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Original Article

The bench press exercise performed with increased range of motion allows for greater bar velocities

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Abstract
Background/objective: The aim of this study was to examine differences in bar velocity between the cambered and standard barbell bench press exercise. Methods: Ten healthy men volunteered for the study (age = 27.9 ± 3.7 years; body mass = 89.6 ± 11.7 kg; experience in resistance training 5.7 ± 2.1 years; bench press one-repetition maximum > 120% body mass). The first session aiming at the determination of the one-repetition maximum was followed by two experimental sessions consisted of performing 3 sets of 3 repetitions of the bench press exercise with the cambered or standard barbell at 50% of one-repetition maximum (of the standard barbell) in randomized order. Results: The two-way repeated measures ANOVA indicated a significant main effect of bar type on mean velocity (p=0.001; η^2=0.739) and peak velocity (p=0.002; η^2=0.661). The post-hoc analysis showed a significantly higher mean velocity for the cambered barbell compared to the standard barbell bench press in Set 1 (p=0.002) and Set 2 (p=0.012), but not in Set 3 (p=0.062). Moreover, there was a significantly higher mean velocity in Set 2, than in Set 1 (p=0.017) during the standard barbell bench press, with no other differences. Furthermore, a significantly higher peak velocity for the cambered barbell in comparison to the standard barbell was observed in all sets of the BP exercise (p<0.001; p=0.014; p=0.048; respectively). Conclusions: The outcomes of this investigation indicated that the cambered barbell used during the bench press training session significantly increases bar velocity compared to the standard barbell with the same external load across the workout.
Keywords: muscular power; performance enhancement; resistance training; sports performance; upper-body power

Introduction

One of the resistance training variables that can be easily manipulated and has a significant effect on training adaptations is the range of motion (ROM) of the exercise (Schoenfeld & Grgic, 2020). Practitioners and coaches often use a partial ROM, believing that it can improve athletes' performance by increasing the specificity of movement. In addition, partial ROM allows lifting higher loads in comparison with full ROM, which results in substantially greater force production (Clark et al., 2008). However, a greater ROM allows for a higher velocity of movement (Drinkwater et al., 2012; Krzysztofik, Zajac, et al., 2020), and recently conducted studies have found that full ROMs after resistance training produces greater neuromuscular adaptations than partial movements (Martínez-Cava, Hernández-Belmonte, et al., 2019; Pallarés et al., 2020). Therefore, the optimal ROM is still a matter of debate in the fitness society (Goto et al., 2019).

While in most exercises the ROM is determined by the physiological capabilities of a joint or several joints, in the case of bench press the ROM is restricted by the bar which touches the chest. So, the major muscles involved in the bench press (pectoralis major, anterior deltoid, triceps brachii) are clearly not going through their full physiological ROM. To overcome this limitation and increase the ROM during the bench press exercise, a cambered barbell was designed. The cambered barbell is U-shaped, which creates additional space for the torso, allowing the lower bottom position in comparison to the standard barbell (Corey, 1991; Krzysztofik, Golas, et al., 2020). Therefore, the greater stretch of the chest and shoulder muscles can be achieved. Nevertheless, to ensure safety, an athlete should be familiar with the cambered barbell bench press, especially when it has to be performed in an explosive manner.

Although cambered barbell has been around for a long time and the bench press performance is one of the most studied resistance exercises there is surprisingly little research investigating its use in training. To date, only two studies analyzed the impact of the cambered barbell on muscle performance (Krzysztofik, Golas, et al., 2020; Krzysztofik, Zajac, et al., 2020). The first of them showed that during the cambered barbell bench press the anterior deltoid is activated to a greater extent than during standard barbell bench press, whereas the standard barbell provided higher pectoralis major and triceps brachii long head muscle activity (Krzysztofik, Golas, et al., 2020). Another indicated that the cambered barbell significantly increased power output and bar velocity in the

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bench press exercise at 50% of one repetition maximum (1RM) compared to the standard barbell (Krzysztofik, Zajac, et al., 2020). This is due to the extra ROM which allows the bar to be accelerated by a considerably longer displacement, which has a positive impact on the achieved velocity. However, these differences were assessed on the basis of only a single set, while the real-world resistance training sessions in trained individuals rarely contain a single set of a particular exercise. This raises the question of whether the observed increase in these variables will also occur in successive sets and indicates the need for further studies to optimize training with the use of cambered barbell during the bench press.

Given that the bench press is one of the most common resistance exercises used to develop upper body strength and power, and that the use of a cambered barbell during bench press can potentially be a good alternative to the standard barbell, the need for research on how affects the muscle performance appears to be justified. Thus, the objective of this study was to examine differences in bar velocity between cambered barbell and standard barbell bench press training session that included 3 sets of 3 repetitions at the same external load (50%1RM of standard barbell bench press). We hypothesized that cambered barbell bench press allows for higher velocity values, especially in the first set of the bench press exercise protocol.

Materials and Methods

Participants

Ten healthy resistance-trained men participated in this study (Table 1). The inclusion criteria were: (a) free from neuromuscular and musculoskeletal disorders, (b) a bench press personal record of at least 120% of body mass; (c) minimum of 3 years of resistance training experience (d) at least 4 weeks of previous experience with cambered barbell bench press (to avoid the potential interference of the learning effect of the bench press exercise technique on the results of the investigation). The study participants were allowed to withdraw from the experiment at any moment.

They were informed about the benefits and potential risks of the study before providing their written informed consent for participation. The study protocol was approved by the Bioethics Committee for Scientific Research, at the Jerzy Kukuczka Academy of Physical Education in Katowice, and performed according to the ethical standards of the Declaration of Helsinki, 2013. To calculate the sample size, statistical software (G*Power, Dusseldorf, Germany) was used. Given the study 2-way analysis of variance (ANOVA) (2 condition and 3 repeated measures), a small overall effect size (ES) = 0.25, an alpha-error < 0.05, the desired power (1-ß error) = 0.8 and correlation among repeated measures = 0.85, the total sample size resulted in 10 participants.

Table 1
Descriptive characteristics of the study participants.

Age [years]	27.9 ± 3.7
Body Mass [kg]	89.6 ± 11.7
Height [cm]	181 ± 6
Experience in RT [years]	5.7 ± 2.1
Standard Bar 1RM [kg]	121 ± 26
Standard Bar ROM [cm]	39.2 ± 1.8
Cambered Bar ROM [cm]	48.5 ± 1.7

Abbreviations: RT – resistance training; 1RM – one repetition maximum; ROM – range of motion.

Procedure

The participants took part in three experimental sessions within 2 weeks performed in random order. The first (Wed) session included the determination of the one-repetition maximum (1RM) load of the flat bench press with the standard barbell while the second and third (Tue and Sat, next week) sessions consisted of performing 3 sets of 3 repetitions of the bench press exercise with the cambered or standard barbell at 50%1RM (of standard barbell) in randomized order (Figure 1).

During each set the mean and peak velocity (MV; PV; respectively) were recorded. The participants were instructed to not perform any additional resistance exercises within 72-h of testing to avoid fatigue. Moreover, they were asked to maintain their normal dietary and sleep habits throughout the study and not to use any supplements or stimulants for 24-h prior to the sessions. The weight of the barbells is the same and more features of the cambered barbell are presented in Figure 2.

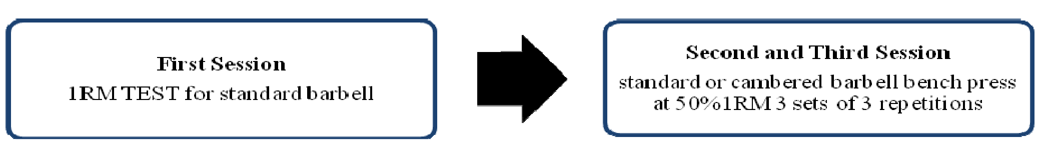

Fig. 1. Schematic representation of the experimental protocol.

Experimental Sessions

Three test sessions were used for the experimental trials. In the first one, the 1RM test was performed with the standard barbell, and the second and third were identical except for the use of the standard or cambered barbell during the bench press exercise. All testing trials were conducted at the same time of the day to avoid circadian variation (in the afternoon between 17:00 and 19:00 pm). The general warm-up for the experimental sessions was identical and comprised of: cycling on an ergometer with the upper-body component for 5 min (Keiser M3i Total Body Trainer, Keiser Corporation, Fresno CA) at a resistance approximately of 100W and cadence within 70-80 rpm; 2 circuits of 10 trunk rotations and side-bends; 10 internal, external and lateral arm swings; 10 bodyweight squats and 10 push-ups. During the first session, the participants performed 15, 10, and 5 bench press repetitions using 20, 40, and 60% of their estimated 1RM with the standard barbell. After that, the participants performed the 1RM bench press test with the standard barbell to assess upper-body maximal muscle strength. During that evaluation, the participants executed a single repetition with a constant tempo of movement (2 s duration of the eccentric phase and maximum velocity in the concentric phase, with no pause in-between) and standardized hand placement on the barbell (150% individual bi-acromial distance). The loading started at 80% estimated 1RM and if the participant successfully lifted the load, the weight was increased by 2.5 to 10kg in following attempts until the 1RM for a particular bar condition was obtained. The 1RM was defined as the highest load completed without any help of the spotters (Seo et al., 2012; Wilk et al., 2019, 2020). Five-minute rest intervals were allowed between the 1RM attempts, and all 1RM values were obtained within five attempts.

During the second and third session, the participants completed 3 sets of 3 repetitions of the bench press exercise with either the standard barbell or cambered barbell in randomized order with a load equivalent to 50% of the participants' 1RM, as measured previously in the 1RM test. This value of the external load was chosen because the range between 40% to 60% of 1RM was indicated as optimal for obtaining the highest values of peak power outputs during a bench press exercise (Siegel et al., 2002), with a low training volume which is recommended for power-oriented resistance training output (Bird et al., 2005) . In addition, for the safety of the participants, and to ensure high practicality and time-efficient testing protocol (which is crucial when a large number of athletes are tested within a single session), the same external load value was used during the cambered barbell bench press (50%1RM of standard barbell bench press) (Clark et al., 2010; McMaster et al., 2014). 3-min recovery periods were introduced between sets. To ensure safety and technical proficiency, two strength and conditioning specialists were present during all attempts, and provided spotting for the participants. The hand placement on the barbell was standardized as during 1RM test (150% individual bi-acromial distance). The eccentric phase of each repetition was performed with a constant duration of 2 s, while the concentric phase at maximal possible velocity, but without bouncing the barbell off the chest, without intentionally pausing at the transition between the eccentric and concentric phases (Haff et al., 2016; Seo et al., 2012). It should be emphasized that since not all participants were able to touch their chests during the cambered barbell bench press, they were instructed to lower the barbell to a range that was comfortable for them. The intra-class correlation coefficient and coefficient of variation for ROM measurements was 0.813 and 5.5% for standard barbell, while for cambered barbell it was 0.836 and 4.9%; respectively.

A linear position transducer system (Tendo Power Analyzer, Tendo Sport Machines, Trencin, Slovakia) was used for the evaluation of bar velocity and range of motion during the bench press exercise. The system consists of a velocity sensor connected to the bar with a kevlar cable, which, through the interface, immediately transmits the vertical velocity reached by the bar to software installed on the computer. The sampling rate is determined by the velocity of the disk's rotation (for example 200Hz for 2 m/s). In previous studies, this linear transducer has emerged as a reliable system for measuring bar velocity during the bench press exercises (intra-class correlation coefficient and coefficient of variation: 0.977 and 9.1% for mean velocity and 0.989 and 9.3% for peak velocity; respectively) (García-Ramos et al., 2018; Goldsmith et al., 2019). The peak bar velocity was obtained from the best repetition performed in particular sets, while mean bar velocity was obtained as the mean of all repetitions performed in a particular set.

Fig. 2. Cambered barbell characteristics as previously presented elsewhere [3]. Weight – 20 kg; (A) overall length – 190 cm; (B) camber depth – 10 cm; (C) space between camber – 55 cm.

Statistical Analysis

All statistical analysis were performed using SPSS (version 25.0; SPSS, Inc., Chicago, IL, USA) and were expressed as means with standard deviations (±SD). Statistical significance was set at $p < 0.05$. The paired samples t-test was performed to assess differences in the mean range of motion in all performed repetitions between the standard and cambered barbell bench press. The normality of data distribution was checked using Shapiro–Wilk tests. Due to the normal distribution of all analyzed data, the mean and peak velocity were analyzed with a two-way (bar × set; 2 × 3) ANOVA with repeated measures. Effect sizes for main effects and interaction were estimated by calculating the partial eta squared (η2). Partial eta squared values were classified as small (0.01 to 0.059), moderate (0.06 to 0.137) and large (>0.137). In the event of a significant main effect, post-hoc comparisons were conducted using the Bonferroni-adjusted significance tests. Magnitude of mean differences were expressed with standardized (Cohen) effect sizes; thresholds for qualitative descriptors of Cohen's d were defined: <0.20 as "trivial", 0.20-0.49 as "small", 0.50-0.79 as "moderate", and >0.80 as "large". Mauchly's test of sphericity was conducted to test for the homogeneity of data and if violated ($p < 0.05$), the Greenhouse–Geisser adjustment value was used. The 95% confidence intervals for mean values were also calculated.

Results

Table 2 contains the differences in performance variables during the standard and cambered bar bench press exercise. The t-test indicated significantly higher mean ROM for the cambered barbell in comparison to the standard barbell (48.5 ± 1.7 cm vs. 39.2 ± 1.8; p<0.001). The two-way repeated measures ANOVA indicated no significant bar × set interaction effect for mean velocity (p=0.098; η2=0.227) as well as for peak velocity (p=0.244; η2=0.147). However, there was a significant main effect of bar type for mean velocity (p=0.001; η2=0.739) and peak velocity (p=0.002; η2=0.661). The post-hoc analysis showed a significantly higher mean velocity for cambered barbell than standard barbell bench press in Set 1 (p=0.002) and Set 2 (p=0.012) but not in Set 3 (p=0.062). Moreover, there was a significantly higher mean velocity in Set 2 than in Set 1 (p=0.017) during standard barbell bench press, with no other differences. There were no significant differences in mean velocity between sets during the cambered barbell bench press. Furthermore, a significantly higher peak velocity for cambered barbell than standard barbell bench press in all sets (p<0.001; p=0.014; p=0.048; respectively) were found.

Table 2
Differences in bar velocity during the standard and cambered bar bench press.

	Standard Bar (95%CI)	Cambered Bar (95%CI)	*ES*	*Bar*	*Set*	*Interaction*
		Mean Velocity [m/s]				
Set 1	0.82 ± 0.17 (0.70 – 0.94)	0.9 ± 0.16 * (0.78 – 1.02)	0.48	p=0.002	p=0.118	p=0.238
Set 2	0.86 ± 0.16 # (0.74 – 0.97)	0.91 ± 0.17 * (0.78 – 1.03)	0.3			
Set 3	0.85 ± 0.15 (0.75 – 0.96)	0.88 ± 0.15 (0.77 – 0.99)	0.15			
		Peak Velocity [m/s]				
Set 1	1.13 ± 0.18 (0.99 – 1.26)	1.26 ± 0.2* (1.12 – 1.41)	0.68	p=0.001	p=0.097	p=0.098
Set 2	1.18 ± 0.18 (1.05 – 1.31)	1.28 ± 0.21* (1.13 – 1.43)	0.51			
Set 3	1.17 ± 0.13 (1.08 – 1.27)	1.25 ± 0.19* (1.11 – 1.39)	0.49			

Abbreviations: CI – confidence interval; ES – effect size; *p<0.05 compared with the corresponding value in the standard bar bench press; # p<0.05 compared with first set.

Discussion

The outcomes of this investigation indicated that the cambered barbell used during the bench press training session significantly increases bar velocity compared to the standard barbell with the same load (kg) across the workout. However, the greatest differences were noted between the first sets and gradually decreased between successive sets. This may indicate that compared to the standard barbell, the use of the cambered barbell during the bench press is likely to induce a higher level of acute fatigue because of longer bar displacement and might require a slightly longer rest interval between successive sets to achieve maximum bar velocities. These results suggest that the cambered barbell can potentially be a good alternative to standard barbell for increasing muscle performance during upper-body explosive training, however further research is needed to confirm this.

Our study confirms the beneficial effects of a greater ROM during resistance exercise on achieving higher bar velocities (Drinkwater et al., 2012; Krzysztofik, Zajac, et al., 2020; Martínez-Cava, Hernández-Belmonte, et al., 2019). Drinkwater et al. (Drinkwater et al., 2012) found that full ROM back squats lead to significantly higher bar velocity compared to partial back squats, regardless of load. Similarly, Martinez-Cava et al. (Martínez-Cava, Hernández-Belmonte, et al., 2019), showed that mean velocity was significantly higher when a greater ROM was applied (full vs. two-third vs. one-third). However, the "full" ROM during the bench press is limited by the barbell, not by physiological capabilities. The use of cambered barbell during the bench press exercise allows to obtain a significantly greater ROM due to its structure (approximately 39 cm vs. 48 cm in this study). Therefore, it seems that acceleration through a greater ROM at the same absolute load results in the production of significantly greater velocities, what probably is associated with a longer propulsive phase

(Krzysztofik, Zajac, et al., 2020; Martínez-Cava, Hernández-Belmonte, et al., 2019). To date, only one study has examined the effect of using a cambered barbell during the bench press on bar velocity (Krzysztofik, Zajac, et al., 2020). The authors found that the cambered barbell during the bench press exercise allowed for higher velocities, but only one set was analyzed. Our research is in line with these reports and, in addition, shows that higher values of bar velocity were also recorded in subsequent sets. Nevertheless, it should be emphasized that the barbell velocity changes found were trivial to small for mean velocity (from 0.15 to 0.48) and small to moderate for peak velocity (from 0.49 to 0.68), however, even a slight increase in performance can affect training adaptation and have an impact on winning in some sports, that require explosive upper-body strength (Grgic et al., 2019; Pyne et al., 2009).

In this study, the same load was used for both standard barbell and cambered barbell (50% 1RM of standard barbell bench press). Our unpublished data indicated that 1RM was significantly lower in the cambered barbell bench press than the standard barbell ($n=18$, 133 ± 16 vs. 140 ± 17 kg; $p<0.0001$) (Krzysztofik et al., n.d.), which is in line with the fact that, the greater the ROM in a given exercise, the lower the 1RM (Martínez-Cava, Morán-Navarro, et al., 2019). Thus, although the applied load actually corresponds to a higher relative load, the bar velocity achieved were still significantly higher. The higher velocity obtained during the cambered barbell than standard barbell bench press may be associated with more efficient use of the stretch and shortening cycle. The optimal pre-stretch allows an athlete to produce more force and achieve a greater velocity of movement. This performance enhancement depends, among others on the magnitude of the pre-stretch (Cronin et al., 2001). Therefore, it appears that a greater pre-stretch due to the use of cambered barbell resulted in greater storage and release of elastic energy, thus increasing bar velocity in the concentric phase of the movement. Moreover, the duration of the eccentric phase for both barbells was fixed at 2 s, which means that during the cambered barbell bench press trial, participants had to lower the barbell at a higher speed to stay within the time set for each repetition. Therefore, also faster execution of the eccentric phase could have contributed to a significant increase of the concentric phase performance (Wilk et al., 2019).

Another finding worthy of discussion was that the greatest difference in bar velocity between the standard barbell and cambered barbell bench press was registered between the first sets and this difference decreased with each subsequent set. Moreover, in Set 2 of the standard barbell bench press, there was a significant increase compared to Set 1. This may indicate that a post-activation performance enhancement phenomenon occurs during the standard barbell bench press. Since, the post-activation performance enhancement effect depends on the balance between fatigue and potentiation (Krzysztofik, Wilk, et al., 2020) it seems that during the standard barbell bench press potentiation exceeds fatigue within subsequent set, while this is not the case in the cambered barbell bench press. It seems, that the additional range of motion due to the use of cambered barbell during bench press induces a higher level of acute fatigue than standard barbell because of longer bar displacement and time under tension (in concentric phase), thus reduce the ability to express high levels of post-activation performance enhancement. While there was no decrease in bar velocity in subsequent sets with the use of the cambered barbell, longer rest intervals should be considered than in the standard barbell bench press exercise.

The experimental procedure employed in this investigation contains several limitations that should be addressed. The first relates to the use of absolute load, which might not provide the optimal loading for each tested condition however, an absolute loading may be more practical (i.e., more time-efficient) in gym-based settings, where a large number of athletes are tested within a single session. Secondly, only one external load and rest interval was investigated, but it is necessary to determine if the cambered barbell also augments bar velocity in other training regimens. Third of all, biomechanical and EMG analysis weren't performed (differences in upper limb joint angles and muscle activity) that could provide further explanations for the obtained differences. Lastly, as the participants were well experienced in resistance training the findings of this study should be generalized with caution. Future research could focus on other training routine combinations, e.g., with longer rest intervals between sets or utilizing the cambered barbell in conditioning activities to induce post-activation performance enhancement.

Authors should discuss the results and how they can be interpreted from the perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

Practical Implications

The results of our study showed that the use of the cambered barbell can be an effective alternative to the standard barbell during the bench press exercise, and even better when the goal is to achieve high bar velocities. Moreover, the use of cambered barbell during bench press can provide an additional stimulus to break through plateaus and to prevent training monotony (Krzysztofik et al., 2019). This may be of particular importance in sport disciplines where there is a lot of explosive movements involving the upper limbs, such as the shot put or discus throw. However, it can be speculated that the use of longer rest intervals between sets than those used in this experimental procedure may provide additional benefits in terms of the post-activation performance enhancement. Additionally, strength and conditioning practitioners should bear in mind that the increased ROM due to the use of the cambered barbell during the bench press exercise may place additional strain on the chest and shoulder muscles. Thus, for safety reasons, the athlete should familiarize himself with the cambered barbell bench press exercise before attempting greater loads.

Conclusions

In conclusion, the results of this investigation revealed that the cambered barbell significantly increases bar velocity compared to the bench press performed with a standard barbell at the same external load. Since the use of a cambered barbell allows for a significant increase of the ROM, it seems that the bar can be accelerated over a longer distance, which may contribute to an increase in velocity. These results suggest that the cambered bar can be assumed as an alternative for the standard barbell to increase barbell velocity during bench press training session. Therefore, the cambered barbell can be considered as an additional resistance training tool to increase movement velocity, especially useful for athletes representing explosive sports disciplines.

Institutional Review Board Statement: The study protocol was approved by the Bioethics Committee for Scientific Research, at the Jerzy Kukuczka Academy of Physical Education in Katowice, and performed according to the ethical standards of the Declaration of Helsinki, 2013.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Conflicts of Interest: The authors declare no conflict of interest.

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