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A Kinetic and Electromyographic Comparison of the Standing Cable Press and Bench Press

Juan Carlos Santana,[1] Francisco J. Vera-Garcia,[2] and Stuart M. McGill[2]

[1]*Institute of Human Performance, Boca Raton, Florida 33432;* [2]*Spine Biomechanics Laboratory, Department of Kinesiology, University of Waterloo, Waterloo, Ontario, Canada.*

Abstract. Santana, J.C., F.J. Vera-Garcia, and S.M. McGill. A kinetic and electromyographic comparison of the standing cable press and bench press. *J. Strength Cond. Res. 21(4):1271–1279. 2007.*—This study compared the standing cable press (SCP) and the traditional bench press (BP) to better understand the biomechanical limitations of pushing from a standing position together with the activation amplitudes of trunk and shoulder muscles. A static biomechanical model (4D Watbak) was used to assess the forces that can be pushed with 2 arms in a standing position. Then, 14 recreationally trained men performed 1 repetition maximum (1RM) BP and 1RM single-arm SP exercises while superficial electromyography (EMG) of various shoulder and torso muscles was measured. The 1RM BP performance resulted in an average load (74.2 ± 17.6 kg) significantly higher than 1RM single-arm SP (26.0 ± 4.4 kg). In addition, the model predicted that pushing forces from a standing position under ideal mechanical conditions are limited to 40.8% of the subject's body weight. For the 1RM BP, anterior deltoid and pectoralis major were more activated than most of the trunk muscles. In contrast, for the 1RM single-arm SP, the left internal oblique and left latissimus dorsi activities were similar to those of the anterior deltoid and pectoralis major. The EMG amplitudes of pectoralis major and the erector muscles were larger for 1RM BP. Conversely, the activation levels of left abdominal muscles and left latissimus dorsi were higher for 1RM right-arm SP. The BP emphasizes the activation of the shoulder and chest muscles and challenges the capability to develop great shoulder torques. The SCP performance also relies on the strength of shoulder and chest musculature; however, it is whole-body stability and equilibrium together with joint stability that present the major limitation in force generation. Our EMG findings show that SCP performance is limited by the activation and neuromuscular coordination of torso muscles, not maximal muscle activation of the chest and shoulder muscles. This has implications for the utility of these exercise approaches to achieve different training goals.

Key Words. press exercise, strength training, trunk muscles, body stability

Introduction

Many sporting activities require strong pressing efforts from a standing position. The pushing tasks performed by football linemen and wrestlers are examples of substantial standing pressing actions. Many functional daily activities can also involve strong pressing efforts from a standing position. For example, pushing a car off the road or pushing furniture is an activity often encountered by the nonathletic population that often require strong pressing actions while standing. Regardless of whether improvements in athletic performance or daily function are part of the training objectives, enhancing the ability to push an object from the standing position appears to be an important attribute.

Discussion exists between strength and conditioning professionals, personal trainers, and therapists as to methodological approaches to train pressing abilities. During the past decade, the concept of "functional training" has received a considerable amount of attention in fitness and strength and conditioning circles. Many fitness conferences dedicate time and resources to the topic of functional training, and articles on the subject often appear in trade journals and popular magazines. Functional training has been defined as "training the respective muscle groups and involved areas to work in the same manner as they are used in activity" (9). Advocates of functional training (9, 21) point to the concept of "training specificity" (13, 18) to support their training philosophy. Harman contends that "the simplest and most straightforward way to implement the principle of specificity is to select exercises similar to the target activity with regards to the joints about which movements occur and the directions of movements. In addition, joint ranges of motion in the training exercises should be at least as great as those in the target activity" (13). On the other hand, a more traditional viewpoint argues that the optimal method of developing pushing strength from a standing position, as well as athletic performance, would be to incorporate more conventional exercises (e.g., various progressions of the squat, deadlift, bench press [BP], snatch, clean and jerk). The basic traditional approach to strength and performance training has been to use the traditional lifts in the weight room to develop strength and practice the skill to get the functional transfer (2, 20). This paper is not intended to enter into this debate, as the specific merits of both approaches are well acknowledged. Simply, analysis of the standing cable press (SCP) when contrasted with the BP will provide data to assist those in designing programs.

The pressing force that can be performed while standing is limited by several factors, such as the strength of the pressing muscle system, the stability of the various joints through the body, the body weight of the individual, the base of support and posture selected to stabilize the press, and the direction of the press. Bench press exercises are often prescribed for developing hypertrophy and general strength in the muscles of the upper body engaged in pressing (e.g., pectorals, anterior deltoids, and triceps) (7, 11); however, because of the supine position used in the BP, stability and balance of the trunk, needed in the pressing motion, may not be challenged. Clearly, the BP and SCP are different exercises, although little is known about the differences. The purpose of this investigation was 2-fold. First, the ability to generate pressing force in the standing pushing position was assessed. To this end, a static biomechanical model was designed to calculate how much force a body can exert on an object from the standing position. Second, the authors wanted to compare the activation levels of trunk and shoulder muscles between the 1 repetition maximum (1RM) BP

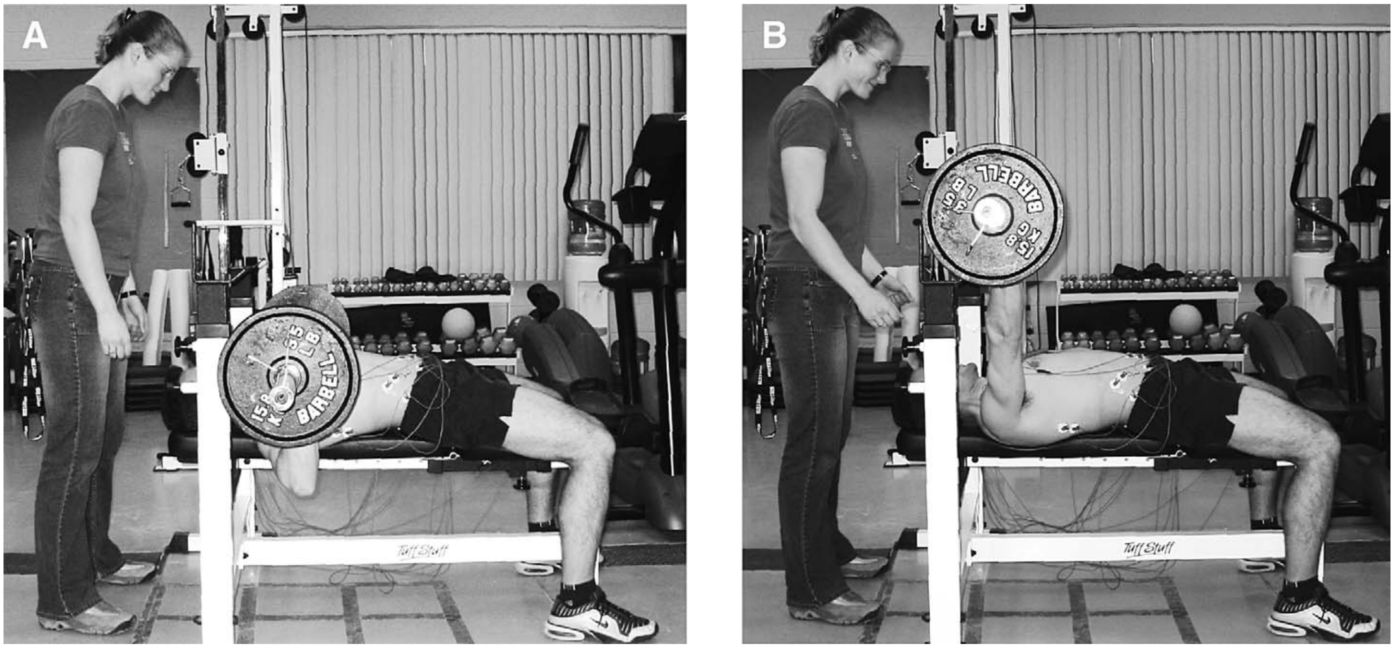

Figure 1. Traditional bench press. (A) Start of the concentric phase. (B) End of the concentric phase.

and the 1RM single-arm SCP. Since the BP is a popular exercise used to develop upper-body hypertrophy and standing pressing strength and power, analyzing the electromyographic data of the 2 exercises would allow for a better appreciation of their functional differences. Furthermore, combining the information from the static pressing model and the electromyographic (EMG) analysis would provide insight as to the limitations and strengths of each exercise approach and how they may relate to specific application. It was hypothesized that the standing position would limit one to apply a pressing force equal to a fraction of one's body weight. It was further hypothesized that EMG comparisons between the 1RM BP and 1RM single-arm SCP would show that the standing position is limited by the control and strength of the core musculature.

Methods

Experimental Approach to the Problem

A linked segment model was used to test the first hypothesis regarding standing pressing ability. Electromyographic signals, normalized to maximal effort, were utilized to test the second hypothesis regarding the determination of musculature that limit pressing tasks.

Subjects

Fourteen recreationally trained men (age = 28.14 ± 8.33 years, height = 1.78 ± 0.05 m, mass = 77.78 ± 10.41 kg) were recruited from the university population. All subjects were right handed and healthy, without current back or shoulder pain. Participants completed a written ParQ and informed consent document approved by the University Office for Research Ethics.

Instrumentation and Data Collection

Exercises. After warming up, all subjects performed BP and single-arm SCP exercises (Figures 1 and 2, respectively). For the BP, subjects were positioned supine with the head and trunk supported by the bench, the knees bent and the feet flat on the floor. One research assistant acted as a spotter and was located behind the bench in the event that the subjects were not able to successfully lift the weight (Figure 1). Subjects grasped the bar equidistant from the middle, unracked the bar, then extended the arms fully to hold the bar for 1 second in the middle of the sternum. They then slowly lowered and pressed the weight upward. For the SCP, subjects were positioned with their feet hip width. The depth of the stance was equal to the distance from the greater trochanter to the floor. The pressing load was applied parallel to the ground and at shoulder height. With the exception of the arm, no body segment can travel beyond the front toe in a staggered stance with the left leg forward and knees slightly bent. While holding a cable pulley handle as shown in Figure 2, they performed a smooth, controlled pressing action to extend the right, keeping their body stable through the entire pressing action. Cable tension was measured using a load-cell force transducer located between the handle and the cable. For both exercises, resistance was progressively increased until reaching the participant's 1RM. Rest periods of 2–5 minutes between trials were utilized in order to avoid muscular fatigue.

Biomechanical Model. Pressing from a standing position imposes great demands on the motor control system to stabilize and balance the body—this imposed constraints on the capacity to push heavy weights independent of muscle strength. An individual is limited in the load that he is able to press from the standing position by when he will violate static equilibrium and fall back. In order to evaluate the maximum hand load in the standing pressing position, a static, 2-dimensional, 15-link segment biomechanical model (4D Watbak, University of Waterloo, Waterloo, ON) was used (Figure 3). This standardized biomechanical model (Figure 2) allows analyses of the moment of force and reaction forces for the major body joints and has been described in detail in earlier publications (e.g., 1, 19). The anthropometrics and joint coordinates from a single subject (gender = male, age = 35 years, height = 1.78 m, mass = 104.3 kg) were input to the model. First it was assumed that all the body

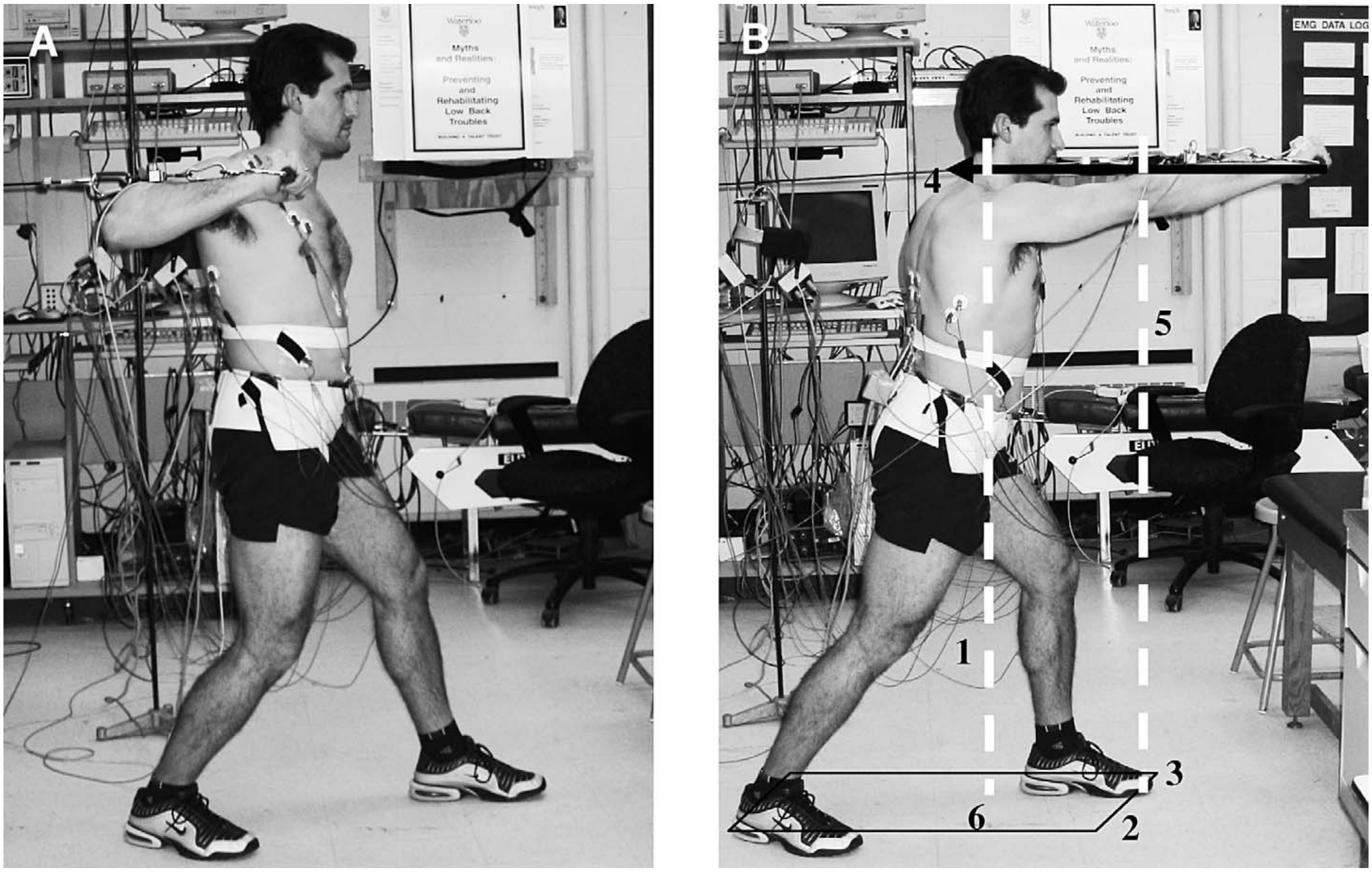

FIGURE 2. Single-arm staggered stance cable press. (A) Start of the concentric phase. (B) End of the concentric phase. For standardizing the position: (1) Greater trochanter to floor. (2) Shoulder width apart. (3) Both feet facing forward, rear foot flat. (4) Force applied through shoulder axis, parallel to ground. (5) Except for the arms, no body part can pass the vertical line passing in front of front foot. (6) Determine center of mass by standing in this position on a custom-made platform with small adjustable fulcrum.

weight was on the rear leg, then the analysis was repeated assuming 90% on the back leg and 10% on the forward leg, 80% on the back leg and 20% on the forward leg, and so on until 50% of the weight was on the forward leg.

Electromyography. Surface EMG signals were collected bilaterally on each subject from the following trunk muscles and locations: rectus abdominis (RA), 3 cm lateral to the umbilicus; external oblique (EO), approximately 15 cm lateral to the umbilicus; internal oblique (IO), halfway between the anterior superior iliac spine of the pelvis and the midline, just superior to the inguinal ligament; latissimus dorsi (LD), lateral to T9 over the muscle belly; and erector spinae at T9, L3, and L5 (ET9, EL3, and EL5, respectively), located 5, 3, and 1 cm lateral to each spinous process. The EMG from the anterior deltoid (AD) and the sternal portion of pectoralis major (PM) was also recorded on the right upper limb. The Ag-AgCl surface electrodes were positioned with an interelectrode distance of 3 cm. The EMG and the load-cell force signals were amplified to produce approximately ± 2.5 and ± 10 V then analog-to-digital converted (12-bit resolution) at 1,024 Hz. The EMG signals were full-wave rectified and low-pass filtered (second-order single-pass Butterworth) with a cutoff frequency of 2.5 Hz (shown to mimic the transfer function between EMG and force production [3]) and then normalized to maximal voluntary isometric contraction (MVIC) amplitudes. The MVICs were obtained in isometric maximal exertion tasks. For the abdominal muscles, each subject was in a sit-up position and manually braced by a research assistant. The subject produced a sequence of maximal isometric efforts in trunk flexion, right lateral bend, left lateral bend, and right twist and left twist directions; little motion took place. For the extensor muscles, an isometric trunk extension was performed with the torso cantilevered over the end of a test table (Biering-Sorensen position). The MVIC for pectoralis major was measured while subjects were positioned with the right shoulder in a flexed, abducted, and externally rotated position with the elbow slightly bent. A research assistant resisted shoulder horizontal adduction, extension, and internal rotation. The anterior deltoid MVIC was performed by resisting shoulder flexion at 90° in the sagittal plane. For shoulder MVICs, subjects were positioned supine on a slightly padded bench.

Three-Dimensional Kinematics. Spine and right-hand kinematics were measured using an electromagnetic tracking instrument (3Space ISOTRAK, Polhemus Inc., Colchester, VT), collected at a sampling frequency of 32 Hz and synchronized to the EMG and load-cell data. This instrument consists of an electromagnetic transmitter and 2 small receivers. For the SCP, the pelvic transmitter was placed over the sacrum, the first receiver over the T12 spinous process and the second receiver on the back of the right hand over the middle of the third metacarpal. For the BP, the transmitter and the thorax receiver locations were modified in order to avoid their contact with the bench. The transmitter was centrally situated be-

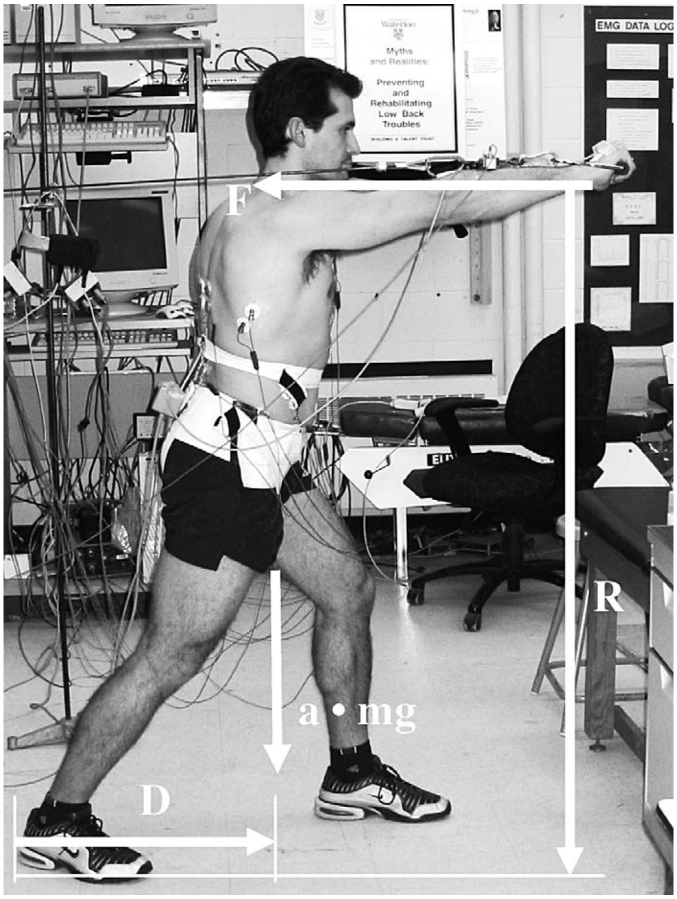

FIGURE 3. Two-arm staggered-stance cable press at the end of the concentric phase. The force at the right hand is calculated by a biomechanical static model (4D Watbak) using the following equation: $F = mg{\cdot}D{\cdot}R^{-1}$, where F is the force applied at shoulder line, R is the distance from floor to top of the shoulder line, D is the distance from center of mass to rear support point, and mg is the subject's body weight on right (back) leg.

tween the navel and the pubis and the first receiver over the xiphoid process. All angular measurements were made relative to the standing anatomical position.

Statistical Analyses

For both exercises, the normalized muscle activity (% MVIC) corresponding to the pushing (concentric) phase of the 1RM was selected in accordance with the displacement of the right hand. Then differences in peak normalized activity for each muscle between exercises and between muscles during each exercise were assessed using a 2-way analysis of variance (muscle/exercise). Significances were calculated using Tukey's honestly significant difference post hoc test ($\alpha = 0.01$).

RESULTS

The results of the static biomechanical model of staggered-stance 2-arm press are presented in Table 1. The model predicted that pushing forces at shoulder height are limited to 40.8% of the subject's body weight before falling back. Furthermore, during the 1RM single-arm SCP, the subjects created an averaged cable load of 26.0 $\pm$ 4.4 kg (33.4% of body weight), significantly smaller than the load pushed in the 1RM BP (95.4% of body weight).

Statistically significant differences ($p < 0.01$) in normalized peak EMG amplitudes were found among muscle sites within each exercise (Figures 4 and 5). For the 1RM BP, anterior deltoid (117.2% MVIC) and pectoralis major (98.7% MVIC) were more activated than the most of the trunk muscles, although this exercise produced important mean levels of trunk muscle activation, especially for right and left erector spinae at T9 (R-ET9 = 71.8% MVIC; L-ET9 = 77.9% MVIC) (Figure 4). In contrast, for the 1RM SCP, the anterior deltoid and pectoralis major activities (R-AD = 120.5% MVIC; R-PM = 61.3% MVIC) were not statistically different from the left internal

TABLE 1. Maximum loads that can be pushed in the standing, staggered-stance, 2-arm press exercise for percentages of body weight (BW) on back foot.

BW on back foot	Load (kg)	BW pushed
100%	42.6	40.8%
90%	35.8	34.3%
80%	29.0	27.8%
70%	22.2	21.3%
60%	15.4	14.8%
50%	8.6	8.3%

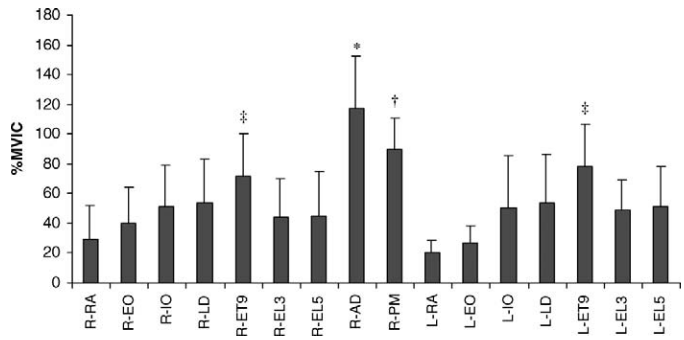

FIGURE 4. Differences in peak normalized electromyographic (EMG) amplitudes between muscles for 1 repetition maximum (1RM) bench press. The highest EMG amplitudes were found for R-AD, R-PM, and ET9 sites. Result of multiple comparison ($p < 0.01$): * = significantly different from all the muscles but R-PM and L-ET9; † = significantly different from right and left RA, EO, EL3, and R-EL5; ‡ = significantly different from right and left RA and L-EO.

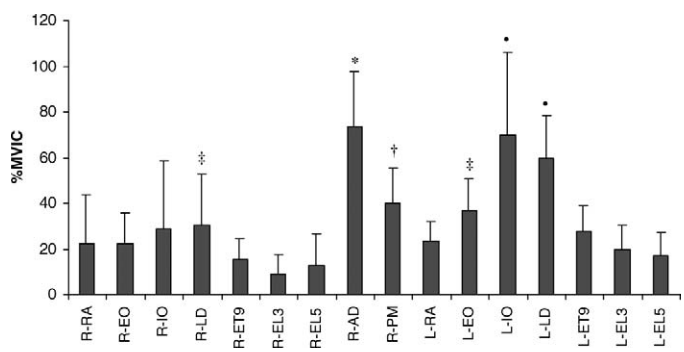

FIGURE 5. Differences in peak normalized electromyographic (EMG) amplitudes between muscles for 1 repetition maximum (1RM) single-arm standing press. The highest EMG amplitudes were found for R-AD, L-IO, and L-LD. Result of multiple comparison ($p < 0.01$): * = significantly different from all the muscles but L-IO and L-LD; · = significantly different from all the muscles but R-AD, R-PM, L-LD, and L-EO; † = significantly different from R-EL3 and R-EL5; ‡ = significantly different from R-EL3.

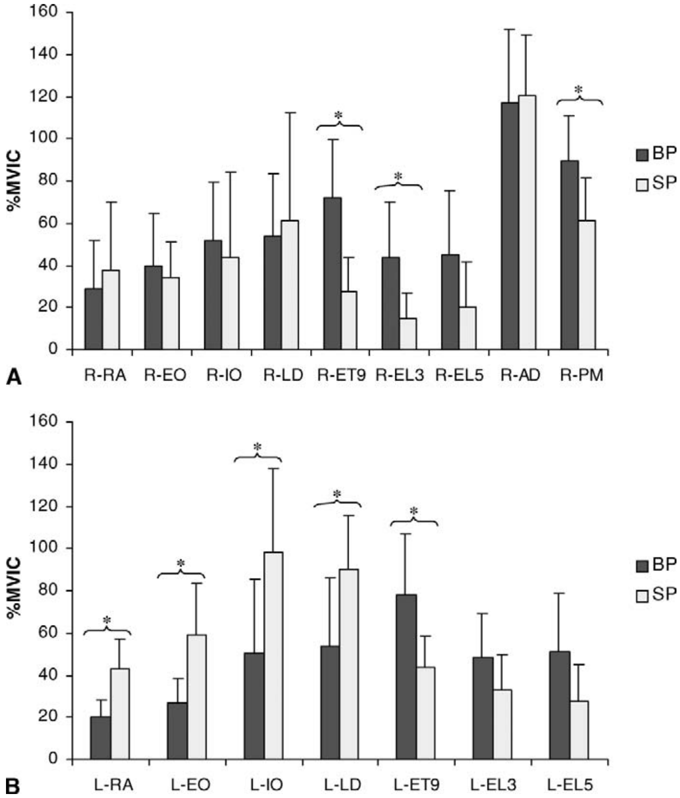

FIGURE 6. Averages and standard deviations of the peak normalized electromyographic (EMG) amplitudes for 1 repetition maximum (1RM) bench press (BP) and single-arm standing press (SP). (A) Right trunk and shoulder muscles. (B) Left trunk muscles. While EMG amplitudes of the erector muscles and pectoralis major were larger for BP, the activation levels of left abdominal muscles and left latissimus dorsi were higher for right-arm SP. * = significance ($p < 0.01$).

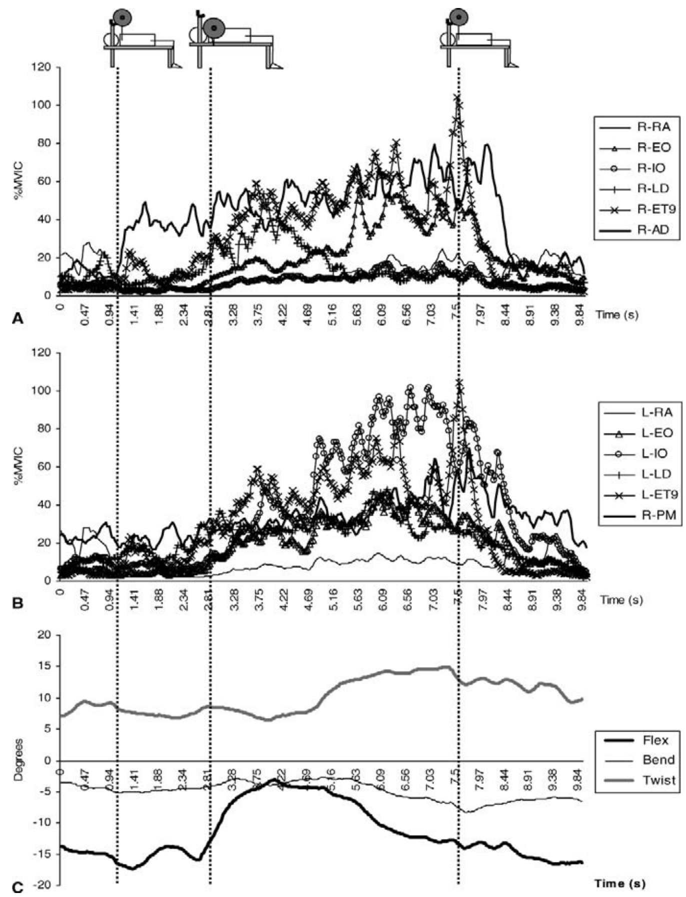

FIGURE 7. Time history of normalized electromyographic (EMG) amplitudes and trunk kinematics for 1 repetition maximum (1RM) bench press of a random subject (no. 13). (A) EMG amplitudes of the right trunk muscles and anterior deltoid. (B) EMG amplitudes of the left trunk muscles and pectoralis major. (C) Angular displacements of the lumbar spine.

oblique and left latissimus dorsi activities (L-IO = 98.4% MVIC; L-LD = 90.1% MVIC). The comparison between exercises showed that since the normalized peak EMG amplitudes of the erector muscles and sternal portion of pectoralis major were larger for the 1RM BP, the peak activation levels of left abdominal muscles and left latissimus dorsi were significantly higher for the right-arm SCP (Figure 6).

A time history of normalized EMG amplitudes and trunk kinematics for 1RM BP and 1RM standing press are shown in Figures 7 and 8. Erector spinae at L3 and L5 EMG amplitudes have been omitted to simplify the analysis.

DISCUSSION

The use of the BP as a general upper-body hypertrophy and strength exercise has been well established and validated as a predictor of performance and upper-body strength test (4, 7, 14, 25). However, concern has been expressed about the ability of an individual to effectively use the majority of the strength developed from traditional exercises, such as the BP, during more functional positions, as in standing activities (8, 9, 17, 22, 23). Based on the results of biomechanical model, which illustrates that one can push only a small fraction of one's body weight from the standing position, this concern appears to be valid. Furthermore, the small EMG activity of the chest musculature and high EMG activity of the core ventral core musculature further add to the theory that the standing pressing motion is not limited by supine pressing strength. Although the participants were able to push approximately 95% of their body weight in the 1RM BP, they pushed only about 33% of their body weight in the 1RM single-arm SCP. Furthermore, the static biomechanical model showed that a 2-arm press from the standing position allows an individual to press maximum 40.8% of body weight even with all weight on the back leg without falling back (see Table 1). When considering the output of the static model, the differences in the magnitude of the chest and core muscle activity during the BP and SCP, and the difference in the BP and SCP loads, it appears that the strength of the upper body is of minimal importance in determining the amount of pressing force generated from the standing position. On the contrary, as the static model showed (Figure 3), there are other important variables: foot position relative to the center of mass, forward lean, bending of knees, and weight of the individual. This model does not take into account dynamic variables that also can affect the standing press action, for example, forward momentum and hand speed. In spite of the limitations of the model, standardizing the standing press position facilitates discussion of comparative mechanics and appropriate training.

Electromyography for the BP has been previously conducted by other investigators. Lagally et al. (15) examined the muscle activation and ratings of perceived exertion during BP exercise in recreational and novice lift-

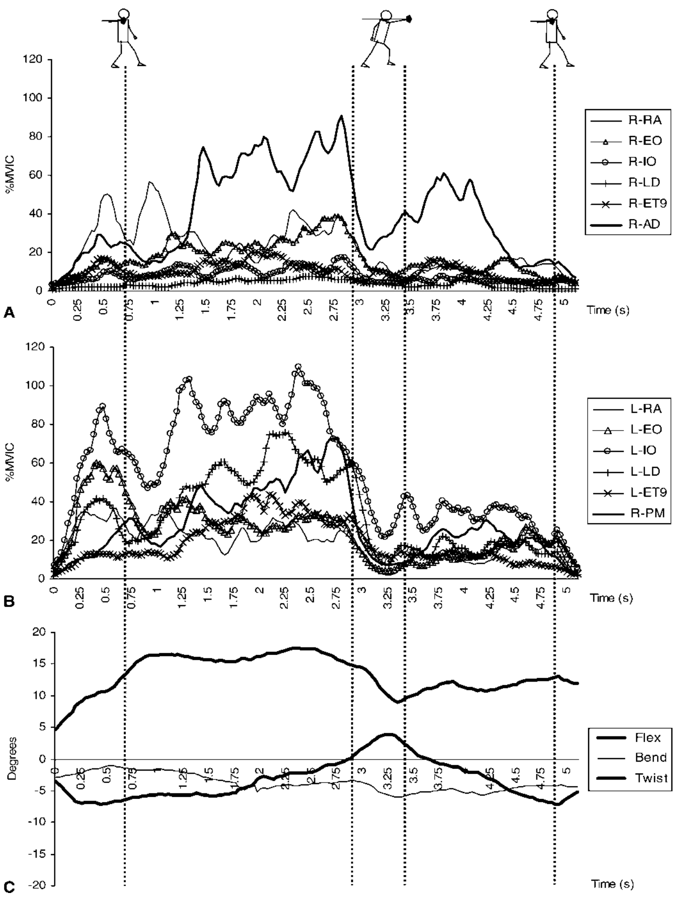

Figure 8. Time history of normalized electromyographic (EMG) amplitudes and trunk kinematics for 1 repetition maximum (1RM) single-arm standing press of a random subject (no. 13). (A) EMG amplitudes of the right trunk muscles and anterior deltoid. (B) EMG amplitudes of the left trunk muscles and pectoralis major. (C) Angular displacements of the lumbar spine.

ers. On the other hand, Elliot et al. (6) executed an EMG and kinetic analysis of the "sticking" phase in the BP. However, to our knowledge, no previous studies have compared the EMG patterns of the BP and the SCP.

The elevated activation of the chest and shoulder musculature during the BP supports the traditional use of the BP as an upper-body exercise to develop hypertrophy and general strength as well as a method of testing and predicting performance (11, 14, 25). As the time history of trunk kinematics shows (Figure 7), during the 1RM BP, the subjects experienced difficulty performing the task solely in the sagittal plane; instead, small trunk rotations were observed. Furthermore, an important level of trunk coactivation also was noticed (Figures 4 and 7). Based on the evidence that abdominal and back muscle coactivation increase torso stiffness and stability (5, 10, 12, 17), some coactivation could be needed to control the lateral displacement of the load. Interestingly, the maximum activity of rectus abdominis was observed while the subjects unracked and racked the bar during the BP (approximately 30% MVIC; Figure 7). Most likely, the contraction of the rectus abdominis was performing a stabilizing role of the torso.

In contrast to the BP, muscle activation data for the 1RM single-arm SCP showed that twisting torque production influenced the contralateral torso musculature (Figures 5 and 8). One of the main findings was that the peak muscular activation of pectoralis major was not higher than the activity of the abdominals and latissimus dorsi. These data seem to indicate that chest strength may not be the most important factor when pressing from a standing position and support our hypothesis that, during a standing cable press, several abdominal muscles are highly challenged and may limit pressing ability. Interestingly, the highest muscular activation was observed in the left abdominal and left latissimus dorsi during the load acceleration phase of the SP (Figure 8). As was noticed during the recording session, this phase was one of the most critical parts of the standing press performance since whenever the load was correctly accelerated, the exercise was successfully completed. These data are consistent with the Serape effect first described by Logan and McKinney (16) and later by expanded by Santana (24). The contrast performed in this paper highlights the sagittal challenge of the BP and the very different "core" requirements of the SCP. In fact, the sagittal, supine strength of the BP appears to have little to do with standing pressing performance.

In conclusion, the results of this study indicate that the mechanics of pressing from a standing position are quite different than those of the traditional supine pressing position. The BP emphasizes the activation of the shoulder, back extensor, and chest muscles and challenges the ability to develop great shoulder torques. This finding further supports the use of the BP to develop hypertrophy and general strength in the chest and shoulders. In contrast to the BP, the SCP appears to demand a greater emphasis on stability and neuromuscular control of the core muscles. In fact, the core muscles appear to set limits of activation levels on the shoulder muscles. This finding begins to provide insight into the importance of core stability with core muscles in standing activities, suggesting that they should be considered during functional "approaches" to strength training that include standing postures. Several teams have adopted training philosophies to ensure a standing "playing posture" when exercising. Coaches and fitness professionals will find these data concerning differences informative when prescribing exercises to develop pushing or pressing abilities. Future studies should examine how dynamic variables (i.e., hand speed and forward momentum) and the lower-body musculature activity affect standing press performance as well as training methods to develop better performance from the standing position.

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Address correspondence to Stuart McGill, mcgill@healthy.uwaterloo.ca.