International Journal of Strength and Conditioning

Atkins, L., Ramirez-Campillo, R., Moody, J. A., Coyle, C., & Byrne, P. J. (2024). Acute Effects of Different Inter-Repetition Rest Intervals During 'Composite' Training on Fast Stretch-Shortening Cycle and Neuromuscular Performance in Hurling Players: A Pilot Study. International Journal of Strength and Conditioning
https://doi.org/10.47206/ijsc.v4i1.277

Acute Effects of Different Inter-Repetition Rest Intervals During 'Composite' Training on Fast Stretch-Shortening Cycle and Neuromuscular Performance in Hurling Players: A Pilot Study

Luke Atkins[1], Rodrigo Ramirez-Campillo[4], Jeremy A. Moody[2,3], Colin Coyle[1] and Paul J. Byrne[1]

[1]*Department of Health and Sport Sciences, South East Technological University, Kilkenny Road Campus, Carlow, Ireland,* [2]*School of Sport and Health Sciences, Cardiff Metropolitan University, Cardiff, UK,* [3]*School of Physical Education and Sports, Nisantasi University, Istanbul, Turkey,* [4]*Exercise and Rehabilitation Sciences Institute, School of Physical Therapy, Faculty of Rehabilitation Sciences, Universidad Andres Bello, Santiago, Chile.*

ABSTRACT

One study to date has compared inter-repetition rest intervals when employing 'composite' training. Thus, the purpose of this study was to compare the acute effects of 2-, 3- and 4-mins 'composite' training inter-repetition rest intervals on fast stretch shortening cycle (SSC) and neuromuscular performance. A randomized crossover research design was employed. Drop jump (DJ), 20m sprint (with 5 and 10m splits), countermovement jump (CMJ) and isometric mid-thigh pull (IMTP) tests were performed pre-session, post-session, and 7 days post-session to observe if supercompensation occurred. A 2-min rest interval showed enhancements in fast SSC DJ performance where supercompensation may have occurred in height, velocity, force and power (Cohen's d = 0.22-0.55). A 3-minute rest interval elicited responses in 5 and 20m sprint performance (Cohen's d = -0.29 to -0.30) and isometric RFD (Cohen's d = 0.35-0.60) 7 days post-session. CMJ measures (Cohen's d = 0.22-0.76) appeared to have experienced supercompensation when employing a 4-minute rest period. Significant ($p < 0.05$) decreases in performance pre- to post-session were found for certain sprint, CMJ and IMTP variables. The 'composite' training inter-repetition rest interval used, appears dependent on the primary goal of a training cycle. However, a 3-min rest interval may be used if there are multiple goals of a training cycle due to enhancements in sprint performance, isometric RFD and CMJ height. 'Composite' training is a time-efficient method of enhancing jump, sprint, and maximal strength, which is suitable for practitioners working in sports such as hurling where time is limited.

Keywords: Plyometric exercise, drop jump, sprinting, team sport athlete.

INTRODUCTION

The sport of hurling is an intermittent field sport which incorporates a variety of different explosive movements such as jumping, sprinting, and cutting (Mullane, Turner & Bishop, 2018; Reilly & Collins, 2008;). Hurling is unique in that the play can switch rapidly due to the large distances the ball can be struck (90-100m), which is distinct from other field sports such as field hockey and soccer. Due to the physiological demands of hurling, high levels of performance training are required with emphasis on vertical jumping, sprint accelerations and maximal strength. Vertical jumping is important to contest for ball possession aerially in both offensive and defensive situations, whereas the ability to accelerate over short distances is necessary as these accelerations occur close to the ball and can determine outcomes of match play (Reilly & Collins, 2008). Hence, high levels of maximum strength and power related qualities are crucial for high levels of performance in hurling (Byrne, Moody, Cooper & Kinsella, 2021).

Post-activation potentiation (PAP) is a physiological mechanism by which the performance of an explosive activity can be enhanced by performing a conditioning activity beforehand (Blazevich & Babault, 2019). This occurs when the conditioning activity is performed at maximal or near maximal levels and occurs through two major mechanisms. These mechanisms are the phosphorylation of light chain myosin and the recruitment of higher order motor units, however other mechanisms such as a decrease in pennation angle have been suggested (Mahlfeld, Franke & Awiszus, 2004; Tillin & Bishop, 2009). The drop jump (DJ) exercise has been shown to enhance acute muscle capabilities in an explosive activity such as a sprint run and vertical jump after 15 s to 2 mins of recovery (Chen, Wang, Peng, Yu & Wang, 2013; Byrne, Kenny & O' Rourke, 2014; Byrne, Moody, Cooper, Callanan & Kinsella, 2020).

'Composite' training is a novel term used to describe a training modality and refers to the combination of a plyometric exercise and an explosive activity such as a sprint run performed as a combined repetition or session (Byrne, Moody, Cooper & Kinsella, 2018). The term 'composite' training has been developed to distinguish from 'complex' training (Comyns, Harrison, Hennessy & Jensen, 2007). The initial acute study on 'composite' training compared different inter-repetition rest intervals (4 and 8 mins) between 2 'composite' training repetitions in a single session. The study found significant decreases in countermovement jump (CMJ) force (absolute and relative) and in drop jump (DJ) measures of height and reactive strength index (RSI) pre- to post-session. Moreover, significant improvements in relative lower limb strength and sprint performance were observed and appear to have been induced by a super compensatory effect 168 hours following a single session (Byrne et al., 2018). A second study examined the acute responses to a single session of six 'composite' repetitions employing a 4-min rest interval and found a significant decrease in certain CMJ measures (height, velocity, and eccentric rate of force development (ECC-RFD) pre- post session, however, a significant increase in 3 repetition maximum (3RM) back squat strength (absolute and relative) occurred following 7 days of recovery (Byrne et al., 2021). The effects of 'composite' training has also been investigated over a 7-week timeframe when performing 2 sessions per week and compared to sprint training alone (Byrne, Moody, Cooper, Farrell & Kinsella, 2022). Both 'composite' and sprint training groups in this study significantly improved 3RM back squat strength (absolute and relative), CMJ peak velocity, and sprint performance (5, 10 and 20m) following the 7-week protocol, however the 'composite' training groups also showed significant performance enhancements in DJ ground contact time (GCT) and in certain CMJ parameters (height, force, and power). From the studies outlined above, 'composite' training with a 4-min inter-repetition rest interval can be effective in enhancing maximal strength, sprint, CMJ and reactive strength performance. However, to date only one study has investigated the effects of different inter-repetition rest periods (4 and 8 mins). The study found that there were no significant differences between 4- and 8-minutes rest periods on DJ, sprint, CMJ or maximal strength performance. Rest periods of less than 4 mins may result in greater performance benefits than longer rest periods (Bompa & Haff, 2009). Furthermore, from a practical standpoint, a reduced rest interval would be more beneficial as strength and conditioning practitioners often have limited time with their athletes in Gaelic games such as hurling.

Work to rest ratios of 1:12 - 1:20 have been recommended for maximal speed and power development (Bompa & Haff, 2009). The baseline 20m sprint times used in the previous literature were within 3-3.2 seconds meaning ~30 to 60 s should be provided to allow for the recovery of stored phosphagens and for maximum power expression. Using shorter than a 4-min rest periods as suggested above may lead to an increase in maximal sprint performance (Bompa & Haff, 2009). Rest durations of 1 to 3 mins between maximal sprint testing trials have also been reported in the literature with the aim of these trials being to attain maximal speed (Byrne et al., 2022; Carr, McMahon & Comfort, 2015; Standing & Maulder, 2019; Styles, Matthews & Comfort, 2016).

'Composite' training as described above is an effective and time-efficient method of improving athletic performance in a vertical jump, sprint run and in both reactive and maximal strength measures. The primary aim of this study was to compare different 'composite' training rest intervals of 2, 3 and 4 mins and their effects on neuromuscular and SSC performance immediately post-session and following 7 days of rest to determine if supercompensation was induced. Based upon previous studies findings, it was hypothesised that there will be no significant difference between the rest intervals and their effects of reactive strength, vertical jump, sprint acceleration and maximal strength performance.

METHODS

Study Design

A randomised crossover research design was used to compare the 'composite' training inter-repetition rest intervals of 2, 3, and 4 mins in a single session consisting of six repetitions. These passive rest intervals were selected based on previous research and published recommendations for recovery between maximal effort repetitions (Bompa & Haff, 2009; Byrne et al., 2022). DJ, 20m sprint, CMJ and isometric mid-thigh pull (IMTP) performance tests were performed pre-session, post-session, and 7 days post-session to observe if supercompensation occurred (Figure 1). The pre- and post-session performance tests were conducted 10 mins prior to and following the completion of the single session.

Participants

Eight (n=8) participants (mean ± SD; age = 26.6 ± 6.1 years, height = 182.8 ± 7.1; and mass 83.6 ± 6.8) competing in the Irish club hurling league season volunteered to participate in this study. Players had a minimum of 12 years' experience playing hurling, 2 years of resistance training experience and 1 year of previous plyometric training. Testing occurred in the participant's off-season period. On average, participants were training 2 times per week, resistance training 3 times per week, playing 1 match per week and performing 1-2 other training sessions (Running and plyometrics). No participant reported an orthopaedic or musculoskeletal lower extremity injury in the 6 months prior to the commencement of the testing. Written consent was obtained from all participants prior to testing. Ethical approval was provided by the lead author's institutional ethics committee.

Reactive strength index (RSI) and drop height determination

Participants performed a maximal DJ test prior to testing to determine their maximal RSI, which was used to assess reactive strength and to determine the individual optimal DJ height to be used in the training sessions. Two DJs were performed from five different heights (0.20m, 0.30m, 0.40m, 0.50m and 0.60m) on an incremental scale so that the stretch load could be progressively increased. To minimize fatigue, 15 s rest will be given between each jump and a further 3 mins rest will be provided between each drop height (Read & Cisar, 2001; Markwick, Bird, Tufano, Seitz & Haff, 2014). The jump with the highest RSI from each drop height was used for analysis. Optimal drop heights were determined using the RSI method, where the drop height that produced the highest RSI, while GCT remained below 0.250 s was deemed the optimal drop height (Byrne, Moran, Rankin & Kinsella, 2010).

CMJ Testing

Participants performed three CMJs with maximal intent by squatting down to a self-selected depth and jumping upward aiming to achieve maximal height. Participants took-off and landed on a portable

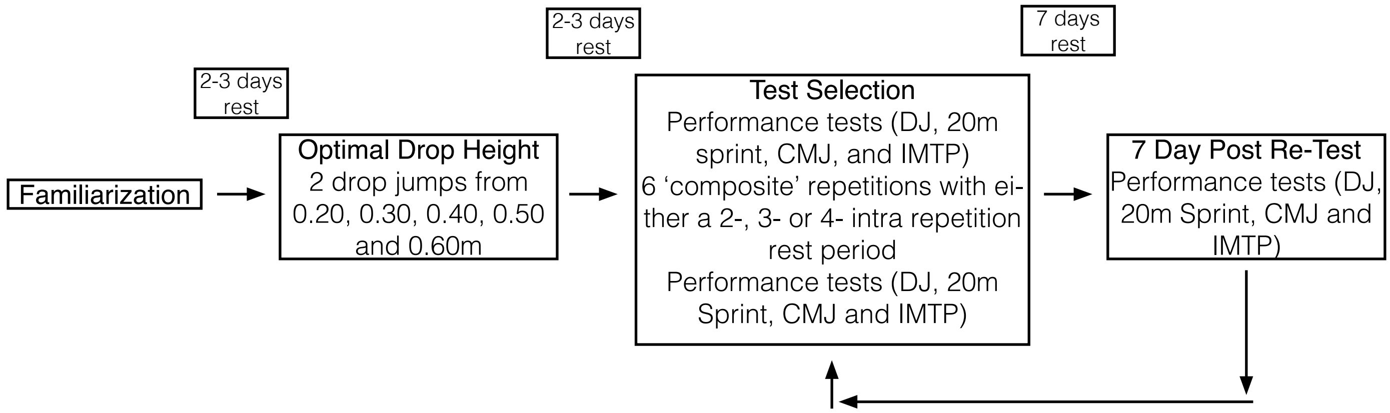

Figure 1. Schematic diagram of the study.

force platform (ForceDecks, VALD, Newstead QLD 4006, Australia). Hands were akimbo for the entire duration of the jumps. To minimize fatigue, 15 s rest was provided between each jump (Read & Cisar, 2001). The best trial of the three jumps in terms of jump height was used for analysis.

Sprint performance testing

Before maximal effort sprint trials, participants completed a sprint warm up compromising of two trials at 50%, and 3 at 80% on a synthetic indoor track in the human performance laboratory (West et al., 2013). Players were allowed 30 s recovery between 50% sprints, 1-min recovery between 80% sprints and 1 min recovery between the final warm up sprint and the first maximal effort sprint trial. Maximal effort trials began with a two-point start, 0.5m behind the behind the first Witty photocell (Microgate, Bolzano, Italy). Three maximal effort sprint trials were used with 3 mins recovery between each. Split times were collected at both 5m and 10m, and the fastest 20m sprint time was used for subsequent analysis.

Isometric mid-thigh pull testing

The IMTP testing was conducted with the participants standing on a portable force platform (ForceDecks, VALD, Newstead QLD 4006, Australia) which was placed in a portable frame (Performance Isometric Mid-Thigh Pull Rack, Perform Better, Warwickshire, England). The bar height was adjustable, to accommodate different sized participants. Once the bar height was established for each participant, each participant performed one trial rep at 50%, 75% and 90% of their perceived maximum with 60 s of rest between trials (Comfort et al., 2018). Following the warm-up trial, two to three maximal trials were performed. A third trial was completed if there was a difference of 250N in peak force between trial 1 and trial 2 (Kraska, Ramsey & Haff, 2009). Two mins recovery was provided between maximal effort trials (Thomas, Comfort, Chiang & Jones, 2015). Minimal pre-tension was allowed so that no 'slack' was in the participants' body at the start of each trial. Each trial began on the researcher's 'clap'. During each trial, each participant was instructed to pull as hard and as fast as possible for a period of approximately 5 s. The metrics of peak force, relative peak force peak rate of force development (RFD), and RFD at various time points (0-30ms, 0-50ms, 0-75ms, 0-100ms, 0-150ms, 0-200ms and 0-250ms) were obtained from the force platform and used for analysis. A sample length of 10 s was used for all trials, with a 2 s pre-trigger phase and a post-trigger phase of 8 s in duration. The 2 s pre-trigger phase represented the quiet standing phase (with slack taken off the bar to avoid any countermovement during the trial) with the IMTP trial commencing sometime at the start of the 8 s post trigger phase. The force platforms calibration was checked before and after each test session.

Data Analysis for Countermovement Jump and Drop Jump Testing

A portable dual force plate with a built-in charge amplifier (ForceDecks, VALD, Newstead QLD 4006, Australia) was used to measure the force-time measures at a sampling frequency of 1,000 Hz, and data was saved and analysed using its accompanying software (Version 2.0 8000). The independent variables of jump height, peak velocity, peak force and peak power were recorded and analysed for both the CMJ and DJ tests. Furthermore, ECC-RFD was recorded and analysed for the CMJ. For the DJ, GCT and RSI were recorded and analysed. All measures were calculated relative to body mass (kg) except for jump height, GCT, RSI and peak velocity.

Jump height for each CMJ and DJ trial was calculated using the following equation (Bosco, Luhtanen & Komi, 1983): $H = (g \times t^2) / 8$, where H = jump height (m); g = gravity (9.81 m/s-2); and t = flight time (s). Ground contact time was defined as the time between the initial foot-contact and take-off. The RSI was calculated based on the equation: RSI = flight time (s) / ground contact time (s).

Concentric peak velocity (m/s) was determined from the highest velocity in the vertical component prior to take-off. Concentric peak force (N) was the peak ground reaction force during the concentric phase. Concentric peak power was the product of peak concentric force and peak concentric velocity. ECC-RFD was determined during the eccentric phase of the CMJ from the force-time curve and commenced from peak negative velocity and ended when velocity equalled zero (Merrigan, Stone, Galster & Hagen, 2022). All variables were derived from the VALD ForceDecks software (Version 2.0 8000).

STATISTICAL ANALYSES

All statistical analyses were conducted in SPSS (Version 27). A three (time: pre-session, post-session, and 7 days post-session) by three (rest periods: 2 mins, 3 mins, and 4 mins) within-within repeated measures ANOVA was performed to determine if there was a main effect of time or rest period. Where significant effects were present, pairwise comparisons were made with a Dunn-Sidak adjustment to the statistical significance level set. Where no significant difference was found in a one-way ANOVA, a paired t-test was performed to investigate significance between two timepoints for each rest period. Where a significant interaction of time x rest period was present in a repeated measures ANOVA, a paired t-test was performed between the difference of the values at two timepoints between two different rest periods. Where no significant difference was found in a one-way ANOVA, a paired t-test was performed to investigate significance between two timepoints for each rest period. Effect sizes were also computed for each of the comparisons by dividing the difference of the two means by the standard deviation of the two samples. Effect sizes for these comparisons were estimated using Cohen's *d* and interpreted as: <0.2 = trivial, 0.2-0.5 = small, 0.5-0.8 = moderate, and >0.8 = large (Cohen, 1988). Statistical significance level was set at $p \leq 0.05$.

RESULTS

Drop Jump Responses

There was a significant effect of time and rest period for jump height in the DJ (Time: p=0.02, partial eta=0.18, power=0.66; rest period: p=0.01, partial eta=0.03, power=0.52). Significant increases in peak power (absolute and relative) were observed from post-session to 7 days post-session (p=0.02 and p=0.02 respectively) when using a 3-min rest period (Table 1).

Sprint Responses

There was a significant effect of time for both the 10m and 20m sprint times (10m: *p*=0.04, partial eta=0.20, and power=0.31; 20m *p*=0.02, partial eta=0.08 and power=0.14). A significant increase in 10m sprint time was observed using a 2-minute rest interval from pre- 7 days post-session (*p*=0.04). Similarly, a significant increase in 20m sprint time was observed from pre- post-session using a 4-min rest interval (*p*=0.04) (Table 2).

Countermovement jump responses

Significant main effects of time were observed for CMJ height and peak velocity (Jump height: *p*=0.01, partial eta=0.02, power=0.070; peak velocity: *p*=0.01, partial eta=0.30, power=0.50). One-way ANOVA reported no significant differences for jump height and peak velocity; however, a paired-t test showed a significant decrease in jump height from pre- to post-session for 2- and 4-min rest periods (*p*=0.02 and *p*=0.00 respectively) and a significant increase in jump height between post and 7 days post-session for the 4-min rest period only (*p*=0.02). Furthermore, there was a significant difference between pre- to post-session and post- 7 days post-session for peak velocity for the 4-min rest period only (*p*=0.02 and *p*=0.01). There was also a significant decrease in relative peak force from pre- 7 days post-session (*p*=0.04). Significant differences for absolute and relative peak power were also observed from pre- post-session using a 3-min rest interval (*p*=0.04 and *p*=0.04 respectively) and from post- 7 days post-session using a 4-min rest interval (*p*=0.02 and *p*=0.03 respectively). Significant interactions time x rest period were reported for CMJ relative peak force and ECC-RFD (relative peak force: *p*=0.02, partial eta=0.32, power=0.37; relative ECC-RFD *p*=0.01, partial eta =0.37, power=0.86). Paired t-tests between differences of pre- and 7 days post-session scores showed significant differences between 2 and 4 mins and 3 and 4 mins for both relative peak force (*p*=0.02 and *p*=0.04 respectively) and ECC-RFD (*p*=0.03 and *p*=0.01 respectively). Furthermore, significant differences between the difference of post- and 7 days post-session scores were observed for 2 and 4 mins and 3 and 4 mins for relative ECC-RFD only (Table 3).

Isometric mid-thigh pull responses

Significant effects of time were observed in peak force (absolute and relative) variables (absolute peak force: *p*=0.01, partial eta=0.25, power=0.40; relative peak force: *p*=0.02, partial eta=0.16, power=0.25). One-way ANOVA tests reported no significant differences in either absolute or relative peak force however, paired t-tests reported significant decreases from pre- to post-session and significant increases from post- to 7 days post-session for both absolute (*p*=0.01 and *p*=0.02) and relative peak force (*p*=0.01 and *p*=0.01 respectively) during the 3-minute rest period. Significant decreases in RFD (0-30ms) were also observed from pre- post-session during the 4-minute rest period (*p*=0.04). No other significant differences were observed for any RFD variable (Table 4).

Table 1. Drop Jump scores (mean ± SD, 95% confidence intervals) for the 2-min, 3-min and 4-min rest periods at pre-, post- and 7 days post- 'composite' training.

	Pre (95% CI)	Post (95% CI)	%Δ1	ES1	7 Days Post (95% CI)	%Δ2	ES2	%Δ3	ES3
JH (m)									
2 Min	31.1 ± 8.2 (29.1-33.1)	33.1 ± 7.0 (31.4-34.8)	6.50	0.59	31.9 ± 6.4 (30.3-33.5)	-3.63	-0.4	2.64	0.26
3 Min	32.4 ± 6.6 (30.8-34.0)	31.6 ± 7.0 (29.9-33.3)	-2.36	-0.49	32.0 ± 7.3 (30.2-33.8)	1.23	0.21	-1.16	-0.16
4 Min	32.9 ± 6.9 (31.2-34.6)	31.8 ± 5.9 (30.4-33.2)	-3.38	-0.41	31.7 ± 7.1 (30.0-33.4)	-0.43	-	-3.80	-0.42
GCT (s)									
2 Min	0.198 ± 0.030 (0.191-0.205)	0.205 ± 0.029 (0.198-0.212)	3.28	0.66	0.197 ± 0.029 (0.190-0.204)	-3.67	-0.65	-0.51	-0.04
3 Min	0.198 ± 0.035 (0.189-0.207)	0.204 ± 0.030 (0.197-0.211)	3.28	0.43	0.200 ± 0.027 (0.193-0.207)	-2.32	-0.58	0.88	0.12
4 Min	0.195 ± 0.028 (0.188-0.202)	0.197 ± 0.030 (0.190-0.204)	0.83	0.14	0.196 ± 0.031 (0.188-0.204)	-0.19	-	0.64	0.24
RSI									
2 Min	1.63 ± 0.56 (1.14-2.13)	1.65 ± 0.40 (1.30-2.01)	5.59	-	1.66 ± 0.41 (1.29-2.03)	0.54	-	5.65	-
3 Min	1.70 ± 0.46 (1.28-2.11)	1.58 ± 0.42 (1.21-1.95)	-6.20	-0.27	1.63 ± 0.41 (1.26-2.00)	3.70	0.12	-2.77	-0.16
4 Min	1.75 ± 0.52 (1.28-2.21)	1.66 ± 0.39 (1.31-2.01)	-3.14	-0.20	1.66 ± 0.48 (1.23-2.09)	-0.25	-	-4.24	-0.18
PV (m/s)									
2 Min	2.55 ± 0.32 (2.47-2.63)	2.64 ± 0.26 (2.58-2.70)	3.38	0.69	2.59 ± 0.24 (2.53-2.65)	-1.71	-0.41	1.62	0.33
3 Min	2.61 ± 0.25 (2.55-2.67)	2.58 ± 0.27 (2.51-2.65)	-1.15	-0.43	2.59 ± 0.27 (2.52-2.66)	0.73	0.23	-0.43	-0.11
4 Min	2.62 ± 0.25 (2.56-2.68)	2.59 ± 0.22 (2.54-2.64)	-1.38	-0.34	2.58 ± 0.28 (2.51-2.65)	-0.43	-0.10	-1.81	-0.42
PF (N)									
2 Min	4,563 ± 1039 (4,308-4,818)	4,460 ± 1,125 (4,184-4,736)	-2.25	-0.21	4,674 ± 1,184 (4,384-4,964)	4.80	0.61	2.44	0.22
3 Min	4,991 ± 1,413 (4,645-5,337)	4,442 ± 740 (4,261-4,623)	-11.01	-0.66	4,669 ± 1,047 (4,412-4,926)	5.11	0.57	-6.47	-0.63
4 Min	4,756 ± 1,169 (4,470-5,042)	4,936 ± 1,371 (4,600-5,272)	3.78	0.36	4,797 ± 1,185 (4,507-5,087)	-2.81	-0.24	0.86	0.26
PF (N/kg)									
2 Min	53.4 ± 9.2 (51.1-55.7)	52.4 ± 10.1 (49.9-54.9)	-1.84	-0.16	54.2 ± 9.7 (51.8-56.6)	3.48	0.47	1.57	0.14
3 Min	58.0 ± 13.3 (54.7- 61.3)	52.1 ± 7.1 (50.4-53.8)	-10.27	-0.69	54.5 ± 9.0 (52.3-56.7)	4.75	0.62	-6.01	-0.60
4 Min	55.9 ± 10.5 (53.3-58.5)	57.8 ± 11.9 (54.9-60.7)	3.29	0.35	56.1 ± 10.6 (53.5-58.7)	-2.82	-0.25	0.38	0.11
PP (W)									
2 Min	13,929 ± 4,282 (12,880-14,978)	14,074 ± 4,327 (13,014-15,134)	1.04	0.21	14,503 ± 4,441 (13,415-15,519)	3.05	0.43	4.12	0.55
3 Min	14,680 ± 4,409 (13,600-15,760)	13,657 ± 3,271 (12,586-14,458)	-6.97	-0.74	14,174 ± 3,307 (13,364-14,984) *	3.79	1.05	-3.44	-0.32
4 Min	14,494 ± 4,224 (13,459-15,529)	14,283 ± 4,365 (13,214-15,352)	-1.46	-0.30	14,370 ± 4,591 (13,245-15,495)	0.61	0.09	-0.86	-0.21
PP (W/kg)									
2 Min	162.5 ± 39.7 (152.8-172.2)	164.9 ± 41.3 (154.8-175.0)	1.48	0.26	168.4 ± 41.4 (158.3-178.5)	2.15	0.34	3.66	0.52
3 Min	171.3 ± 43.2 (160.7-181.9)	159.7 ± 31.0 (152.1-167.3)	-6.74	-0.78	165.9 ± 29.8 (158.6-173.2) *	3.86	1.02	-3.14	-0.28

	Pre (95% CI)	Post (95% CI)	%Δ1	ES1	7 Days Post (95% CI)	%Δ2	ES2	%Δ3	ES3
4 Min	158.4 ± 25.1 (152.3-164.5)	168.1 ± 43.7 (157.4-178.8)	6.10	0.28	168.6 ± 45.2 (157.5-179.7)	0.33	-	6.46	0.26

*ES1 = effect size from pre- to post-session; ES2 = effect size from post- to 7 days post-session; ES3 = effect size from pre- to 7 days post-session; GCT = ground contact time; PF = peak force; PP = peak power; PV = peak velocity; RSI = reactive strength index; * p<0.05 Significant increase from post- to 7 days post-session.*

Table 2. Sprint performance (5, 10 and 20 m) scores (mean ± SD, 95% confidence intervals) for the 2-min, 3-min and 4-min rest periods at pre-, post- and 7 days post-'composite' training session.

	Pre	Post	%Δ1	ES1	7 Days Post	%Δ2	ES2	%Δ3	ES3
5m (s)									
2 Min	1.07 ± 0.06 (1.06-1.08)	1.07 ± 0.04 (1.06-1.08)	-	-	1.08 ± 0.07 (1.06-1.10)	0.58	-	0.58	0.11
3 Min	1.08 ± 0.04 (1.07-1.09)	1.11 ± 0.07 (1.09-1.13)	2.19	0.46	1.07 ± 0.05 (1.06-1.08)	-3.28	-0.70	-1.15	-0.30
4 Min	1.09 ± 0.05 (1.08-1.10)	1.12 ± 0.10 (1.10-1.14)	3.11	0.52	1.11 ± 0.07 (1.09-1.13)	-1.12	-0.15	1.96	0.38
10m (s)									
2 Min	1.81 ± 0.07 (1.79-1.83)	1.83 ± 0.07 (1.81-1.85)	1.24	0.69	1.85 ± 0.08 (1.83-1.87) **	0.89	0.27	2.14	0.85
3 Min	1.83 ± 0.07 (1.81-1.85)	1.86 ± 0.07 (1.84-1.88)	1.36	0.49	1.83 ± 0.07 (1.81-1.85)	-1.68	-0.49	-0.34	-0.14
4 Min	1.84 ± 0.05 (1.83-1.85)	1.88 ± 0.11 (1.85-1.91)	2.18	0.56	1.85 ± 0.08 (1.83-1.87)	-1.33	-0.24	0.82	0.24
20m (s)									
2 Min	3.14 ± 0.12 (3.11-3.17)	3.17 ± 0.09 (3.15-3.19)	1.07	0.77	3.17 ± 0.11 (3.14-3.20)	-0.12	-0.11	0.96	0.61
3 Min	3.15 ± 0.12 (3.12-3.18)	3.19 ± 0.12 (3.16-3.22)	1.07	0.58	3.14 ± 0.11 (3.11-3.17)	-1.53	-0.73	-0.48	-0.29
4 Min	3.16 ± 0.10 (3.14-3.18)	3.22 ± 0.15 (3.18-3.26) #	2.02	0.86	3.16 ± 0.12 (3.13-3.19)	-1.75	-0.55	0.24	0.13

*ES1 = effect size from pre- to post-session; ES2 = effect size from post- to 7 days post-session; ES3 = effect size from pre- to 7 days post-session. # p<0.05 Significant increase from pre- to post-session. ** p<0.05 Significant increase from pre- to 7 days post-session.*

Table 3. Countermovement jump scores (mean ± SD, 95% confidence intervals) for the 2-min, 3-min and 4-min rest periods at pre-, post- and 7 days post- composite training session.

	Pre	Post	%Δ1	ES1	7 Days Post	%Δ2	ES2	%Δ3	ES3
JH (m)									
2 Min	41.9 ± 7.5 (40.1-43.7)	40.1 ± 6.9 (38.4-41.8) #	-4.18	-1.05	41.0 ± 5.8 (39.6-42.4)	2.15	0.33	-2.12	-0.28
3 Min	41.4 ± 7.5 (39.6-43.2)	40.5 ± 7.5 (38.7-42.3)	-2.05	-0.51	41.9 ± 6.7 (40.3-43.5)	3.27	0.68	1.15	0.20
4 Min	41.4 ± 6.2 (39.9-42.9)	39.7 ± 6.4 (38.1-41.3) #	-4.19	-2.27	42.1 ± 7.3 (40.3-43.9) *	6.05	1.13	1.60	0.37
PV (m/s)									
2 Min	2.79 ± 0.19 (2.74-2.84)	2.74 ± 0.20 (2.69-2.79)	-1.92	-0.70	2.79 ± 0.18 (2.75-2.83)	1.82	0.38	-0.13	-
3 Min	2.82 ± 0.21 (2.77-2.87)	2.79 ± 0.19 (2.74-2.84)	-1.28	-0.46	2.83 ± 0.17 (2.79-2.87)	1.39	0.57	0.09	-
4 Min	2.85 ± 0.19 (2.80-2.90)	2.77 ± 0.22 (2.72-2.82) #	-2.89	-1.11	2.87 ± 0.21 (2.82-2.92) *	3.61	1.74	0.61	0.22
PF (N)									
2 Min	2,011 ± 361 (1,923-2,099)	1,977 ± 376 (1,885-2,069)	-1.72	-0.57	1,836 ± 243 (1,776-1,896)	-7.13	-0.48	-8.73	-0.59
3 Min	1,978 ± 280 (1,909-2,047)	1,987 ± 307 (1,912-2,062)	0.49	0.10	1,913 ± 322 (1,834-1,992)	-3.73	-0.56	-3.26	-0.61
4 Min	1,938 ± 272 (1,871-2,005)	1,963 ± 318 (1,885-2,041)	1.33	0.21	1,997 ± 275 (1,930-2,064)	1.70	0.31	3.05	0.76
PF (N/kg)									
2 Min	23.6 ± 3.0 (22.9-24.3)	23.2 ± 3.2 (22.4-24.0)	-1.64	-0.53	22.3 ± 2.4 (21.5-23.1) **	-3.78	-0.63	-5.36	-0.92
3 Min	23.2 ± 2.6 (22.6-23.8)	23.3 ± 2.6 (22.7-23.9)	0.27	-	22.4 ± 2.5 (21.8-23.0)	-3.82	-0.49	-3.56	-0.54
4 Min	22.9 ± 2.5 (22.3-23.5)	23.1 ± 2.7 (22.4-23.8)	0.93	0.14	23.6 ± 2.4 (23.0-24.2)	1.78	0.30	2.73	0.74
PP (W)									
2 Min	4,444 ± 1,003 (4,198-4,690)	4,400 ± 1,005 (4,154-4,646)	-1.00	-0.36	4,149 ± 619 (3,997-4,301)	-5.70	-0.27	-6.65	-0.33
3 Min	4,559 ± 965 (4,323-4,795)	4,422 ± 972 (4,184-4,660) #	-3.00	-0.87	4,525 ± 948 (4,293-4,757)	2.33	0.78	-0.74	-0.24
4 Min	4,497 ± 917 (4,272-4,722)	4,402 ± 927 (4,175-4,629)	-2.12	-0.66	4,603 ± 957 (4,369-4,837) *	4.57	1.06	2.36	0.58
PP (W/kg)									
2 Min	51.9 ± 8.5 (49.8-54.0)	51.4 ± 8.6 (49.3-53.5)	-0.87	-0.30	50.3 ± 5.8 (48.9-51.7)	-2.16	-0.20	-3.01	-0.33
3 Min	53.2 ± 8.1 (51.2-55.2)	51.5 ± 8.0 (49.5-53.5) #	-3.10	-0.87	52.7 ± 7.5 (50.9-54.5)	2.35	0.74	-0.82	-0.21
4 Min	52.8 ± 7.4 (51.0-54.6)	51.6 ± 7.8 (49.7-53.5)	-2.27	-0.61	54.0 ± 8.3 (52.0-56.0) *	4.60	1.01	2.22	0.52
ECC-RFD (N/s)									
2 Min	6,271 ± 3,434 (5,430-7,112)	6,130 ± 3,747 (5,212-7,048)	-2.25	-0.22	4,948 ± 1,944 (4,472-5,424)	-19.29	-0.44	-21.11	-0.58
3 Min	6,084 ± 2,847 (5,386-6,782)	5,841 ± 2,727 (5,173-6,509)	-4.00	-0.22	5,165 ± 2,431 (4,469-5,761)	-11.57	-0.40	-15.11	-0.59
4 Min	5,455 ± 2,468 (4,850-6,060)	5,755 ± 2,905 (5,043-6,467)	5.50	0.23	6,449 ± 2,647 (5,800-7098)	12.05	0.56	18.21	0.73

	Pre	Post	%Δ1	ES1	7 Days Post	%Δ2	ES2	%Δ3	ES3
ECC-RFD (N/kg)									
2 Min	73 ± 35 (64-82)	71 ± 38 (62-80)	-2.75	-0.24	61 ± 23 (55-67)	-14.49	-0.48	-16.84	-0.72
3 Min	72 ± 32 (64-80)	68 ± 29 (61-75)	-4.54	-0.24	60 ± 26 (54-66)	-12.25	-0.38	-16.23	-0.56
4 Min	65 ± 28 (58-72)	68 ± 32 (60-76)	4.45	0.19	76 ± 28 (69-83)	12.22	0.54	17.21	0.72

*ECC-RFD = eccentric rate of force development; ES1 = effect size from pre- to post-session; ES2 = effect size from post- to 7 days post-session; ES3 = effect size from pre- to 7 days post-session; PF = peak force; PP = peak power; PV = peak velocity. # p<0.05 Significant decrease from pre- to post-session. * p<0.05 Significant increase from post- to 7 days post-session. ** p<0.05 Significant decrease from pre- to 7 days post-session.*

Table 4. Isometric midthigh pull scores (mean ± SD, 95% confidence intervals) for the 2-min, 3-min and 4-min rest periods at pre-, post- and 7 days post- composite training session.

	Pre	Post	%Δ1	ES1	7 Days Post	%Δ2	ES2	%Δ3	ES3
Force (N)									
2 Min	2,351 ± 320 (2,273-2,429)	2,308 ± 291 (2,237-2,379)	-1.83	-0.48	2,359 ± 298 (2,286-2,432)	2.24	0.51	0.36	0.17
3 Min	2,435 ± 341 (2,351-2,519)	2,335 ± 359 (2,247-2,423) #	-4.10	-1.16	2,419 ± 338 (2,336-2,502) *	3.60	1.04	-0.65	-0.17
4 Min	2,388 ± 316 (2,311-2,465)	2,335 ± 293 (2,263-2,407)	-2.22	-0.71	2,388 ± 329 (2,307-2,469)	2.28	0.46	0.01	-
Force (N/kg)									
2 Min	28 ± 2 (28-28)	27 ± 2 (27-27)	-3.84	-0.54	28 ± 2 (28-28)	3.76	0.44	-0.22	-
3 Min	29 ± 3 (28-30)	27 ± 3 (26-28) #	-5.40	-1.16	28 ± 3 (27-29) *	3.70	1.27	-1.90	-0.16
4 Min	28 ± 3 (27-29)	28 ± 3 (27-29)	-2.18	-0.65	28 ± 3 (27-29)	1.66	0.31	-0.56	-0.11
Peak RFD (N/s)									
2 Min	3,492 ± 2,164 (2,962-4,022)	3,244 ± 1,700 (2,828-3,661)	-7.09	-0.17	3,038 ± 1,329 (2,712-3,364)	-6.35	-0.17	-12.99	-0.28
3 Min	3,337 ± 1,414 (2,991-3,683)	2,932 ± 1,128 (2,656-3,208)	-12.14	-0.44	3,841 ± 2,236 (3,293-4,389)	30.99	0.56	15.09	0.35
4 Min	3,953 ± 1,974 (3,469-4,437)	3,204 ± 2,089 (2,692-3,716)	-18.94	-0.47	3,513 ± 2,089 (3,001-4,025)	9.64	0.17	-11.12	-0.21
RFD (0-30) (N/s)									
2 Min	805 ± 501 (682-928)	694 ± 524 (566-822)	-13.86	-0.39	634 ± 253 (572-696)	-8.54	-0.12	-21.22	-0.37
3 Min	687 ± 242 (628-746)	739 ± 294 (667-811)	7.44	0.14	1,128 ± 1,058 (869-1,387)	52.78	0.34	64.14	0.42
4 Min	1,381 ± 1,238 (1,078-1,684)	767 ± 662 (605-929) #	-44.48	-0.84	926 ± 563 (788-1,064)	20.75	0.25	-32.96	-0.37
RFD (0-50) (N/s)									
2 Min	1,528 ± 1,023 (1,277-1,779)	1,173 ± 802 (977-1,369)	-23.20	-0.45	1,004 ± 462 (891-1,117)	-14.44	-0.22	-34.29	-0.52
3 Min	894 ± 373 (803-985)	998 ± 463 (885-1,111)	11.61	0.22	1,998 ± 2,012 (1,505-2,491)	100.25	0.46	123.50	0.60

	Pre	Post	%Δ1	ES1	7 Days Post	%Δ2	ES2	%Δ3	ES3
4 Min	1,971 ± 1,794 (1,531-2,411)	1,334 ± 1,201 (1,040-1,628)	-32.29	-0.53	1,788 ± 1,347 (1,458-2,118)	34.00	0.31	-9.26	-
RFD (0-75) (N/s)									
2 Min	2,548 ± 1,861 (2,092-3,004)	1,740 ± 1,388 (1,400-2,080)	-31.71	-0.53	1,575 ± 893 (1,356-1,794)	-9.47	-0.13	-38.17	-0.6
3 Min	1,483 ± 764 (1,296-1,670)	1,442 ± 782 (1,250-1,634)	-2.79	-	2,767 ± 2,723 (2,100-3,434)	91.96	0.44	86.61	0.55
4 Min	2,557 ± 2,169 (2,026-3,088)	2,088 ± 1,983 (1,602-2,574)	-18.32	-0.24	2,547 ± 2,152 (2,020-3,074)	21.94	0.23	-0.40	-
RFD (0-100) (N/s)									
2 Min	3,209 ± 2,314 (2,642-3,776)	2,257 ± 1,882 (1,796-2,718)	-29.66	-0.50	2,019 ± 1,262 (1,710-2,328)	-10.55	-0.14	-37.08	-0.62
3 Min	2,141 ± 1,139 (1,862-2,240)	1,948 ± 1,078 (1,684-2,212)	-9.00	-0.13	3,097 ± 2,833 (2,403-3,791)	58.94	0.37	44.63	0.42
4 Min	3,051 ± 2,191 (2,514-3,588)	2,611 ± 2,338 (2,038-3,184)	-14.42	-0.20	2,741 ± 2,191 (2,204-3,278)	4.96	0.07	-10.18	-0.10
RFD (0-150) (N/s)									
2 Min	3,029 ± 1,913 (2,560-3,498)	2,755 ± 1,919 (2,285-3,225)	-9.03	-0.19	2,691 ± 1,505 (2,322-3,060)	-2.32	-0.05	-11.14	-0.20
3 Min	2,984 ± 1,448 (2,629-3,339)	2,469 ± 1,157 (2,186-2,752)	-17.26	-0.32	3,269 ± 2,346 (2,694-3,844)	32.42	0.34	9.56	0.18
4 Min	3,608 ± 1,090 (3,341-3,875)	2,806 ± 2,119 (2,287-3,325)	-22.22	-0.44	2,983 ± 1,951 (2,505-3,461)	6.31	0.09	-17.31	-0.32
RFD (0-200) (N/s)									
2 Min	2,941 ± 1,785 (2,504-3,378)	2,984 ± 1,545 (2,605-3,365)	1.44	-	2,869 ± 1,313 (2,547-3,191)	-3.84	-0.11	-2.45	-
3 Min	3,192 ± 1,463 (2,834-3,550)	2,785 ± 1,185 (2,495-3,075)	-12.75	-0.40	3,685 ± 2,104 (3,170-4,200)	32.33	0.59	15.45	0.40
4 Min	3,747 ± 1,920 (3,277-4,217)	2,810 ± 1,912 (2,342-3,278)	-25.02	-0.65	2,997 ± 1,672 (2,587-3,407)	6.64	0.11	-20.04	-0.47
RFD (0-250) (N/s)									
2 Min	2,675 ± 1,489 (2,310-3,040)	2,676 ± 1,076 (2,412-2,940)	-	-	2,776 ± 1,048 (2,519-3,033)	3.75	0.14	3.79	-
3 Min	3,036 ± 1,303 (2,717-3,355)	2,834 ± 1,117 (2,560-3,108)	-6.67	-0.28	3,411 ± 1,639 (3,009-3,816)	20.39	0.62	12.36	0.36
4 Min	3,392 ± 1,730 (2,968-3,816)	2,727 ± 1,558 (2,345-3,109)	-19.61	-0.55	2,799 ± 1,356 (2,467-3,131)	2.66	-	-17.47	-0.49

*ES1 = effect size from pre- to post-session; ES2 = effect size from post- to 7 days post-session; ES3 = effect size from pre- to 7 days post-session. # p<0.05 Significant decrease from pre- to post-session. * p<0.05 Significant increase from post- to 7 days post-session.*

DISCUSSION AND CONCLUSIONS

The current study compared the acute effects of different rest intervals between 'composite' training repetitions on DJ, sprint, CMJ and isometric strength performance pre- to post-session and 7 days post-session. The study findings indicated that CMJ height decreased significantly when using a 2-min rest interval, CMJ peak power (absolute and relative) and isometric force (absolute and relative) significantly decreased when using a 3-min rest interval and 20m sprint time, certain CMJ measures (jump height and peak velocity) and isometric RFD (0-30) when using a 4-min rest period decreased significantly immediately after a session. Moreover, DJ peak power (absolute and relative) scores and isometric peak force (absolute and relative) significantly increased using a 3-min rest duration and certain neuromuscular measures from the CMJ (jump height, peak velocity, and peak power (absolute and relative)) significantly increased using a 4-min rest period from post- to 7 days post-session. When considering pre-session to 7 days post-session CMJ measures relative peak force (p=0.04) and 10m sprint (p=0.04) performance using a 2-min rest period significantly declined. From the finding of this study a 4-min rest interval appears to induce primarily metabolic fatigue, a 3-min rest period appears to induce neural fatigue and a 2-min rest period appears to induce a combination of neural and metabolic fatigue (MacDougall & Sale, 2014). Based upon the findings of this study in relation to inter-repetition rest intervals examined for possibly inducing supercompensation, 2 mins appears to be appropriate for DJ, 3 mins seems best for sprint performance and isometric RFD and 4 mins appears to be appropriate for inducing improvements in CMJ performance. The hypothesis that there would be no difference between rest intervals and their effects of restive strength, vertical jump, sprint acceleration and isometric strength and RFD is rejected as the optimal inter-repetition rest period appears to be dependent on the primary training outcome.

Drop Jump Responses

In this study, a significant increase was observed in both absolute and relative peak power (p=0.02 and p=0.02 respectively) from post-session to 7 days post-session using a 3-min rest interval. No significant changes were observed in the other variables for the rest of the timepoints when using a 2-, 3-, or 4-min rest interval. A previous study using the same session with a 4-min rest period reported significant increases in jump height and RSI from post- to 7 days post-session (Byrne et al., 2021). No significant increases in DJ height and RSI were observed in this study. This could be due to the training age of the participants used. Although, all participants had a minimum of 1 year of plyometric training experience, their experience with the DJ exercise is unknown. This new stimulus could influence the recovery time between post-session and 7 days post-session (McMahon & Jenkins, 2002).

Although no significant increases from pre-session to 7 days post-session were observed, effect sizes indicated trivial-moderate improvements in DJ variables for the 2-min rest interval from pre- 7 days post-session (See Table 1). Trivial improvements were found for GCT, RSI and relative peak force; small improvements were noted for jump height, peak velocity and absolute peak force; and moderate improvements were also noted for DJ peak power (absolute and relative). It appears that supercompensation may have occurred for DJ variables that experienced a small to moderate effect (based on effect size) suggesting that a 2-min rest interval may be suitable when implementing 'composite' training if reactive strength improvements are the primary goal.

Sprint Responses

There was a significant decline in 20m sprint performance for the 4-min rest interval from pre- post session. Given that CMJ jump height, peak velocity, and isometric RFD (0-30ms) also significantly reduced from pre- post-session for the 4-min rest period, metabolic fatigue may be the cause of these performance declines. In high-intensity exercise such as sprinting, there is a rapid depletion of the high energy compound ATP and the most rapid energy resynthesis pathway PCr in conjunction with increases in ADP and Pi concentrations (Allen, Lamb & Westerblad, 2008). Increased ADP decreases maximal shortening velocity by decreasing the rate of cross-bridge cycling (Allen et al., 2008). Increased Pi levels reduces Ca2+ sensitivity, hence reducing the number of active cross-bridges, and the force generated per cross-bridge (Allen et al., 2008). Hence, we can say that the decline in 20m sprint performance from pre- post session is due to metabolic factors.

Based upon effect sizes, the 3-min rest interval appears the most appropriate for possibly inducing supercompensation in sprint performance as trivial improvement was shown for 10m sprint time and small improvements were shown in 5m and 20m sprint performance from pre- 7 days post-session. However, a significant 10m sprint performance decrement was observed from pre-session to 7 days post-session using a 2-min rest interval. Trivial-small performance decrements were also found for the 4-min rest interval for all sprint distances. Previous literature showed trivial and small improvements in 10m and 20m sprint times from pre-session to 7 days post-session using a 4-min rest interval (ES=-0.16 and ES=-0.23 respectively) (Byrne et al., 2021). In this study, similar improvements were observed in 5m, 10m, and 20m sprint performance using a 3-min rest period (ES=-0.30, ES=-0.14 and ES=-0.29 respectively) suggesting that a 3-min rest interval may be superior to a 4-min rest interval for inducing improvements in sprint performance. Thus, using a 3-min inter-repetition rest interval for sprint acceleration improvements is suggested.

Countermovement jump responses

The significant decreases from pre-post session in jump height observed in this study using a 2- (-4.18%) and 4-min (-4.19%) (*p*=0.02 and *p*=0.01 respectively) rest intervals were less than that of previous studies consisting of 2 repetitions (10%) and 6 repetitions (17%) using a 4-min rest interval (Byrne et al., 2018; Byrne et al., 2021). This decline in CMJ (7%) height is also less than a session consisting of 50 DJs (Skurvydas, Sipaviciene & Krutulyte, 2006). Decreases in both absolute and relative peak power using a 3-min rest interval (~3.3%) are also lower than what was reported in previous studies using a 4-min rest interval (10%) (Byrne et al., 2021). In this aforementioned study, consisting of six repetitions of 'composite' training, the decrease in peak power that occurred was less than the decrease that occurred in a study that used 2 repetitions using a 4-min rest interval (6.4-7.8%) (Byrne et al., 2018). In this study significant increases were observed in several CMJ parameters (height, peak velocity, peak power (absolute and relative)) from post-session to 7 days post-session for the 4-min rest interval which is in agreement with Byrne et al, (2021) who found significant improvements for height and peak power (absolute and relative).

Based on effect size in this study, supercompensation may have occurred for all CMJ variables using a 4-min inter-repetition rest interval from pre-session to 7 days post-session. Small improvements were seen shown in height and peak velocity and moderate improvements in peak force (absolute and relative), peak power (absolute and relative) and ECC-RFD (absolute and relative). However, the 2- and 3-min rest intervals induced moderate and large decreases in absolute and relative peak force respectively when using a 2-min rest period. Similarly, moderate decrements occurred in peak force (absolute and relative) and ECC-RFD (absolute and relative) when using a 3-min rest interval. Thus, a 4-min inter-repetition rest interval may be appropriate when enhancing jump performance is the primary aim of a training programme.

Isometric Mid-Thigh Pull Responses

There was a significant decrease in both absolute and relative isometric peak force from pre-session to post-session (*p*=0.01 and *p*=0.01 respectively) followed by a significant increase from post-session to 7 days post-session (*p*=0.02 and *p*=0.01 respectively) using a 3-min rest interval. This decline in maximal isometric strength could be explained by neural fatigue caused by the 'composite' training session with a 3-min inter-repetition rest interval. Neural mechanisms of fatigue such as reduced excitation from higher centres, altered reflex inputs to motoneurons, decreased motoneuron excitability and neuromuscular transmission failure can lead to a decrease in the number of cross bridges and a decrease in the force per cross-bridge, thus influencing maximal force production (Amann & Secher, 2010; Borg, Grimby & Hannerz, 1983; Enoka & Duchateau, 2008; Gandevia, 2001; Kernell & Monster, 1982; Spielmann et al., 1993).

There was a non-significant decline in absolute maximal strength from pre- post-session using a 4-min rest interval which is in agreement with previous studies (Byrne et al., 2018; Byrne et al., 2021). No significant change was observed in peak force (absolute or relative) from pre- 7 days post-session was observed in this study. This is in contrast to the aforementioned study where supercompensation occurred resulting in a significant increase in maximal strength (absolute and relative) from pre- 7 days post-session (Byrne et al., 2021). The previous study used a 3 RM back squat to measure maximal strength, despite the strong correlation between 1 RM back squat and IMTP peak force (0.97), the differences in maximal strength tests utilised makes it difficult to compare between studies (Byrne et al., 2021; McGuigan, Newton & Winchester, 2010).

Based on effect sizes, the most appropriate inter-repetition rest interval for the IMTP may be the 3-min rest interval. This rest interval showed increases in all RFD measures from pre-session to 7 days post-session from trivial (RFD - 0-150ms), small (peak

RFD, RFD - 0-30ms, RFD - 0-100ms, RFD - 0-200ms and RFD - 0-250ms) and moderate (RFD - 0-50ms and RFD - 0-75ms). These improvements in RFD may be of importance to hurling players as explosive vertical jumping and fast sprint accelerations are key requirements for success in the game (Reilly & Collins, 2008). In contrast, no improvement was observed for peak force from pre- post-session. The authors suggests that cross-bridge cycling rate and rate of cross-bridge activation had recovered in the 7-day recovery time as all IMTP RFD measures increased from pre- 7 days post-session using the 3-min rest period. Furthermore, trivial – moderate improvements were observed in absolute and relative DJ ECC-RFD (ES=0.62 and ES=0.11 respectively). Hence, the recovery of cross-bridge cycling rate and rate of cross-bridge activation may explain why increases in isometric and DJ RFD were observed, but improvements in isometric peak force were not.

The primary aim of this study was to determine the most appropriate 'composite' training inter-repetition rest interval, however, based on the findings outlined above, it is suggested that the optimal rest period may be dependent on the primary aim of a training programme. A 2-min rest period showed the best enhancements in fast SSC performance through a DJ test. Three min rest intervals elicited adaptations in sprint performance as well as improvements in isometric RFD. The best improvements in CMJ measures were shown to be greatest using a 4-min rest period. In conclusion, the optimal 'composite' training rest period is dependent on the adaptations that need to be targeted.

A limitation of this study was the limited sample size as participant recruitment proved to be difficult due to the time-commitments required by the participants college coursework, varying work schedules and training regimes. Recruitment was also challenging due to the on-going COVID-19 pandemic. In terms of future research, additional timepoints such as 2 days and 3 days post-session would be valuable to develop a greater understanding of the recovery pattern following a single session of 'composite' training. Future research should investigate the optimal recovery period between 'composite' training sessions with a larger sample size.

The current study has shown that a single session of 'composite' training can enhance SSC, sprint, jump and RFD performance in hurling players using different inter-repetition rest intervals (based upon effect size). The results suggest that altering the inter-repetition rest interval may be required depending on the specific goals of a training programme. From a practical standpoint, a 2-min inter-repetition rest interval appears to be effective in enhancing fast SSC adaptations whereas a 3-min inter-repetition rest interval seems to be appropriate to improve RFD and sprint performance. For vertical jump improvements, a 4-min inter-repetition rest interval may be suitable. Thus, 'composite' training can provide an effective, time-efficient (~16-26 mins depending on the rest period utilised) method of enhancing various components of sport performance for hurling players with minimal equipment as supercompensation (based on effect size) has been shown to occur in DJ, sprint, CMJ and IMTP RFD variables with specific rest periods. This is valuable as time with a strength and conditioning practitioner working with hurling players is often limited.

ACKNOWLEDGEMENTS

The authors would like to thank the players who agreed to volunteer their time and participate in this study.

REFERENCES

1. Allen, D.G., Lamb, G.D., & Westerblad, H. (2008). Skeletal muscle fatigue: cellular mechanisms. Physiological Reviews, 88(1), 287–332. doi: 10.1152/physrev.00015.2007.
2. Amann, M., & Secher, N.H. (2010). Point: Afferent feedback from fatigued locomotor muscles is an important determinant of endurance exercise performance. Journal of Applied Physiology, 108(2), 452–454. doi: 10.1152/japplphysiol.00976.2009.
3. Blazevich, A.J., & Babault, N. (2019). Post-activation potentiation versus post-activation performance enhancement in humans: Historical perspective, underlying mechanisms, and current issues. Frontiers in Physiology, 10, 1359. doi: 10.3389/fphys.2019.01359.
4. Bompa, T.O., & Haff, G.G. (2009). Periodization: Theory and Methodology of Training. Champaign, IL: Human Kinetics.
5. Borg, J., Grimby, L., & Hannerz, J. (1983). The fatigue of voluntary contraction and the peripheral electrical propagation of single motor units in man. Journal of Physiology, 340(1), 435–444. doi: 10.1113/jphysiol.1983.sp014771.
6. Bosco, C., Luhtanen, P., & Komi, P.V. (1983). A simple method for measurement of mechanical power in jumping. European Journal of Applied Physiology and Occupational Physiology, 50(2), 273–282. doi: 10.1007/BF00422166.

7. Byrne, P., Kenny, J., & O'Rourke, B. (2014). Acute potentiating effect of depth jumps on sprint performance. Journal of strength and conditioning research, 28(3), 610-615. doi: 10.1519/JSC.0b013e3182a0d8c1.
8. Byrne, P.J., Moody, J., Cooper, S.-M., Callanan, D., & Kinsella, S. (2020). Potentiating response to drop-jump protocols on sprint acceleration: Drop-jump volume and intrarepetition recovery duration. Journal of Strength and Conditioning Research, 34(3), 717-727. doi: 10.1519/JSC.0000000000002720.
9. Byrne, P.J., Moody, J.A., Cooper, S.-M., Farrell, E., & Kinsella, S. (2022). Short-term effects of "composite" training on strength, jump, and sprint performance in hurling players. J Strength Cond Res. 2022; 36(8): 2253-2261. doi: 10.1519/JSC.0000000000003820.
10. Byrne, P., Moody, J., Cooper, S.-M., & Kinsella, S. (2018). 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 and Sports. 7(4), 1–13. doi: 10.26524/ijpefs1841.
11. Byrne, P.J., Moody, J.A., Cooper, S.-M. and Kinsella, S. (2021). Acute effects of 'composite' training on neuromuscular and fast stretch-shortening cycle drop jump performance in hurling players. Journal of Strength and Conditioning Research, 35(12), 3474-3481. doi: 10.1519/JSC.0000000000003327.
12. Byrne, P.J., Moran, K., Rankin, P., & Kinsella, S. (2010). A comparison of methods used to identify 'optimal' drop height for early phase adaptations in depth jump training. Journal of Strength & Conditioning Research, 24(8), 2050-2055. doi: 10.1519/JSC.0b013e3181d8eb03.
13. Carr, C., McMahon, J.J., & Comfort, P. (2015). Relationships between jump and sprint performance in first-class county cricketers. Journal of Trainology, 4(1), 1–5.
14. Chen, Z.-R., Wang, Y.-H., Peng, H.-T., Yu, C.-F., & Wang, M.-H. (2013). The acute effect of drop jump protocols with different volumes and recovery time on countermovement jump performance. Journal of Strength and Conditioning Research, 27(1), 154–158. doi: 10.1519/JSC.0b013e3182518407.
15. Cohen, J. (1988). Statistical power analysis for the behavioral sciences. Hillsdale, N.J.: L. Erlbaum Associates.
16. Comfort, P., Dos'Santos, T., Beckham, G., Stone, M., Guppy, S.. & Haff, G. (2018). Standardization and methodological considerations for the isometric midthigh pull. Strength and Conditioning Journal, 41(2), 57-79. doi: 10.1519/SSC.0000000000000433.
17. Comyns, T., Harrison, A., Hennessy, L., & Jensen, R. (2007). Identifying the optimal resistive load for complex training in male rugby players. Sports Biomechanics, 6(1), 59–70. doi: 10.1080/14763140601058540.
18. Enoka, R.M., & Duchateau, J. (2008). Muscle fatigue: what, why and how it influences muscle function. Journal of Physiology, 586(1), 11–23. doi: 10.1113/jphysiol.2007.139477.
19. Gandevia, S.C. (2001). Spinal and Supraspinal Factors in Human Muscle Fatigue. Physiological Reviews, 81(4), 1725–1789. doi: 10.1152/physrev.2001.81.4.1725.
20. Kernell, D., & Monster, A.W. (1982). Motoneurone properties and motor fatigue. Experimental Brain Research, 46(2), 197–204.
21. Kraska, J.M., Ramsey, M.W., Haff, G.G., Fethke, N., Sands, W.A., Stone, M.E., & Stone, M.H. 2009. Relationship between strength characteristics and unweighted and weighted vertical jump height. International Journal of Sports Physiology and Performance, 4(4), 461–473. doi: 10.1123/ijspp.4.4.461.
22. MacDougall, D., & Sale, D. (2014). The physiology of training for high performance. OUP Oxford.
23. Mahlfeld, K., Franke, J., & Awiszus, F. (2004). Postcontraction changes of muscle architecture in human quadriceps muscle. Muscle & Nerve, 29(4), 597–600. doi: 10.1002/mus.20021.
24. Markwick, W., Bird, S., Tufano, J., Seitz, L., & Haff, G. (2014). The intraday reliability of the reactive strength index (rsi) calculated from a drop jump in professional men's basketball. International Journal of Sports Physiology and Performance, 10(4), 482-488. doi: 10.1123/ijspp.2014-0265.
25. McGuigan, M.R., Newton, M.J., Winchester, J.B., & Nelson, A.G. (2010). Relationship between isometric and dynamic strength in recreationally trained men. Journal of Strength and Conditioning Research, 24(9), 2570–2573. doi: 10.1519/JSC.0b013e3181ecd381.
26. McMahon, S., & Jenkins, D. (2002). Factors affecting the rate of phosphocreatine resynthesis following intense exercise. Sports Medicine, 32(12), 761–784. doi: 10.2165/00007256-200232120-00002.
27. Merrigan, J. J., Stone, J. D., Galster, S. M., & Hagen, J. A. (2022). Analysing force-time curves: Comparison of commercially available automated software and custom MATLAB analyses. Journal of Strength and Conditioning Research, 36(9), 2387-2402. doi: 10.1519/JSC.0000000000004275.
28. Mullane, M., Turner, A., & Bishop, C.J. (2018). Strength and Conditioning Considerations for Hurling: An Amateur Gaelic Games Sport. Strength and Conditioning Journal, 40(4), 72-84. doi: 10.1519/SSC.0000000000000381.
29. Read, M.M., & Cisar, C. (2001). The influence of varied rest interval lengths on depth jump performance. Journal of Strength and Conditioning Research, 15(3), 279–283.
30. Reilly, T., & Collins, K. (2008). Science and the Gaelic sports: Gaelic football and hurling. European Journal of Sport Science, 8(5), 231–240. doi: 10.1080/17461390802251851.
31. Skurvydas, A., Sipaviciene, S., Krutulyte, G., Gailiuniene, A., Stasiulis, A., Mamkus, G., & Stanislovaitis, A. (2006). Dynamics of indirect symptoms of skeletal muscle damage after stretch-shortening exercise. Journal of Electromyography and Kinesiology, 16(6), 629–636. doi: 10.1016/j.

jelekin.2005.11.002.
32. Spielmann, J.M., Laouris, Y., Nordstrom, M.A., Robinson, G.A., Reinking, R.M., & Stuart, D.G. (1993). Adaptation of cat motoneurons to sustained and intermittent extracellular activation. Journal of Physiology, 464, 75–120. doi: 10.1113/jphysiol.1993.sp019625.
33. Standing, R., & Maulder, P. (2019). The effectiveness of progressive and traditional coaching strategies to improve sprint and jump performance across varying levels of maturation within a general youth population. Sports, 7(8), 186. doi: 10.3390/sports7080186.
34. Styles, W.J., Matthews, M.J., & Comfort, P. (2016). Effects of strength training on squat and sprint performance in soccer players. Journal of Strength & Conditioning Research. 30(6), 1534–1539. doi: 10.1519/JSC.0000000000001243.
35. Thomas, C., Comfort, P., Chiang, C.-Y., & Jones, P.A. (2015). Relationship between isometric mid-thigh pull variables and sprint and change of direction performance in collegiate athletes. Journal of Trainology, 4(1), 6–10.
36. Tillin, N., & Bishop, D.J. (2009). Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. Sports Medicine, 39(2), 147–66. doi: 10.2165/00007256-200939020-00004.
37. Turki, O., Chaouachi, A., Behm, D.G., Chtara, H., Chtara, M., Bishop, D., Chamari, K., & Amri, M. (2012). The effect of warm-ups incorporating different volumes of dynamic stretching on 10- and 20-m sprint performance in highly trained male athletes. Journal of Strength & Conditioning Research, 26(1), 63-72. doi: 10.1519/JSC.0b013e31821ef846.
38. West, D.J., Cunningham, D.J., Bracken, R.M., Bevan, H.R., Crewther, B.T., Cook, C.J., & Kilduff, L.P. (2013). Effects of resisted sprint training on acceleration in professional rugby union players. Journal of Strength and Conditioning Research, 27(4), 1014–1018. doi: 10.1519/JSC.0b013e3182606cff.