Influence of Rest Interval Duration on Muscular Power Production in the Lower-Body Power Profile

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Abstract

Nibali, ML, Chapman, DW, Robergs, RA, and Drinkwater, EJ. Influence of rest interval duration on muscular power production in the lower-body power profile. *J Strength Cond Res* 27(10): 2723–2729, 2013—There is a paucity of evidence-based support for the allocation of rest interval duration between incremental loads in the assessment of the load-power profile. We examined the effect of rest interval duration on muscular power production in the load-power profile and sought to determine if greater rest is required with increasing load (i.e., variable rest interval). Ten physically trained men completed 4 experimental conditions in a crossover balanced design. Participants performed jump squats across incremental loads (0–60 kg) on 4 occasions, with an allocated recovery interval of 1, 2, 3, or 4 minutes. The mean log-transformed power output at each load was used for comparison between conditions (rest intervals). Unloaded jump squats (0 kg) maximized power output at each condition. The maximal mechanical power output was 66.6 ± 6.5 $W \cdot kg^{-1}$ (1 minute), 66.2 ± 5.2 $W \cdot kg^{-1}$ (2 minutes), 67.1 ± 5.9 $W \cdot kg^{-1}$ (3 minutes), and 66.2 ± 6.5 $W \cdot kg^{-1}$ (4 minutes). Trivial or unclear differences in power output were observed between rest intervals at each incremental load. As expected, power declined per 10 kg increment in load, the magnitude of decrease was 13.9–14.5% (confidence limits [CL]: ±1.3–2.0%) and 13.4–14.6% (CL: ±2.4–3.9%) for relative peak and mean power, respectively, yet differences in power output between conditions were likely insubstantial. The prescription of rest intervals between loads that are longer than 1 minute have a likely negligible effect on muscular power production in the jump squat incremental load-power profile. Practitioners should select either a 1- to 4-minute rest interval to best accommodate the logistical constraints of their monitoring sessions.

Key Words jump squats, incremental load-power profile, maximal power production, optimal load

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Introduction

The load that results in the greatest maximal mechanical power output (Pmax) has been referred to as the "optimal" load (5,7,26). Training at the optimal load results in superior improvements in power (3,18,24) because of specific neuromuscular adaptations and transfer to dynamic athletic performance (18,26). Identification of Pmax and the corresponding optimal load is determined via assessment of the highest power output attained while performing a plyometric, ballistic, Olympic-style, or traditional resistance training exercise across incremental loads. The ability of athletes to generate maximal power (4,24) is an essential component for success in competitive sports (5,20) because of its established association with improvements in jumping, sprinting, and agility performance (21). Accordingly, pursuit of training methods that are superior for the development of muscular power is a primary consideration of sports practitioners.

Differences in methodological procedures used in the assessment of the load-power profile have resulted in equivocal reporting of the optimal load (9,12,24), ranging from external loads of 0% (5,7,23) to 59% (4) of 1-repetition maximum (1RM); the system internal load of body mass is not considered part of this common reporting procedure. Previous investigations have predominately focused on methodological considerations pertaining to the identification of Pmax and the corresponding optimal load (4,12), the mode of exercise (7) and loading intensities used (2), data collection methods (6,10), and the appropriateness of reporting peak vs. mean power output (10). To date, the rest interval provided between incremental loads and the influence it has on muscular power production in the assessment of subsequent loads have not yet been systematically investigated. Although some researches have recommended or reported using rest intervals ranging from 1 to 5 minutes (5,7,12), others have failed to make any mention of the rest interval provided (4,23). Exacerbating inconsistencies in the reporting of the rest interval in the literature is the lack of evidence-based data to substantiate the selection of rest intervals routinely utilized in load-power profile assessments. In an investigation by Cormie et al. (7), a variable rest interval was employed in which the allocated rest duration was extended throughout the incremental load-power assessment to accommodate the increasing load. The researchers allocated a 2-minute rest interval between incremental loads of 0% and 12% of 1RM, and a 3-minute rest interval between loads of 27–85% of 1RM; however, no rationale was provided for the use of 2 different rest intervals. Despite a lack of evidence to substantiate the use of a variable rest interval, it is plausible that this approach is appropriate to negate any confounding influence previous loads have on the power production of subsequent loads in the incremental load-power profile because of accumulative fatigue.

Muscular power is defined as the amount of work produced in a given time (work/time) during muscular contractions and is limited by the force-velocity relationship that describes the inverse association between force and velocity in concentric muscle contractions (13,19). As such, the production of muscular power is dictated by factors that affect the force generating capacity or the maximal shortening velocity of muscle. The underlying mechanisms responsible for fatigue-induced changes in force production and shortening velocity differ (1) and may affect the recovery duration required between incremental loads when the relative contribution of force and velocity to power production shifts to accommodate the increasing load, in accordance with the force-velocity relationship (13,19). Conversely, the potential influence of post-activation potentiation, a phenomenon characterized by the facilitation of force production in response to previous muscle activation (14,22), on power output of subsequent incremental loads and the influence this may have on the selection of a rest duration must also be considered. The presence of fatigue or potentiation that may manifest as a result of insufficient recovery between incremental loads is discernable via differences in performance variables between rest conditions at each load.

Therefore, the purpose of this investigation was to examine the effect of different durations of rest intervals on muscular power production in the incremental load-power profile and to determine if longer duration rest intervals are required with increasing load (i.e., determine efficacy of using a variable rest interval). We further sought to determine the load that maximizes power output in the jump squat in a cohort of physically trained men. This analysis will provide practitioners with a sound rationale for selection of the rest interval duration allocated between incremental loads in the assessment of lower-body load-power profiles.

Methods

Experimental Approach to the Problem

Physically trained men performed a lower-body incremental load-power profile on 4 separate occasions, differing only in the rest interval duration allocated between loads. Subjects were assessed using jump squats to determine their power output across a spectrum of incremental loads. The mean log-transformed power output at each load was used for comparison between conditions (rest intervals). Magnitudes of the standardized differences in the load-power data between rest interval conditions were assessed qualitatively to determine the influence of differing rest duration on subsequent jump squat performance.

Subjects

Ten physically trained men were recruited to participate in this study (age: 29.7 ± 6.2 years; body mass: 80.7 ± 7.8 kg; estimated 1RM squat: 137.8 ± 25.3 kg; repetition maximum to body mass ratio [RM:BM]: 1.73 ± 0.38). Subjects 1RM squat was not measured directly but estimated using the reps and load from their most recent squat performance (11). Participants were recruited on the basis that they had a minimum of 12 months resistance training experience, were familiar with performing lower-body power exercises such as Olympic lifts and/or jump squats, and were free of injury or illness. Throughout the investigation, participants were requested to maintain their regular diets, not to take anti-inflammatory medications, and to refrain from caffeine intake in the 3 hours before each testing session. Participants provided written consent after all procedures were fully explained to them and were informed of the possible risks. This study was approved by the institutional Human Research Ethics Committee (Charles Sturt University, Bathurst, Australia), with procedures conforming to the Statement on Human Experimentation by the National Health and Medical Research Council of Australia.

Procedures

Each participant performed a standard warm-up consisting of 10-minute cycle ergometry, dynamic stretches of the lower-body musculature associated with the jump squat, and 3 sets of 3 repetitions of unloaded jump squats performed at a self-assessed 70%, 80%, and 90% intensity with 30 seconds rest allocated between sets. The jump squat has previously been defined as a countermovement jump with a barbell held across the shoulders (8) and is not synonymous with the concentric-only squat jump. After completion of the warm-up, a 3-minute rest period was given before commencement of the incremental load jump squat testing. Before assessment of experimental trials, participants completed a familiarization trial where they performed jump squats across external incremental loads (0–60 kg) to ensure familiarization with performing unloaded and loaded jump squats. To assess the influence of rest interval duration on jump squat power output, participants performed load-power profiles on 4 separate occasions separated by a minimum of 48 hours. On each occasion, participants completed the load-power profile and were allocated a 1-, 2-, 3-, or 4-minute rest interval between incremental loads. Rest interval conditions were completed using a Latin square design.

Load-Power Profile Testing. Participants performed 3 maximal-effort jump squats to a self-selected depth across a spectrum of 10 kg incremental loads (0–60 kg; equivalent to 0–44.8 ± 7.4% squat 1RM). Participants were instructed to perform each jump squat as explosively as possible to achieve maximal power output and to reset their position between each jump effort; all 3 jumps were performed within 18 seconds. Performance of the unloaded jump squats (i.e., 0 kg jump squat) involved participants holding a 1.5-m-long aluminum bar weighing 0.4 kg across their shoulders; for the 10 kg intensity, participants again used the aluminum bar and wore a weight vest over their torso. For all other intensities, participants performed jump squats using a 20 kg Olympic weightlifting barbell with the addition of the appropriate weight plates for the desired intensity. Participants were instructed to maintain constant downward pressure on the bar throughout each jump squat trial to maintain constant contact between shoulder and the bar.

Data Collection and Signal Analysis. All jump squat trials were performed with the subject standing on a commercially available force plate (400 Series Performance Force Plate; Fitness Technology, Adelaide, Australia) with a linear position transducer (LPT; Ballistic Measurement System; Fitness Technology) attached approximately 50 cm to the right of the center of the bar. Both force plate and LPT were interfaced with computer software (Ballistic Measurement System; Fitness Technology) that allowed direct measurement

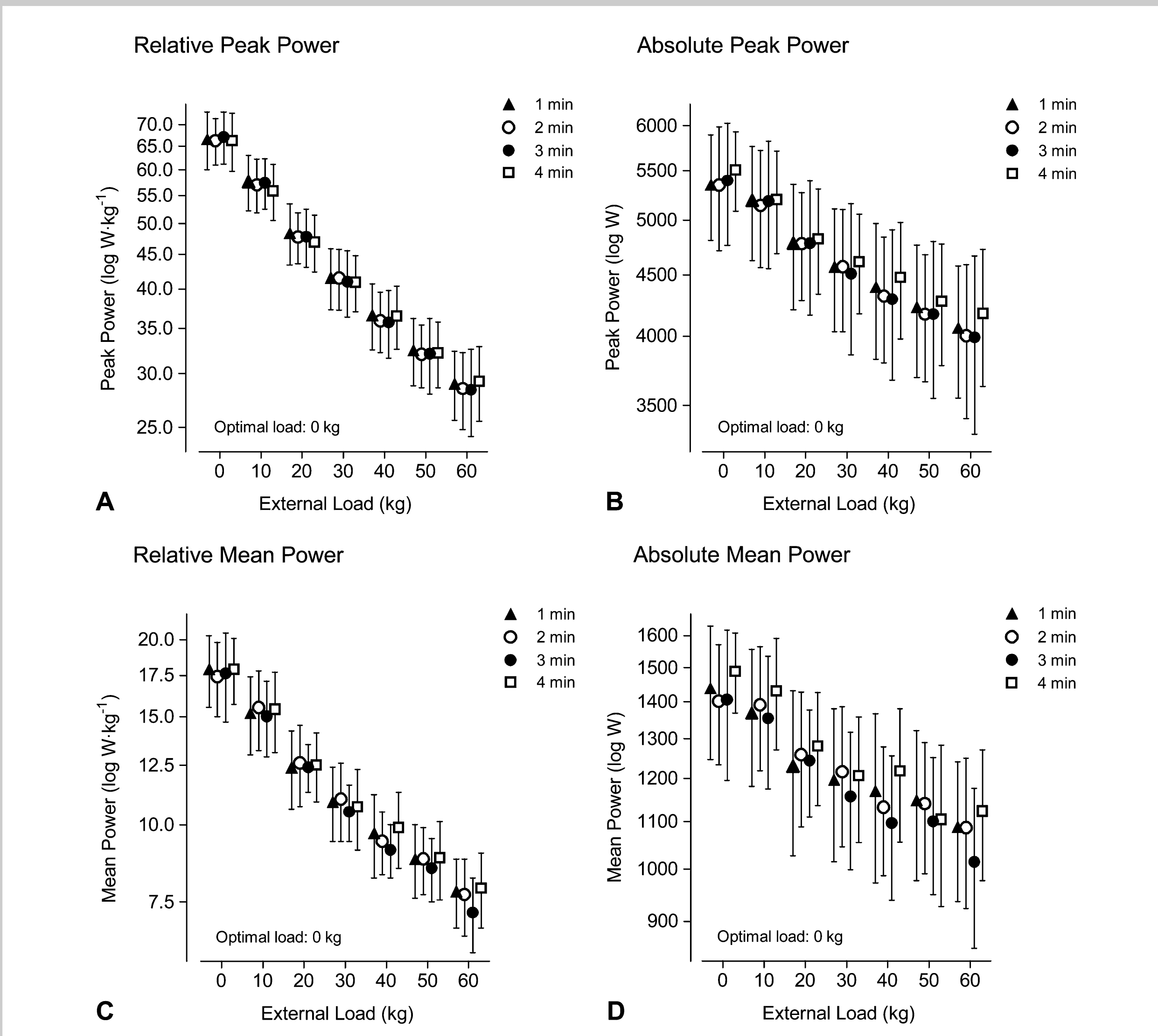

Figure 1. Mean (±*SD*) relative (A) and absolute (B) peak power output and relative (C) and absolute (D) mean power output across incremental loads (in kg) in the jump squat for different rest interval conditions: 1 min (▲); 2 min (○); 3 min (•); 4 min (□). Data points on *x*-axis are offset to accommodate ±*SD* error bars.

of force-time data (force plate) and displacement-time data (LPT), sampling at a frequency of 200 Hz. Differentiation of the displacement-time data was used for calculation of instantaneous velocity. The velocity signal from the LPT was filtered using a fourth-order low-pass Butterworth digital filter with a cutoff frequency of 15 Hz. Power output was calculated as the product of instantaneous velocity and vertical ground reaction force (VGRF) data using the system mass (i.e., body mass + barbell mass). Before each data collection session, the force plate and LPT were calibrated using a known mass and distance.

Analysis of jump squat kinetic variables was performed using custom designed software (LabVIEW; National Instruments, Sydney, Australia) for automated batch analysis. Performance variables were assessed for the concentric phase of the jump squat, defined as the next sample (0.005 seconds) from the end of the eccentric phase (minimum displacement of the countermovement) to the point of take-off (VGRF < 5 N). Peak and mean power output were calculated as the instantaneous maximal power output and average power output, respectively, obtained during the concentric phase. Peak and mean power output are expressed relative to the system mass (i.e., body mass + barbell mass) in Watts per kilogram ($W \cdot kg^{-1}$) and as absolute power [in Watts (W)]. Reliability of power output measures was assessed using the log-transformed baseline data (0 kg jump squat) from each condition (rest interval). Typical errors expressed as coefficients of variation (CV) and intraclass correlations (ICC) are reported for relative peak power (CV: 4.3% ×/÷ 1.3; ICC: 0.79 ± 0.15), absolute peak power (CV: 4.5% ×/÷ 1.3; ICC: 0.89 ± 0.11), relative mean power (CV: 4.9% ×/÷ 1.4; ICC: 0.90 ± 0.09), and absolute mean power (CV: 4.9% ×/÷ 1.4; ICC: 0.89 ± 0.10).

Statistical Analyses

The average of the 3 jump squats (25) measured at each load was used to calculate peak and mean power output for each subject, with the mean response calculated for each condition (rest interval). The maximal mechanical power output and the corresponding optimal load for each condition were determined as the highest relative and absolute peak power output achieved in the load-power profile. A publicly available spreadsheet was used to assess the magnitude of differences in relative (in ($W \cdot kg^{-1}$)) and absolute (in W) peak and mean power output at each load between conditions and to assess the magnitude of difference in these variables across incremental loads relative to values at Pmax load in all conditions (15). The change in power output per 10 kg increment in load in each condition was calculated as the average

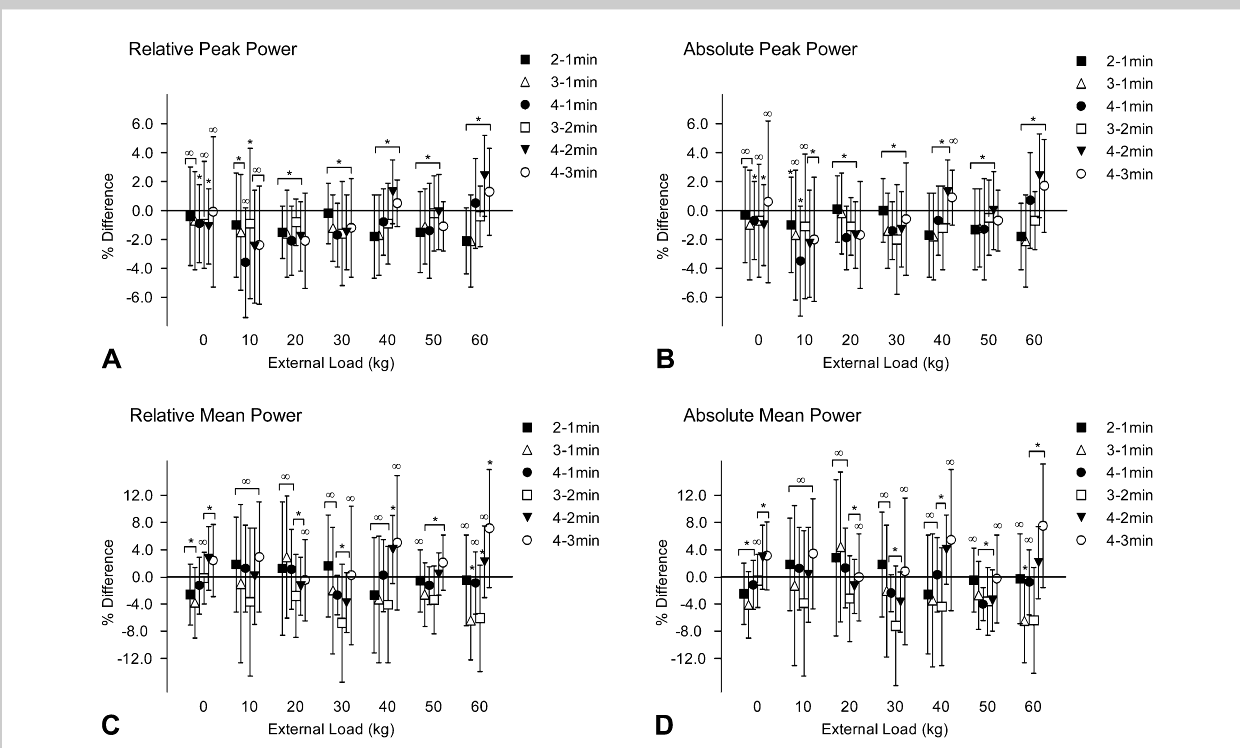

Figure 2. Mean percent difference (±CL) between conditions (interload rest) in relative (A) and absolute (B) peak power output, and relative (C) and absolute (D) mean power output at incremental loads (in kg) in the jump squat: 2–1 min (■); 3–1 min (Δ); 4–1 min (•); 3–2 min (□); 4–2 min (▼); 4–3 min (○). Data points on *x*-axis are offset to accommodate ±CL error bars. Standardized differences (effect sizes) between conditions (rest intervals) at each incremental load: Trivial (*); unclear (∞).

Table 1. Mean decline in jump squat relative and absolute peak and mean power output per 10 kg increment in load in rest interval conditions.*

Jump squat variable	Decline in power output(%)			
	1-min rest	2-min rest	3-min rest	4-min rest
Peak power (W·kg^{-1})	13.9 ± 1.5	14.1 ± 1.3	14.5 ± 2.0	14.4 ± 1.8
Peak power (W)	4.7 ± 1.4	4.9 ± 1.4	5.2 ± 1.8	5.5 ± 1.6
Mean power (W·kg^{-1})	14.6 ± 2.6	13.4 ± 2.4	14.5 ± 3.9	14.4 ± 3.0
Mean power (W)	5.5 ± 2.6	4.1 ± 2.3	5.3 ± 3.6	5.5 ± 2.8

*Mean ± 90% confidence limits.

difference in the log-transformed power output at each load relative to the Pmax value and then back-transformed and expressed as a percentage. Mean and *SD* values are used to represent measures of centrality and spread of data (mean ± *SD*). Magnitudes of standardized differences between conditions of <0.2, <0.6, <1.2, <2.0, and >2.0 are interpreted qualitatively as trivial, small, moderate, large, and very large effect sizes (ES), respectively (16,17). Where confidence limits (±CL) for the ES extend beyond the boundaries of -0.2 to 0.2, effects are deemed unclear. Uncertainty of the estimates is reported as CL at the 90% level, which is appropriate for the kind of mechanistic measures reported here (17). Confidence limits are expressed as "±" for uncertainty of differences in mean values and as "×/÷" factor uncertainties for coefficients of variation.

Results

The maximum relative peak power for each condition was 66.6 ± 6.5 W·kg^{-1} (1 minute), 66.2 ± 5.2 W·kg^{-1} (2 minute), 67.1 ± 5.9 W·kg^{-1} (3 minute), and 66.2 ± 6.5 W·kg^{-1} (4 minute) (Figure 1A). Expressed as absolute power, Pmax was 5,352.3 ± 542.6 W (1 minute), 5,348.4 ± 636.3 W (2 minute), 5,394.4 ± 630.3 W (3 minute), and 5,506.0 ± 420.8 W (4 minute) (Figure 1B). Unloaded (0 kg) jump squats maximized relative (Figure 1A) and absolute (Figure 1B) peak power in all conditions. Percentage differences in relative and absolute peak power between rest conditions at each incremental load revealed trivial or unclear differences in power output (Figures 2A,B). Mean declines in relative and absolute peak power output of 13.9–14.5% (CL: ±1.3–2.0%) and 4.7–5.5% (CL: ±1.4–1.8%), respectively, were observed per 10 kg increment in load across rest conditions (Table 1); yet, differences between conditions are likely insubstantial.

The maximum relative mean power for each condition was 17.9 ± 2.4 W·kg^{-1} (1 minute), 17.4 ± 2.4 W·kg^{-1} (2 minutes), 17.6 ± 2.9 W·kg^{-1} (3 minutes), and 17.9 ± 2.2 W·kg^{-1} (4 minutes) (Figure 1C). Expressed as absolute power, Pmax was 1,437.7 ± 191.9 W (1 minute), 1,400.2 ± 168.1 W (2 minutes), 1,404.6 ± 211.0 W (3 minutes), and 1,486.7 ± 119.9 W (4 minutes) (Figure 1D). Unloaded (0 kg) jump squats maximized relative (Figure 2A) and absolute (Figure 2B) mean power in all conditions. Percentage differences in relative and absolute mean power between rest conditions at each incremental load revealed trivial or unclear differences in power output (Figures 2C,D). Mean declines in relative and absolute mean power output of 13.4–14.6% (CL: ±2.4–3.9%) and 4.1–5.5% (CL: ±2.3–3.6%), respectively, were observed per 10 kg increment in load across conditions (Table 1); yet, differences between conditions are likely insubstantial.

Discussion

The present investigation is the first to examine the effect of the duration of the rest interval on muscular power production in the incremental load-power profile and to establish if longer duration rest intervals are required with increasing load. We found insubstantial differences in power output across incremental loads between the 1- to 4-minute rest interval conditions, thus providing no rationale for the allocation of longer recovery durations with incremental loads. This information affords practitioners a sound rationale for selection of the recovery duration between incremental loads in the assessment of jump squat load-power profiles.

Peak muscular power in all rest interval conditions was optimized during unloaded jumps (i.e., 0 kg or 0% 1RM) (Figures 1A,B), which has been reported previously (2,5,7). We observed trivial and unclear differences in peak and mean power output at Pmax and across incremental loads between rest conditions regardless of how power was expressed (relative or absolute). It should be noted that for the majority of differences, the magnitude of effects (Figure 2) are within the typical error reported for relative and absolute peak (CV: 4.3% ×/÷ 1.3 and 4.5% ×/÷ 1.3) and mean power (CV: 4.9% ×/÷ 1.4 and 4.9% ×/÷ 1.4), providing support to the contention that rest intervals longer than 1 minute duration have a trivial effect on power output in the incremental load-power profile. Unclear differences are observed between conditions at some loads because of the span of the upper and lower CL across substantially negative and positive values (15), consequent to the inherent between-trial variability observed in jump squat performance. The variability observed cannot be explained by any effect of potentiation or fatigue as this would manifest as a substantial increase or decrease (respectively) in the power output per 10 kg increment in load between rest conditions, or conversely, it would present as substantially greater power output at particular loads for different rest intervals. Our findings do not support either of these scenarios and provides clarity to the practitioner as to which rest interval will best suit their situation.

Examination of the influence of the duration of recovery on power production of jump squats across incremental loads revealed trivial to unclear differences between conditions. On average, relative and absolute peak power declined per 10 kg increment in load, 13.9–14.5% (CL: ±1.3–2.0%) and 4.7–5.6% (CL: ±1.4–1.8%), respectively, between conditions. Similarly, declines in relative and absolute mean power output between conditions of 13.4–14.6% (CL: ±2.4–3.9%) and 4.1–5.6% (CL: ±2.3–3.6%), respectively, per 10 kg increment in load were observed (Table 1). Although there is a substantial decline in power output with incremental load (e.g., power output at 0 kg compared with 60 kg) because of the nature of the force-velocity relationship, the average declines in power per 10 kg increment in load between conditions (e.g., 1- vs. 4-minute rest) were insubstantial or unclear. In an investigation to determine the optimal load for maximal power production in the jump squat, Cormie et al. (7) adjusted the rest duration allocated with increasing load, providing a 2-minute rest for loads of 0% and 12% of 1RM and a 3-minute rest for loads of 27–85% of 1RM. Our findings do not support the presumption that greater rest is required with increasing load when assessing jump squats in the load-power profile. However, the loads assessed by Cormie et al. (7) extended to heavier external loads than those used in our study (i.e., 0–85% 1RM vs. approximately 0–45% 1RM [0–60 kg], respectively). It is feasible that the assessment of external loads approaching 85% of 1RM may in fact require a longer rest interval and supports the rationale for using a variable rest interval, although this was not verified by Cormie et al. Furthermore, we cannot discount the possibility that the rest duration between loads would have a more pronounced influence on power output when the loads assessed are randomized and not assessed incrementally. It may be that performance of the 60 kg jump squat at the start of the load-power profile, for example, may have a deleterious effect on subsequent load jump squat power output, thus requiring allocation of a longer rest interval between loads. The influence of rest interval on power output in the load-power profile in which assessment of higher external loads are used and in which loads are randomized requires further investigation. We would contend although that in a practical working environment with athletes, "normal" practice would be to move incrementally through an assessment protocol with a standardized approach.

Practical Applications

Practitioners should assess the incremental load-power profile for identification of Pmax and the corresponding optimal load, thus allowing for improved prescription of training loads to enhance maximal power production. Unloaded jumps are optimal for peak and mean power production irrespective of the rest interval allocated between incremental loads. Our findings suggest that rest intervals of 1- to 4-minute duration have a seemingly negligible effect on jump squat power output in the incremental load-power profile, and, furthermore, that the magnitude of decline in power output with increasing load is not improved with the allocation of longer recovery between loads. As such, the inclusion of a single rest interval of 1, 2, 3, or 4 minutes duration is appropriate for use in the assessment of jump squat incremental load-power profiles of moderate intensity (i.e., up to 60 kg external load) and can be governed by testing constraints such as the number of athletes to be monitored and the session duration. The application of our findings allows practitioners the flexibility of selecting a rest interval to accommodate the constraints of their training/monitoring environment; however, it is recommended that the same rest interval be used in the routine monitoring (i.e., retest) of individual athletes to ensure consistency in testing conditions and thus data integrity.

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