BDJs. The intensity of the BDJs was determined from RSI testing described later in the methods to identify each player's individualized drop height. A 15-second rest (41) was employed between the three BDJ repetitions with a 2-minute recovery between sets (13). Three repetitions of the BDJs was 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 one with respect to volume to compare two different intra-repetition BDJ recovery periods of 15 and 60 seconds. These two time frames were chosen as previous work has shown that 15 seconds is as effective as a recovery period between drop jumps as is 30 seconds and 60 seconds. A 60-second intra-repetition 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 due to 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 two baseline measures and for the subsequent recordings at 15 seconds, 4, 8 and 12-minutes post BDJ protocols throughout the study. Each 20m sprint began in a static upright position 0.5 meters behind the first photocell (Microgate, Bolzano, Italy) and were started by the lead author through the instruction, “3, 2, 1, go”.

Countermovement jump (CMJ) testing

Subjects performed three 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 three trials was used for analysis. Scores were recorded as the trial that produced the greatest height in m.

Reactive strength index (RSI) testing and drop height determination

Subjects performed RSI testing within two to seven 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 two jumps for measurement were provided. Two BDJs from five 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 non-significant due to familiarization of the BDJs provided and two minutes of rest given between drop heights to minimize fatigue (57). The recovery time period used between CMJs (15 seconds) was also used between BDJs across all the heights with a two-minute recovery period used between each group of jumps (practice jumps, test jumps and between drop heights). The best RSI of two jumps for each drop height was used for analysis. Drop height was determined by employing 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 drop-jump has to be less than 0.250 seconds (45).

Data analysis for CMJ, reactive strength testing and drop height determination

A portable multi-component force plate with a built-in charge amplifier (Type 92886AA, Kistler Instruments Ltd, Hook, United Kingdom) was used to measure force-time measures at a sampling frequency of 1000 Hz and data was saved and analyzed using BTS-SMART software, using a tailor-made protocol (BTS Spa, Milan, Italy). Jump height for the CMJs and BDJs were calculated from flight time using the following equation (7):

$$H = (g \times t^2)/8$$

Where: H = jump height (m); g = gravity (9.81 m. s^{-2}); 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 reactive strength index (RSI) was calculated based on the equation:

$$RSI = \text{jump height (m)} / \text{contact time (s)}$$

Three repetition maximum (3RM) back squat strength testing

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 of two sets of eight repetitions of 50% of their predicted 1RM followed by four repetitions at 70% 1RM. After completing the four repetitions, attempts at performing three 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 repetition maximum 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 means and standard deviations. Data was found to be normally distributed from the Shapiro-Wilk test. Two-way within-within repeated measures ANOVAs were performed to determine where significant differences existed for part one of the study examining the acute effect of the three different volumes of BDJs and part two, where two different BDJ intra-repetition 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 12minutes post the BDJ protocols for part one and part two were also assessed. Where multiple pair-wise mean comparisons were analyzed, a Dunn-Sidak adjustment was used. Paired t-tests were employed in part one 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. In part two, a paired t-test was employed to show a significant improvement in performance from baseline to 15 seconds post the BDJ protocol for 10 m. Effect size 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: = 0.95; 20 m: = 0.96; absolute and relative 3RM: = 0.99). The reliability of the CMJ and drop jump measures have been previously established (10). Statistical significance was set at $P \leq 0.05$. All statistical analyses were computed using the Statistics Package for Social Sciences (Version 23.0).

Results

Table 2 displays Cohen's *d* effect sizes 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 minutes, 8 minutes and 12 minutes).

Part one

No significant ($P > 0.05$) change for sets were evident for 5, 10 and 20 m sprint times when comparing 1, 2 and 3 sets of three BDJ repetitions.

5 m sprint time

A significant change for time ($F = 3.86$, $P = 0.008$, partial eta squared = 0.22, power = 0.86) and for sets by time interaction was evident ($F = 2.76$, $P = 0.01$, partial eta squared = 0.17, 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 one set of BDJs (see Figure 2). However, paired samples t-tests showed that one set of three 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 ($F = 6.28$, $P = 0.0001$, partial eta squared = 0.32, power = 0.98) and for sets by time interaction was evident ($F = 3.40$, $P = 0.002$, partial eta squared = 0.20, power = 0.97). One set of three BDJ's 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 (see Figure 2). However, paired samples t-tests showed that 1 set of three 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, partial eta squared = 0.45, power = 0.99) and for sets by time interaction was evident (*F* = 2.69, *P* = 0.01, partial eta squared = 0.17, power = 0.92). A significant increase in 20 m time was found from baseline to 15 seconds after one and two sets of three BDJs (*P* = 0.05 and *P* = 0.007 respectively). One set of three BDJs led to a significant decrease in 20 m time between 15seconds and 4 minutes and 15 seconds and 12 minutes (*P* = 0.03 and *P* = 0.02 respectively) (see Figure 2). Three sets of three BDJs led to a significant decrease in 20 m time from 15 seconds to 8 minutes (*P* = 0.02). One set of three BDJs resulted in a non-significant improvement of -1% from baseline to 12 minutes (3.16 ± 0.11 seconds vs 3.13 ± 0.13 seconds).

Part two

No significant (*P* > 0.05) changes were evident for 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 recovery period by time interaction was evident (*F* = 3.90, *P* = 0.007, partial eta squared = 0.21, power = 0.87). A significant (F = 3.69, *P* = 0.01, partial eta squared = 0.20, power = 0.85) improvement in 5 m time of -3.38% from baseline to 15 seconds after one set of BDJs with a 15 second intra-repetition was found (1.16 ± 0.06 seconds vs 1.11 ± 0.06 seconds). One set of three BDJs with a 15 second intra-repetition recovery period resulted in a non-significant improvement of -3.06%, -2.75% and -1.00% from baseline to 4minutes; baseline to 8 minutes and baseline to 12 minutes respectively (see Figure 3).

10 m sprint time

A paired samples t-test found that 1 set of three BDJs with a 15 second intra-repetition recovery period led to a significant decrease from baseline time to 15 seconds (-2.07%; t = 2.55; P = 0.02). One set of three BDJs with a 15 second intra-repetition recovery period resulted in a non-significant improvement of -1.95%, -1.44%, -1.36% from baseline to 4 minutes; baseline to 8 minutes and from baseline to 12 minutes respectively (see Figure 3).

20 m sprint time

One set of three BDJs using a 15 second intra-repetition recovery period led to a non-significant improvement of -0.94% (3.17 ± 0.09 seconds vs 3.14 ± 0.07 seconds) in 20 m time from baseline to 15 seconds (see Figure 3).

Discussion

This is the first study to have investigated the potentiating response to different BDJ volumes and different BDJ intra-repetition recovery periods on sprint acceleration over 5, 10 and 20 m. The findings of this study have shown that in part one, one set of three BDJs led to an improvement in 5 and 10 m sprint performance between baseline and 4 minutes and baseline and 12 minutes. In part two, 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 upon these findings, a drop-jump protocol employing one set of three repetitions of individualized BDJs with a 15 second intra-repetition recovery period is effective in enhancing sprint performance over 5, 10 and 20 m from 15 seconds to at least 12 minutes. In part one, one set of three BDJs led to significant increases in sprint performance over 5 and 10 m between baseline and 4minutes (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 two, a 15 second BDJ intra-repetition 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 employed 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 three to five 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 (MVC) or five tuck jumps. However, our study supports the significant improvements in sprint performance when using similar recovery times (4mins in part one) despite our study using a BDJ protocol. The BDJ protocol employed a high velocity power based fast SSC exercise compared to heavy loading protocols that employed 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 to 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 5min recovery using 10 repetitions using a heavy loaded protocol (back squats) (12). Furthermore, significant improvements in average speed have been shown from 10-20 and 30-40 m splits during a 40 m sprint in male strength trained athletes using a loading protocol (front and back squats) for 30-70% 11-RM for a total of 12 repetitions after a 4 min 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 three 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 employing 2 sets of 5 repetitions with a 15-second BDJ intra-repetition 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-minutes recovery and after 4 and 8 minutes respectively with a volume of three sets of ten. When considering the use of BDJs to enhance CMJ performance, Chen et al. (13) employed one and two sets of five 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 three sets of five alternate single leg BDJs with a 10-second intra-repetition recovery period caused a significant increase in CMJ height and a non-significant 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 employed a drop-jump protocol with individualized drop height with one or two sets of three to five repetitions showed significant improvements in the performance measure after one to two minutes (9, 13). Part two 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 employed multiple sets of alternate leg bounds and double footed and single legged DJs from pre-determined drop heights found that sprint and CMJ performance improvements occurred 4, 8, 10 and 15minutes later. It appears that when designing a ‘composite’ repetition (plyometric exercise combined with a sprint) to enable a PAP response, too high a volume and / or intensity 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 upon the findings of the current study. In terms of using a BDJ, the RSI method appears 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 (GTO) which monitors muscle force (29).

In part one, 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 three 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 post the BDJ protocol for all sets employed, 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 one set. In addition, two and three sets of the BDJ protocol appears to have caused a dampening in the expression of PAP. In support of our one-set argument, research has suggested that fatigue and potentiation can co-exist 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 plyometric exercise produces moderate PAP effects after a shorter recovery time (0.3 – 4 minutes) in comparison to traditional high intensity exercises (heavy back squats for example). Part one of the current study supports the 4 minutes' recovery time reported by Seitz and Haff (47) across all sprint distances for one set, but multiple sets supports the 4-minute time frame at 5 m only. Furthermore, part two of the current study is in agreement that a 15-second recovery period post the BDJ protocol led to the most improved sprint performance over the three distances assessed. The 15-second intra-repetition recovery period caused an enhanced expression of PAP in comparison to the 60-second intra-repetition recovery period, which dampened the PAP response in sprint performance. This may have occurred because the intra-repetition time and the time between the BDJ protocol and the subsequent performance had been extended for too long, thus reducing the ability to express PAP (46). Another explanation is that lower limb stiffness may have been effected and has been suggested to be another mechanism behind the expression of PAP (37). Previous research has reported that complex training caused three single leg drop jumps to increase in leg stiffness by 10.9% (17). However, this study (17) found a decrease in drop-jump flight time of 3.4%. This finding shows that an increase in leg stiffness does not necessarily lead to enhanced performance. However, Arampatzis et al. (3) has proposed that an increase in leg-spring stiffness will enhance power generation until an athlete's optimal threshold is achieved, thereafter, further increases beyond this threshold will weaken power generation. A decrease in power generation is believed to cause an increase in muscle shortening velocity which reduces force development efficiency (39). We suggest that the multiple sets as well as the 60-second intra-repetition recovery period resulted in players' leg-spring stiffness exceeding their optimal threshold, leading to a decrease in power generation due to reduced force development.

When considering the strength level of players, Seitz and Haff (47) have stated that weaker athletes require multiple sets of plyometrics to induce a PAP response. In the current study, players were considered relatively weak based upon the mean body weight to maximum strength ratio derived from the back squat test. However, a single set of BDJs led to the best improvement in sprint performance for the players. The effectiveness of the single set of BDJs may be due to individualizing the intensity (i.e. BDJ drop height) through the use of the RSI method (11). Drop height individualization seems to have benefited the players' by requiring a single set of three BDJ repetitions to produce a PAP response. If this is the case, the balance between volume and intensity for the conditioning activity may be critical to design a protocol that is user friendly and time efficient.

The BDJ protocols employed in parts one and two of the current study may have increased the players' ability to apply an enhanced force capacity against the ground during the sprint measures (21). This study reported enhanced acute force 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 non-significant improvement in 10 m sprint performance. Even though 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 two 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 bodyweight 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 pre-stretch 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 utilizes 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 drop jump (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 actin, 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 appear to confirm that the maximal activation of the lower limbs and the use of eccentric muscle actions by means of BDJs is critical in stimulating a PAP response in hurling players. The explosiveness of the BDJs used in our protocols that recruit type two motor units appear 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 employed, a number of limitations were present in the current study. Players were requested not to perform any strenuous exercise for 24 hours prior to testing. This was a limitation during part 1 of the study due to the lack of control we had over external commitments of the players and relied on their honesty. Based upon the data from part 1, we believe this lack of recovery during the 24-hour period prior to testing led to the delay in enhancement in acceleration in comparison to 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 appeared 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 one set of three BDJs with a 15-second intra-repetition rest period is effective at improving sprint acceleration over 5, 10 and 20 m after 15 seconds of recovery in hurling players. Furthermore, it appears 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 one set of three BDJs using RSI to determine individualized drop height with a 15-second intra-repetition 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 pre-determined 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 drop jump 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 employing this form of combination training which the authors are referring to as “composite training”.

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Figures

Figure 1. A schematic diagram of the experimental design for parts 1 and 2 of the study.

Figure 2. Percentage change (mean ± SD) between baseline and the respective time points (15 s, 4, 8 and 12 mins) for one, two and three sets of three BDJs for 5, 10 and 20 m.

Note:

a denotes a significant difference between 15 s and 4 mins for set 1.

b denotes a significant difference between 15 s and 12 mins for set 1.

c denotes a significant difference between baseline and 4 mins for set 1 for 5 and 10 m.

d denotes a significant difference between baseline and 12 mins for set 1 for 5 and 10 m.

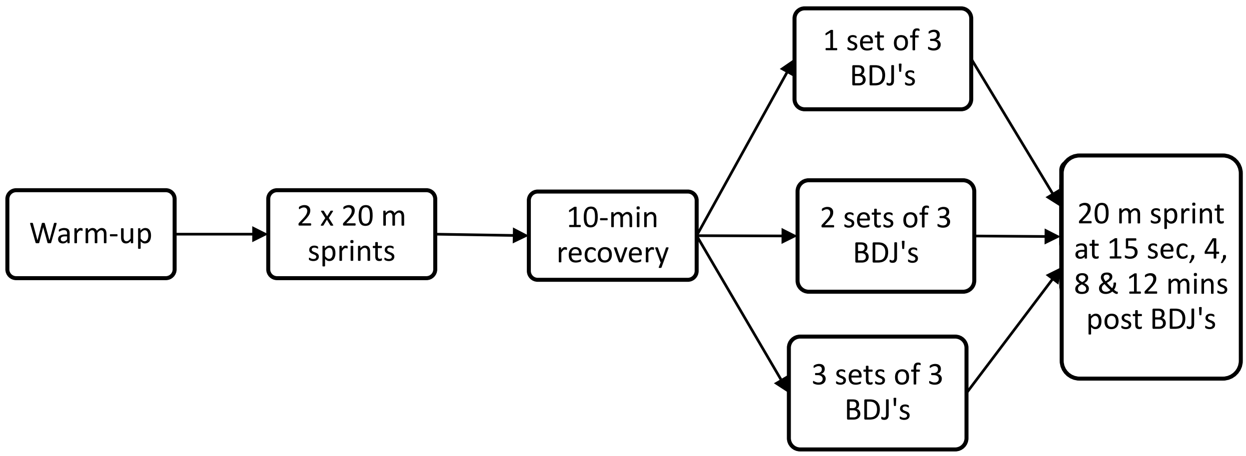
Figure 3. Percentage change (mean ± SD) between baseline and the respective time points (15 s, 4, 8 and 12 mins) for 15 s and 60 s BDJ intra-repetition recovery periods for one set of three BDJs for 5, 10 and 20 m.

Note:

a denotes a significant difference between baseline and 15 s.

Figure 1.

Part 1



Part 2

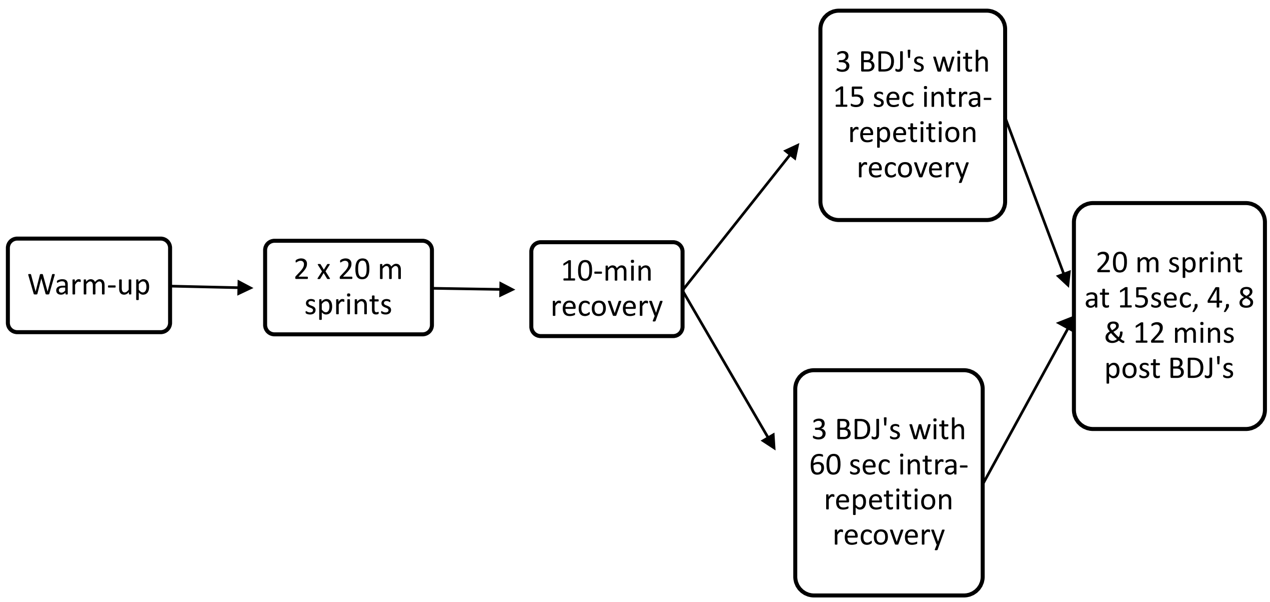


Figure 2.

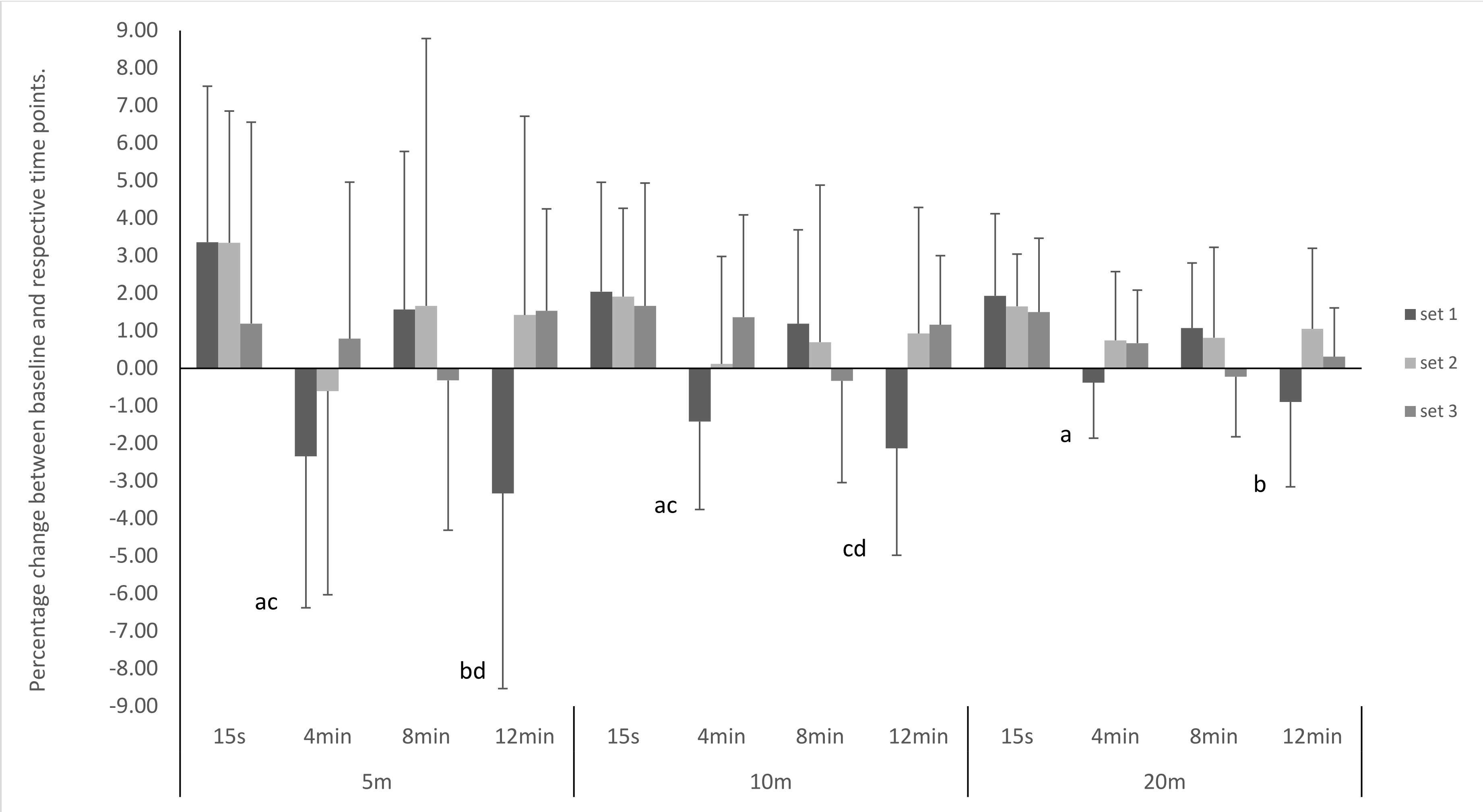

Percentage change between baseline and respective time points.
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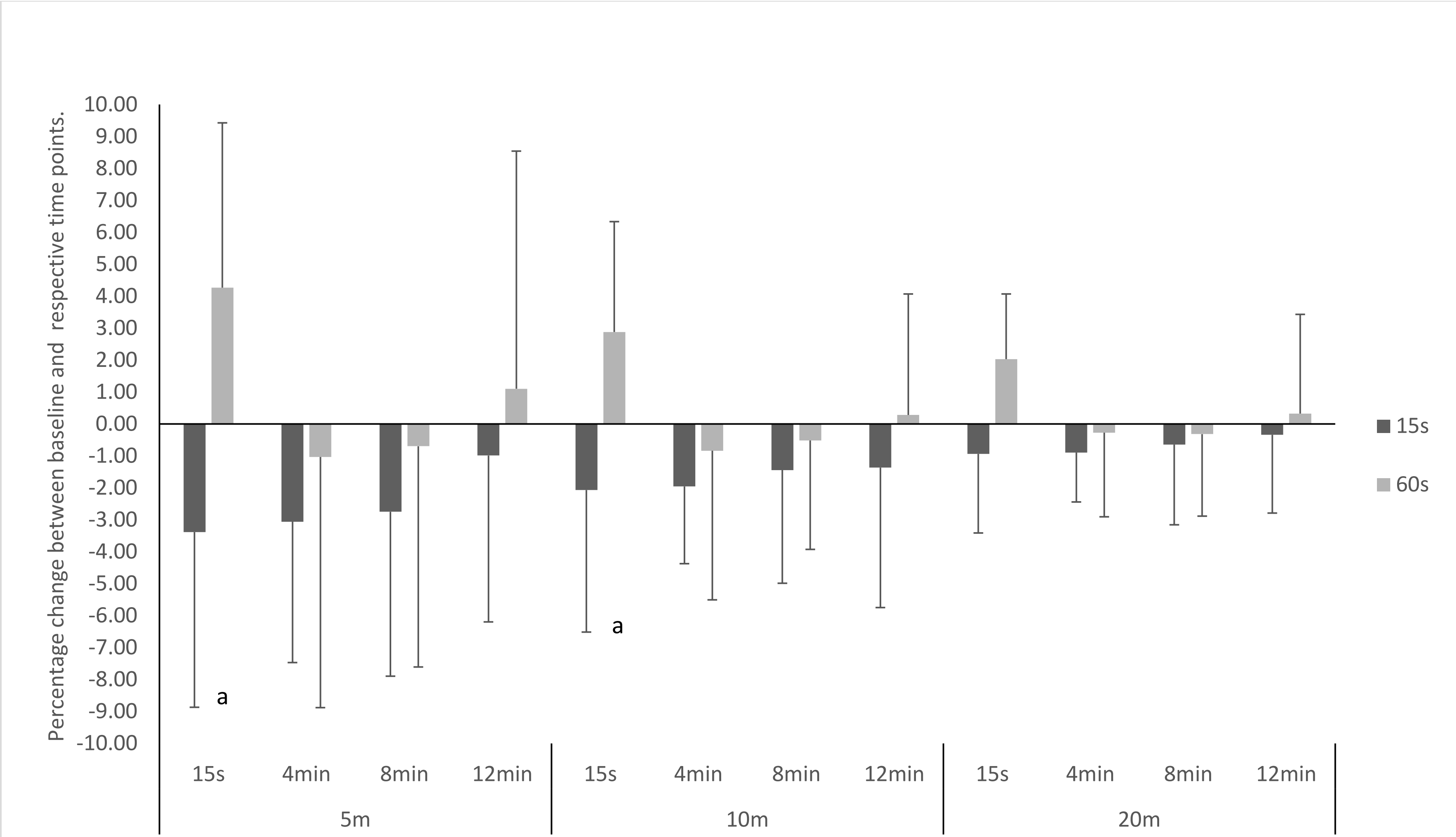
Figure 3.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20m
15s
60s

Tables

Table 1. Additional performance measures (means ± SD) and median BDJ drop height for parts one and two of the study.

Measures	Part one	Part two
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/BW	1.50 ± 0.22	1.56 ± 0.21

*CMJ = countermovement jump; RSI = reactive strength index; 3RM = absolute 3 repetition maximum back squat strength; 1RM = absolute 1 repetition maximum back squat strength; 1RM/BW = relative 1 repetition maximum back squat strength.

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).

	15s	4min	8min	12min
Part 1				
5m				
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
10m				
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
20m				
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