Acute effects of ‘composite’ training on neuromuscular and fast stretch-shortening cycle drop-jump performance in hurling players

Abstract

‘Composite’ training is a term developed by the authors and defined as the combination of a plyometric exercise with an explosive activity such as a sprint run, performed as a ‘combined repetition’ / session. The purposes of this study were to investigate the acute effect of a ‘composite’ training session on neuromuscular and fast stretch-shortening cycle bounce drop-jumps (BDJ) in hurling players’ immediately, post-session and post 7-days of recovery. Eight hurling players first completed a DJ test to identify individual BDJ drop height, followed seventy-two hours later with a single ‘composite’ training session. Three-repetition maximum (3RM) back squat strength, BDJ, countermovement jump (CMJ) and sprint performance testing were performed 10 mins pre- and immediately post-session and 7-days post-session. An ANOVA reported a significant decrease in CMJ measures (height, velocity and eccentric rate of force development (ECC-RFD)) and sprint performance from pre- to post-session ($p \leq 0.05$). Moreover, a significant increase was evident for CMJ performance (height and power), sprint performance (5 and 20 m), 3RM back squat strength and BDJ performance (RSI and height) from post-session to post 7-days recovery ($p \leq 0.05$). Pair-wise comparisons indicated that absolute and relative 3RM strength significantly increased from pre-session to post 7-days (absolute 3RM: $p = 0.0001$; relative 3RM: $p = 0.01$). The findings indicate that ‘composite’ training results in an immediate decline in CMJ measures post-session possibly due to acute muscle fatigue and super compensation augments maximum lower limb strength following 7-days of recovery.

Keywords: Maximum strength; sprint; countermovement jump; fatigue; super compensation.

INTRODUCTION

The stick and ball invasion, field sport of hurling is a form of high intensity intermittent exercise where random bouts of high-intensity activity are combined with periods of low-intensity activity (28). Furthermore, hurling match-play is unique as play can switch rapidly because of the ball being struck large distances and requires players to compete for possession aerially or on the surface of the pitch (29). Thus, hurling players are required to possess the ability to jump and catch the ball in offensive and defensive situations alongside performing high-speed runs or sprint accelerations (13). This ability to sprint accelerate is essential, as accelerations occur close to the ball and can determine the outcome of key events during match-play (29). These explosive skills, jumping and sprinting, are underpinned by appropriate levels of maximum strength to enable their effective execution (34). As these athletes compete at amateur level, training time is limited and novel training approaches are required to maximize training availability to the practitioner, hence the development of the term ‘composite’ training that aims to exploit the development of reactive strength in relation to the fast stretch-shortening cycle.

‘Composite’ training is a novel term developed from the design of a training protocol to enhance maximum strength, jumping and sprinting performance. This term was developed to differentiate from complex training, defined as resistance exercises performed prior to biomechanically similar plyometric exercises within a single session (26). ‘Composite’ training is previously defined as a combination of a plyometric exercise and an explosive activity such as jumping or sprinting used in the same combined repetition and same session (8). The inclusion of a plyometric exercise is to elicit postactivation potentiation (PAP) to enhance performance in the subsequent explosive activity i.e. jumping or sprinting. This form of training is underpinned by PAP, where force and power potentiation is sought to occur to enhance maximum and explosive strength, leading to the improved performance of jumping and sprinting (7). Previous work has shown that bounce drop-jumps (BDJ) express PAP acutely through the enhancement of sprinting over various distances (7, 24). BDJs enhance 50m sprint performance after 10-mins and 15-mins recovery and over distances of 5 to 20-m when employing a 15-s recovery (7, 24). These studies provide support for the development of ‘composite’ training as this form of training is based upon the outcome of these previous studies and are underpinned by PAP. To date, our work has compared different inter-repetition rest intervals in a ‘composite’ training session.

The author’s previous work has shown that a 4-min inter-repetition rest interval was adequate to restrict the decline in countermovement jump (CMJ) and bounce DJ (BDJ) performance immediately post-session and elicited a significant improvement in 20m sprint performance after a rest period of 7-days (8). When considering responses to a single session of plyometrics, untrained males and elite long-distance runners experience similar reductions in jump performance immediately post-session and 20 mins post, after performing countermovement DJs (32, 33). These studies did not state the plyometric experience of subjects, which may explain their post-session responses. Nonetheless, males maintained jump performance immediately post-session after performing hurdle jumps and DJs and this may be due to their familiarity with performing plyometrics (11). Moreover, national level rugby players performing various hurdle jump volumes experienced no change in jump performance immediately post-session (10). This response may be a result of players having performed hurdle jumps prior to the commencement of the study and having 2 years plyometric training experience. A further study examined responses to vertical jumps in recreational males and reported a significant reduction in sprint acceleration performance and isokinetic peak torque up 24 hrs post-session (20). This evidence appears to highlight the importance of plyometric training experience. To date, one study has examined responses to maximal sprint training in academy rugby players and reported a significant reduction in jump performance immediately post-session, despite having a minimum of 2 years’ experience of strength, power and speed training (21). However, jump power scores were similar to pre-session scores following 24 hrs of rest, but jump height and rate of force development remained significantly attenuated. The limitation of this study was that additional time points (i.e. 48 and 72 hrs) were not included in the study design to ascertain the level of recovery reached.

When focusing on a rest period of 7-days, two studies have measured plyometric and ‘composite’ training responses (8, 20). One of the studies reported a significant improvement in relative maximum 3RM strength and 20m sprint performance from pre- to post 7-days (8). Nonetheless, Highton *et al*. (20) reported sprint acceleration and peak torque scores at 7-days post-session to be similar to pre-session scores. In light of the research to date, there is a need to understand the response to a ‘composite’ training session using an appropriate volume and inter-repetition rest period.

The examination of six repetitions of ‘composite’ training where the repetition volume is based upon program recommendations suggested to improve sprint acceleration performance in track and field sprinters (19) would be valuable to understand how fatigue may affect neuromuscular and BDJ performance and to determine if super compensation is induced. Therefore, the purposes of this study were to a) report the neuromuscular and BDJ responses to a ‘composite’ training session immediately post-session and b) to investigate if super compensation would transpire following 7-days of rest.

METHODS

Experimental approach to the problem

The current study examined the 3-repetition maximum (3RM) back squat strength, BDJ (reactive strength index, height and ground contact time (GCT)), CMJ (kinetics and kinematic measures) and sprint (5, 10 and 20-m) performance responses to six repetitions of ‘composite’ training. To examine these responses, a repeated measures design was employed to compare to pre-session measures at 2 time points, immediately post-session and post 7-days of recovery (see Figure 1). A ‘composite’ training repetition was designed based upon the appropriate BDJ volume, BDJ intra-repetition recovery period and the recovery period between the BDJs and a subsequent 20-metre sprint (7).

****Figure 1 about here****

Subjects

Eight male hurling players (mean ± SD; Age = 20.3 ± 2.3 years; mass = 80.6 ± 2.5 kg; height = 185. 6 ± 2.5 cm) competing in the Irish collegiate championship season and at club level volunteered to participate in this study. Players had on average thirteen years’ experience playing the game, four years of weight training experience and one year of plyometric experience. The study took place during the players pre-season and were hurling training on average twice per week, weight training twice per week and playing a match once per week. Subjects’ had no orthopedic or musculoskeletal injuries to the lower extremities in the previous six months and written consent was obtained. Ethical approval was provided by ITCarlow and the Cardiff School of Sport and Health Sciences (Sport), Cardiff Metropolitan University.

Procedures

Subjects were tested at the same time of day to account for diurnal variations and testing was performed indoors in the laboratory. A dynamic warm-up was utilised at the beginning of the familiarization session; pre-testing and post 7-days testing in relation to the ‘composite’ training session. The warm-up comprised of five minutes of self-paced low intensity jogging, followed by a protocol of five dynamic stretches targeting the gluteals, hamstrings, adductors, quadriceps and gastrocnemius, performed over a 10 m distance (35). A week post familiarization, the first testing session determined BDJ drop height from BDJ testing from the highest reactive strength index (RSI). After a seventy-two-hour rest period, subjects performed a ‘composite’ training session of six repetitions using a 4-min inter-repetition recovery period (8). A volume of six repetitions was studied based upon programming guidelines for sprint acceleration training (19). Pre- and post-testing of CMJ, BDJ, 20 m sprint (including 5 and 10 m split times) and 3RM back squat strength were performed 10 mins prior to and immediately post-session. A second post-test was conducted after 7-days of no training to observe this period of recovery on neuromuscular and fast SSC DJ responses.

CMJ testing

Subjects were required to perform three maximal CMJs by squatting to a self-selected depth, followed by jumping upward for maximum height, taking-off and landing on a portable force plate (Type 92886AA, Kistler Instruments Ltd, Hook, United Kingdom). Hands were akimbo for the entire jump movement, and the best trial, based upon jump height was used for subsequent analysis.

Reactive strength index (RSI) testing and drop height determination

Subjects performed a BDJ test to determine their maximum RSI, which was utilized to monitor RSI and to identify drop height for BDJ training. Two BDJs from five different drop heights (0.20 m, 0.30 m, 0.40 m, 0.50 m and 0.60 m) were performed using an incremental protocol so that the stretch load (intensity) could be progressively increased. Fatigue was minimized by prescribing a 2-min rest interval between drop heights (38). The highest RSI of two BDJs for each drop height was recorded for analysis. Drop height was determined by employing the RSI method (9); which identified the drop height employed as the height that produces the maximum RSI. GCT for each BDJ jump was required to be < 0.250 s (30).

Sprint performance testing

Before maximal effort sprints, subjects performed a sprint warm-up comprising of two sprints at 50%, and three at 80% of maximum, over 20-m on a synthetic indoor track which was located in the laboratory (37). Players were allowed 30 s recovery between the 50% sprints, 1-min recovery between the 80% sprints, and 1-min recovery between the final 80% sprint and the first maximal sprint trial. Maximal 20-m sprinting commenced with players using a two-point sprint start, 0.5-m behind the first Witty photocell (Microgate, Bolzano, Italy) and were instructed when to start. Subjects performed three maximal sprints with 3-mins recovery. Split times were collected at both 5-m and 10-m, and the fastest 20-m sprint time were used for analysis.

3RM back squat strength testing

After the third maximal 20-m sprint trial was completed, a 3-min rest interval was provided before the subjects performed a modified 3RM back squat strength test protocol (16). A warm-up began with two sets of eight repetitions at 50% of predicted 1-RM followed by four repetitions at 70% predicted 1-RM. After completing the latter four repetitions, subjects attempted to perform three repetitions at a 3RM load. Testing required subjects to squat down, with a weighted bar across their shoulders, until their thighs were parallel with the ground; this position was set individually by means of a bench placed behind the lifter. A 2-min recovery and a 5-min recovery were allowed between the warm-up sets and the 3RM attempts respectively. The 3RM trials continued until the subject was unable to complete the lift through the designated range of movement. Relative strength (RS) was calculated as: RS = 3RM (kg) / body mass (kg).

Data analysis for CMJ, RSI testing and drop height determination

A portable multi-component force plate with an in-built charge amplifier (Type 92886AA, Kistler Instruments Ltd, Hook, United Kingdom) was utilized to measure force-time indices at a sampling frequency of 1000 Hz. Data were saved and analyzed using bespoke BTS-SMART software (BTS Spa, Milan, Italy).

The measures of jump height, peak velocity, peak force, peak power and average eccentric rate of force development (ECC-RFD) were calculated from the CMJ test data. Variables were derived as absolute and relative (to body mass (kg)) values except for jump height and peak velocity. Peak force was considered as the highest ground reaction force (GRF) in the vertical component during the concentric phase of the jump. Peak power was computed from the product of peak force and peak velocity of the center of mass from the CMJ. To calculate peak velocity, center of mass velocity was derived from the numerical integration of vertical acceleration; calculated by dividing the vertical GRF by the participant’s body mass. ECC-RFD was calculated during the eccentric phase of the CMJ from the force-time curve when force exceeded body weight (N), and ended when velocity was equal to zero (bottom of descent before moving in an upward direction towards take-off) (23). Jump height (H) for the CMJ and BDJ was calculated from flight time using the following equation (5):

$H = gt^2 / 8$ where: g = acceleration due to gravity ($9.81 ms^{-2}$); t = flight time (s)

BDJ GCT during the amortization phase (the timeframe in which a participant is in contact with the ground before the subsequent jump) was calculated as the time between initial foot contact and take-off (18). The RSI was calculated as: RSI = jump height (m)/contact time (s).

Statistical analyses

Means (95% confidence intervals) and SDs were provided for all measures. A one-way repeated measures ANOVA with post-hoc pair-wise comparisons using a Dunn-Sidak adjustment was performed to determine if significant differences existed between the time points of pre-session, post-session and post 7-days in relation to the composite training session. Individual pair-wise comparisons were performed on 20-m sprint time and BDJ GCT post-session to post 7-days. Effect size was calculated using Cohen's *d* where the mean of the pre-session score was subtracted from the post-session or the post 7-day score and divided by the respective pooled SD. Effect size (*d*) was interpreted as <0.2 to be trivial, 0.2-0.5 as small, 0.5-0.8 as moderate and 0.8 and above as a large *d* (12). CMJ, BDJ, 3RM back squat strength test and 20-m sprint performance measures were found to be reliable based upon ICC values ranging from 0.88 to 0.99. Statistical significance was set at $p \leq 0.05$. Statistical analyses were conducted in Statistical Package for Social Sciences Version 23 (SPSS Inc., Chicago, Illinois).

****Tables 1 and 2 about here****

RESULTS

Neuromuscular responses

CMJ

A time effect was observed for CMJ height (p = 0.0001; partial eta = 0.81; power = 1.0), peak velocity (p = 0.01, partial eta = 0.46, power = 0.80), absolute ECC-RFD (p = 0.01, partial eta = 0.43, power = 0.75) and relative ECC-RFD (p = 0.007, partial eta

= 0.50, power = 0.87). Pair-wise comparisons indicated that height and relative ECC-RFD significantly decreased from pre to post-session (height: p = 0.002; relative ECC-RFD: p = 0.04) and significantly increased from post-session to post 7-days (height: P = 0.001; relative ECC-RFD: p = 0.04). Velocity (p = 0.02) and absolute ECC-RFD (p = 0.03) showed a significant decrease from pre to post-session. Peak power (Absolute peak power: p = 0.03; relative peak power: p = 0.03) significantly increased from post-session to post 7-days (see Table 1).

Sprint performance

A time effect was evident for 5-m, 10-m and 20-m sprint time (5-m: p = 0.01, partial = 0.44, power = 0.76), 10-m (p = 0.03, partial eta = 0.57, power = 0.94) and 20-m sprint time (p = 0.001, partial eta = 0.64, power = 0.98). Pair-wise comparisons indicated that 5, 10 and 20-m time significantly increased from pre to post-session (5-m and 10-m: P = 0.04; 20-m: p = 0.03) and significantly decreased from post-session to post 7-days (5-m: p = 0.01; 10-m: p = 0.07; 20-m: p = 0.009) (see Table 2).

3RM strength

A time effect was evident for absolute 3RM (p = 0.0001, partial eta = 0.69, power = 0.99) and relative 3RM back squat strength (p = 0.001, partial eta = 0.61, power = 0.97). Pair-wise comparisons indicated that absolute and relative 3RM strength significantly increased from pre-session to post 7-days (absolute 3RM: p = 0.0001; relative 3RM: 0.01) and significantly increased from post-session to post 7-days (absolute: p = 0.01; relative 3RM: p = 0.03) (see Table 3 and Figure 2).

Fast stretch-shortening cycle drop-jumps

Pair-wise comparisons indicated significant increases in RSI (p = 0.05) and jump height (p = 0.04) from post-session to post 7-days (see Table 4).

****Tables 3 and 4 and figure 2 about here****

DISCUSSION

The current study was the first to report the neuromuscular and fast SSC DJ responses immediately post-session and following 7-days of recovery to a 'composite' training session, when using a specific volume of repetitions (19) suggested to improve sprint acceleration. The study findings indicated that certain neuromuscular measures from the CMJ (height, peak velocity and ECC-RFD) and sprint performance (5, 10 and 20-m) decreased significantly immediately post-session. Moreover, CMJ measures (height, power and relative ECC-RFD) and sprint performance (5 and 20-m) significantly increased post-session to 7-days post-session. When considering pre- to 7-days post-session, CMJ measures (Force: 10.63-11.47%, *d* = 0.82-1.07; Power: 3.53-5.45%, *d* = 0.28-0.46; Absolute ECC-RFD: 7.80%, *d* = 0.22) and 20-m (*d* = -0.23) sprint performance, displayed a trend of surpassing pre-session scores despite no statistical significance. When considering fast SSC responses, DJ height and RSI experienced significant improvements from post-session to post 7-days nevertheless did not display a trend to surpass pre-session scores. Nonetheless, GCT showed a trend to improve pre- to post-session (-4.80%, *d* = -0.33) and pre- to post 7-days (-5.48%, *d*= -0.39) despite being statistically non-significant. In terms of 3RM back squat strength, absolute and relative measures remained unchanged pre- to post-session, however, a significant improvement was evident for both measures pre-session to post 7-days recovery (Absolute 3RM: 4.73%, *d* = 0.69; Relative 3RM: 8.16%, *d* = 0.56) suggesting that super compensation transpired.

The significant decrease in CMJ height (-16.98%) post-session (Table 1) exceeds the decreases in CMJ height (10%) after a sprint training session (21) and after a drop-jump session of 50 jumps (7%) (33). Post-session power decreases (-9.9%, $p > 0.05$) in the current study are comparable to decreases after performing two repetitions of ‘composite’ training with a 4-min recovery (6.4% - 7.8%) (8), nonetheless, the power decreases are double that previously reported (4.6% - 4.7%) (21). A significant decline in ECC-RFD post-session was considerably higher when compared to athletes performing two ‘composite’ training repetitions (3.6%) (8) and the 4.9% reported by Johnston *et al*. (21). Peak concentric velocity declined significantly pre- to post-session, which is comparable to our previous work, even though the decline was insignificant (8).

The current study findings for sprint performances are challenging to compare to the literature, because a previous study assessed 5m and 10m sprint performance 24 hrs post a vertical jump training session and not immediately post-session as in our study (20). Nonetheless, our previous work (8) showed no change, whereas in the current study, sprint performance decreased significantly pre- to post-session across all distances (2.78-3.20%, *d* = 0.74-0.91).

Maximum strength responses are comparable between the current study and our previous work, from pre- to post-session and post-session to post 7-days despite the difference in repetition volume (8). However, comparing maximum strength changes in the lower limb to other studies is challenging, as to the best of our knowledge, the current study and our previous work (8) are the first to assess 3RM back squat strength changes in relation to jump, sprint or combined jump-sprint training sessions. Nonetheless, non-significant changes in concentric peak torque are evident immediately post a session of 100 drop-jumps and following 120 hrs of recovery (11).

It appears that decreases in neuromuscular performance measures, namely CMJ (height, peak velocity and ECC-RFD) and sprint performance post-session are sensitive to training volume and this provides scope for further research in terms of programming and fatigue monitoring. This volume sensitivity is based upon the responses in our previous work and the current study (8). Nevertheless, factors including the participant experience level of performing BDJs and sprints, maximum strength level, reactive strength level, training type, rest intervals, volume, intensity and duration of the training intensity should be considered. These factors appear to affect the level of fatigue experienced post-session and may influence adaptation to elicit super compensation (39).

In the current study, all BDJ measures (RSI: 10.16%; BDJ height: 14.0% and GCT: 4.8%) displayed non-significant decreases pre- to post-session which are comparable to our previous work, however, BDJ height displayed a significant pre- to post-session decrease (4-min = 14.5%) (8). Both of our studies show greater declines than that previously reported where DJ height decreased in excess of 8.7% after 8-mins post-100 DJs in untrained males (33). Furthermore, 20-mins post a session of 50 DJs, untrained males and sprinters experienced a decline in DJ height of 11.3% and 8.9% respectively (32). Comparing our findings with these two studies is challenging since differences exist in study design related to the exercise, volume and post-session rest times employed. Furthermore, Skurvydas *et al*. (33) required subjects to perform DJs with a 90-degree countermovement. A countermovement DJ technique generates attenuated GRFs, torque and power when compared to the BDJ employed in the current study (3). This technique difference may explain why our subjects experienced a greater decrease in BDJ height as torque maybe compromised. The non-significant decrease in BDJ height in the current study may be attributed to decreased knee peak joint moments, however, this variable was not measured in our study. This argument is plausible as a previous study has shown that BDJ training increases BDJ height that may have be partly due to a non-significant improvement in peak knee joint torque (1). Another possible explanation for the decrease in BDJ and CMJ height pre- to post-session is from an increase in leg stiffness. Previous research has shown that complex training increased leg stiffness (10.9%) in three single-leg DJs (15), albeit with a decrease of 3.4% in DJ flight time.

In the current study CMJ absolute and relative force displayed a small positive effect size (~3%, 0.29-0.47, $p > 0.05$) pre- to post-session, which may have enhanced leg stiffness. This possible increase in leg stiffness may have induced a non-significant reduction in BDJ GCT (-4.80%), which was found to have a small effect size (-0.33) pre- to post-session. This increase in concentric force is possibly caused by increased MTU stiffness, which may be attributed to an increased H-reflex response (2).

Augmented MTU stiffness enables elastic energy storage in the series elastic component, predominantly the tendon (4). The efficient use of this stored elastic energy occurs during the SSC pre-stretch phase is allowed by some level of leg stiffness, which is requisite for optimal SSC usage (6). Optimized fast SSC functioning requires landing with a stiff leg action coupled with minimizing GCT (14).

From our findings it appears that the cause of decreased neuromuscular and BDJ functioning may be due to peripheral fatigue mechanisms (17). Fatigue may have occurred through decreased cross-bridge activation rate and cycling rate which attenuate velocity. Decreased cross-bridge activation rate may have transpired because of impaired excitation-coupling induced by reduced Ca^+ release (25). In relation to decreased cross-bridge cycling rate, the accumulation of ADP is attributed to a decrease in peak concentric velocity (25). Furthermore, the force-velocity relationship maybe affected through decreased maximum velocity and increased curvature of this relationship, contributing to a large decrease in concentric force. Increased curvature of this relationship lowers force at intermediate velocities whereas velocity decreases at a set load, for example body mass (25). This increased curvature with a lower velocity at a given load as observed in the current study, has been related to reduced relaxation in the presence of fatigue and maybe a result of cross-bridge cycling rate decline (22). This decline in cross-bridge cycling rate in conjunction with decreased cross-bridge activation rate probably translates to a decline in ECC-RFD and peak concentric power (25). Thus, it appears these declines in ECC-RFD and peak concentric power are accountable for performance decreases in sprinting and jumping in the current study.

When comparing sprint performances from pre- to post 7-days of recovery, one study has shown 5-m sprint performance to surpass pre-session measures despite being non-significant (8). This study observed a moderate effect size (-0.82 to 0.86) for 5-m and 20-m sprint performance pre- to post 7-days. However, our current 20-m sprint performance findings display a non-significant small effect size pre- to post 7-days (*d* = -0.23).

In terms of 3RM back squat maximum strength findings pre- to post 7-days, the current study is comparable to our previous work where relative maximum strength increased significantly. However, our current findings also observed a significant absolute maximum strength improvement which had a moderate effect size whereas previous work has shown a small effect (*d* = 0.43). This finding may be attributed to a greater repetition volume and a higher maximum pre-session strength level in players.

Our findings for CMJ peak concentric force and 3RM back squat strength are in agreement with a review where maximal voluntary contractile strength recovers subsequent to a 144- to 192-hrs of rest following SSC performance (27). However, as DJs and 20-m sprint runs employ the SSC, our results provide evidence that a single session of ‘composite’ training induces a significant improvement in 3RM maximum lower limb strength after 7-days of recovery. Furthermore, the players involved in the study would be deemed to be relatively weak (31) and it appears that the training response was enhanced maximum strength (*d* = 0.56-0.69) and peak concentric force (*d* = 0.82-1.07). Future research may consider investigating whether weaker and stronger athletes respond differently to a session of ‘composite’ training in terms of CMJ peak force and maximum strength. Despite the significant increase in maximum strength pre to post 7-days, it appears that additional training sessions are required to induce dynamic correspondence leading to improved CMJ and sprint performance (36). Thus, future research could consider the minimum volume of sessions to achieve these performance improvements and to determine the effect of short-term ‘composite training.

A few limitations existed in our study. The first limitation was the reduced sample size, which came about because the recruitment of players from this amateur sport proved challenging due to their college coursework and training regime. Moreover, hurling generally lacks a transition phase in the annual training cycle for player recovery that would have been suitable for these players to participate in the study. A second limitation was the lack of re-testing at additional time points (i.e. 48 and 72 hrs). These time points were not included as the authors’ deemed that additional 3RM back squat testing, would have influenced the findings at 7-days of recovery. Nonetheless, one of the aims of the current study was to examine the acute effect of the training session and how players would respond to a period of rest to determine if the experimental design would induce super compensation.

PRACTICAL APPLICATIONS

The current study has shown that a ‘composite’ training session comprising of six repetitions (a repetition consists of 3 BDJs followed by a 20-m sprint subsequent to a 15 s rest interval) with a 4-min inter-repetition rest interval is effective at inducing a small increase in force production (based upon effect size) immediately post-session and appears to induce super compensation through enhanced 3RM back squat strength. From our data, it appears that the monitoring of peak concentric velocity and peak concentric force provides a means to understand the possible metabolic fatigue factors. Furthermore, these parameters provide insight into how ‘composite’ training acutely effects the force-velocity relationship. When focusing on the 7-day rest period, it appears that super compensation transpired in terms of peak force (large effect size) and 3RM back squat strength. Thus, performing a ‘composite’ training session where BDJs are performed with an individualized drop height induces gains in peak force production and maximum lower limb strength after 7-days of rest in relatively weak hurling players. The advantage of this form of training besides this training effect is the time efficiency of the session and minimal equipment required.

REFERENCES

1. Alkjaer, T, Meyland, J, Raffalt, PC, et al. Neuromuscular adaptations to 4 weeks of intensive drop jump training in well-trained athletes. *Physiol Rep*, 1, 2013.

2. Arampatzis, A, Schade, F, Walsh, M, et al. Influence of leg stiffness and its effect on myodynamic jumping performance. *J Electromyogr Kinesiol* 11: 355–364, 2001.

3. Bobbert, MF, Huijing, PA, van Ingen Schenau, GJ. Drop jumping. I. The influence of jumping technique on the biomechanics of jumping. *Med Sci Sports Exerc*, 19, 332-338, 1987.

4. Blazevich, A. The stretch-shortening cycle (SSC). In: *Strength and Conditioning: Biological Principles and Practical Applications*. M Cardinale, R Newton and K Nosaka, eds. Oxford, London: Wiley-Blackwell, 2011. pp. 209–222.

5. Bosco, C, Luhtanen, P, Komi, PV. A simple method for measurement of mechanical power in jumping. *Eur J Appl Physiol* 50: 273–282, 1983.

6. Butler, RJ, Crowell, HP, Davis, IM. Lower extremity stiffness: Implications for performance and injury. *Clin Biomech* 18: 511–517, 2003.

7. Byrne, PJ, Moody, JA, Cooper, S-M, et al. The potentiating response to drop-jump protocols on sprint acceleration: Drop jump volume and intrarepetition recovery duration. *J Strength Cond Res*. 2018 Jul 2. doi: 10.1519/JSC.0000000000002720. [Epub ahead of print].

8. Byrne, PJ, Moody, J, Cooper, S-M, et al. Neuromuscular and Bounce Drop-Jump Responses to Different Inter-Repetition Rest Intervals during A Composite Training

Session in Hurling Players. *International Journal of Physical Education, Fitness & Sports* 7: 1-12, 2018.

9. Byrne, PJ, Moran, K, Rankin, P, et al. A comparison of methods used to identify “optimal” drop height for early phase adaptations in depth jump training. *J Strength Cond Res* 24: 2050 – 2055, 2010.

10. Cadore, EL, Pinheiro, E, Izquierdo, M, et al. Neuromuscular, hormonal, and metabolic responses to different plyometric training volumes in rugby players. *J Strength Cond Res* 27: 3001-3010, 2013.

11. Chatzinikolaou, A, Fatouros, IG, Gourgoulis, V, et al. Time course of changes in performance and inflammatory responses after acute plyometric exercise. J Strength Cond Res 24: 1389-1398, 2010.

12. Cohen, J. Statistical Power Analysis for the Behavioral Sciences (2nd ed.). Hillsdale, NJ: L. Erlbaum Associates, 1988. pp. xxi, 567–1988.
13. Collins, K, McRobert, A, Morton, JP, et al. The work-rate of elite hurling match-play. *J Strength Cond Res* 32: 805–811, 2018.
14. Comyns, TM, Harrison, AJ, 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: 2177–2184, 2011.

15. Comyns, T. M., Harrison, A. J., Hennessy, L., et al. Identifying the optimal resistive load for complex training in male rugby players, *Sport Biomech* 6: 59–70, 2007.

16. Cunningham, DJ, West, DJ, Owen, NJ, et al. Strength and power predictors of sprinting performance in professional rugby players. *J Sports Med Phys Fitness* 53: 105–111, 2013.

17. Drinkwater, EJ, Lane, T, Cannon, J. Effect of an acute bout of plyometric exercise on neuromuscular fatigue and recovery in recreational athletes. *J Strength Cond Res* 23: 1181-1186, 2009.

18. Flanagan, EP, Ebben, WP, Jensen, RL. Reliability of the reactive strength index and time to stabilization during depth jumps. *J Strength Cond Res* 22: 1677–1682, 2008.

19. Francis, C. *The structure of training for speed*. Retrieved 7 December 2016 from charliefrancis.com, 2008.

20. Highton, JM, Twist, C, Eston, RG. The effects of exercise-induced muscle damage on agility and sprint running performance. *J Exerc Sci Fit* 7: 24-30, 2009.

21. Johnston, M, Cook, CJ, Crewther, BT, et al. Neuromuscular, physiological and endocrine responses to a maximal speed training session in elite games players. *Eur J Sport Sci* 15: 550-556, 2015.

22. Jones, DA. Changes in the force-velocity relationship of fatigued muscle: implications for power production and possible causes. *J Physiol* 588: 2977-2986, 2010.

23. Laffaye, G, Wagner, PP, Tombleson, TI. Countermovement jump height: Gender and sport-specific differences in the force-time variables. *J Strength Cond Res* 28: 1096-1105, 2014.

24. Lima, JB, Marin, D, Barquilha, G, et al. Acute effects of drop jump potentiation protocol on sprint and countermovement vertical jump performance. *Human Movement* 12: 324-330, 2011.

25. MacDougall D. & Sale D. *The physiology of training for high performance*. Oxford University Press, 2014.

26. Mihalik, JP, Libby, JJ, Battaglini, CL, et al. Comparing short-term complex and compound training programs on vertical jump height and power output. *J Strength Cond Res* 22: 47-53, 2008.

27. Nicol, C, Avela, J, Komi, PV. The stretch-shortening cycle. *Sports Med* 36: 977-999, 2006.

28. O'Donoghue, PG, Donnelly, O, Hughes, L, et al. Time-motion analysis of Gaelic games. *J Sport Sci* 22: 255-256, 2004.

29. Reilly, T, Collins, K. Science and the Gaelic sports: Gaelic football and hurling. *Eur J Sport Sci* 8: 231 – 240, 2008.

30. Schmidtbleicher, D. Training for power events. In: *Strength and Power in Sport*. PV Komi, ed. Boston,MA: Blackwell, 1992. pp. 381–395.

31. Seitz, LB, de Villarreal, ES, Haff, GG. The temporal profile of postactivation potentiation is related to strength level. *J Strength Cond Res* 28: 706–715, 2014.

32. Skurvydas, A, Dudoniene, V, Kalvenas, A, et al. Skeletal muscle fatigue in long-distance runners, sprinters and untrained men after repeated drop jumps performed at maximal intensity. *Scand J Med Sci Sports* 12: 34–39, 2002.

33. Skurvydas, A, Sipaviciene, S, Krutulyte, G, et al. Dynamics of indirect symptoms of skeletal muscle damage after stretch-shortening exercise. *J Electromyogr Kinesiol* 16: 629-636, 2006.

34. Suchomel, TJ, Nimphius, S, Stone, MH. The importance of muscular strength in athletic performance. *Sports Med* 46: 1419-1449, 2016.

35. Turki, O, Chaouachi, A, Behm, DG, et al. The effect of warm-ups incorporating different volumes of dynamic stretching on 10 and 20 m sprint performance in highly trained male athletes. *J Strength Cond Res* 26: 63–72, 2012.
36. Verkhoshansky, Y, Siff, MC. Supertraining (6th edn). Rome: Verkhoshansky, 2009.
37. West, DJ, Cunningham, DJ, Bracken, RM., et al. Effects of resisted sprint training on acceleration in professional rugby union players. J Strength Cond Res 27: 1014-1018, 2013.
38. Young, WB, Wilson, GJ, Byrne, C. A comparison of drop jump training methods: effects on leg extensor strength qualities and jumping performance. *Int J Sports Med* 20: 295-303, 1999.
39. Zatsiorsky, VM, Kraemer, WJ. *Science and practise of strength training* (2nd ed). Champaign, IL: Human Kinetics, 2006.

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Figure legends

Figure 1. Schematic diagram of study. CMJ = countermovement jump, BDJ = bounce drop-jump, 3RM = three repetition maximum back squat test.

Figure 2. 3RM back squat strength (mean ± SD) for pre-session, post-session and post 7-days the ‘composite’ training session.

*$p \leq 0.05$ increase from pre-session to post 7-days. **$p < 0.01$ increase from pre-session to post 7-days.

¥$p \leq 0.05$ increase from post-session to post 7-days.

Figure 3. Individual subject absolute 3RM back squat strength scores from pre-session to post 7 days the ‘composite’ training session.

Figure 1.

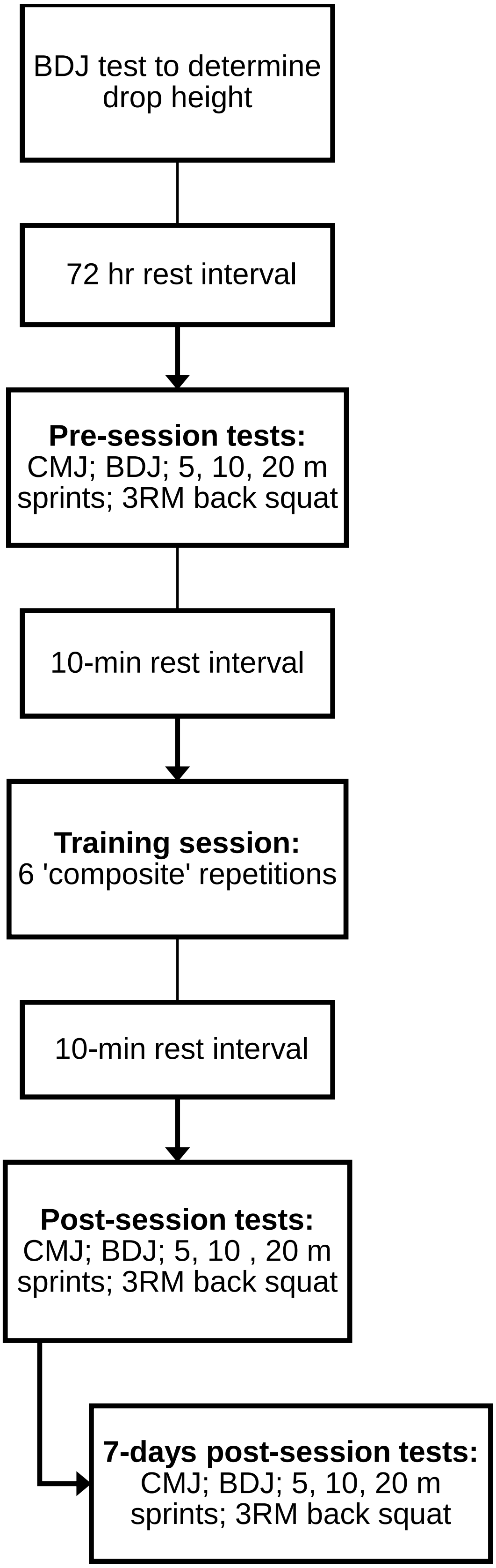
BDJ test to determine drop height
72 hr rest interval
Pre-session tests: CMJ; BDJ; 5, 10, 20 m sprints; 3RM back squat
10-min rest interval
Training session: 6 'composite' repetitions
10-min rest interval
Post-session tests: CMJ; BDJ; 5, 10 , 20 m sprints; 3RM back squat
7-days post-session tests: CMJ; BDJ; 5, 10, 20 m sprints; 3RM back squat

Figure 2.

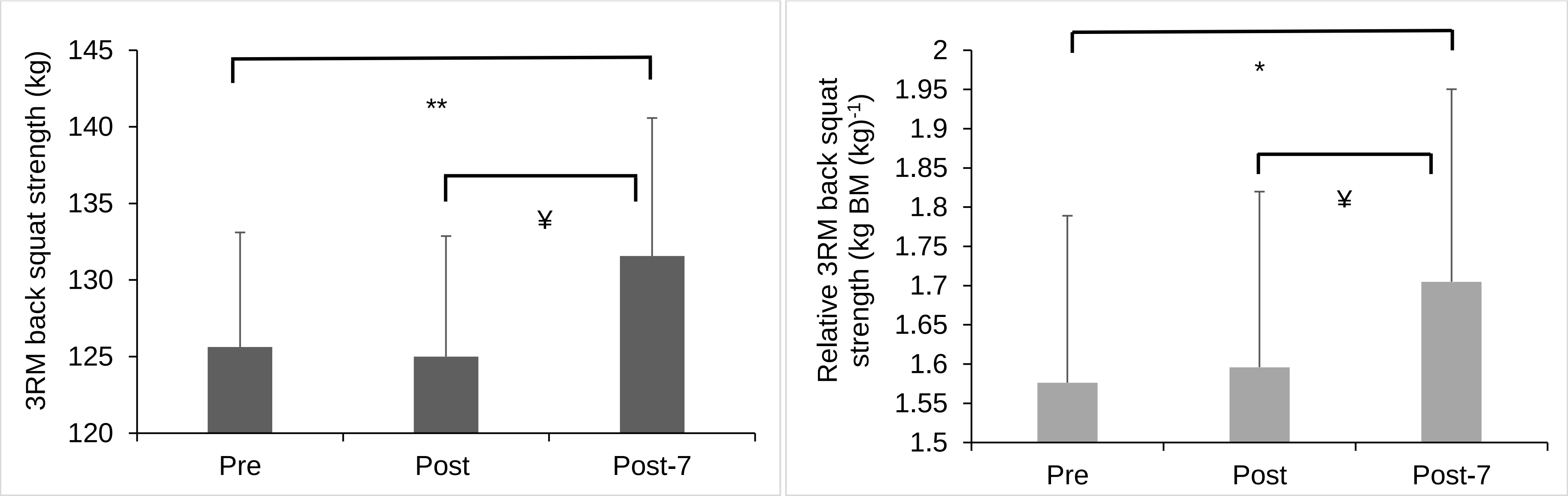
3RM back squat strength (kg)
145
140
135
130
125
120
**
¥
Pre
Post
Post-7
Relative 3RM back squat strength (kg BM (kg)-1)
2
1.95
1.9
1.85
1.8
1.75
1.7
1.65
1.6
1.55
1.5
*
¥
Pre
Post
Post-7

Figure 3.

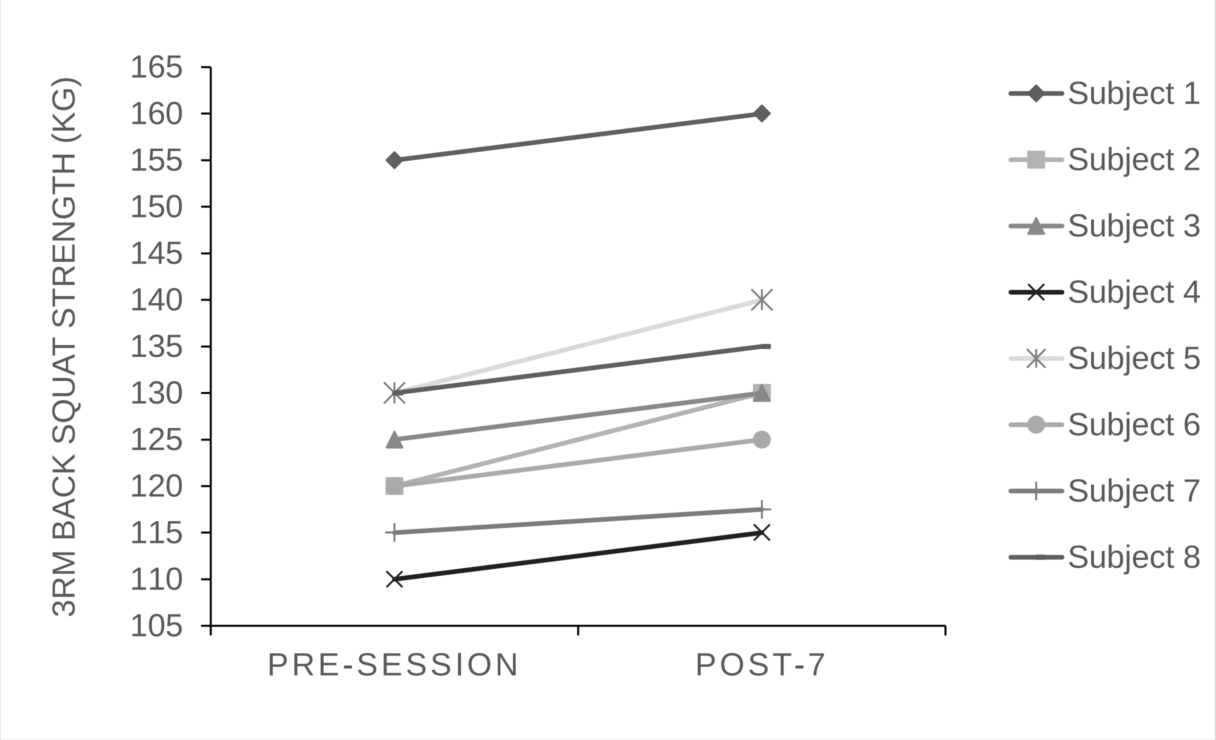
3RM BACK SQUAT STRENGTH (KG)
165
160
155
150
145
140
135
130
125
120
115
110
105
PRE-SESSION
POST-7
Subject 1
Subject 2
Subject 3
Subject 4
Subject 5
Subject 6
Subject 7
Subject 8

Table 1. CMJ measures (mean ± SD) at pre-, post- and post 7-days of the ‘composite’ training session.

	Pre (95% CI)	Post (95% CI)	%Δ1	*d*1	Post 7 (95% CI)	%Δ2	*d*2	%Δ3	*d*3
H	0.40 ± 0.01	0.33 ± 0.02**	-16.98	-1.77	0.40 ± 0.03 ¥¥	20.18	1.51	-0.22	-
(m)	(0.39-0.41)	(0.32-0.36)			(0.38-0.43)				
PV	3.01 ± 0.21	2.64 ± 0.29*	-12.28	-1.19	2.92 ± 0.19	10.74	1.02	-2.86	-0.43
(m s^{-1})	(2.83-3.18)	(2.39-2.88)			(2.76-3.08)				
PF	1745 ± 232	1804 ± 185	3.38	0.29	1931 ± 212	7.01	0.64	10.63	0.82
(N)	(1603-1991)	(1694-2003)			(1751-2105)				
PF	2.24 ± 0.18	2.32 ± .18	3.65	0.47	2.50 ± 0.27	7.54	0.76	11.47	1.07
(N kg^{-1})	(2.13-2.42)	(2.19-2.49)			(2.24-2.69)				
PP	5434 ± 853	4896 ± 829	-9.90	-0.63	5626 ± 490¥	17.03	0.96	3.53	0.28
(W)	(4721-6148)	(4202-5588)			(5216-6036)				
PP	66.47 ± 7.35	59.89 ± 9.67	-9.91	-0.74	70.09 ± 8.53¥	14.92	1.00	5.45	0.46
(W kg^{-1})	(61.33-73.63)	(53.02-69.20)			(63.63-77.90)				
RFD	5612 ± 2044	4615 ± 1421*	-17.76	-0.56	6050 ± 2040	31.08	0.79	7.80	0.22
(N s^{-1})	(4035-7453)	(3609-5984)			(4356-7767)				
RFD	7.55 ± 3.09	6.13 ± 2.00*	-18.70	-0.54	7.55 ± 2.66¥	23.11	0.59	-	-
(N kg^{-1})	(4.96-10.12)	(4.46-7.80)			(5.33-9.77)				

%Δ1 = pre- to post- percentage change; *d*1 = effect size pre- to post-session; %Δ2 = post-session to post 7-days; *d*2 = post-session to post 7-days, %Δ3 = pre- to post 7-days; *d*3 = pre- to post 7-days. H = height; PV = peak concentric velocity; PF = peak concentric force; PP = peak concentric power; RFD = eccentric rate of force development. *$p \leq 0.05$ decrease from pre- to post-session. ** $p < 0.01$ decrease from pre- to post-session. ¥$p \leq 0.05$ increase from post-session to post 7-days. ¥¥$p < 0.01$ increase from post-session to post 7-days.

Table 2. Sprint performance measures (mean ± SD) at pre-, post- and post 7-days the ‘composite’ training session.

	Pre (95% CI)	Post (95% CI)	%∆1	*d*1	Post 7 (95% CI)	%∆2	*d*2	%∆3	*d*3
5m (s)	1.01 ± 0.04 (0.98-1.04)	1.04 ± 0.05* (1.01-1.08)	3.20	0.74	1.01 ± 0.05¥ (0.97-1.05)	-3.22	-0.66	-0.12	-
10m (s)	1.76 ± 0.05 (1.72-1.80)	1.81 ± 0.07* (1.75-1.87)	2.98	0.81	1.75 ± 0.06 (1.69-1.80)	-3.38	-0.84	-0.50	-0.16
20m (s)	3.05 ± 0.08 (2.98-3.12)	3.13 ± 0.09* (3.06-3.21)	2.78	0.91	3.03 ± 0.08¥¥ (2.96-3.10)	-3.31	-1.05	-0.61	-0.23

%∆1 = pre- to post- percentage change; *d*1 = effect size pre- to post-session; %∆2 = post-session to post 7-days; *d*2 = post-session to post 7-days; %∆3 = pre- to post 7-days; *d*3 = pre- to post 7-days. *p ≤ 0.05 increase from pre- to post-session. ¥ p ≤ 0.05 decrease post-session to post 7-days. ¥¥ p < 0.01 decrease post-session to post 7-days.

Table 3. 3RM back squat measures (mean ± SD) for the 4-min and 8-min groups at pre-, post- and post 7-days the ‘composite’ training session.

	Pre (95% CI)	Post (95% CI)	%Δ1	*d*1	Post 7 (95% CI)	%Δ2	*d*2	%Δ3	*d*3
(kg)	125.63 ± 7.50 (114.13-137.11)	125.0 ± 7.80 (113.17-136.82)	-0.50	-0.05	131.56 ± 9.00**¥ (119.69-143.43)	5.25	0.47	4.73	0.69
(kg / BW)	1.58 ± 0.22 (1.39-1.76)	1.56 ± 0.23 (1.36-1.75)	1.25	0.09	1.66 ± 0.24*¥ (1.45-1.86)	6.83	0.47	8.16	0.56

%Δ1 = pre- to post- percentage change; *d*1 = effect size pre- to post-session; %Δ2 = post-session to post 7-days; *d*2 = post-session to post 7-days; %Δ3 = pre- to post 7-days; *d*3 = pre- to post 7-days. *p ≤ 0.05 increase from pre-session to post 7-days. **p < 0.01 increase from pre-session to post 7-days. ¥p ≤ 0.05 increase from post-session to post 7-days.

Table 4. BDJ measures (mean ± SD) at pre-, post- and post 7-days the ‘composite’ training session.

	Pre (95% CI)	Post (95% CI)	%∆1	*d*1	Post 7 (95% CI)	%∆2	*d*2	%∆3	*d*3
RSI (m s^{-1})	1.40 ± 0.22	1.29 ± 0.24	-	-0.61	1.42 ± 0.18*	9.85	0.57	-1.31	-
	(1.21-1.59)	(1.09-1.50)	10.16		(1.26-1.57)				
H (m)	0.29 ± 0.06	0.25 ± 0.06	-	-0.67	0.28 ± 0.04*	8.99	0.43	-6.28	-0.35
	(0.23-0.34)	(0.20-0.30)	14.00		(0.23-0.31)				
GCT (s)	0.206 ± 0.032	0.197 ± 0.029	-4.80	-0.33	0.195 ± 0.028	-	-0.05	-5.48	-0.39
	(0.179-0.233)	(0.173-0.222)			(0.172-0.218)	0.72			

%∆1 = pre- to post- percentage change; *d*1 = effect size pre- to post-session; %∆2 = post-session to post 7-days; *d*2 = post-session to post 7-days; %∆3 = pre- to post 7-days; *d*3 = pre- to post 7-days. RSI = reactive strength index; H = jump height; GCT = ground contact time. *p ≤ 0.05 increase from post-session to post 7-days.