Original research article

International Journal of Sports Science & Coaching

International Journal of Sports Science & Coaching
1–10

DOI: 10.1177/17479541231174316
journals.sagepub.com/home/spo
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The stability of the deadlift three repetition maximum

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Abstract

This study investigated the stability of three repetition maximum (3RM) strength during the deadlift. Eleven participants performed four testing sessions comprising a one repetition maximum test and 3RM tests separated by 48 h. Preparedness was assessed before each testing session using countermovement jumps and by measuring barbell velocity during each set of deadlifts. Trivial statistically significant differences were determined for the 3RM between T1 and both T2 ($p = 0.012$; ES [95% CI] = −0.1 [−0.58, 0.41]) and T3 ($p = 0.027$; ES [95% CI] = −0.09 [−0.57, −0.43]). No significant differences were noted between T2 and T3 ($p = 0.595$; ES [95% CI] = 0.01 [−0.49, 0.50]). No significant differences in jump height ($p = 0.071$), time-to-take-off ($p = 0.862$), eccentric displacement ($p = 0.209$), or mean force during any countermovement jump sub-phase were found between each session ($p = 0.529$–0.913). Small differences in barbell mean velocity were found between both T1–T2 (effect size statistics (ES) = −0.21–0.27) and T2–T3 (ES = 0.31–0.48), while trivial differences were found at others. Therefore, 3RM deadlift strength appears stable enough over a microcycle to continue using traditionally recommended heavy/light programming strategies.

Keywords

Barbell, load-velocity profile, resistance training, strength, vertical jump

Introduction

Resistance training is prescribed by strength and conditioning professionals when seeking to improve the physical qualities that underpin successful sports performance, such as the athlete's ability to generate force.[1] To achieve this goal, the loads performed by the athlete have typically been prescribed as a function of a known maximum (i.e. the athlete's one repetition maximum (1RM) or a predetermined number of repetitions (xRM) with a known load).[1] However, some researchers and practitioners have suggested that the use of loads corresponding to percentages of the athlete's 1RM is excessively hazardous for non-strength sports athletes and does not adequately account for daily fluctuations in strength due to factors such as sleep, nutrition, and general preparedness.[2,3]

It has been suggested that 1RM back squat strength estimated using a load-velocity profile (LVP) can vary daily by as much as ±18% of 1RM,[2,4,5] which would lead to strength and conditioning professionals either under- or overloading their athlete relative to their current physical capacity when using traditional programming methods. Contrary to this contention, Banyard et al.[6] and Ruf et al.[7] both demonstrated that directly measured 1RM back squat and deadlift did not vary by this amount, while Vernon et al.[8] reported that 1RM back squat strength was unaffected in the 96 h following a resistance training bout of five sets of back squats not performed to failure. Peak velocity during the countermovement jump (CMJ) was also unchanged, while moderate differences in mean velocity (MV) during back squats with ≥60% 1RM were found, indicating that variation in performance may be specific to the testing modality used.[8] Additionally, even after 24 h of sleep loss, both 1RM

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clean and jerk and snatch performance have been reported to remain unchanged from baseline.[9] However, when substantial volumes of resistance training are performed to failure 1RM does not appear to return to pre-exercise levels after 48 h of recovery.[10] Further, differing temporal profiles of recovery have been reported for CMJ performance versus maximal isometric strength after multiple resistance exercises performed to failure,[11] indicating differential effects of training on athlete preparedness depending on the mode of resistance exercise and monitoring test performed.

While directly measured 1RM lower-body strength seems relatively stable between days unless moderate to high volumes of highly fatiguing maximal intensity training is performed, it is common for novice lifters or non-strength athletes not to use 1RM tests when assessing their maximal dynamic strength. Instead, tests like the three repetition maximum (3RM) are commonly recommended,[12,13] with little information regarding their stability available in the current body of scientific literature. Given the increase in volume that xRM testing entails, it is plausible that a greater level of fatigue will be induced and therefore preparedness will be suppressed for an elongated period of time.[14,15] Moreover, the fact that xRM testing is performed to volitional failure may lead one to hypothesize that the possible increased levels of fatigue associated with this practice will exacerbate the variability of an athlete's strength levels on a day-to-day basis.[2] Whether this is the case, however, remains unknown. This presents a conundrum for strength and conditioning professionals wishing to use results from dynamic strength tests such as a 3RM or five repetition maximum (5RM) to prescribe training loads, as fluctuations in strength over the course of a microcycle may result in them inadvertently over or under-loading the athlete in relation to their capacity on a given day.[2]

As such, the primary aims of the study was to determine whether the 3RM deadlift changed over the course of a microcycle and the impact of repeated lower-body strength testing on commonly used measures of preparedness such as the CMJ and barbell velocity during submaximal warm-up sets.[16,17] To determine whether the reported variation in lower-body maximum strength was a result of the method used to estimate it on a daily basis, we also aimed to determine the agreement between 3RM estimated using an LVP and the directly measured 3RM. We hypothesized that 3RM strength and CMJ jump height would not vary across the microcycle,[6–8] but time-dependent CMJ variables and the velocity during each warm-up set of deadlifts would change from session to session.[8,18] Finally, we hypothesized that the LVP estimation of 3RM would not agree with directly measured 3RM.[19]

Materials and methods

Experimental approach

A within-participant, repeated measures design was used to determine whether the 3RM deadlift changed over the course of a microcycle and the impact of repeated lower-body strength testing on measures of preparedness. Participants undertook four sessions during this study. The first session (T0) involved the collection of signed informed consent, the recording of anthropometric data (i.e. height and body mass), and the assessment of the participants' 1RM deadlift. The next three sessions (T1, T2, and T3) involved the assessment of the participants' 3RM deadlift during each testing session, with barbell displacement captured during each warm-up and maximal effort repetition. Before commencing each 3RM deadlift test, participants performed a series of maximal CMJs, which served as a practical measure of fatigue.[20] T0 and T1 were separated by 72 h, and T1, T2, and T3 were each separated by 48 h.

Participants

Based on a detectable effect size of $f = 0.2$, an expected repeated measures correlation of $r = 0.9$, and an expected power of 0.8 ($1 - \beta = 0.82$), an estimated sample size of 10 participants was calculated using G*Power software (version 3.1.9.4).[21] Eleven resistance-trained participants were recruited to take part in this study (body mass: 97.6 ± 19.3 kg; height: 1.8 ± 0.1 m; age: 28 ± 4 years; 1RM deadlift: 182.3 ± 34.1 kg, Relative 1RM deadlift: 1.9 ± 0.1 kg/kg). Participants were included in the study if they were between the ages of 18 to 40, could deadlift >1.5× body mass, and had been resistance training for longer than one year. Before undertaking any experimental protocols, participants were provided information regarding the potential risks and benefits of participating in the study and returned voluntarily signed informed consent. Ethical approval for the study was granted by the Edith Cowan University Human Research Ethics Committee (Project 2020-01193).

CMJ testing and analysis

After a standardized warm-up of dynamic stretches, bodyweight (BW) exercises (i.e. squats and lunges), and submaximal vertical jumps, participants performed five maximal CMJs while standing on dual in-ground force plates (Type 9287; Kistler Instruments, Winterthur, Switzerland). Participants were instructed to stand as still as possible for a minimum of 1 s with arms akimbo for at least 1 s before a countdown of "3, 2, 1, Jump!"[20] Upon receiving this countdown, participants jumped "as fast and as high as possible," with each trial separated by 1 min. Trials were repeated if a stable pre-trial force trace was not maintained or the participant's hands left their hips during the movement.[20] Vertical ground reaction force was collected at 1000 Hz using Vicon Nexus software (version 2.12; Vicon, Oxford, UK) and exported for analysis in a custom Excel spreadsheet (Microsoft Corp, WA, USA) as a summated force-time curve. Before processing, summated force-time curve data were filtered using a fourth-order, zero-lag Butterworth low-pass filter with a cut-off frequency of 65 Hz.[22] The cut-off frequency for the low-pass filter was determined via residual analysis.[22] After calculating BW as the average force during a 1-s quiet standing period,[23] the start of the jump was identified using a two-step process. The first meaningful change in force was identified as the point where force exceeded BW ± 5 SDs.[23] A backward search of the force-time curve data was then performed from this point to identify the last instance where BW occurred, which indicated the start of the jump.[24] Center of mass velocity was calculated by dividing the net force by body mass and integrating the product with respect to time using the trapezoid rule.[25] Center of mass displacement was then calculated by integrating the velocity-time record, again using the trapezoid rule.[25] Take-off was defined as the first instance where force was <20 N.[26] Subphases of the CMJs were identified based on previous recommendations.[26] Jump height was calculated from the vertical velocity at take-off plus the vertical displacement of the center of mass at take-off.[27] Mean force (MF) during specific subphases (eccentric yielding, eccentric braking, and concentric), eccentric displacement, and time-to-take-off were also calculated to assess changes in jump strategy.[28] The five trials were then averaged for statistical analysis.

Maximum strength testing

The 1RM testing during T0 was performed according to the procedures outlined by Ruf et al.[7] Briefly, the participants performed a series of low-volume sets of deadlifts with a standard 20 kg barbell (Armortech, Australia), using loads relative to their estimated 1RM (20%, 40%, and 60% 1RM). Once they reached 80% of their estimated 1RM, only single repetition sets were performed. A maximum of five 1RM attempts were allowed, with 5 min of rest between each attempt. During the warm-up sets in the 3RM testing sessions, participants performed three repetitions at 40%, 60%, 80%, and 90% of their estimated 3RM. The first 3RM attempt was set at approximately 92% of the participant's deadlift 1RM.[29] During all repetitions, participants were instructed to perform the concentric phase as fast as possible while keeping their feet flat on the ground.[7] Approximately 1.5 s separated each repetition to ensure the lift began from a stationary position.[30] If an attempt was successful, the load was increased by a minimum of 2.5 kg, with the exact magnitude of the increase determined through discussion between the participant and the investigator. If an attempt was unsuccessful, the participant was allowed one further attempt at the same load. The load of the last successful attempt was recorded and used for further analysis. Warm-up sets were separated by 3 min of rest and maximal attempts by 5 min of rest.[31]

Data acquisition and processing

During each repetition, barbell displacement was recorded using 3D motion capture. A 20 mm reflective marker was placed at each end of the barbell, with the displacements of these markers recorded via an eight-camera motion capture system (Vicon MX; Vicon, Oxford, UK) sampling at 250 Hz using Vicon Nexus software (version 2.12; Vicon, Oxford, UK). Before each testing session, the capture space was calibrated according to the manufacturer's instructions, with a maximum acceptable image error of 1.5 mm. After collection and gap-filling using standard procedures, marker displacement-time data were exported for offline analysis in a custom Excel spreadsheet. Displacement-time data were smoothed using a fourth-order, zero-lag Butterworth low-pass filter with an 8 Hz cut-off frequency.[22] The cut-off frequency was determined via residual analysis. Displacement at the center of the barbell was then calculated by averaging the positions of the markers at each end, with barbell velocity then calculated as the first derivative of displacement and time using the central difference method.[22] The start of each trial was identified as the first frame where the barbell rose more than 30 mm from its initial position, while the end of the concentric phase was identified as the frame where peak displacement occurred.[32] MV was calculated as the average velocity between these two points. The fastest MV during each warm-up set was carried forward for statistical analysis.[33] To determine whether the reported difference in strength between baseline and a daily estimation was a function of the method used to assess it, deadlift 3RM in each session was then estimated by constructing individualized load-velocity profiles using these velocities in a custom Excel spreadsheet.[2]

Statistical analyses

Descriptive statistics were calculated as means and standard deviations. After visual inspection of Q–Q plots and performing the Shapiro–Wilk test to confirm the assumption of normality was met, differences in 3RM deadlift strength, jump height, sub-phase MF, eccentric displacement, and time-to-take-off between testing sessions were assessed using separate 1 × 3 (session) repeated measures analysis of variances (ANOVAs). The alpha level was set at $\alpha = 0.05$. Where the assumption of sphericity was violated, the Greenhouse–Geisser correction was applied. Where non-normal distributions were found (3RM strength, time-to-take-off, CMJ MF, and eccentric displacement), a Friedman test was performed, and sequentially rejective Conover tests were used to explore any differences found. To estimate the magnitude of the difference in MV during each warm-up set between testing sessions, Hedges *g* effect sizes were calculated and interpreted as trivial (<0.2), small (0.2–0.6), moderate (>0.6–1.2), large (>1.2–2.0), and very large (>2.0).[34,35] Cliff's delta effect size statistics (ES) were used to assess the magnitude of differences in 3RM strength between sessions due to the occurrence of non-normal distributions and were interpreted as trivial (<0.147), small (0.147–0.33), moderate (>0.33–0.474), or large (>0.474).[36] Agreement between actual and LVP estimated deadlift 3RM was assessed by calculating the mean bias and 95% limits of agreement.[37] Limits of agreement of <±5 kg were considered acceptable.[38] Proportional bias was deemed present if the intercept for the relationship between the averages and the differences differed significantly from zero.[39] Statistical analyses were performed in the R programming language (version 4.2).[40] Repeated measures ANOVAs were performed using the *afex* package (version 1.1-1),[41] post hoc tests were performed using the *emmeans* package (version 1.7.4-1),[42] and both Hedges *g* and Cliff's delta ESs with bias-corrected and accelerated 95% confidence intervals (CIs) were calculated in a custom script.[35,36,43] Friedman's tests and Kendall's W effect size calculations were performed using the *rstatix* package (version 0.7.0).[44] Sequentially rejective Conover tests were performed using the *PMCMRplus* package (version 1.9.4).[45] Then 95% limits of agreement were calculated according to the procedures of Bland and Altman[37] and were adjusted where proportional bias was present.[39] Between-session reliability of each variable was determined by calculating the intra-class correlation ($ICC_{3,1}$) with 95% CIs using the *irr* package (version 0.84.1)[46,47] and the coefficient of variation (CV) in a custom script.[48] The ICCs were interpreted based on the lower bound of the 95% CI, with values of <0.5, 0.5–0.75, >0.75–0.9, and >0.9 indicative of poor, moderate, good, and excellent relative reliability.[47] The magnitude of the CV was interpreted as good (<5%), moderate (5%–10%), and poor (>10%), respectively.[49] The smallest detectable difference for each measure was also calculated in a custom script.[50]

Results

A statistically significant difference in 3RM strength was detected between sessions ($\chi^2 = 10.333$, $p = 0.006$; $W = 0.470$). Based upon the sequentially rejective Conover tests, 3RM strength was statistically greater during T2 ($p = 0.012$) and T3 ($p = 0.027$) compared to T1 (Figure 1). However, there were no statistical differences between T2 and T3 ($p = 0.595$). Trivial ESs were noted between T1 and T2 (ES [95% CI] = −0.01 [−0.58, 0.41]), T1 and T3 (ES [95% CI] = −0.09 [−0.57, 0.43]), and T2 and T3 (ES [95% CI] = 0.01 [−0.49, 0.50]). No statistical differences in jump height ($p = 0.071$, $\eta_p^2 = 0.248$), time-to-take-off ($p = 0.862$, $\eta_p^2 = 0.007$), or MF during the yielding ($\chi^2 = 0.545$, $p = 0.761$, $W = 0.025$), braking ($\chi^2 = 0.182$, $p = 0.913$, W = 0.008), and concentric phases ($\chi^2 = 1.273$, $p = 0.529$, $W = 0.058$) were determined (Figure 3). There were also no statistically significant differences in eccentric displacement between sessions ($p = 0.209$, $\eta_p^2 = 0.147$). Small differences in MV at 40 and 90% 3RM were noted between T1 and T2, with faster velocities generated during T2 at 40% and slower velocities generated at 90% of 3RM (Figure 4). Trivial differences were found at 60% and 80% of 3RM. Small differences in MV were found at 40% and 80% 3RM between T2 and T3, with slower velocities generated during T3. Trivial differences were found between T2 and T3 for the MV at 60% and 90% 3RM. LVP estimations of deadlift 3RM did not agree with the actual 3RM as the 95% limits of agreement exceeded the ±5 kg acceptable difference in all sessions (Figure 2). Further, proportional bias was found between actual and estimated deadlift 3RM in T1 ($p = 0.022$, $R^2 = 0.46$). No proportional bias was found between actual and estimated 3RM in T2 ($p = 0.346$; $R^2 = 0.09$) or T3 ($p = 0.343$, $R^2 = 0.10$).

Excellent between-session relative reliability was determined between T1 and T2 for 3RM strength (ICC [95% CI] = 1.00 [0.99–1.00]) and between T2 and T3 (ICC [95% CI] = 1.00 [0.99, 1.00]). Good CV values of 1.00% and 0.84% were also found between T1 and T2 and T2 and T3, respectively. The between-session reliability of the CMJ variables and MV during each 3RM warm-up set are reported in Table 1. The smallest detectable difference and standard error of the measurement for each measure in this study are reported in Table 2.

Discussion

The primary aim of this study was to investigate the stability of deadlift 3RM over the length of a typical microcycle and the impact of repeated maximum strength testing on measures of preparedness. Our primary finding was that the 3RM was statistically different between T1 and T2 and T1 and T3, but not between T2 and T3. However, the magnitude of these differences was trivial, with an average change in 3RM of 2.27 kg (range = 0–5 kg; 95% CI = 1.14, 3.86 kg) between T1 and T2 and 1.82 kg (range = 0–5 kg; 95% CI = 0.91, 3.41 kg) between T1 and T3 (Figure 1). We also found that the 3RM deadlift is reliable between sessions, with excellent ICCs and good CVs between each session (Table 1). In alignment with our hypotheses, there were no significant differences in jump height between sessions (Figure 3). However, contrary to our hypotheses, time-dependent CMJ variables (sub-phase MF and time-to-take-off) were also not statistically different between sessions. In partial alignment with our hypotheses, small changes in MV were found at some relative intensities while trivial changes in MV were found in

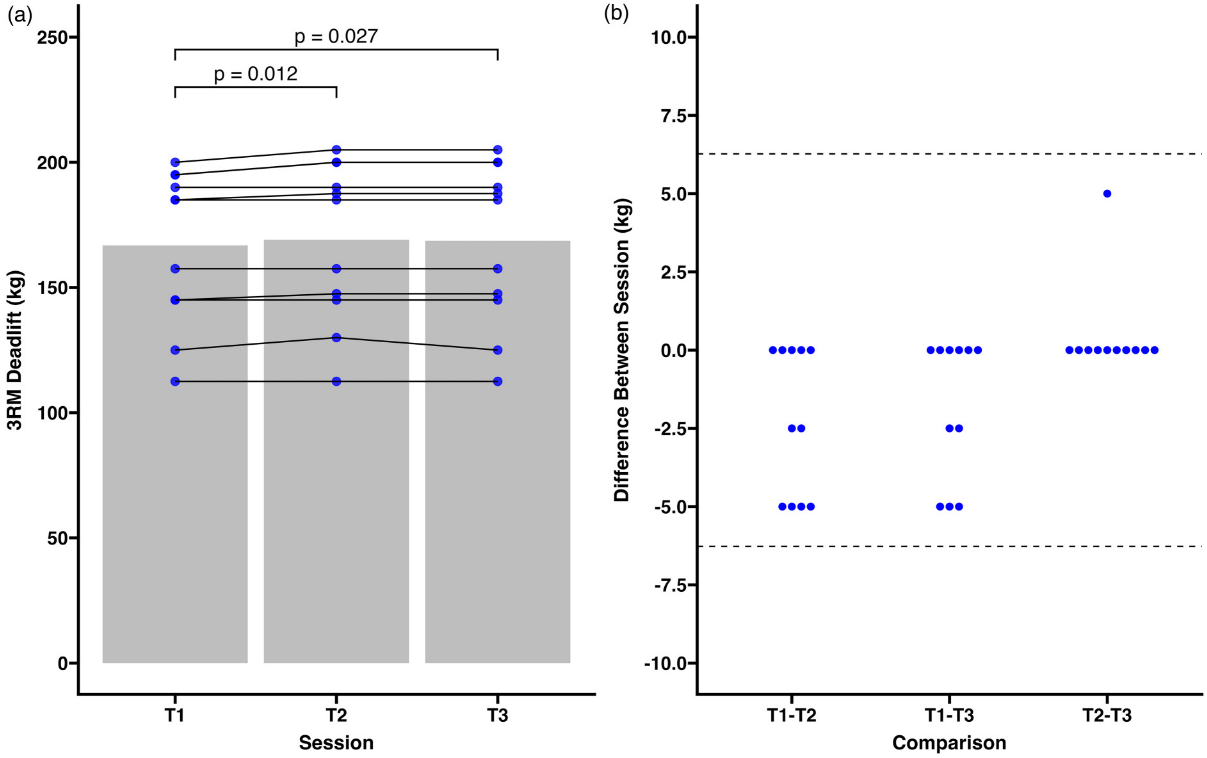

Figure 1. (a) Three repetition maximum (3RM) deadlift results in each session; (b) individual differences in 3RM deadlift between sessions. Dotted lines represent the smallest detectable difference.

others. Finally, deadlift 3RM estimated using an LVP did not agree with directly measured 3RM.

Previous investigations of the stability of lower-body maximum strength have reported that it does not vary markedly from day to day when assessed via a 1RM test.[6–9] The results of the current study largely align with those previous reports, as although there were statistically significant differences in the 3RM between sessions, in practical terms, they were trivial. Importantly, the absolute differences between sessions were less than the smallest detectable difference (Figure 1(b)) and therefore should be considered normal measurement error rather than a meaningful change in strength. Further, when considered in the context of a periodized training program, the variation in strength from day to day on both a group and individual level is well within the typical reduction in training intensity (~10%–20%) recommended when implementing a programming structure that accounts for accumulated fatigue (i.e. heavy/light days).[51–53] The variation in strength found in this study also falls within the range commonly used when prescribing training loads relative to the number of repetitions in the set (i.e. 80%–85% of RM or the set-rep best),[51,54] indicating that traditional methods of controlling training loads in response to natural variations in strength are still viable. However, if traditional methods of prescribing resistance training load are used, it may be more appropriate to implement relative intensity "bands" rather than prescribing a single target %1RM, as this enables the strength and conditioning professional to control the targeted training intensity while still allowing some autoregulation to occur on the part of the athlete as they can select the load within the prescribed band that best fits their current perceived level of readiness.[51,52]

The results of this study and those of previous studies investigating the stability of the 1RM also contradict the contention that strength is highly variable when assessed daily.[2] Instead, the differences in estimated daily 1RM and a pre-training baseline presented by Jovanovic and Flanagan[2] of ±18% can likely be attributed to the method used to estimate lower-body maximum strength. There is a substantial volume of research indicating that using an LVP calculated from the velocity during submaximal warm-up sets is not a valid method of predicting 1RM.[6,7,19,55] For example, Macarilla et al.[19] reported an average overestimation of 38.53 kg and limits of agreement of ±82 kg when comparing directly measured back squat 1RM to back squat 1RM estimated using an LVP, while Hughes et al.[56] reported limits of agreement of ±19.65 to ±395.43 kg. The results of the current study align with the previous data, as deadlift 3RM estimated using the LVP did not agree with the directly measured 3RM (Figure 2). Although the mean bias between the measures was quite low (<5 kg), the limits of agreement exceeded the acceptable difference of ±5 kg in each session

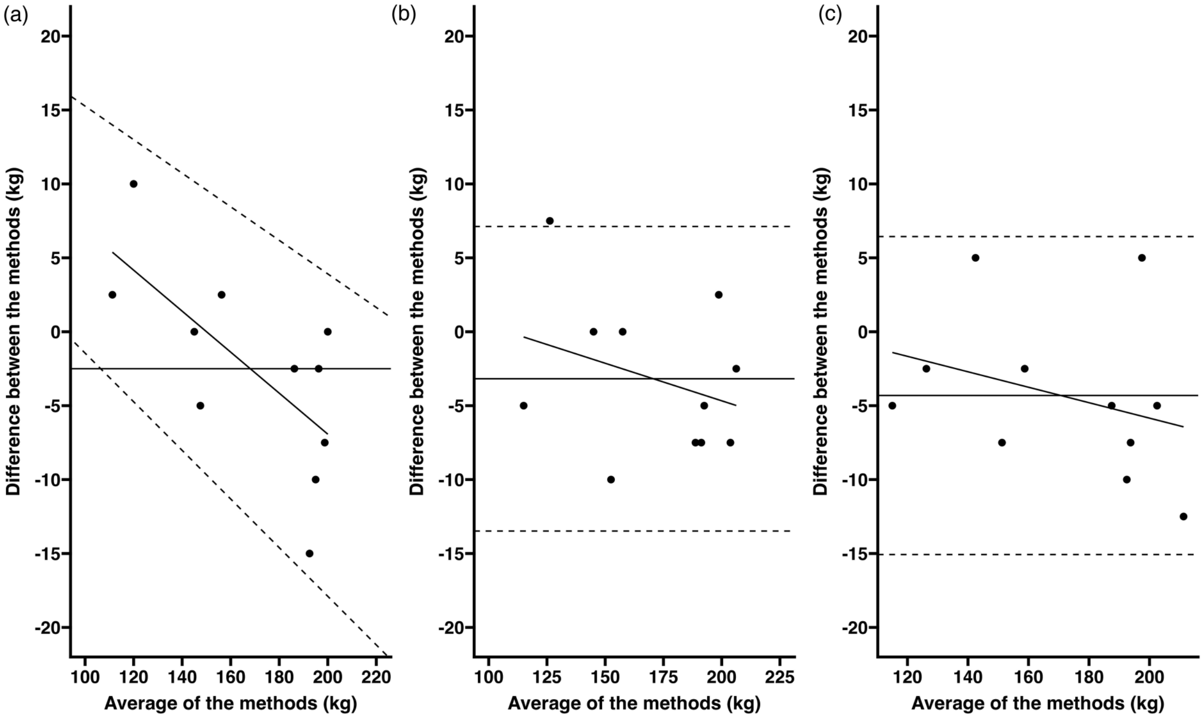

Figure 2. Bland-Altman plots demonstrating the agreement between actual three repetition maximum (3RM) and 3RM estimated via a load-velocity profile in each session: (a) T1, (b) T2, (c) T3. The horizontal line shows the mean bias, the dashed lines the 95% limits of agreement, and the tilted solid line the relationship between the average and differences. All differences are calculated as actual minus estimated.

(Figure 2), and clearly demonstrate that the LVP does not provide accurate estimates of deadlift 3RM. Interestingly, these limits of agreement represent ±12% to 15% differences from the mean 3RM deadlift in each session, quite similar to the ±18% difference in estimated back squat 1RM from the directly measured baseline 1RM noted by Jovanovic and Flanagan.[2] Based on the proportional bias between the measures in T1 (Figure 2(a)), it may also be concluded that the magnitude of this error depends on the strength of the athlete, a phenomenon that has also been shown in the back squat.[10] This further confounds the use of the LVP as a method for estimating lower-body maximum strength during free-weight exercises.

It is also important to note that although 1RM back squat or 3RM deadlift strength does not change meaningfully in response to a resistance training bout or maximal intensity strength testing, the velocity at each %1RM is attenuated in the 48 h after training.[8] Based on the results of the present study, velocity changes after maximal intensity lifting independent of changes in strength, with the velocity at 40% of 3RM increasing between T1 and T2 before decreasing between T2 and T3 despite there being no change in 3RM between the last two testing sessions. Further, MV at 80% of 3RM demonstrated a trivial increase between T1 and T2 before a small decrease between T2 and T3. Based on the data from this study and Vernon et al.,[8] using an LVP to predict lower-body maximum strength will generate daily estimations that do not reflect the athlete's actual physical capacity. When considered alongside the fact that the purported ±18% change in estimated strength relative to a baseline 1RM is only representative of a single individual's response to training[2] and is likely a function of the method used to make the daily estimation of 1RM, the contention that strength varies widely daily should be treated with skepticism as a justification for implementing a programming strategy.

It is also notable that there appears to be little impact on CMJ performance from fatigue accumulated due to repeated 3RM testing, with no statistical changes in CMJ jump height or common markers of CMJ movement strategy found (Figure 3). The lack of change in CMJ performance between sessions is likely due to the "dose" of resistance exercise performed, with Vernon et al.[8] previously reporting that performing a back squat session of five sets of five repetitions performed with 80%1RM resulted in trivial reductions in CMJ peak velocity 24, 48, 72, and 96 h post-training but small to moderate changes in back squat MV 24 and 48 h post-training. Conversely, Jackman et al.[11] reported substantial reductions in CMJ peak force 24- and 48-h after a multi-exercise lower-body resistance training session performed with six repetition maximum (6RM) loads. Similarly, Kennedy and Drake[57]

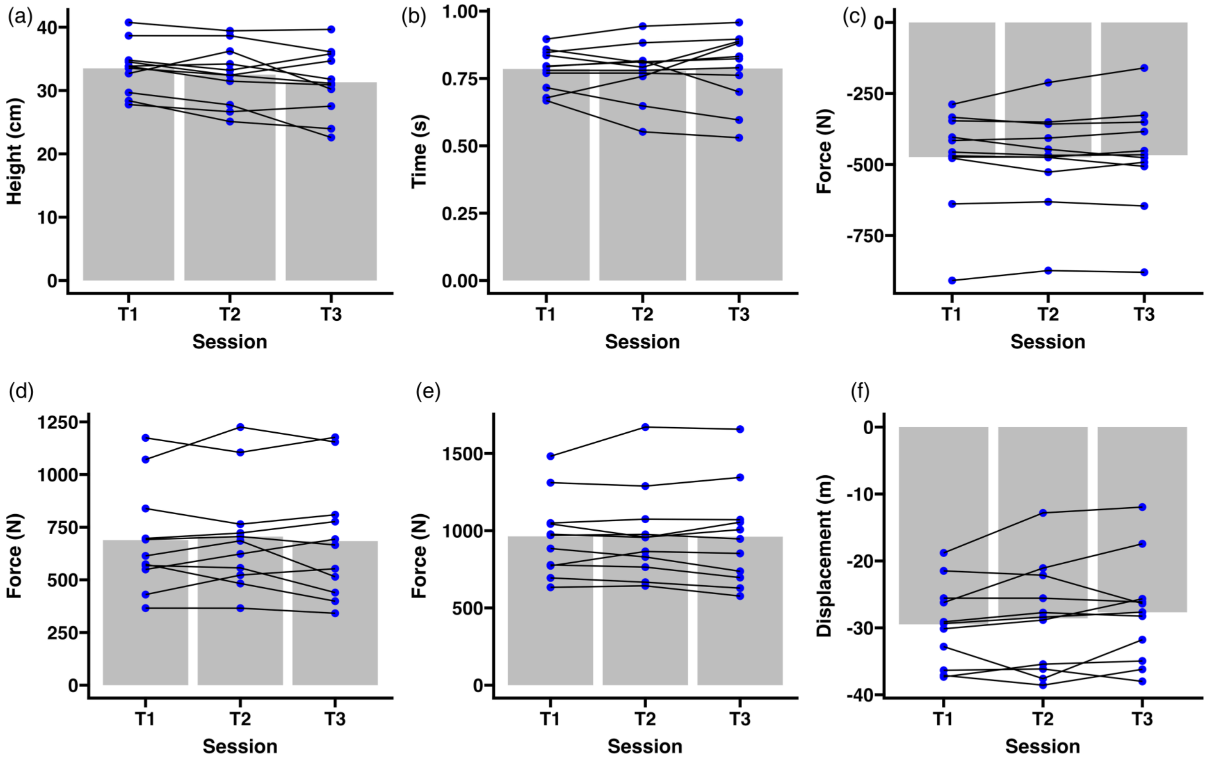

Figure 3. Countermovement jump variables in each three repetition maximum (3RM) testing session: (a) jump height; (b) time-to-take-off; (c) yielding mean force; (d) braking mean force; (e) concentric mean force; and (f) eccentric displacement.

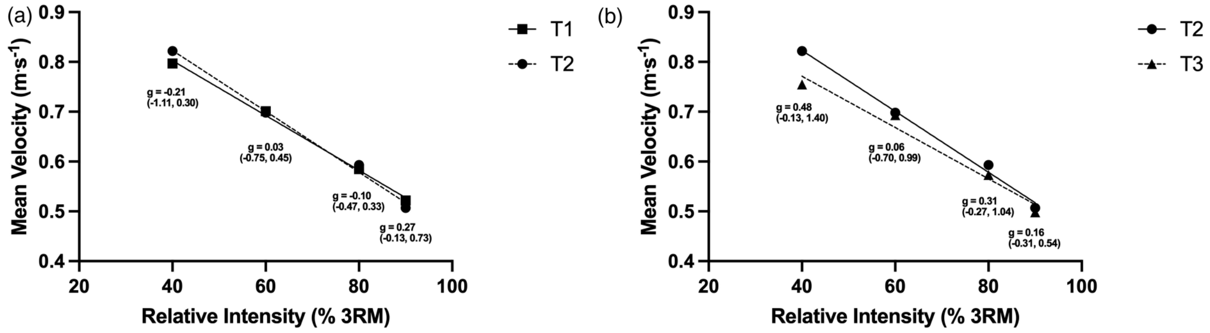

Figure 4. Hedges g effect size comparisons of mean velocity during each warm-up set between three repetition maximum (3RM) testing sessions: (a) T1–T2; (b) T2–T3; g = Hedges g effect size.

found significant decreases in multiple CMJ variables, such as jump height, peak velocity, peak force, and peak power, 48 h after the completion of a maximal intensity box squat training bout. Given the lack of change in CMJ performance in response to the 3RM testing in this study, we would suggest that strength and conditioning professionals carefully consider the test and metrics selected when attempting to monitor the neuromuscular status of their athletes and the impacts of accumulated fatigue on preparedness.

Some limitations to our study should be kept in mind when considering these results and the applicability of our findings to other populations. First, each 3RM testing session was separated by 48-h where no other lower-body resistance training was performed, which is unlikely to occur in most applied settings. Second, only male participants volunteered to take part in our study, so the results should only be considered representative if working with resistance-trained males. Although we do not expect different outcomes between sexes, whether the 3RM deadlift is as stable for females as the males tested in the present study requires further investigation. Finally, the use of discrete variables extracted from CMJ force-time curve data has recently been suggested as a potentially sub-optimal

Table 1. Between-session reliability statistics for 3RM deadlift strength, countermovement jump variables, and barbell mean velocity during each warm-up set.

	Comparison					
	T1–T2		T1–T3		T2–T3	
Variable	ICC (95% CI)	% CV	ICC (95% CI)	% CV	ICC (95% CI)	% CV
3RM deadlift	1.00 (0.99, 1.00)	1.00	1.00 (0.99, 1.00)	0.82	1.00 (0.99, 1.00)	0.84
Jump height	0.90 (0.68, 0.97)	3.09	0.90 (0.66, 0.97)	4.36	0.84 (0.52, 0.96)	4.92
Eccentric displacement	0.92 (0.72, 0.98)	10.32	0.85 (0.54, 0.96)	14.53	0.94 (0.79, 0.98)	7.64
Time-to-take-off	0.80 (0.42, 0.94)	6.05	0.59 (0.02, 0.87)	10.05	0.85 (0.55, 0.96)	6.08
Yielding mean force	0.98 (0.92, 0.99)	8.16	0.96 (0.86, 0.99)	14.72	0.99 (0.96, 1.00)	6.88
Braking mean force	0.95 (0.84, 0.99)	8.11	0.92 (0.74, 0.98)	14.47	0.95 (0.84, 0.99)	10.13
Concentric mean force	0.96 (0.87, 0.99)	4.70	0.95 (0.83, 0.99)	6.99	0.98 (0.94, 1.00)	5.01
MV 40% 3RM	0.53 (−0.07, 0.85)	11.86	0.87 (0.60, 0.96)	5.72	0.35 (−0.28, 0.77)	16.18
MV 60% 3RM	0.68 (0.17, 0.90)	7.73	0.73 (0.27, 0.92)	6.10	0.15 (−0.47, 0.67)	12.32
MV 80% 3RM	0.81 (0.45, 0.95)	5.73	0.56 (−0.02, 0.86)	8.25	0.51 (−0.09, 0.84)	8.36
MV 90% 3RM	0.78 (0.37, 0.93)	5.36	0.78 (0.38, 0.94)	5.30	0.80 (0.41, 0.94)	5.33

3RM: three repetition maximum; MV: mean velocity; ICC: intra-class correlation coefficient, CV: coefficient of variation; CI: confidence interval.

Table 2. Standard error of the measurement and smallest detectable difference for each variable.

Variable	Standard error of the measurement	Smallest detectable difference
3RM (kg)	2.26	6.27
Jump height (m)	0.01	0.04
Time-to-take-off (s)	0.04	0.11
Eccentric displacement (m)	0.02	0.06
Yielding mean force (N)	23.60	65.41
Braking mean force (N)	53.30	147.75
Concentric mean force (N)	51.03	141.45
40% mean velocity (m/s)	0.08	0.22
60% mean velocity (m/s)	0.05	0.13
80% mean velocity (m/s)	0.03	0.09
90% mean velocity (m/s)	0.03	0.08

3RM: three repetition maximum.

approach compared to wave-form analysis techniques that enable the detection of differences in the entire force-time curve between conditions rather than only at specific time points or phases.[58] It is possible that their use in this study has masked changes in jump strategy, and, therefore, fatigue induced by 3RM testing, which may be revealed by statistical techniques such as statistical parametric mapping.[58]

Acknowledgements

The authors would like to thank the participants for their time and efforts throughout this study. They would also like to thank Shayne Vial, Jordan Meester, Tinka Smolarek, and Carlos Barrero for their assistance with data collection.

Declaration of conflicting interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: JPL provides consultancy services and is the Director of Education for Hawkin Dynamics, a portable force-plate manufacturer and analysis software company. No Hawkin Dynamics products were used in this study, nor did the company have any role in the design of the study, collection, and analysis of the data, or preparation of any decision to publish the manuscript. The authors have no other potential conflicts of interest to disclose.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study was supported by an Australian Government Research Training Program Scholarship.

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