Journal of Sports Sciences
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713721847

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First published on: 06 April 2010

To cite this Article van den Tillaar, Roland andEttema, Gertjan(2010) 'The "sticking period" in a maximum bench press', Journal of Sports Sciences, 28: 5, 529 — 535, First published on: 06 April 2010 (iFirst)
To link to this Article: DOI: 10.1080/02640411003628022
URL: http://dx.doi.org/10.1080/02640411003628022

Journal of Sports Sciences, March 2010; 28(5): 529–535

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The "sticking period" in a maximum bench press

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(Accepted 15 January 2010)

Abstract

The purpose of this study was to examine muscle activity and three-dimensional kinematics in the ascending phase of a successful one-repetition maximum attempt in bench press for 12 recreational weight-training athletes, with special attention to the sticking period. The sticking period was defined as the first period of deceleration of the upward movement (i.e. from the highest barbell velocity until the first local lowest barbell velocity). All participants showed a sticking period during the upward movement that started about 0.2 s after the initial upward movement, and lasted about 0.9 s. Electromyography revealed that the muscle activity of the prime movers changed significantly from the pre-sticking to the sticking and post-sticking periods. A possible mechanism for the existence of the sticking period is the diminishing potentiation of the contractile elements during the upward movement together with the limited activity of the pectoral and deltoid muscles during this period.

Keywords: *Kinematics, electromyography, strength, bench press*

Introduction

Bench press is one of the most popular lifts used in strength training for the upper body. The lift is typically performed lying supine on a bench using a barbell. The barbell is first lowered to the chest and then pushed up until the elbows are fully extended (McLaughlin & Madsen, 1984). A successful maximal performance is recorded if the barbell is moved to this fully extended position. However, if the weight attempted is too heavy, the barbell will not be pushed all the way up and the lift will fail. Madsen and McLaughlin (1984) found that in successful attempts at one-repetition maximum (1-RM), there is an instant at which the upward barbell movement decelerates or even stops completely for a short time. This is referred to as the first local minimum of the upward velocity ($T_{v\min}$) of the bar (Madsen & McLaughlin, 1984), or the "sticking point". Both Newton et al. (1997) and Madsen and McLaughlin (1984) acknowledged the existence of the sticking point. Madsen and McLaughlin (1984) stated that at a certain position of the upper extremity, the individual's capacity to exert force might be substantially less than it is at nearby positions. Newton et al. (1997) reported that this sticking point occurred in lifts of 90% 1-RM, but not when lifting lighter weights. They also reported that this sticking point occurs at around 35–45% of the upward movement displacement. Elliott and colleagues (Elliott, Wilson, & Kerr, 1989) showed that this sticking point only occurs during maximal and supramaximal attempts and not during submaximal attempts (80% 1-RM) in elite strength training athletes.

It should be noted that the sticking point does not necessarily mark the end of a bench press attempt. Rather, it marks the end of a period during which the velocity decreases from peak velocity to the first local minimum velocity (Elliott et al., 1989). Thus, after the sticking point, the barbell velocity increases once more. The period of decreasing velocity is also referred to as the "sticking period" (Lander, Bates, Swahill, & Hamill, 1985) or "sticking region" (Elliott et al., 1989). During this period, the pushing force is less than gravity on the barbell, leading to a deceleration of the barbell. Therefore, from a functional point of view, it is better to consider this feature as a sticking period rather than a sticking point in analysis of the bench press.

It was previously hypothesized that during the sticking period a poor mechanical force position

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ISSN 0264-0414 print/ISSN 1466-447X online © 2010 Taylor & Francis
DOI: 10.1080/02640411003628022

occurs at which the lengths and mechanical advantages of the muscles involved are such that their capacity to exert force is reduced in this period (Elliott et al., 1989; Madsen & McLaughlin, 1984). Newton et al. (1997) argued that a sticking period occurs due to the loss of enhanced force at the start of the concentric movement. Force enhancement may be caused by potentiation of the contractile element of muscle due to the eccentric downward movement (for a review, see Herzog, Lee, & Rassier, 2006). If this enhancement is lost over a short period, one becomes (relatively speaking) weaker during the concentric part of the bench press, which in turn may result in a sticking phase (van den Tillaar & Ettema, 2009).

Elliott et al. (1989) performed several biomechanical analyses with a focus on the sticking period. They found that during the sticking period, the elbows were moved laterally, whereas McLaughlin (1985) suggested that the elbows moved medially, which could influence the external moment arm of the elbow. Furthermore, Elliott et al. (1989) found that the sticking period was not caused by an increase of the resultant moment arm at the shoulder or elbow by the barbell, or by a reduction of muscular activity of the prime movers (long head of triceps brachii, anterior deltoid, the sternal portion of pectoralis major) during this period. However, Elliott et al. (1989) only provided a global description of the electromyogram signals and no details about the different stages during the lift; they also used elite strength training athletes. The difference in standard of performance could explain the discrepancy in kinematics between the studies of McLaughlin (1985) and Elliott et al. (1989).

Thus, a number of explanations have been proposed in the literature: a change in external lever, position-dependent strength, reduced effect of eccentric muscle potentiation, and altered muscle activation (which may be related to the other mechanisms). To our knowledge, limited research has been conducted on muscle activity patterns. Only Elliott et al. (1989) described these patterns, in general terms.

Through visual inspection, they indicated that the prime movers in the bench press achieved maximal activation at the start of the ascent phase of the lift, and that this level was essentially unchanged throughout the upward movement of the bar. However, they did not compare muscle activity between the different periods during the lift.

The aim of the present study, therefore, was to further our understanding of the sticking period. We examined muscle activity in the ascending part of the lift around the sticking period during a successful 1-RM bench press attempt in recreational weight training athletes. It was hypothesized that the muscle activity of the prime movers would be less during the sticking period than before and after the sticking period (referred to as the pre- and post-sticking period respectively).

Methods

Twelve males (age 21.9 ± 1.7 years, mass 80.7 ± 10.9 kg, height 1.79 ± 0.07 m) with at least one year of bench press training experience (bench press training once or twice a week to enhance bench press performance) participated in this study. The study complied with the requirements of the local committee for medical research ethics and current Norwegian law and regulations.

Procedure

After a general warm-up of the upper body, the participants followed a standardized protocol with bench pressing (van den Tillaar & Ettema, 2009). The participants started by pressing the barbell (20 kg) 40 times ($\sim$20% 1-RM), followed by two series of six repetitions at 40% assumed 1-RM, one series of three repetitions at 60% 1-RM, one series of two repetitions at 75% 1-RM, one series of two repetitions at 85% 1-RM, and one attempt at assumed 1-RM. The assumed 1-RM was set based on information provided by the participants on maximal lifts performed in the previous 6 months. There was a pause of 3–5 min between the series to avoid possible fatigue. When the assumed 1-RM was successful, the weight was increased by 2.5 kg; when it was unsuccessful, the weight was decreased by 2.5 kg. Three attempts were performed in total. The highest weight lifted successfully was used for further analysis.

Participants performed a traditional bench press (descending and ascending the barbell). No marked pause between descending and ascending the barbell was necessary. However, the participants were not permitted to "bounce" the barbell off the chest and were not allowed to raise the lower back from the bench.

Measurements

Three-dimensional (3D) positions were measured using a 3D motion capture system (Qualysis, Gothenburg, Sweden). Eight cameras (500 Hz) tracked the position of the reflective markers (2.6 cm diameter) on the following anatomical landmarks on each side of the body: lateral tip of the acromion, lateral epicondyle of the elbow, and styloid process of the ulna. One marker was attached to the upper part of the sternum and two markers to the middle of the barbell 0.2 m from each other to measure the displacement of the barbell.

Horizontal shoulder adduction/abduction (often referred to as horizontal shoulder flexion), shoulder abduction/adduction, and elbow flexion/extension angles (Figure 1) were determined from lines formed between the centres of the reflective markers for the whole attempt. Thus, the angles were estimates of the anatomical angles. All calculations were done in Matlab 7.0. The zero time point (T_0) was defined as the moment when the barbell was at the lowest position, with upward movement positive and downward movement negative.

Electromyogram (EMG) signals were measured at both upper limbs using surface electrodes (DE-2.3, Delsys, Boston, MA) and a wireless EMG system (Myomonitor IV, Delsys, Boston, MA) attached over the middle of the belly of the long head of the triceps brachii, the anterior deltoid, the sternal portion of the pectoralis major, and the biceps brachii. Before the electrodes were attached, the skin was shaved, cleaned with alcohol, and a small amount of conducting gel was applied to each electrode to reduce contact impedance. The common-mode rejection ratio was 92 dB and the input impedance between each electrode pair was $> 10^{15}$ Ω. The EMG signals were sampled at a rate of 1000 Hz and synchronized with the kinematic data. The EMG and 3D kinematics were synchronized by a signal that was produced by a goniometer (Delsys, Boston, USA) mounted on the floor that was started when the lift was initiated. This signal was recorded by both systems synchronously. Signals were bandpass filtered (20–450 Hz), rectified, and integrated (integrating moving average filter with 100 ms width).

Three isometric contraction exercises were made to normalize the muscle activities at 1-RM. The isometric contraction exercises were a biceps curl with the participant standing upright and the elbow flexed 90°. The second exercise was in the same position, but with the participant pushing the barbell down as hard as possible. In the third exercise, the participant performed an isometric bench press with the barbell in his hands. Every isometric contraction was performed twice with maximum effort and the highest EMG activity averaged in a 1 s period, for each of these exercises, was used as a reference for normalizing the muscle activity during the maximal bench press trials. Normalization was performed to obtain a rough indication of the level at which the muscles were active.

To compare muscle activity during the upward bench press movement, three periods were assigned. The first period (pre-sticking period) was from the lowest barbell point (T_0) until maximal barbell velocity ($T_{v\max}$); the second period (sticking period) was from maximal barbell velocity until the first located lowest vertical barbell velocity ($T_{v\min}$); and the third period was from the instant that vertical acceleration of the barbell became positive again (post-sticking period) with the same period length as for the second period. The muscle activities were averaged for each of these three periods for comparison. These three periods were used to identify differences in muscle activity that could be responsible for an increase or decrease in barbell velocity.

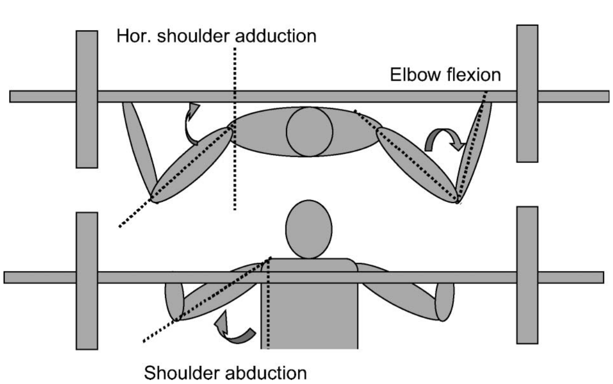

Figure 1. Joint angles measured during the bench press exercise.

Statistical analysis

To assess differences in muscle activity during the bench press movement, we used one-way repeated-measures analysis of variance (ANOVA). When the sphericity assumption was violated, the Huyn-Feldt adjustment for P-values is reported. Paired t-tests for repeated measures were conducted to identify differences in muscle activity between the left and the right side. Statistical significance was set at $P \leq 0.05$.

Results

The average weight successfully lifted by the participants at 1-RM was 99 ± 16 kg. Eight participants lifted their assumed 1-RM successfully and two lifted more than their assumed 1-RM. Four participants achieved 2.5–5 kg less than their assumed 1-RM, and this was after trying once or twice at the assumed 1-RM. Thus, they were not tired before performing 1-RM. Each participant experienced the sticking period in the upward movement during the 1-RM trial. Figure 2 shows a typical example of the development of the velocity and acceleration during the bench press exercise with the sticking period from $T_{v\max}$ to $T_{v\min}$. After $T_{v\min}$, velocity increased again and eight participants obtained a clearly higher peak velocity after than before $T_{v\min}$. Four participants experienced only a minor increase. The time of the peak velocity was only calculated for the first maximum in the upward movement and was on average 0.19 s (6% of the total upwards movement) after the onset of the upward movement (Table I). The sticking period lasted for about 0.86 s (24.4% of the total upward movement) and v_{min} occurred on average after 1.05 ± 0.5 s at a height of 0.12 m (34% of the total height) from the deepest point of the barbell.

Since no significant differences were observed ($P > 0.05$) between the joint angles on the left and right sides at T_0, at maximal barbell velocity (T_{vmax}), and at T_{vmin}, the averaged angle at these moments was used for further analysis. In the sticking period, the shoulder abduction angle increased on average 6°, horizontal shoulder adduction angle increased by 23°, and the elbow flexion angle increased on average 14° from T_{vmax} to T_{vmin} (Figure 2 and Table II).

The electromyograms (Figure 3) showed that there were significant differences in muscle activity during the bench press movement (Figure 4).

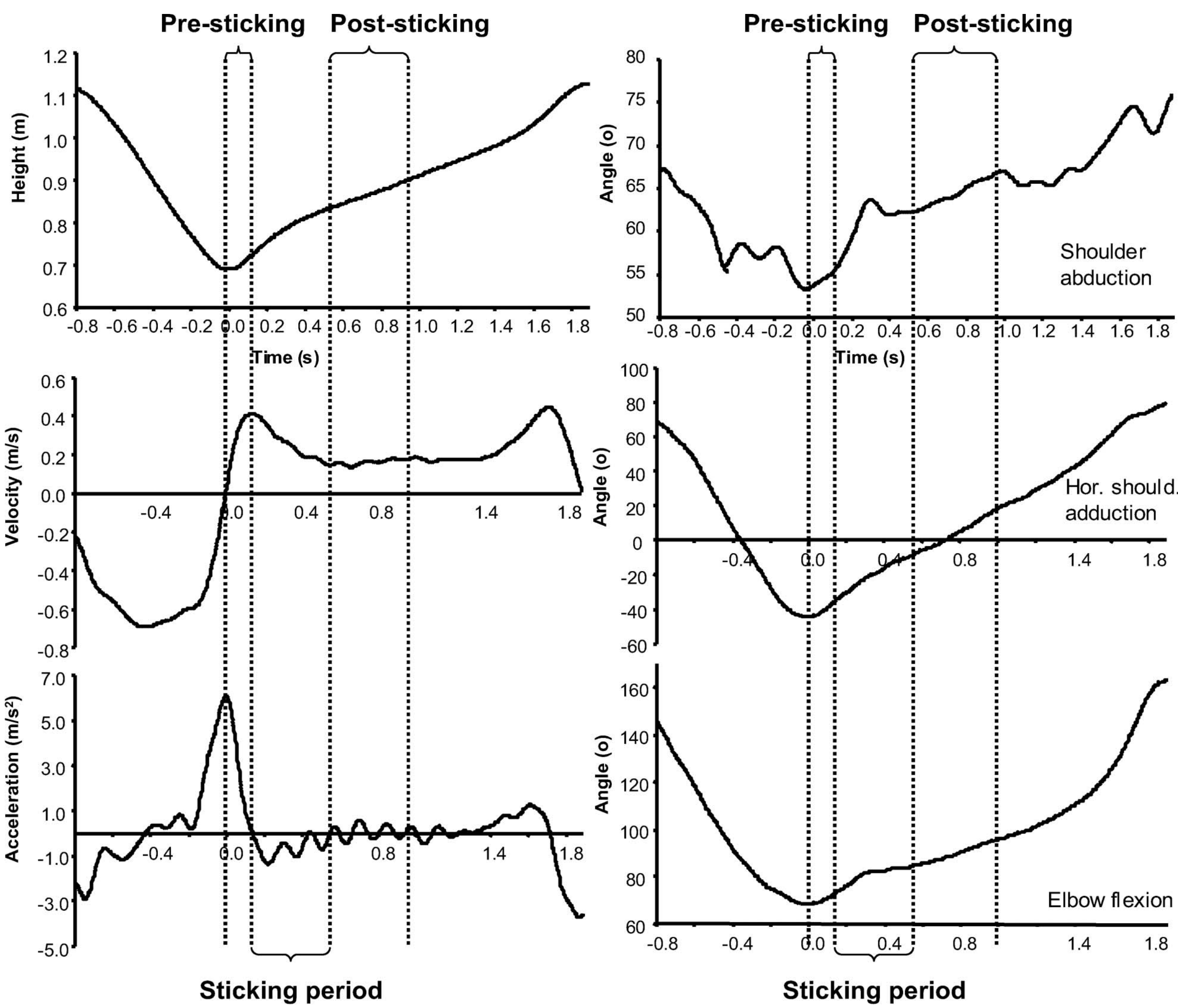

Figure 2. Typical vertical barbell movement, velocity, acceleration, and angles of the different joints in a successful 1-RM bench press for the pre-sticking, sticking, and post-sticking period.

Table I. Selected parameters during the bench press movement.

			Timing (s)	
Variable	Absolute	Relative (%)	Absolute	Relative
Peak barbell acceleration ($m \cdot s^{-2}$)	2.83 (1.28)		0.015 (0.037)	
Peak barbell velocity ($m \cdot s^{-1}$)	0.26 (0.08)		0.193 (0.078)	
Height of barbell at v_{max} (m)	0.028 (0.011)	7.7 (3)	0.193 (0.078)	6.1 (3.3)
Height of barbell at v_{min} (m)	0.117 (0.049)	34.2 (9)	1.051 (0.51)	30.3 (11)

Note: The relative values are percentage of maximum value during the same attempt.

Table II. Mean joint angles (and standard errors) at lowest barbell point (T_0), maximal barbell velocity ($T_{v\max}$), and first located lowest vertical barbell velocity ($T_{v\min}$).

Joint angle	T_0	$T_{v\max}$	$T_{v\min}$
Shoulder abduction	60.8 (3.3)	65.4 (3.7)	71.3 (3.4)
Horizontal shoulder adduction	128.7 (2.0)	122.0 (2.7)	89.7 (3.4)
Elbow flexion	77.5 (3.3)	82.1 (3.2)	96.0 (3.3)

Note: All angles were significantly different at these different points in the upward movement of the bench press.

No significant differences were observed between the muscle activity on the left and right side. Since the aim of the study was not to examine differences between right and left sides of the body, data for the two sides were averaged and used in further analysis.

One-way repeated-measures ANOVA indicated significant main effects for the biceps ($F_{2,22} = 7.15$, $P = 0.013$), pectoralis ($F_{2,22} = 6.72$, $P = 0.005$), and deltoid ($F_{2,22} = 5.07$, $P = 0.024$) muscle activity during the three periods. *Post hoc* comparisons revealed that activity of the pectoralis and deltoid muscles increased significantly from the sticking period to the post-sticking period. The biceps muscles showed the opposite, a significant decrease in activity from the pre-sticking period to the sticking period (Figure 4).

Discussion

In this study, we examined the muscle activity of four muscles in the ascending part of the bench press around the sticking period. For three of the four muscles investigated, a change occurred during the different periods around the sticking period. All participants showed a sticking period during the 1-RM attempts, which is in accordance with the literature (Elliott et al., 1989; Hamilton, 1995; Lander et al., 1985; Madsen & McLaughlin, 1984; McLaughlin & Madsen, 1984; Newton et al., 1997). The sticking period started about 0.2 s after the initial upward movement of the barbell, which was also reported by Lander et al. (1985) and was somewhat earlier than in elite weight training athletes (0.34 s) (Elliott et al., 1989). Time spent in the sticking period was 24%, similar to that in other studies (Elliott et al., 1989; Lander et al., 1985; McLaughlin & Madsen, 1984; Newton et al., 1997).

The joint angles during the upward movement were comparable with those of earlier studies. Shoulder abduction increased from 60 to 71° (Table II), which is in agreement with Elliott et al. (1989). Elbow angle increased during the movement from 77° (T_0) to 96° ($T_{v\min}$) (Table II), which is in line with participants who used a narrow grip (Lander et al. 1985). Shoulder abduction increased

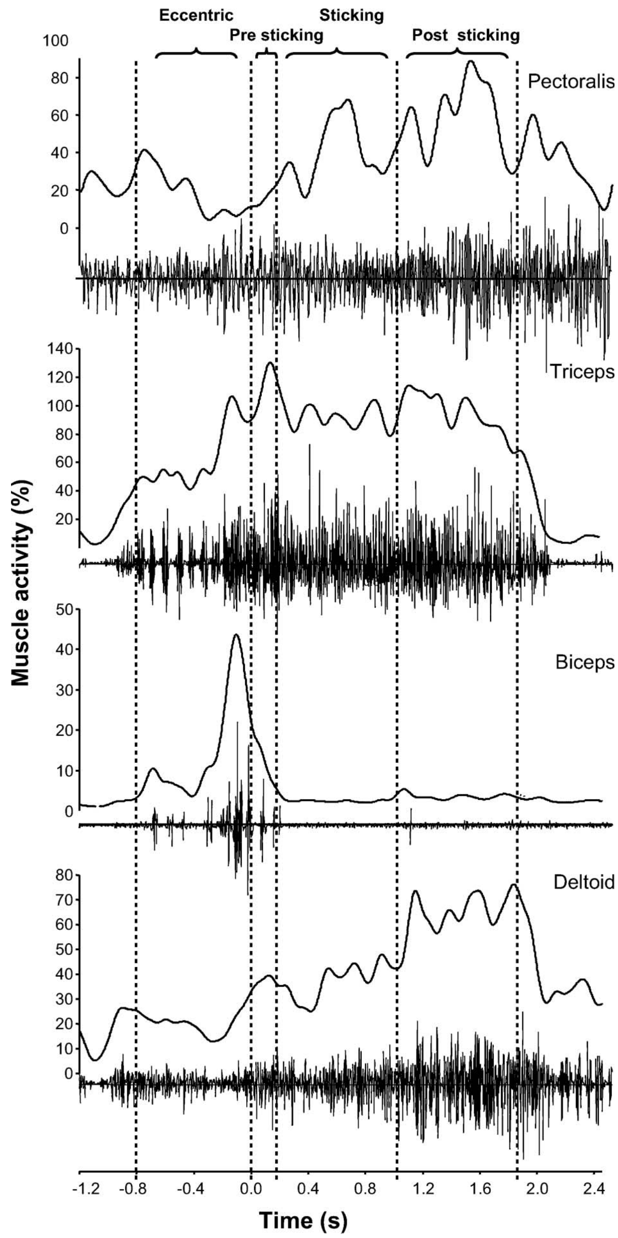

Figure 3. Typical development of muscle activity (raw and iEMG) of the pectoralis, triceps, biceps, and deltoid muscles in 1-RM bench press for the pre-sticking, sticking, and post-sticking period.

during the sticking period; the elbow moved laterally, which was also found by Elliott et al. (1989) and Lander et al. (1985). In the current study, the grip was not controlled, which could have influenced performance.

It was previously hypothesized that during the sticking period a poor mechanical force position occurs at which the lengths and mechanical advantages of the muscles involved are such that their capacity to exert force is reduced in this period (Elliott et al., 1989; Madsen & McLaughlin, 1984). However, Elliott et al. (1989) found that the external moment arms on the elbow and shoulder decreased

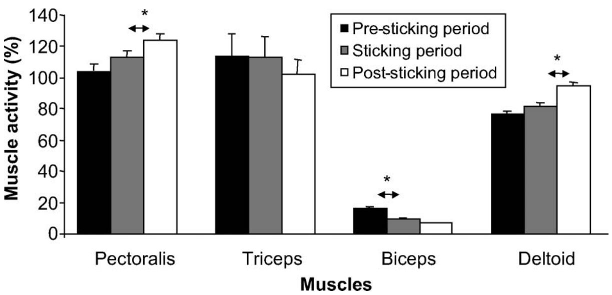

Figure 4. Mean (and standard error) normalized muscle activities of the pectoralis, triceps, biceps, and deltoid muscles during the pre-sticking, sticking, and post-sticking period in the upward part during bench press. Note that a maximal-effort isometric contraction was used for normalization, which resulted in high but not necessarily maximal voluntary EMG values for the muscles in question. Thus, 100% does not indicate maximal values. *Significant difference in muscle activity ($P < 0.05$) between these two periods.

during the sticking period. In the current study, the participants also moved the barbell close to the shoulder joint, as indicated by the increased shoulder abduction during the sticking period that resulted in a decreased horizontal distance from the shoulder axis (van den Tillaar & Ettema, 2009). This was similar to the change in joint angles reported by Elliott et al. (1989). This would result in a decrease of the external moment arms on the shoulder and elbow during the sticking period. Factors such as internal moments, muscle force–length and joint angle–muscle length relationships could result in a poor mechanical force position during the sticking period. However, this was not addressed in the present study. Elliott et al. (1989) found that the muscle activity did not change during the different periods, and suggested that the occurrence of this sticking period is caused by a reduction in strain energy of the serial elastic components and a poor mechanical force production position. However, in the current study, the activity of the pectoral and deltoid muscles increased from the sticking period to the post-sticking period and that of the biceps muscle decreased from the pre-sticking period to the sticking period. A similar activity pattern of the deltoid and pectoralis muscles was reported for dumbbells and barbell bench press with an intensity of 6-RM (Welsch, Bird, & Mayhew, 2005). The lower activity of the deltoid and pectoral muscles during the sticking period, the period when the effort made is greatest, seems paradoxical at first. However, we propose a new hypothesis that requires further research to support it. If one needs to lift a certain weight in a stretch–shortening contraction movement, the contractile system is potentiated by the stretch and is able to perform better for a short time (i.e. produce more force during the early shortening period). This results in a higher absolute force at the onset of shortening generated by the system, but also later during shortening. The potentiating effects appear to have been lost completely after about 300 ms in these types of strength tasks (Walshe, Wilson, & Ettema, 1998). The release of extra series elastic energy, which may occur during shortening after stretch, seems to be less important, as its release depends completely on the force transients that occur, and thus on the interaction between task requirements and muscle force capacity. We do not dispute that series elastic energy can be used to enhance performance. However, this is more related to timing of muscle work and release of this work into joint movements to increase its efficacy rather than increasing the total amount of mechanical energy (see, for example, Bobbert, 2001). We propose that by moving a given weight through the stretch–shortening bench press movement, the prime muscles are active to the extent required to move the weight. During the movement, the contractile capacity diminishes (reduction of the potentiation effect), resulting in a reduction in movement velocity. Next, an activity enhancement of the prime movers is required to avoid a full stop and failure. Such an enhancement of activity will logically occur with a certain (neural) delay and thus towards the end of the sticking period. In other words, the activity enhancement found in this study occurs as a reaction to and compensation for – and thus after – the mechanical weakening of the muscles (sticking period). An assumption for this mechanism is that activity in individual muscles during a maximal effort is not necessarily maximal. This is possible because a maximal effort (e.g. 1-RM) is also a coordinated action that is unlikely to occur if simply the major muscles involved are activated fully at all times during the movement. In the case of a failed attempt – that is, pushing a weight with (near) maximal activity of the major muscles at the onset of the ascent – failure would occur during or at the end of the sticking period because increasing activity cannot compensate for diminishing potentiation. In other words, we propose that the sticking period does occur not because of a lack of mechanical muscle strength *per se*, but because the strength is diminishing, causing a delayed neural reaction. This movement and neural pattern in bench pressing may be seen independent of the mechanism that causes muscle weakening. The potentiation effect is not necessarily abolished after an isometric "pause" at the lowest point in the bench press (Wilson, Elliott, & Wood, 1991) as the force enhancement may be present (but diminishing) for many seconds in an isometric contraction after stretch (see Herzog et al., 2006). Clearly, further work is needed to test if this hypothesis is plausible; the movement pattern should, for example, be compared for a bench press without countermovement.

Conclusions

Electromyography during maximal 1-RM bench pressing revealed that the muscle activity of the prime movers changed significantly changed between the pre-sticking, sticking, and post-sticking periods. A possible mechanism for the existence of the sticking period is the reduced potentiation of the contractile elements during the upward movement together with the limited activity of the pectoral and deltoid muscles during this period.

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