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Research article

The Effects of Eccentric Cadence on Power and Velocity of the Bar during the Concentric Phase of the Bench Press Movement

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Abstract
Training at a specific movement tempo is a relatively new concept in resistance training. It is based on manipulation of the duration of particular phases of a movement. General studies have demonstrated that faster movement tempo in resistance training leads to an increase in muscle power, whereas lower movement speed is beneficial in the development of muscle strength and hypertrophy. However, the studies in this area are inconclusive and do not relate precisely to various tempos and movement speeds. The aim of the study was to determine the effect of duration of the eccentric cadence ECC_{REG} (2/0/X/0) and ECC_{SLO} (6/0/X/0) on muscular power generated in the concentric phase of the movement expressed in maximal P_{MAX}, V_{MAX} and average values P_{AVE}, V_{AVE}. For the ECC_{SLO} (6/0/X/0) cadence, a significantly lower value of P (401.95 ± 65.42 W) was observed compared to the ECC_{REG} 2/0/X/0 tempo (467.65 ± 79.18 W), at p = 0.007. The same was true for power evaluated in maximal values (P_{MAX}), as significantly higher values were recorded for the regular ECC_{REG} (2/0/X/0) (671.55 ± 115.79 W) compared to the slow tempo ECC_{SLO} (6/0/X/0) (565,70 ± 117,37 W), at the level of significance of p = 0.007. The velocity evaluated for ECC_{REG} (2/0/X/0) tempo expressed in average values (V_{AVE}) 0.60±0.09 m/s was significantly higher compared to the ECC_{SLO} (6/0/X/0) tempo (0.52 ± 0.08 m/s), with p=0.004. When maximal velocity (V_{MAX}), was considered higher values for ECC_{REG} (2/0/X/0) tempo was registered (0.79 ± 0.10 m/s) compared to the ECC_{SLO} (6/0/X/0) tempo (0.69 ± 0.13 m/s), at significance of p = 0.001. The main finding of the study indicates that the duration of the eccentric phase of the movement has a significant impact on muscular power and velocity during the concentric phase of the movement.

Key words: Resistance exercise, tempo, time under tension.

Introduction

Development of muscle strength and power is one of the leading concerns of coaches and sport scientists due to its critical role in various sport disciplines. The basic objective of resistance training is to increase muscle strength and power generated during a specific movement. Resistance training stimulates specific adaptive changes, which allow for increased muscular strength, hypertrophy and improvements in the rate of power development, which is of key importance in explosive sport activities. The bench press is one of the fundamental exercises used to develop upper-body strength and power. Despite numerous scientific studies, it is still unclear which velocity of particular movement phases (ECC-CON) is optimal for the development of muscle hypertrophy, strength and power (Fry 2004; Roig et al., 2009; Wilk et al. 2018a).

Training at a specific movement tempo is an alternative concept in resistance training, where the duration of particular movement phases are manipulated. The findings of previous investigations suggest that changes in movement tempo during resistance training impacts exercise volume, the level of generated force and power, and muscular hypertrophy (Hatfield et al., 2006; Headley et al., 2011; Hunter et al., 2003; Keeler et al., 2001; Sakamoto and Sinclair 2006; Westcott et al., 2001; Wilk et al., 2018a; 2018b). Movement tempo has been defined in seconds which correspond to individual movement cadences (ECC/pause/CON/pause). Value X for the concentric movement represents maximal intended movement velocity. Results of Wilk et al. (2018a), suggest that movement tempo and duration of individual movement phases should be controlled and taken into consideration when designing resistance training programs.

Research indicates that particular eccentric (ECC) and concentric (CON) cadence values cause different adaptive responses. Bird et al. (2005) showed that for the development of power, explosive movement tempo should be used, while for the development of maximum strength the 1/1/1/0 tempo seems most appropriate, while for the greatest gains in muscle hypotrophy the 2/1/2/1 tempo is preferable. Hatfield et al. (2006) demonstrated declines in power generated in a group of athletes that used the 10/0/10/0 tempo compared to a group that trained with volitional movement velocity. Westcott et al. (2001) examined the effects of an 8-week resistance training program with regular cadence (2/1/2/0) and with Super-Slow cadence (4/0/10/0). The Super-Slow training resulted in a 50% greater increase ($p < 0.001$) in strength for both men and women than training at volitional speed. Neils et al. (2005) compared the effects of an 8-week resistance training program with a 4/0/2/0 cadence and a super slow cadence of 5/0/10/0. Peak power for the CMJ increased significantly after the 4/0/2/0 cadence (23.0 ± 5.5 W/kg to 25.0 ± 6.3 W/kg), while no such increase was observed after the slow 5/0/10/0 cadence. The results of this study suggest that faster cadences are more effective for improving peak power. However, the available data regarding this issue is inconclusive, and refers to chronic changes of generated power only (Keeler et al., 2001; Neils et al., 2005). Furthermore, there is no scientific data, related to the acute effects of movement tempo on power and velocity. Morrissey et al. (1998) did not demonstrate differences in the generated power, both in maximal and average values between groups which trained three times per week for 7 weeks with different durations of the eccentric phase of movement. Furthermore, there is no data to support the direct effect of different ECC cadences on the CON velocity of the move-

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ment and power output. Many studies using modern apparatus have determined the optimal level of external load (% RM) at which the athlete develops peak power (Argus et al., 2013; Jandacka and Vaverka, 2008). However, these studies have not taken into consideration movement velocities, both in the ECC and CON phases of resistance exercises.

Most studies that have analysed the level of power or effectiveness of utilization of the SSC cycle have performed the ECC phase at voluntary or maximal effort, but neither speed nor duration of the cadence were precisely controlled. There are no scientific reports which would verify whether changes in the cadence of the ECC phase of movement affect the level of power generated during the CON part of the movement during isotonic resistance exercises. Increasing the transition between the ECC and CON phases of movement can inhibit the SSC effect (Malisoux et al., 2006). Furthermore, many studies that have analysed the effect of movement tempo on the level of generated strength and power have used isokinetic equipment (Farthing and Chilibeck, 2003; Lacerte et al., 1992; Shepstone et al., 2005). Training at a slow speed seems to generate strength gains, at all velocities (Adeyanju et al., 1983; Caiozzo et al., 1981; Garnica 1986; Moffroid and Whipple 1970; Pipes and Wilmore 1975; Smith and Melton 1981). Isokinetic testing conducted by Seaborne and Taylor (1984) revealed greater strength gains for subjects using a fast tempo (108°/sec), compared to a slow one (36°/sec). Moffroid and Whipple (1970) found significant gains only for the fast training group (108°/sec), while Ewing et al. (1990) observed significant gains, for both the slow and the fast training tempo groups. General gains in power were also found for slow (Garnica 1986) and fast training regimes (Garnica 1986; Timm 1987). However it must be concluded, the results from isokinetic equipment have limited empirical and practical value. Such equipment is expensive, difficult to configure and generally unavailable in everyday conditioning. Therefore, the effect of movement tempo on adaptive changes in the body should be analysed through isotonic contractions using available training equipment, most often free weights.

Considering the above, the determination of the duration of the ECC phase on the level of power generated in the CON phase represents a significant research problem, and requires additional analyses. Therefore, the aim of this study was to determine the effect of manipulating eccentric cadence on concentric power and velocity outputs.

Methods

All testing was performed in the Strength and Power Laboratory at the Academy of Physical Education in Katowice. The experiment was performed following a randomized crossover design, where each participant performed a familiarization session with a 1RM test, as well as two different testing protocols a week apart. During the experimental sessions, subjects performed three sets of the bench press (BP) exercise using 70% 1RM and two different tempos: 2/0/X/0 eccentric regular cadence (ECC_{REG}), and 6/0/X/0 eccentric slow cadence (ECC_{SLO}). Subjects were required to refrain from resistance training 72 hours prior to each experimental session, were familiarized with the exercise protocol and were informed about the benefits and risks of the study, before expressing their written consent for participation.

Participants

Thirty-three (33) healthy strength trained men volunteered for the study after completing an ethical consent form (age = 24.0 ± 4.2 years, body mass = 77.3 ± 5.7 kg, bench press 1RM = 107,4 ± 13.5 kg; data presented as mean ± standard deviation [SD]) with a minimum one year of strength training experience (2.2 ± 0.57 years; mean ± standard deviation [SD]). All subjects were over 18 years old. Furthermore the subjects participating in the experiment were expected to be able to perform a bench press with the load of at least 120% of their body mass (Outlaw et al., 2014). The participants were allowed to withdraw from the experiment at any moment and were free of any pathologies or injuries. The study protocol was approved by the Bioethics Committee for Scientific Research, at the Academy of Physical Education in Katowice, Poland (10/2018) according to the ethical standards of the Declaration of Helsinki, 1983. Subjects were instructed to maintain their normal dietary habits over the entire study period and not to use any dietary supplements or stimulants for the duration of the study.

Procedures

Familiarization session and one repetition maximum test

The participants arrived at the laboratory at the same time of day as the upcoming experimental sessions (in the morning between 09:00 and 11:00) and cycled on an ergometer for 5 minutes at an intensity that resulted in a heart rate of around 130 bpm, followed by a general upper body warm-up of 10 pull ups and 15 push-ups. Next, they performed 15, 10, and 5 BP repetitions using 20%, 40%, and 60% of their estimated 1RM using a 2/0/X/0 cadence. Hand placement on the barbell was individually selected, but the forefinger had to be inside of the 81-cm mark on a standard powerlifting IPF bar. The positioning of the hands was recorded to ensure consistent hand placement during all testing sessions. The participants then executed single repetitions using a volitional cadence with a 5 min rest interval between successful trials. The load for each subsequent attempt was increased by 2.5 kg, and the process was repeated until failure.

Experimental sessions

The general and specific warm-up for the experimental sessions was identical to the one used for the familiarization session. Following the warm up, the participants started the main examinations and performed 3 consecutive sets of the bench press (BP_{Set1}, BP_{Set2}, BP_{Set3}) with one repetition in every sets using 70%1RM with metronome guided movement cadence in the eccentric phase (Korg MA-30, Korg, Melville, New York, USA). The tests were carried out at random, and particular sessions were performed using fast (2s) and slow (6s) eccentric cadence. The concentric phase was performed at maximal possible speed. Power [W] was expressed in maximal (P_{MAX}) and average values (P_{AVE}), similarly to velocity [m/s], expressed as (V_{MAX}) and (V_{AVE})

average. A linear position transducer systems "Tendo Power Analyzer" (Tendo Sport Machines, Trencin, Slovakia) was used for the evaluation of bar velocity (Cormie et al., 2007; Goldsmith 2018; Gray and Paulson, 2014; Jennings et al., 2005; Jones et al., 2008; Stock et al., 2011). The system consists of a velocity sensor connected to the load by a kevlar cable which, through an interface, instantly transmits the vertical velocity of the bar to a specific software installed in the computer (Tendo Weight-lifting Analyzer 5.0). Data related to average and peak velocity as well as power of the concentric phase was recorded. The rest interval between sets was 5 minutes. The interval between the two stages of the experiment was 7 days. During each BP set, the participants were encouraged to perform at maximal engagement according to the recommendations by Brown and Weir (2001). All repetitions were performed without bouncing the barbell off the chest, without intentionally pausing at the transition between the eccentric and concentric phases, and without raising the lower back off the bench.

Statistical analysis

Descriptive statistics (arithmetic average, standard deviation, standard error and confidence intervals) were determined to evaluate the level of power [W] and velocity [m/s] in average and maximal values during the bench press movement performed with a regular ECC_{REG} (2/0/X/0) and slow ECC_{SLO} (6/0/X/0) tempo, in particular sets (BP_{set1-3}). Before the analytical process, we performed the Shapiro-Wilk test where normal distribution was demonstrated at the level of significance of $p>0.05$. This was used for choosing parametric statistical methods during further analysis.

Significance of differences in P and V values between ECC_{REG} (2/0/X/0) and ECC_{SLO} (6/0/X/0) for particular sets of the bench press (BP_{set1-3}) measured as average (AVE) and maximal (MAX) values was evaluated by one-way analysis of variance (ANOVA). Homogeneity of variance was verified using the Levene's test and confirmed at the level of significance of $p > 0.05$. The examination was aimed to evaluate differences in the levels of power (P) and velocity (V) generated for the movement between the regular ECC_{REG} (2/0/X/0) and slow ECC_{SLO} (6/0/X/0) tempo of movement. A one-way analysis of variance (ANOVA) was performed to analyse the implicit multidimensional structure formed by dependent and independent variables. The F values and level of significance were determined.

Results

The P expressed in maximal values (P_{MAX}) was significantly higher in BP_{set1-3} for ECC_{REG} (2/0/X/0) compared to ECC_{SLO} 6/0/X/0, at the level of significance of $p = 0.007$ (Figure 1, Table 1, 2 and 3). Power expressed in average values (P_{AVE}) was significantly higher in BP_{set1-3} for ECC_{REG} (2/0/X/0) compared to ECC_{SLO} (6/0/X/0), at the level of significance of $p = 0.007$ (Figure1). When velocity was expressed in maximal values (V_{MAX}) in BP_{set1-3}, also significantly higher results were observed for ECC_{REG} 2/0/X/0 compared to the ECC_{SLO} 6/0/X/0, at the level of significance of $p = 0.001$ (Figure 2). When velocity was expressed in average values (V_{AVE}), it was significantly higher in BP_{set1-3} for the ECC_{REG} (2/0/X/0) tempo, compared to the ECC_{SLO} (6/0/X/0) tempo, at the level of significance of $p = 0.004$ (Figure 2, Table 1, 2 and 3).

Table 1. Power and velocity expressed in average and maximal values during the first set of the BP using the 2/0/X/0 and 6/0/X/0 tempos. Data are presented as mean ± standard deviation (SD).

Variables		Tempo	X ± SD	95% CI of mean difference	ANOVA F	ANOVA p
Ave	Power [W]	2/0/X/0	467.65 ± 79.18	430.59-504.71	8.18	0.007
		6/0/X/0	401.95 ± 65.42	371.33-432.57		
	Velocity [m/s]	2/0/X/0	0.60 ± 0.09	0.56-0.64	9.42	0.004
		6/0/X/0	0.52 ± 0.08	0.48-0.56		
Max	Power [W]	2/0/X/0	671.55 ± 115.79	617.36-725.74	8.24	0.007
		6/0/X/0	565.70 ± 117.37	510.77-620.63		
	Velocity [m/s]	2/0/X/0	0.79 ± 0.10	0.74-0.83	7.46	0.01
		6/0/X/0	0.69 ± 0.13	0.62-0.75		

Ave - average values, Max – maximal values, F - variance test (Fisher), p - level of statistical significance.

Table 2. Power and velocity expressed in average and maximal values during the second set of the BP using the 2/0/X/0 and 6/0/X/0 tempos. Data are presented as mean ± standard deviation (SD).

Variables		Tempo	X ± SD	95% CI of mean difference	ANOVA F	ANOVA p
Ave	Power [W]	2/0/X/0	480.05 ±82.10	441.62-518.48	10.6	0.002
		6/0/X/0	400.05 ±73.05	365.86-434.24		
	Velocity [m/s]	2/0/X/0	0.62 ± 0.09	0.58-0.66	13.02	0.0009
		6/0/X/0	0.52 ± 0.09	0.47-0.56		
Max	Power [W]	2/0/X/0	702.25 ± 129.50	641.64-762.86	7.28	0.01
		6/0/X/0	587.90 ± 138.48	523.09-652.71		
	Velocity [m/s]	2/0/X/0	0.82 ± 0.11	0.77-0.87	8.58	0.006
		6/0/X/0	0.70 ± 0.15	0.63-0.77		

Ave - average values, Max – maximal values, F - variance test (Fisher), p - level of statistical significance.

Table 3. **Power and velocity expressed in average and maximal values during the third set of the BP using the 2/0/X/0 and 6/0/X/0 tempos. Data are presented as mean ± standard deviation (SD).**

Variables		Tempo	X ± SD	95% CI of mean difference	ANOVA F	ANOVA p
Ave	Power [W]	2/0/X/0	492.15±87.61	451.15-533.15	12.41	0.001
		6/0/X/0	397.00±83.20	358.06-435.94		
	Velocity [m/s]	2/0/X/0	0.62±0.10	0.58-0.67	14.43	0.0005
		6/0/X/0	0.51±0.09	0.47-0.55		
Max	Power [W]	2/0/X/0	713.10±132.72	650.99-775.21	13.55	0.0007
		6/0/X/0	563.10±124.93	504.63-621.57		
	Velocity [m/s]	2/0/X/0	0.81±0.11	0.76-0.87	12.43	0.0001
		6/0/X/0	0.68±0.13	0.62-0.74		

Ave - average values, Max – maximal values, F - variance test (Fisher), p - level of statistical significance.

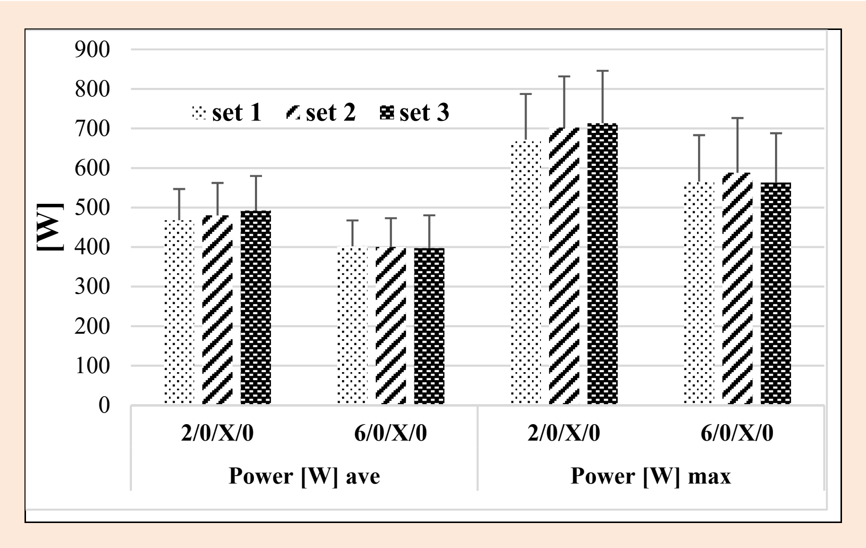

Figure 1. **Power expressed in average values and maximal values during the 3 sets of the bench press using the 2/0/X/0 and 6/0/X/0 tempos.**

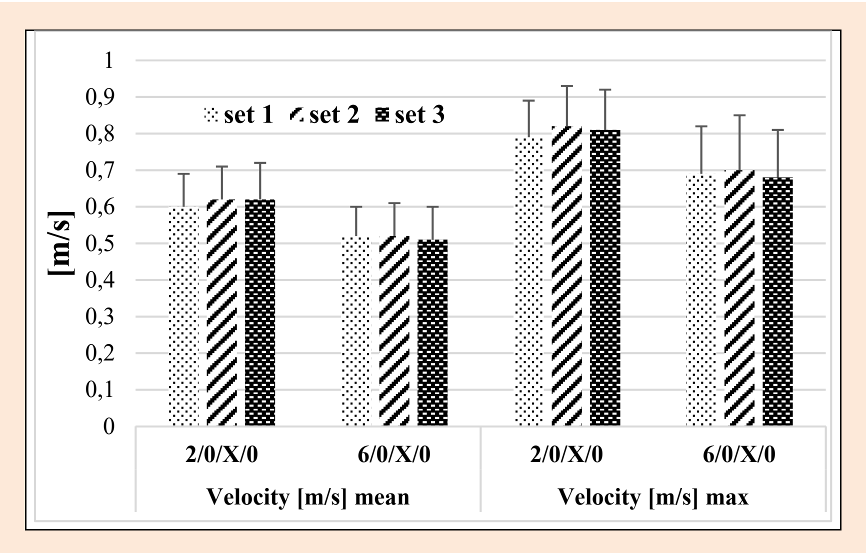

Figure 2. **Velocity expressed in average values and maximal values during the 3 sets of the bench press using the 2/0/X/0 and 6/0/X/0 tempos.**

Discussion

The main finding of the present study is that a slow ECC cadence has an adverse effect on power and velocity during the CON phase of the movement. Significant differences between the ECC_{REG} (2/0/X/0) and ECC_{SLO} (6/0/X/0) tempos were observed for both maximal P_{MAX}, V_{MAX} as well as average P_{AVE}, V_{AVE} values for each set of the BP_{Set1-3} (Tab.1-3). These results indicate that even in training, where the main focus is on the development of muscle power, one should focus not only on maximal explosiveness of the CON phase of the movement but also on the cadence of the ECC phase. This is especially important when using higher external loads (>70%1RM) where inhibition (breaking) in the ECC phase has been often observed in practice, regardless of the athlete's safety and elevated injury risks. The bench press is generally considered a potential risk factor for developing injuries to the shoulder area. The reason for this belief is often explained with the fact that the lift involves high loads of the shoulder in outer range positions. However, some authors recommended a wide grip (like in this study) in the context of minimising the risk of injury to the shoulder complex by minimising the range of motion (Haupt, 2001; Kolber et al., 2010; Lavallee and Balam, 2010). Additionally, to minimize the risk of injuries in the BP, fast ECC cadence should be used first with lower loads, and gradually increased, in accordance with linear periodization.

The results of this study are partially consistent with suggestions of Wilk et al. (2018a) and previous findings of Hatfield et al. (2006) who demonstrated declines in power generated in a group of athletes that used slow movement cadence in resistance exercises. However, the emphasis should be on the fact that Hatfield et al. (2006) did not use maximal velocities in the concentric phase of the movements and, therefore, the evaluation of power was not reliable, especially when the concentric cadence duration was 10s. Clark et al. (2010) demonstrated that maximal power and velocity used during the CON movement depend on the choice of resistance exercise and are higher when the CON movement is performed immediately after the ECC one. Greater values of both power and movement velocities (Tab.1-3) for the ECC_{REG} tempo can be related to a more effective use of elastic energy generated during the eccentric contraction, and it's release during the CON phase of the movement (Clark et al., 2010; Cronin et al., 2001; Cronin and Henderson, 2004; Lindstedt et al., 2002; Newton et al.,1997). Decreases in maximal values of P_{MAX}, and V_{MAX}, as well as average values of P_{AVE}, and V_{AVE} in the ECC_{SLO} tempo are linked to less efficient utilization of the SSC. Apart from the effect of the SSC on P_{MAX}, V_{MAX}, P_{AVE}, V_{AVE} between the ECC_{SLO} and ECC_{REG} tempos, additional consequences can be attributed to the time under tension (TUT), which was significantly different in the ECC phase of the movement (ECC_{SLO} - 6s; ECC_{REG} - 2s). A higher value of TUT can have a significant effect on adaptive changes related to maximal muscle strength (Neils et al., 2005; Tanimoto and Ishii, 2006; Westcott et al., 2001), the level of generated power and cross-section of muscle tissues (Shepstone et al., 2005; Tanimoto and Ishii, 2006). A three times higher value of TUT for the ECC_{SLO} tempo compared to TUT for the ECC_{REG} tempo, according to the guidelines of Wilk et al. (2018a), indicates a higher exercise volume for ECC_{REG}. A higher exercise volume in ECC_{SLO} is linked to greater energy expenditure during the eccentric contraction. Apart from less efficient utilization of the SSC, higher energy expenditure can explain a lower level of both muscle power and velocity of the movement in the CON phase when performing the BP with a 6s cadence (ECC_{SLO}). Another significant factor in the level of power generated during the CON movement is the duration of the transition phase between ECC and CON contractions. Extending the duration of the transition phase leads to a reduction in the ability to recover the elastic energy stored in the muscle (Turner and Jeffreys, 2010). However, the duration of the transition phase was similar for both ECC_{SLO} and ECC_{REG} tempos. The results of this study documented that it is not only the dynamic phase of transition from the ECC to CON phase that influence power variables, but also the duration and velocity of the entire ECC phase. Although the results of this study suggest that introduction of a slower movement cadence in the ECC phase leads to a decline in P and V values, this does not relate to chronic stages of muscular adaptation.

Despite the fact that the results showed a significant increase in power and velocity in the CON phase of the movement after the 2/0/X/0 cadence, the research does not indicate whether this effect occurred due to the higher ECC velocity or as a result of an efficient use of kinetic power associated with the SSC. It is possible that both factors contributed to greater values of power and higher speed in the CON phase of movement.

However, there is a further need for research which should explore the effects of different duration of the ECC phase of the movement on both acute and chronic changes in the level of generated power and velocity during the CON phase of the movement.

Conclusion

These studies demonstrated that the control of the movement tempo or values of the ECC and CON cadences significantly influence the efficiency of resistance training. In order to develop a high level of muscular power during CON contractions, one should strive for maximally dynamic performance of the ECC phase. The research does not specify long-term adaptations, however, for chronic effects power training requires high values of movement velocity in the ECC phase, also when using very heavy loads. However such training protocols do not stimulate hypertrophy, as the TUT is extremely short. Increasing the TUT during the ECC phase of the movement with submaximal and maximal loads could selectively stimulate hypertrophy in FT muscle fibers. Future research should additionally compare the results of power, velocity in an isolated CON cadence to a full movement sequence, yet with a long pause between the ECC and CON phase of the movement.

Furthermore, through modification of the duration of the ECC phase of the movement, one can introduce additional stages of periodization in the development of power, which opens new opportunities for modification of strength training variables.

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Key points

- Slow ECC cadence has an adverse effect on power and velocity during the CON phase of the movement.
- Significant differences between the 2/0/X/0 and 6/0/X/0 tempos were observed for both, maximal P_{MAX}, V_{MAX} as well as average P_{AVE}, V_{AVE} values of the bench press.
- Significance of differences were observed concerned both the first set and the second and the third set of the bench press.
- The movement tempo or values of the ECC and CON cadences significantly impacts the efficiency of resistance training.

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