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Research article

Range of Motion and Sticking Region Effects on the Bench Press Load-Velocity Relationship

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Abstract
This study aimed to analyze the influence of range of motion (ROM) on main biomechanical parameters of the bench press (BP) exercise: i) load-velocity relationship by mean (MV) and mean propulsive velocity (MPV), ii) one-repetition maximum strength (1RM); iii) contribution of the propulsive and braking phases, and iv) presence of the sticking region key parameters (first peak barbell velocity: V_{max1}, minimum velocity: V_{min} and second peak barbell velocity: V_{max2}). Forty-two strength-trained males performed a progressive loading test, starting at 20 kg and gradually increasing the load in 10 kg until MPV ≤ 0.50 $m \cdot s^{-1}$ and 5 down to 2.5 kg until 1RM, in three different ROMs: full ROM (BP_{FULL}), two-thirds ($BP_{2/3}$) and one-third ($BP_{1/3}$). While significant differences were detected in the velocity attained against loads between 30-95% 1RM (BP_{FULL}, $BP_{2/3}$ and $BP_{1/3}$, $p < 0.05$), both MV and MPV showed a very close relationship to %1RM for the three BP variations ($R^2 = 0.935$-0.966). The contribution of the braking phase decreased progressively until it completely disappeared at the 80%, 95% and 100% 1RM loads in $BP_{1/3}$, $BP_{2/3}$ and BP_{FULL}, respectively. The 1RM increased as the ROM decreased ($BP_{FULL} < BP_{2/3} < BP_{1/3}$, $p < 0.05$). Despite the three biomechanical parameters that define the sticking region on the velocity-time curves were only observed in BP_{FULL} variation, in 54.5% of the cases the subjects started their $BP_{2/3}$ displacement before reaching the position at which the V_{min} occurs in their BP_{FULL} exercise. The complete or partial presence of the sticking region during the concentric action of the lift seems to underlie the differences in the 1RM strength, load-velocity profiles and the contribution of the propulsive phase in the BP exercise at different ROMs.

Key words: Resistance training, biomechanics, maximum strength, sticking point, testing.

Introduction

The bench press (BP) is one of the most popular exercises used to strengthen the musculature of the upper body, primarily the chest, shoulders, and arms (Kompf and Arandjelović, 2017; Sánchez-Medina et al., 2010; 2014). Lying supine on a bench, this exercise starts with the subject holding a barbell with both hands, straight arms and elbows locked. The barbell is lowered to the chest and then pushed against the direction of gravity until the full extension of the elbows (Gomo and van den Tillaar, 2016). The BP has proved to be a safe and effective exercise on the musculoskeletal system when performed with the correct technique, proper loads and following an adequate learning progression (Kompf and Arandjelović, 2017; Sánchez-Medina et al., 2010; 2014). A number of studies have found that increases in upper-body strength following BP training transfer positively to athletic performance in short duration actions that demand maximal neuromuscular activation of the upper body (García-Pallarés et al., 2011; Gorostiaga et al., 2006; Ortega-Becerra et al., 2018). Additionally, greater functional and specific performance improvements have been reported in medium to long distance athletes (e.g. rowing, swimming or canoeing) following resistance training with BP as a main exercise (García-Pallarés et al., 2009; Izquierdo-Gabarren et al., 2009; Nevin et al., 2018).

Variations in the range of motion (ROM) of the BP concentric phase influences several biomechanical factors which are related to the specificity of the movement pattern and can affect the development of force, rate of force development, activation and synchronization of motor units (Mookerjee and Ratamess, 1999). Specifically, during a lift at near maximal loads (>80% 1RM) there is an instant where the upward barbell movement decelerates or even stops completely for a short time (Kompf and Arandjelović, 2017; Król et al., 2010; McLaughlin and Madsen, 1984; van den Tillaar and Ettema, 2010). This period in which the pushing force is less than gravity, leading to a deceleration of the barbell (van den Tillaar and Ettema, 2010) is referred to as "sticking period" (Lander et al., 1985) or "sticking region" (Elliott et al., 1989). This sticking region is thought to coincide with a poor mechanical force position, where the length and moment arms of the muscles involved are such that their capacity to exert force is reduced (McLaughlin and Madsen, 1984; van den Tillaar et al., 2012). To account for this biomechanical limitation, most studies have employed a full ROM in the concentric phase of the BP lift to maximize gains in functional performance of upper body (García-Pallarés et al., 2009; Gavanda et al., 2018; Gorostiaga et al., 2006). However, some authors have reported similar (Massey et al., 2004) or even higher strength gains (Mookerjee and Ratamess, 1999) when training at partial ROM. These controversial results have been attributed to the fact that partial ROM allows the lifting of heavier loads. Since no other explanation has been found about physiological mechanisms which relates the reduction in ROM to additional strength gains, further research is required to explain this relationship (Mookerjee and Ratamess, 1999).

To this purpose, the state-of-the-art velocity-based resistance training (VBRT) could be a very effective method for quantifying force production and power output

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in BP at different ROMs based on barbell velocity and displacement (González-Badillo and Sánchez-Medina, 2010; González-Badillo et al., 2014; Sánchez-Medina and González-Badillo, 2011). Evidence supports that the VBRT is a valid, reliable and highly sensitive method to: (1) determine an athlete's maximum strength without the need to perform one repetition maximum (1RM) or maximum number of repetitions to failure (nRM) tests (González-Badillo and Sánchez-Medina, 2010); (2) determine the % 1RM that is being used from the first repetition performed at maximal voluntary velocity for a given load (Sánchez-Medina et al., 2010); (3) estimate the muscle power output production (Sánchez-Medina et al., 2014); and (4) quantify the neuromuscular fatigue induced by resistance exercise using a noninvasive and objective method (González-Badillo et al., 2011; Morán-Navarro et al., 2017a; 2017b; Pareja-Blanco et al., 2017a; 2017b). The sticking region of the BP at different ROMs can be detected using velocity-based methods (i.e. the velocity-time curve), between the first barbell peak velocity and its first local minimum thereafter (Elliott et al., 1989; van den Tillaar et al., 2012). Previous studies have established a velocity-time curve in BP exercise using the VBRT approach (Sánchez-Medina et al., 2014; van den Tillaar and Ettema, 2010; 2013). However, there is no information available about the relationship between velocity and time in full ROM compared to different partial ROMs in BP. Only one study has examined the velocity-time curve for different ROMs in the squat exercise (Martínez-Cava et al., 2019), which encourages further research.

The concentric portion of a lift can be further subdivided into propulsive (barbell acceleration is greater than acceleration due to gravity,) and braking () phases (Martínez-Cava et al., 2019; Sánchez-Medina et al., 2010). The identification of these two phases allows practitioners to make a more accurate assessment of both the neuromuscular performance and the effect of training, since only during the propulsive phase the athlete is applying internal force to accelerate the barbell (González-Badillo et al., 2017). However, although these phases have been previously identified in the traditional BP (Sánchez-Medina et al., 2010; 2014), no evidences exist about how different ROMs may alter the relative contribution of the propulsive and braking phases.

The purpose of this study was to investigate whether a different ROM may alter performance in BP exercise in a large sample of experienced strength-trained athletes by exploring the following parameters: i) load-velocity relationships, ii) the one-repetition maximum strength (1RM); iii) the contribution of the propulsive and braking phases, and iv) the presence of the sticking region key parameters. Additionally, we aim to assess the possibility of using barbell velocity to estimate loading magnitude (% 1RM) in this exercise executed at maximum and submaximum ROM.

Methods

Participants

Forty-two men (age 23.0 ± 4.2 years, body mass 75.7 ± 12.7 kg, height 1.75 ± 0.07 m, body fat 11.1 ± 5.2%) volunteered to take part in this study. Participants were required to have the following criteria to be eligible: (i) having a 1RM strength/body mass ratio higher than 0.80 in full BP exercise and (ii) no physical limitations, health problems, or musculoskeletal injuries that could affect the technical executions. In the 12 months preceding the study, participants had been performing 2-4 resistance training sessions per week and all incorporated the BP as part of their physical conditioning. The study, which was conducted according to the Declaration of Helsinki, was approved by the Ethics Commission of the Local University. All participants signed a written consent form after being informed of the purpose and experimental procedures.

Testing procedures

Each participant performed a total of 13 sessions separated by 48-72 h. The first session was used for body composition assessment, personal data and health history questionnaire administration, medical examination and identification of the BP starting position for each of the three ROM variations: full (BP_{FULL}), two-thirds ($BP_{2/3}$) and one-third ($BP_{1/3}$), described later in detail. Then, in random order, each subject performed three familiarization sessions for each BP variation (i.e. nine sessions in total). After a resting day, three progressive loading tests up to the 1RM were conducted on separate days and in random order, one for each ROM variation.

Velocity-load relationship and 1RM strength determination

Following the familiarization sessions, the individual load-velocity relationships were determined by means of a progressive loading test up to the 1RM for the three BP variations in a Smith machine (Multipower Fitness Line, Peroga, Murcia, Spain). Following a standardized warm-up protocol, the initial load was set at 20 kg and was gradually increased in 10 kg increments until mean propulsive velocity (MPV) was ≤ 0.50 $m \cdot s^{-1}$. Thereafter, load was individually adjusted with smaller increments (5 down to 2.5 kg) so that the 1RM could be precisely determined. The 1RM was considered as the heaviest load that each subject could properly lift while completing full ROM for each BP variation, without any external help. Absolute loads (kg), % 1RM and 1RM to body mass ratio (1RM/BM) were analyzed. The reproducibility and repeatability of this testing protocol has been recently described (Courel-Ibáñez et al., 2019) with excellent reliability (ICC = 0.999, 95% CI = 0.999–0.999, CV = 1.8%).

Bench press execution technique

The individual ROM for the three BP variations was carefully determined during the first familiarization session, and subsequently replicated in each trial with the help of two telescopic (±1 cm precision) barbell spotters placed at the left and right sides of the Smith machine (Pallarés et al., 2014). This strategy was used in all the BP variants analyzed in order to: i) precisely control and replicate the individual eccentric ROM between trials, and ii) allow participants to momentarily release the weight of the barbell on the spotters for 2 seconds, therefore minimizing the contribution of the stretch-shortening cycle (i.e. rebound effect) and performing a purely concentric action, thus increasing measurement reliability (Pallarés et al., 2014).

For the three BP variations, participants lay supine on a flat bench, with their feet resting flat on the floor and hands placed on the barbell slightly wider (5–7 cm) than shoulder width. The position on the bench was carefully adjusted so that the vertical projection of the barbell corresponded with each participant's intermammary line. Both bench position and grip widths were individually recorded for each participant to be reproduced on every lift. Participants were not allowed to bounce the barbell off their chests nor raise the shoulders or trunk off the bench. With the elbows fully extended and shoulders in contact with the bench (final position) participants were required to descend in a continuous motion until reaching their previously determined concentric initial position for each BP variation:

Full (BP_{FULL}): descent until the barbell contacted with the spotters at 1 cm of the chest, i.e. full ROM.
Two-thirds ($BP_{2/3}$): descent until the barbell reaches two-thirds of the full ROM.
One-third ($BP_{1/3}$): descent until the barbell reaches one-thirds of the full ROM.

For all trials, participants were required to always perform the concentric phase in an explosive manner (at maximal intended velocity), while controlling the eccentric phase at mean velocity between 0.45-0.65 $m \cdot s^{-1}$ (Pallarés et al., 2014; Sánchez-Medina et al., 2017).

A linear velocity transducer (T-Force System®, Ergotech, Murcia, Spain) with a sampling frequency of 1,000 Hz automatically determined the eccentric and concentric phases of every repetition as well as the propulsive phase, defined as that portion of the concentric phase during which barbell acceleration is greater than acceleration due to gravity (Sánchez-Medina et al., 2010). Measures from the mean velocity (MV), mean propulsive velocity (MPV) and position of the barbell were analyzed both, in absolute ($m \cdot s^{-1}$ and cm) and relative (%) terms, during the propulsive phase in the three BP variations. For each subject, the velocity-time curve corresponding to the 1RM load in each of the three BP variations were examined to identify the main sticking region parameters: first peak barbell velocity (V_{max1}); ii) minimum velocity (V_{min}); and iii) second peak barbell velocity (V_{max2}).

Statistical analyses

Standard statistical methods were used for the calculation of means, standard deviations (SD), confidence intervals (CI) and Pearson product-moment correlation coefficients (r). Relationships between load (% 1RM) and velocity were studied by fitting second-order polynomials (R^2) to data. 1RM strength and concentric displacement for the three BP variations were analyzed using one-way ANOVA. After a significant F-test, differences among means were identified using pairwise comparisons with Scheffé's method. Significance was accepted at $p < 0.05$ level. Analyses were performed using SPSS software version 20.0 (IBM Corp., Armonk, NY).

Results

As shown in Table 1, both 1RM and 1RM/BM strength were significantly different between exercises, the greater the ROM, the less the 1RM: $BP_{FULL} < BP_{2/3} < BP_{1/3}$. Concentric displacement of the barbell in absolute and relative terms decreased as the ROM decreased: $BP_{FULL} > BP_{2/3} > BP_{1/3}$. No differences were detected in the MPV attained at the 1RM load between the three BP variations ($p > 0.05$).

An example of the actual velocity-time and displacement-time curves for a representative subject when lifting his 1RM load in the three BP variations analyzed is provided in Figure 1. Once the displacement of the barbell started, no decrease in velocity (V_{min}) was observed in any curve of the $BP_{2/3}$ or $BP_{1/3}$ exercises, and therefore the sticking region (yellow) was only observed in the BP_{FULL} executions (100% of the participants analyzed) (Figure 1). The position, in absolute or relative terms, of the V_{max1} during the 1RM in BP_{FULL} was always prior to the beginning of the $BP_{2/3}$ or $BP_{1/3}$ movement. However, in 54.5% of the cases, the subjects started their $BP_{2/3}$ displacement before reaching the position at which the V_{min} occurs in their BP_{FULL} exercise. Finally, the position at

Table 1. Comparison of 1RM strength, concentric displacement and measured 1RM mean velocity of the three bench press variations analyzed: full ROM (BP_{FULL}), two-thirds ($BP_{2/3}$) and one-third ($BP_{1/3}$). Sticking region at 1RM load: Velocity and position of the first (V_{max1}) and second peak velocity (V_{max2}) and the minimum velocity (V_{min}) during the 1RM of the BP_{FULL} (n = 42).

			BP_{FULL}	$BP_{2/3}$	$BP_{1/3}$
1RM strength and displacement		1RM (kg)	77.8 ± 14.7	90.9 ± 15.3*	111.8 ± 22.2*#
		1RM/BM	1.01 ± 0.21	1.16 ± 0.22*	1.42 ± 0.24*#
		1RM MPV ($m \cdot s^{-1}$)	0.16 ± 0.04	0.18 ± 0.03	0.17 ± 0.03
		Concentric displacement (cm)	43.3 ± 3.11	29.6 ± 2.62*	14.8 ± 2.18*#
		% Full displacement (%)	100	68 ± 1*	34 ± 1*#
Sticking region at 1RM load	***First peak barbell velocity (V_{max1})***	MPV	0.20 ± 0.04		
		Position (cm)	5.5 ± 2.4		
		Position (%)	12.7 ± 5.5		
	Minimal velocity (V_{min})	MPV	0.08 ± 0.04		
		Position (cm)	16.0 ± 4.0		
		Position (%)	35.5 ± 11.8		
	Second peak barbell velocity (V_{max2})	MPV	0.46 ± 0.11		
		Position (cm)	38.7 ± 2.3		
		Position (%)	89.4 ± 2.7		

1RM: one-repetition maximum; 1RM/BM: 1RM to body mass ratio; MPV: mean propulsive velocity; *significantly different to the BPFULL; #significantly different to the BP2/3 ($p < 0.05$). *significantly different to the BPFULL; #significantly different to the BP2/3 ($p < 0.05$).

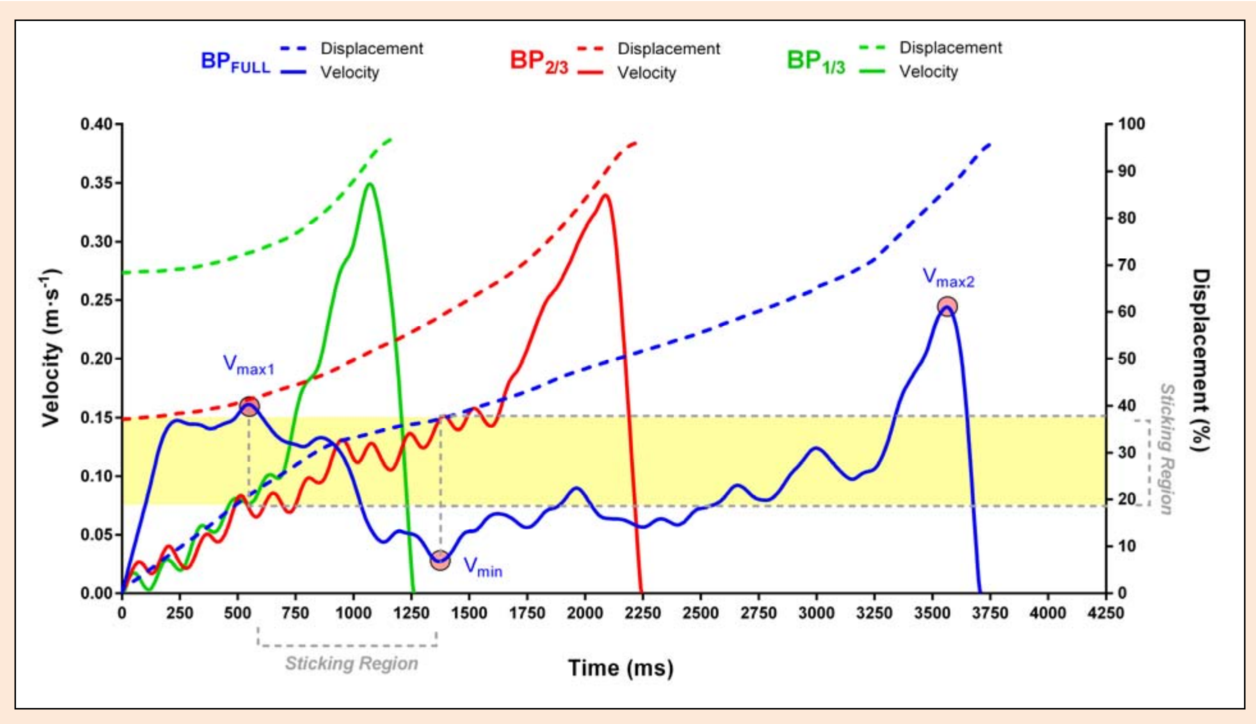

Figure 1. Example of the upwards barbell movement velocity (continuous line) and displacement (dash line) during a concentric 1RM for the BP_{FULL} (blue), $BP_{2/3}$ (red) and $BP_{1/3}$ (green) variations. Yellow zone denotes the % concentric displacement in which occurs the sticking region (only in the BP_{FULL} variant).

which the V_{max2} occurs during the 1RM in BP_{FULL} was always posterior to the beginning of the $BP_{2/3}$ or $BP_{1/3}$ movement in all subjects (Table 1, Figure 1).

A very close fit between the bar velocity and % 1RM was found for the three BP exercises (Figure 2), both for MPV (BP_{FULL}: $R^2 = 0.965$, $BP_{2/3}$: $R^2 = 0.960$, $BP_{1/3}$: $R^2 = 0.935$) and MV (BP_{FULL}: $R^2 = 0.966$, $BP_{2/3}$: $R^2 = 0.961$, $BP_{1/3}$: $R^2 = 0.945$), yielding the following second order polynomial equations:

For MPV:

BP_{FULL} *Load* $= 11.74\ MPV^2 – 82.96\ MPV + 115.6$

$BP_{2/3}$ *Load* $= 26.02\ MPV^2 – 112.46\ MPV + 120.9$

$BP_{1/3}$ *Load* $= 61.60\ MPV^2 – 165.93\ MPV + 125.56$

For MV:

BP_{FULL} *Load* $= 10.20\ MV^2 – 84.34\ MV + 116.2$

$BP_{2/3}$ *Load* $= 28.277\ MV^2 – 119.1\ MV + 122.6$

$BP_{1/3}$ *Load* $= 67.677\ MV^2 – 177.55\ MV + 128.1$

Individual curve fits for each test gave an R^2 of 0.991 ± 0.008 (range: 0.970-0.999; CV = 0.81 %) for BP_{FULL}, R^2 of 0.993 ± 0.004 (range: 0.975-1.000; CV = 0.4 %) for $BP_{2/3}$ and R^2 of 0.989 ± 0.009 (range: 0.965-0.997; CV = 0.93 %) for $BP_{1/3}$ (Figure 2).

The MPV estimated for each % 1RM (Table 2) was different in each BP variation at loads between 30-95% 1RM ($p < 0.05$), but similar at 1RM loads (0.21 ± 0.03 for BP_{FULL}, 0.20 ± 0.03 for $BP_{2/3}$ and 0.17 ± 0.04 for $BP_{1/3}$; $p > 0.05$). The propulsive phase accounted for ~73% of concentric duration at 30% 1RM, progressively increasing until reaching 100% at the 80% 1RM in the $BP_{1/3}$, at the 95% 1RM in the $BP_{2/3}$ and at the 100% 1RM in the BP_{FULL}.

Discussion

The main finding of this study indicates that the absence of one or more of the key parameters that define the sticking region in the velocity-time curve of the BP_{FULL} would explain the critical differences in the 1RM strength, load-velocity profiles and the contribution of the propulsive phase when the BP exercise is performed at shorter ROMs.

The fact that MPV attained against the 1RM load was very similar between the three BP variations confirms that velocity-based methods are robust, non-invasive and highly sensitive to estimate key performance indicators in strength training, such as the relative loading intensity (% 1RM), maximum strength (1RM), the level of effort and neuromuscular fatigue incurred during a set (González-Badillo and Sánchez-Medina, 2010; Martínez-Cava et al., 2019; Morán-Navarro et al., 2017a; 2017b; Pareja-Blanco et al., 2017a; 2017b; Sánchez-Medina et al., 2011). Our findings add new insight into VBRT applications for training prescription by providing data on the complete load-velocity relationship in BP at three different ROMs. As could be expected (Martinez-Cava et al., 2019), the MPV attained at loads lower than 1RM (30-95% 1RM) was higher the greater the ROM ($BP_{FULL} > BP_{2/3} > BP_{1/3}$). Despite this, close relationships were observed between relative load and MPV for BP_{FULL} ($R^2 = 0.965$), $BP_{2/3}$ ($R^2 = 0.960$) and $BP_{1/3}$ ($R^2 = 0.935$), and an even more fitted relationship was found when individual curves for each test were analyzed: BP_{FULL} ($R^2 = 0.991$), $BP_{2/3}$ ($R^2 = 0.993$) and $BP_{1/3}$ ($R^2 = 0.989$). These extremely close relationships make possible to determine with great precision the load (% 1RM) being used in each BP variation "on the go", as soon as the first repetition with any given absolute load is performed with maximal voluntary effort (Martínez-Cava et al., 2019; Morán-Navarro et al., 2017a; Sánchez-Medina et al., 2014, 2017).

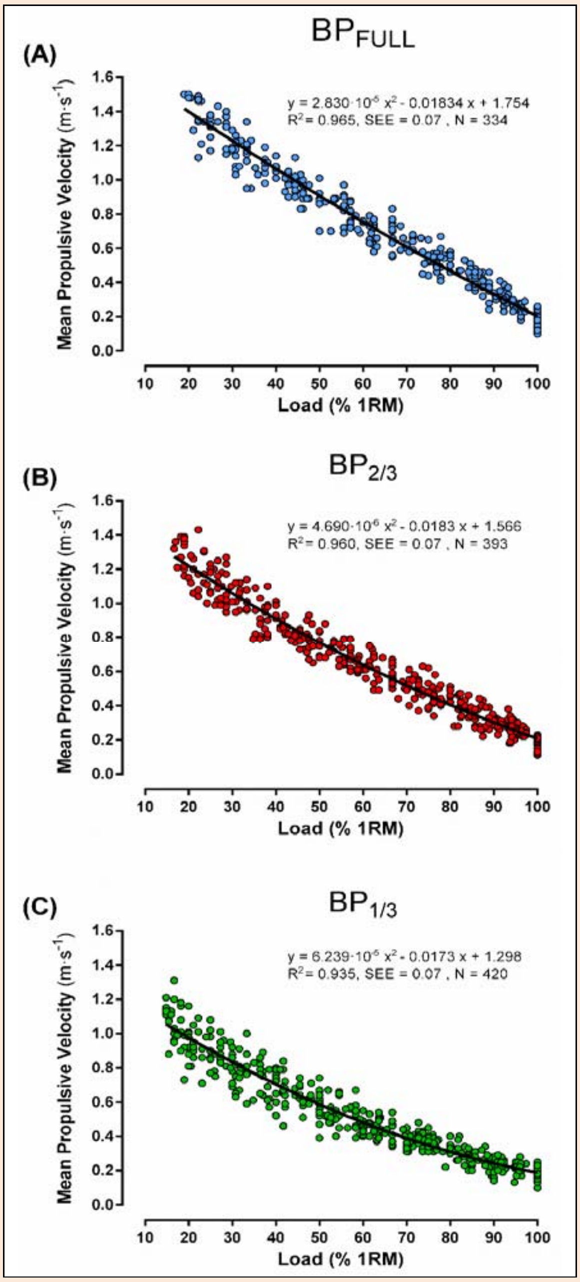

Figure 2. Relationships between relative load (% 1RM) and MPV for the three bench press variations analyzed: (A) BP_{FULL}; (B) $BP_{2/3}$; (C) $BP_{1/3}$. Raw load-velocity data pairs were obtained from the 42 progressive loading tests performed.

The present study found a different contribution of the propulsive phase both in function of BP ROM and % 1RM. The propulsive phase corresponds to the part of the concentric movement in which the athlete is accelerating the barbell against the direction of gravity, while the braking phase makes reference at the end of the concentric movement in which the athlete decelerates the barbell (Sánchez-Medina et al., 2010). According to our results, the propulsive phase accounted for ~73% of the concentric duration at 30% 1RM (Table 2) but progressively increased as loads were higher. This is in line with previous studies in BP (Sánchez-Medina et al., 2010, 2014), squat (Martinez-Cava et al., 2019; Sánchez-Medina et al., 2017) and prone bench pull (Sánchez-Medina et al., 2014). Interestingly, the present study found that the time of the propulsive phase was different depending on the BP ROM. This phase reached its 100% of contribution at the 80% 1RM in the $BP_{1/3}$, at the 95% 1RM in the $BP_{2/3}$ and at the 100% 1RM in the BP_{FULL} (Table 2). No previous studies have investigated the influence of the ROM in this biomechanical aspect. A main practical implication of this finding is that the velocity assessment during the propulsive phase (MPV) allows differentiating the actual performance of athletes (strength, velocity and power generated during a concentric action) with more accuracy than taking into account the mean velocity during the whole concentric movement (MV) – and thus is a better variable for 1RM estimation – because of the negative effect of the braking phase (Sánchez-Medina et al., 2010). For instance, against the same low to moderate relative load (20% to 70% 1RM), strong athletes with high 1RM that reach fast velocities will subsequently produce a long braking phase; in turn, slower velocities attained by weaker athletes will result in a shorter braking phase. As a consequence, the MV will underestimate the neuromuscular potential in stronger athletes while overestimating the values in the weaker ones (Gonzalez-Badillo et al., 2017).

With reference to the sticking region parameters, the present study found that V_{max1}, V_{min} and V_{max2} took place at 5.5 cm (12.7%), 16.0 cm (35.5%) and 38.7 cm (89.4%) of the mean concentric displacement of BP_{FULL} exercise, respectively (Table 1). In agreement with the present study, van den Tillaar et al., (2012) found the V_{max1}, V_{min} and V_{max2} variables at 3 cm, 13 cm and 31 cm of the concentric displacement, respectively. These results were also similar to those found by Gomo and van den Tillaar (2016) and van den Tillaar and Ettema (2013). It would be pertinent to comment that these minor differences could be explained by the pause between the eccentric and concentric phase performed in the present study. This pause minimizes the contribution of the stretch-shortening cycle and performing a purely concentric action, thus increasing measurement reliability (Pallarés et al., 2014). Other authors have found that the modification of factors such as the grip width can modify the moments in which the sticking region parameters take place. For instance, Wagner et al., (1992) found that for a middle grip, the sticking region was found to occur later in vertical displacement in comparison with both narrow and wide grips. For its part, Gomo and van den Tillaar (2016) reported that the sticking region starts earlier with narrower grips. Another technical modification which could alter the sticking region is the "bounce" against the chest. Van den Tillaar and Ettema, (2013) found that performing a bounce would generate an earlier occurrence of V_{max1}, V_{min} and V_{max2} variables, in comparison with a pure concentric lift.

On the other hand, an interesting finding was detected in the relationship between the displacement and the 1RM. Whereas mean concentric displacement showed a proportional decrease between the three BP

Table 2. Mean propulsive velocity (m · s^{-1}) estimated for each load (% 1RM) and relative contribution of the propulsive phase to the total concentric duration in the three bench press variations: full ROM (BP_{FULL}), two-thirds ($BP_{2/3}$) and one-third ($BP_{1/3}$) (n = 42).

Load (%1RM)	BP_{FULL} MPV (m·s^{-1})	BP_{FULL} 95% CI (m·s^{-1})	BP_{FULL} Propulsive phase (%)	$BP_{2/3}$ MPV (m·s^{-1})	$BP_{2/3}$ 95% CI (m·s^{-1})	$BP_{2/3}$ Propulsive phase (%)	$BP_{1/3}$ MPV (m·s^{-1})	$BP_{1/3}$ 95% CI (m·s^{-1})	$BP_{1/3}$ Propulsive phase (%)
30	1.23 ± 0.07	1.20 -1.25	73	1.06 ± 0.07#	1.04-1.08	72	0.83 ± 0.08#*	0.80-0.85	73
35	1.15 ± 0.06	1.13-1.17	76	0.99 ± 0.07#	0.97-1.01	76	0.77 ± 0.07#*	0.75-0.79	78
40	1.07 ± 0.06	1.06-1.09	79	0.91 ± 0.07#	0.89-0.93	79	0.70 ± 0.07#*	0.68-0.72	82
45	0.99 ± 0.06	0.97-1.01	81	0.84 ± 0.06#	0.82-0.86	82	0.64 ± 0.06#*	0.62-0.66	85
50	0.91 ± 0.05	0.89-0.93	84	0.77 ± 0.06#	0.75-0.78	85	0.58 ± 0.06#*	0.56-0.60	89
55	0.83 ± 0.05	0.81-0.85	86	0.70 ± 0.06#	0.69-0.72	88	0.53 ± 0.06#*	0.51-0.55	92
60	0.76 ± 0.05	0.75-0.78	88	0.64 ± 0.05#	0.63-0.66	90	0.48 ± 0.06#*	0.46-0.50	94
65	0.68 ± 0.05	0.67-0.70	90	0.57 ± 0.05#	0.56-0.59	92	0.43 ± 0.05#*	0.41-0.45	96
70	0.61 ± 0.05	0.60-0.63	92	0.51 ± 0.05#	0.50-0.53	94	0.38 ± 0.05#*	0.36-0.39	98
75	0.54 ± 0.05	0.53-0.55	94	0.45 ± 0.04#	0.44-0.47	96	0.34 ± 0.05#*	0.32-0.35	99
80	0.47 ± 0.04	0.46-0.48	95	0.40 ± 0.04#	0.39-0.42	97	0.30 ± 0.04#*	0.28-0.31	100
85	0.41 ± 0.04	0.40-0.42	97	0.35 ± 0.04#	0.34-0.36	99	0.26 ± 0.04#*	0.24-0.27	100
90	0.34 ± 0.04	0.33-0.35	98	0.30 ± 0.04#	0.29-0.31	99	0.23 ± 0.04#*	0.22-0.24	100
95	0.28 ± 0.03	0.27-0.29	99	0.25 ± 0.04#	0.24-0.26	100	0.20 ± 0.04#	0.19-0.21	100
100	0.21 ± 0.03	0.19-0.22	100	0.20 ± 0.03	0.19-0.22	100	0.17 ± 0.04	0.16-0.19	100

MPV: Mean propulsive velocity; CI: confidence interval; #significantly different to the BP_{FULL}; * significantly different to the $BP_{2/3}$ ($p < 0.001$).

variations (BP_{FULL} vs. $BP_{2/3}$: -13.7 cm, 31.6%; $BP_{2/3}$ vs. $BP_{1/3}$: -14.8 cm, 34.2%), the 1RM values showed a disproportional increase between $BP_{2/3}$ and $BP_{1/3}$ (BP_{FULL} vs. $BP_{2/3}$: +13.1 kg, 14.4%; $BP_{2/3}$ vs. $BP_{1/3}$: +20.9 kg, 18.7%) (Table 1). This large and disproportional increase in 1RM strength associated to $BP_{1/3}$ in comparison with $BP_{2/3}$ could be explained by the fact that approximately half of the participants started their $BP_{2/3}$ lift before reaching the position at which the V_{min} occurs in their BP_{FULL} exercise. Although it cannot be observed in the velocity-time curve, the presence of this poor mechanical force position (i.e., not the whole sticking region), has a noticeable effect on the athletes' maximum dynamic strength (Table 1, Figure 1). In the same line, Massey et al., (2004) and Mookerjee and Ratamess (1999) have shown that subjects were able to lift higher weights with partial range (avoiding the sticking region) in comparison to full range in BP exercise. This disproportional 1RM increase as the concentric displacement decreased was also observed by Martínez-Cava et al., (2019) in back squat. These authors justified that the absence of the sticking region in half squat could explain the differences in 1RM in comparison to full and parallel squat, where a complete sticking region was identified. Indeed, this strategy of avoiding the sticking region to increase 1RM is common in powerlifters. These athletes have as their main goal to lift as much weight as possible in BP, between other exercises (International Powerlifting Federation, 2019). Powerlifters generate a voluntary BP ROM reduction through different strategies such as postural modifications (e.g., a pronounced lumbar arch, an accentuated scapular retraction) (García-Ramos et al., 2018), wide grips (Gomo and van den Tillaar, 2016; Wagner et al., 1992) or the inclusion of external materials like boards (Swinton et al., 2009), reducing the BP displacement from a full ROM (BP_{FULL}) to two-thirds ($BP_{2/3}$), or even one-third ROM ($BP_{1/3}$). Just like it has been seen in this study, this technique would allow them to take advantage of the partial or complete absence of the sticking region increasing their 1RM.

Conclusion

The main finding of the present study allows us to conclude that the complete or partial presence of the sticking region generated by different ROMs seems to underlie the differences in the 1RM strength, load-velocity profiles and the contribution of the propulsive phase in the BP exercise. Due to the differences between BP variations, these results could have implications for both load prescription and monitoring the effect of the training.

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Key points

- Although load-velocity relationships were significantly different in function of ROM in BP, a very close relationship was observed between relative load, MV and MVP for the three BP variations.
- The contribution of the braking phase was also different between BP variations decreasing until it completely disappeared at the 80%, 95% and 100% 1RM loads in $BP_{1/3}$, $BP_{2/3}$ and BP_{FULL}, respectively.
- The 1RM strength was significantly lower the greater the ROM ($BP_{FULL} < BP_{2/3} < BP_{1/3}$).
- Despite the fact that the three key biomechanical parameters that define the sticking region were only observed in BP_{FULL} variation, in 54.5% of the cases, the subjects started their $BP_{2/3}$ displacement before reaching the position at which the V_{min} occurs in their BP_{FULL} exercise.
- Modifications in the presence of key parameters of the sticking region through an alteration of ROM would explain the differences in the 1RM strength, load-velocity profiles and the contribution of the propulsive phase.

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