The Role of Resting Duration in the Kinematic Pattern of Two Consecutive Bench Press Sets to Failure in Elite Sprint Kayakers

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Key words
- average repetition velocity
- acceleration phase
- sets to failure
- bench press

Abstract

This study aimed to investigate the role of rest period duration (RP) on the time course of the acceleration portion (AP) and mean velocity of the concentric phase across two bench press sets to failure with a submaximal load (60% of the 1RM) using different RP. Ten elite junior kayakers performed, on four different days, two consecutive bench press sets to failure, allowing randomly 1-, 2-, 3- and 4-min RP between sets. AP reached a maximal value of 66% of the concentric movement time. This maximal AP was observed in repetition number 2 or 3, and then AP declined during the set, with a significant decrease when the number of repetitions was over 80% of the total number of repetitions performed. AP and lifting velocity patterns of the concentric phase were not altered during a second set to failure, regardless of RP. However, when velocity was expressed in absolute terms, 1-min RP was insufficient to maintain the average lifting velocity during the second set, compared to the first one. These results may be of use in selecting number of repetitions and resting duration in order to ensure optimal maintenance of the accelerative portion of concentric movement time with different resting-period durations.

Introduction

Kinematics associated with resistance exercises (e.g., velocity and acceleration) have been proposed as one of the most important stimuli for maximal strength and muscle power resistance training-induced adaptations [12]. Many studies have investigated single-repetition kinematics (e.g., deceleration phase) using different resistance exercises and loads [3, 5, 9, 15]. The deceleration phase is an important part of the lift. In this phase, bar velocity decreases because it is unintentionally decelerated by the performer [14]. It has been shown that during bench press, with a load of 45% of 1RM, the deceleration phase was shorter (40% of the concentric movement time) [14] compared to the slower bench press with heavy loads (51.7% of the concentric movement time with a load of 81% of 1RM) [4]. Furthermore, Newton and coworkers [14] also showed that for a given load of 45% of 1RM, bench press action involved a longer deceleration phase (40% of the movement) compared with a bench throw condition (4% of the concentric movement time). Bench throws are ballistic movements in which the athlete releases the load at the end of the concentric phase. It has also been suggested that when a subject attempts to perform a powerful press movement and maximize bar velocity, he reduces the length of this deceleration phase [4, 14].

Very few studies have focused on kinematics associated with resistance exercises across multiple repetitions, even though this is the inherent nature of a typical strength-training session. In a recent study, it has been shown that over a set of repetitions leading to volitional exhaustion (referred to as "sets to failure"), the speed of the repetitions slows naturally and performance becomes progressively more difficult as fatigue increases [7]. For all intensities tested (75%, 70%, 65% and 60% of 1RM), the reduction observed in the average repetition velocity (expressed as a percentage of the average velocity achieved during the initial repetition) occurred when the number of repetitions was above 34% of the total number of repetitions performed [7]. A significant increase of the concentric-phase duration from the first repetition to the last repetition during a 5RM bench press has also been also reported [13]. However, to the best of our knowledge, the time-course of the acceleration-decel-

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eration profile across a set to failure is not known. Hence, the primary purpose of this study was to examine the acceleration-deceleration profile during a bench press set to failure. It was hypothesized that the acceleration phase would decrease during a set to failure.

Time-course decreases in unintentional velocity may also vary between consecutive sets of the same exercise using different rest period durations. For example, when training protocols include sets to failure, a longer rest between sets leads to a larger total volume completed during a training session [18,24,25]. Moreover, it has been suggested that training with sets to failure is more beneficial for enhancing upper-body local muscular endurance, which is a critical capacity in many muscle endurance-oriented sports (e.g., kayaking) [8]. In addition, performance in several sport modalities is not only related to performing a high number of repetitions with a submaximal pretraining load, but also to maintaining a high repetition velocity along a given exercise [4–6]. In regards to this, the impact of resting-period duration manipulation on the lifting-velocity pattern over consecutive sets remains to be elucidated. Therefore, a secondary purpose of the present study was to analyze the effect of resting duration over lifting-velocity and acceleration-deceleration profiles on two consecutive bench press sets to failure in elite junior kayakers. It was hypothesized that duration of resting period would induce differences on the kinematic profile of a second set to failure, compared to the first one.

Methods
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Subjects and experimental design

Ten elite junior kayakers (5 women and 5 men), with international competitive level in 500-m and 1000-m flatwater, volunteered for the study. All the subjects were members of the Federación de Castilla y León de Piragüismo. The subjects' mean (± SD) age, height, body mass and percentage of body fat were 17.2 (± 2.1) years, 167.9 (± 7.6) cm, 64.6 (± 8.2) kg and 17.3 (± 6.4) %, respectively. The subjects had moderate to extensive weight training experience ranging from 1 year to beyond 2 years, and all of them could bench press at least their own body mass. All the subjects had experience in training leading to failure. Concerning the annual periodization, the study was carried out during the general preparatory phase (December to February). In such a period, all the subjects shared a unique training routine (off- and on-water). Prior to data collection, the subjects were informed of the requirements associated with participation and they provided written informed consent. The study was conducted according to the Declaration of Helsinki and was approved by the University's Committee on Human Research.

Data collection took place over a period of 5 weeks with 1 testing session carried out each week. Testing sessions were carried out on the same day of the week, at the same time of the day and in all cases after a resting day. During the first experimental session, one-repetition maximum (1RM) for the bench press was determined. During the next 4 testing sessions, 2 sets of bench press were performed to failure, randomly allowing 1-, 2-, 3- or 4-minute rest intervals between sets. A counterbalance procedure was used to determine the resting duration between sets for each testing session. The subjects were not aware of the resting duration for each particular session.

Maximal strength measurement

1RM bench press was assessed using a previously established protocol [20]. Briefly, after a light warm-up on the bench press using a Smith Machine (Telju, Toledo, Spain), the subjects attempted to lift a load that was increased progressively, allowing 3 minutes of rest between attempts. 1RM value was obtained using as few attempts as possible (5 attempts maximum).

Bench press protocols

Each bench press protocol consisted of performing the bench press exercise for two sets to failure, with a load equivalent to subject's 60% of 1RM and an inter-set resting period of 1-, 2-, 3-, and 4-min, respectively. Thus, 4 minutes after a standard warm-up (5 minutes of stationary cycling and 3 sets of bench press comprising 5 repetitions at a load of 50% 1RM, allowing 1 min of rest between sets), individuals were asked to move the barbell as fast as possible during the concentric phase of each repetition, until volitional exhaustion. The subjects were not permitted to raise the shoulders off the bench, and no pause was allowed between the eccentric and concentric phases. Lastly, the subjects could not "bounce" the barbell off the chest. Failure was defined, according to a previously established criterion [7], as the time point when the barbell ceased to move, if the subject paused more than 1 s when the arms were in the extended position, or if the subject was unable to reach the full extension position of the arms. Kinematics parameters of each repetition were monitored by attaching a transducer to the end of the barbell, which was linked to a rotary encoder (Globus Real Power, Globus, Codogne, Italy). The rotary encoder recorded the position of the barbell with an accuracy of 0.1 mm and time events with an accuracy of 0.001 s. Total repetitions for each set as well as average velocity for each repetition and percentage of time in which the barbell was accelerated (during the concentric phase of each repetition) were determined. For comparison purposes, the number of repetitions was expressed as a percentage of the total number of repetitions (10%, 20%, 30%,… 100%).

Statistical procedures

Statistical analyses were conducted using SPSS 12.0 for Windows (SPSS Inc., Chicago, IL, USA). Normality of the dependent variables (accelerative portion, average velocity and number of repetitions) was checked and subsequently confirmed using the Kolmogorov–Smirnov test. Then a three-way ANOVA was performed. The 3 factors considered were resting period (RP; 1, 2, 3 or 4 min), set (set 1 vs. set 2) and percentage of the total number of repetitions (10, 20, 30,… or 100%). When a significant F-value was achieved, pairwise comparisons were performed using a Bonferroni post hoc procedure. Statistical significance was set at $p < 0.05$.

Results
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Accelerative portion

During the first set, the repetition with the highest accelerative portion (AP) (66%) corresponded to the second or the third repetition. The AP decreased significantly ($p < 0.01$) throughout the first set. The repetition at which a significant decrease in the AP took place corresponded to 79% of the total number of repetitions achieved. During the last repetition, the barbell was accelerated for 38% of the concentric movement. The AP decreased significantly ($p < 0.01$) also during the second set. Thus, the rep-

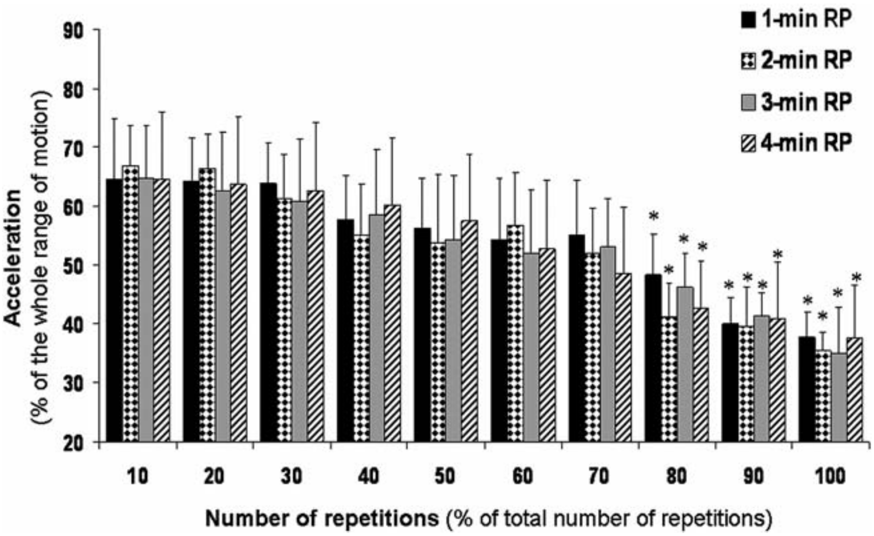

Fig. 1 Percentage of the concentric phase in which the barbell is accelerated, during set 2, for all RP schemes. Number of repetitions is expressed as a percentage of total number of repetitions completed. Values are means ± SD. * Significantly different from repetition with the highest AP ($p < 0.05$).

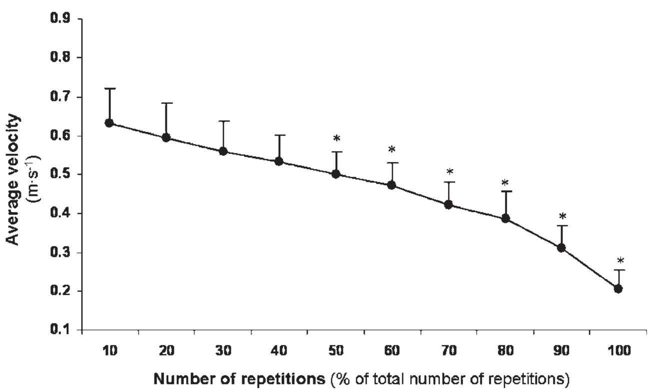

Fig. 2 Average repetition velocity during set 1 (average of the four testing days). Number of repetitions is expressed as a percentage of total number of repetitions completed. Values are means ± SD. * Significantly different from fastest repetition ($p < 0.05$).

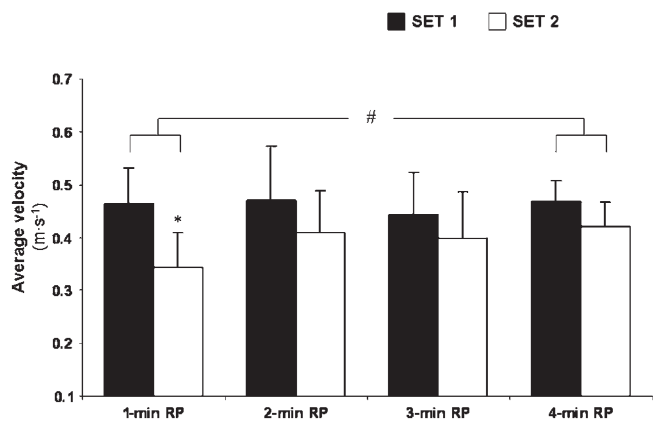

Fig. 3 Average repetition velocity during set 1 and set 2 for all RP schemes. Values are means ± SD. * Significantly different from set 1 ($p < 0.05$). # Significantly different from mean velocity lost in the 1-min RP scheme.

etition at which a significant decrease in AP occurred corresponded to 80%, 73%, 76% and 75% of the total number of repetitions achieved in 1-min RP, 2-min RP, 3-min RP and 4-min RP conditions, respectively (**Fig. 1**). Again, the repetition with the highest AP corresponded to the second or the third repetition. The APs of the last repetition performed during the second set were 44 ± 5%, 42 ± 4%, 41 ± 9% and 44 ± 11% in 1-min RP, 2-min RP, 3-min RP and 4-min RP, respectively. No set × RP interaction was detected regarding the AP profile. That is, AP profile was similar in the first set compared to the second set, regardless of the resting duration.

Lifting velocity

As shown in **Fig. 2**, average velocity decreased ($p < 0.001$) throughout the first set. Maximal mean velocity (0.63 ± 0.12 $m \cdot s^{-1}$) was achieved within the first three repetitions. The repetition at which a significant decrease in the initial relative velocity occurred (repetition number 12) corresponded to 48% of the total number of repetitions achieved. The average velocity attained during the last repetition performed (0.21 ± 0.05 $m \cdot s^{-1}$) corresponded to 35% of the average velocity attained during the initial three repetitions.

Fig. 3 displays average lifting velocity for all conditions. A significant set effect concerning average lifting velocity in absolute values was observed. There was a significant set × RP interaction ($F_{1,10} = 98.9$; $p < 0.001$), with a significant decrease of the velocity during the second set compared to the first one in 1-min RP (27%; $p < 0.001$). In fact, in the 1-min RP scheme, the post hoc test showed a significant lower velocity during the second set for repetitions until 60% of the total number of repetitions performed (**Fig. 4**). Although slight decreases were also detected in 2-min RP (13%), 3-min RP (10%) and 4-min RP (10%) conditions, the difference did not reach statistical significance. However, when velocity was expressed as a percentage of maximal value, no significant set effect ($F_{1,10} = 1.64$; $p = 0.201$) nor set × RP interaction ($F_{1,10} = 0.732$; $p = 0.533$) was observed. The repetition at which a significant decrease in the initial relative velocity occurred corresponded to 52%, 46%, 48% and 49% of the total number of repetitions achieved during the second set in 1-min RP, 2-min RP, 3-min RP and 4-min RP conditions, respectively (**Fig. 4**). The average velocity attained in the last repetition performed during the second set was 0.19 ± 0.07 $m \cdot s^{-1}$, 0.17 ± 0.06 $m \cdot s^{-1}$, 0.20 ± 0.07 $m \cdot s^{-1}$ and 0.20 ± 0.05 $m \cdot s^{-1}$ in 1-min RP, 2-min RP, 3-min RP and 4-min RP conditions, respectively. Thus, velocity attained during the last repetition of the second set

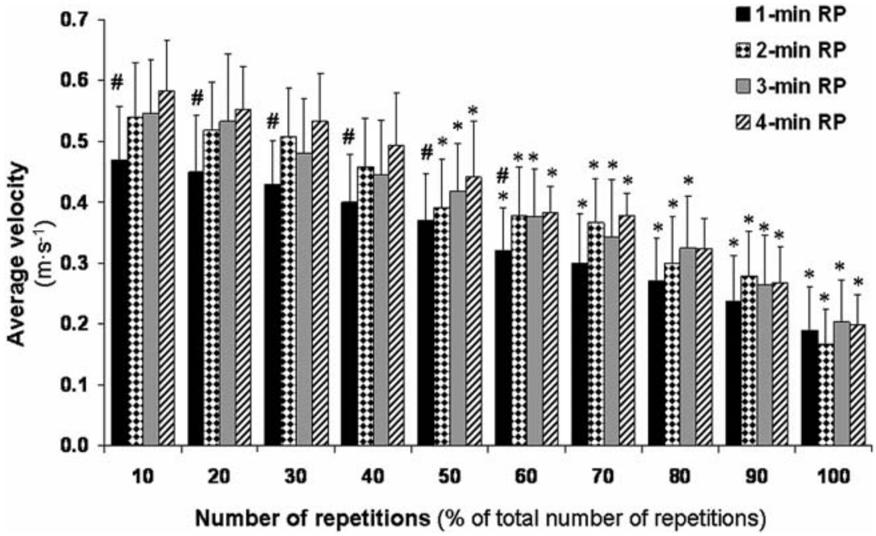

Fig. 4 Average repetition velocity, during set 2, for all RP schemes. Number of repetitions is expressed as a percentage of total number of repetitions completed. Values are means ± SD. * Significantly different from the repetition with the highest AP ($p < 0.05$). # Significantly different from corresponding first-set repetition.

ranged from 30% to 38% of the average velocity attained during the initial three repetitions, with no set × RP interaction.

Number of repetitions

During the first set (averaging the results of the four testing days), the number of repetitions achieved was 25.5 ± 3.2. A significant set effect ($F_{1,10} = 83.3$; $p < 0.001$) was observed regarding the number of repetitions achieved. Moreover, there was a set × RP interaction ($F_{1,10} = 2.94$; $p < 0.05$). That is, the number of repetitions decreased significantly during set 2 when compared to set 1 in 1-min RP (50%; $p < 0.001$), 2-min RP (33%; $p < 0.001$), 3-min RP (25%; $p < 0.001$) and 4-min RP (21%; $p < 0.01$) schemes. The relative decay in the number of repetitions was statistically greater ($p < 0.01$) in the 1-min RP condition when compared to the 3-min RP and 4-min RP condition (**Fig. 5**). Finally, the total number of repetitions (including set 1 and set 2) was significantly higher ($p < 0.05$) in 3-min RP and 4-min RP schemes than in 1-min RP and 2-min RP schemes.

Discussion

The primary finding of the present study is that AP of concentric phase declines naturally over a bench press set to failure in elite junior kayakers, with a significant decrease when the number of repetitions is over 79% of the total number of repetitions performed. Our data indicate that when elite junior kayakers perform a bench press with a load of 60% of 1RM, they can accelerate the barbell during 66% of the concentric movement time. These results are in line with those of Newton and coworkers [14], who observed that the AP can reach 60% of the concentric movement time in recreationally trained men when using a load equivalent to 45% of 1RM. The deceleration phase is inherent to the lift, and it occurs even when there is an attempt to increase or maintain movement speed, particularly when using light resistances and athletes try to lift them quickly. It has been demonstrated that large deceleration phases, which are undesirable when attempting to maximize power performance, can be reduced by means of ballistic movements (i.e., bench throws) [14]. However, in a group of power-lifters using higher loads (81% of 1RM), it has been found that the AP can be reduced to 48.3% of the concentric movement time [4]. Some methodological differences existing between that study and the present study could explain the lower AP observed by Elliot and coworkers [4], even though they used a higher load. First, they allowed only one attempt, whereas it has been reported in previous studies that the first repetition is used to gradually achieve the maximum repetition velocity [7], which agree with our results. In fact, studies focused on peak power measurement during free weight movements usually elicit 3 repetitions [21]. Second, Elliot and coworkers [4] performed the bench press using a traditional bench rack, with an Olympic-style barbell, while the present study, as well as Newton's study [14], were carried out using a Smith machine. Previous data indicate that exercises performed on a Smith machine do not entail a large deceleration period [15], although to the best of our knowledge, no studies have compared kinematics of free-weight vs. Smith machine bench press. A rationale for this apparent lower deceleration period observed in a Smith machine bench press may be provided by the path of the bar during the lift. That is, the Smith machine, with its fixed vertical guided motion, does not allow the normal curve usually observed during free-weight bench press, which can explain the lower force produced during bench press performed with a Smith machine, compared to a free-weight technique [2]. Therefore, the acceleration of the barbell may be more difficult during a Smith machine vs. free-weight bench press. Hence, a longer acceleration period is needed on a Smith machine. Further investigations are needed in order to clarify the different kinematics associated with both bench press techniques. Finally, it is necessary to mention at this point that the use of a Smith machine in the present study could induce a limitation regarding practical applications, given that the bench press on the Smith machine only involves a single plane of motion, while the kayaking technique does not involve only one plane of motion.

To the best of our knowledge, this is the first study analyzing the time-course of AP across a set of repetitions to failure. As fatigue increases, performance of repetitions becomes progressively more difficult, which explains the natural decay in lifting velocity observed during a set to failure in the present study and others [7,13,16]. In fact, the last repetitions of a set to failure using moderate loads (i.e., 60% of 1RM) are similar to maximal lifts (i.e., 100% of 1RM), regarding kinematic aspects [7]. In the current research, the acceleration-time curve observed during the initial repetitions differed from the one corresponding to the last

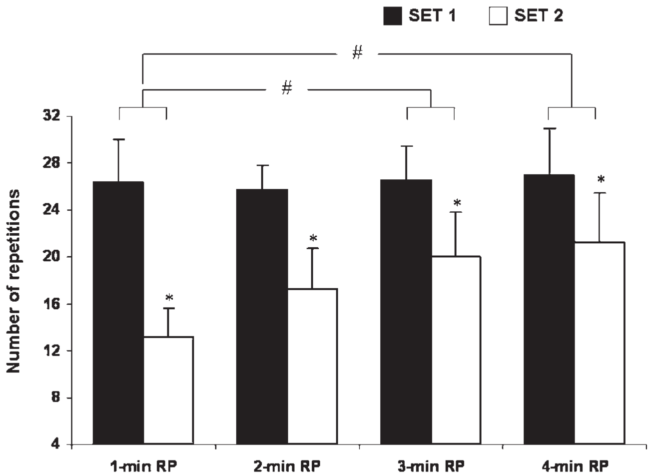

Fig. 5 Total number of repetitions completed in set 1 and set 2 for all RP schemes. Values are means ± SD. * Significantly different from set 1 ($p < 0.05$). # Significantly different from number of repetitions lost in the 1-min RP scheme.

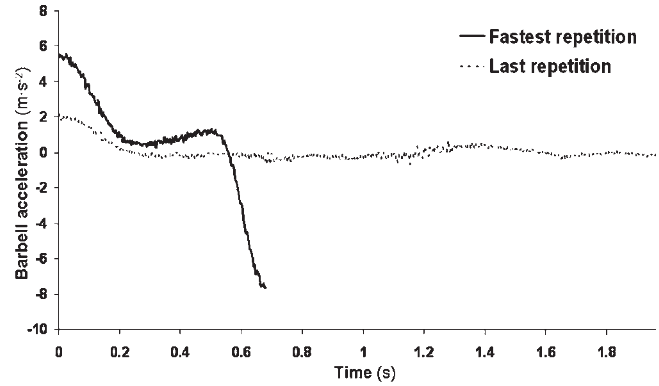

Fig. 6 Acceleration-time curve for fastest and last repetition exerted by a representative subject during the first set.

repetition (see ▶ **Fig. 6**). In both curves, the highest acceleration is reached during the first portion of concentric movement. Then, in the fastest repetition, acceleration decays just until the "sticking region", as referred to in literature [4,10]. The sticking region or sticking point is the position in the concentric phase in which the lifter experiences apparent difficulty in exerting force against the bar, and it is caused by a relative poor mechanical force-producing position, in combination with a gradual disappearance of released strain energy stored in the series elastic components of the muscle [4]. Once the sticking region has been overcome, acceleration increases again and then drops dramatically, yielding negative values, in order to stop the barbell. The sequence is similar in the last repetitions, but the curve is smoother.

In agreement with previous studies, we found that over a set of repetitions until failure the speed of the repetitions slows naturally [7,13,16], with this decrease being significant when the number of repetitions was over 50% of the total number of repetitions performed. Izquierdo and coworkers [7], who used the same exercise and the same relative load, observed a significant decline in lifting velocity when the number of repetitions reached 40% of the total number of repetitions [7]. This difference may be due to the usual training routine of the subjects in the present study, given that kayakers normally perform muscular endurance-type training. It is also interesting to point out that during the first set, the number of repetitions performed by kayakers in the present study (over 25 repetitions) was slightly higher than the number of repetitions achieved by Basque ball players [7] or free-weight trained subjects [19], performing the bench press also at 60% of 1RM. Again, the long-term training specificity could explain the small difference existing between these two studies data and the present results [6].

An interesting finding of this study is that both AP and lifting velocity decline patterns of the concentric phase are not altered during a second set to failure, regardless of RP duration. Actually, during the second set, a significant reduction in AP and lifting velocity occurred at 76.5% and 49% of the total number of repetitions achieved, respectively. However, when velocity was expressed in absolute values, 1-min RP is not sufficient to maintain the average lifting velocity during a second set to failure, compared to the first one. This is in line with a recent study, in which the effects of different RP durations on metabolic responses and bench press lifting performance (load and set duration) were examined [17]. In this study, resistance-trained men performed 10 randomized protocols (five sets with 75 or 85% of 1RM for ten and five repetitions, respectively, using different RP intervals). Resistance was modified when necessary in order to maintain the prescribed number of repetitions. The authors observed that lifting performance was maintained over two consecutive sets when a RP of at least 2 min was allowed [17]. Others have studied the effect of RP on muscular power during 10 sets of 6 repetitions with 70% of 1RM [1]. The results did not show significant power decay when comparing set 1 and set 2, even with a 1-min RP. This underlines the importance of considering whether sets are performed to failure. The high metabolic demand of a submaximal-load set to failure requires a longer RP if maintenance of repetition velocity is the goal, as pointed out in the present results.

Finally, our results indicate that elite kayakers are unable to maintain the number of repetitions during consecutive bench press sets to failure when a RP of 4 minutes or less are allowed. Although it could be expected that highly muscular-endurance trained subjects (e.g., elite kayakers) would be able to repeat their performances with shorter rest periods, given a likely enhanced energy restoration capacity [1], recent studies show similar results in comparison with less trained subjects. For example, Willardson and Burkett [27] did not show in recreationally-trained lifters significant differences in the sustainability of bench press repetitions during sets to failure by using different rest periods (30 s, 1 min and 2 min) [27]. However, it should be pointed out that in this study a standardized cadence was used for the eccentric and concentric portion of movements, while in the present work, subjects were asked to lift the barbell as fast as possible. In a different study and using a similar population, the same authors demonstrated that a 3-min RP is not enough to sustain repetitions with a bench press set at a load of 50% 1RM [26]. In agreement with these studies, with recreationally trained lifters, a significant decay in the number of repetitions with 75% 1RM in a bench press exercise with a RP of 1, 3 and 5 minutes has been reported [18]. On the contrary, when using maximal loads, (≥ 90% 1RM) rest intervals of 1 minute to 2 minutes can be sufficient between attempts in order to maintain the number of repetitions [22,23]. Therefore, the duration of the RP needed to sustain repetitions may depend on the magnitude of the load lifted, as well as the velocity of movements.

In summary, the present study shows that the AP of the concentric phase declines naturally over a bench press set to failure in elite junior kayakers, with a significant decrease when the number of repetitions is over 80% of the total number of repetitions performed. Moreover, the AP and lifting velocity time-course patterns of the concentric phase are not altered during a second set to failure, regardless of the RP duration. However, when velocity is expressed in absolute terms, a 1-min RP is not sufficient to maintain the average lifting velocity during a second set to failure, when compared to the first one. The present results may be useful for evaluating the optimal lifting-velocity pattern over consecutive sets of repetitions to ensure optimal maintenance of the proportion of concentric movement time in which the barbell is accelerated (accelerative portion, AP) with different resting-period durations. In kayaking, as well as in other sports, performance is not only related to the capacity to carry out a high number of repetitions, but also to maintaining a high repetition velocity along a given exercise. Although classical resistance training exercises differ in nature from stroke technique, the training-specificity principle indicates that the training stimulus should be specific to sport modality in order to provide the greatest transfer of training effects. In line with this, it is known that flatwater kayak performance is enhanced when the blade is accelerated over a high portion of the whole stroke. Thus, unspecific training exercises (i.e., bench press) should ensure optimal maintenance of the AP. Our study indicates a consistent and similar pattern of decline in AP over consecutive sets to failure, pointing out that the amount of repetitions performed during submaximal-load sets should not reach 80% of the total number of repetitions potentially completed, in order to avoid a significant decrease in AP. Finally, a 2-min resting period between sets to failure might be enough when the goal is a maintenance of average repetition velocity.

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