Medicina Sportiva
Med Sport 17 (3): 100-105, 2013
DOI: 10.5604/17342260.1068220

COMPARATIVE PERFORMANCE AND LACTATE DATA FROM BENCH PRESSES AT SUBMAXIMAL LOADS

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Abstract

Introduction: Bench presses done at submaximal loads produce localized muscle fatigue that undermines exercise performance. Such changes are manifested through elevated blood lactate concentration ([BLa^-]) values.

Objective: To examine and compare bench press performance at submaximal loads and resultant changes to the [BLa^-].

Methods: Thirty men performed three workouts; each entailed a warm-up followed by four sets done to failure at a single load (40, 55, or 75% of the 1RM). With an accelerometer affixed to the barbell, peak power (PP) was displayed after each set. The highest PP from each workout was used for analysis. Per workout, the number of repetitions from each set was summed and used for analysis. [BLa^-] were recorded before and five minutes after workouts.

Results: Inter-load effects occurred for PP (40% > 75%) and the number of repetitions per workout (40% > 55% > 75%). However [BLa^-] results merely yielded a time effect (post > pre). At the lightest load, repetitions occurred at higher rates to elicit greater PP values.

Conclusions: Results imply when comparing similar exercise paradigms done at different barbell masses, similar degrees of post-workout lactate accrual occur with bench presses done at the aforementioned loads. Yet, given the parameters of the current study and our statistical results, there does not appear to be a submaximal load where such increases are most prevalent.

Key words: *fatigue, power, resistive exercise, metabolic acidosis, accelerometry*

Introduction

The bench press is an index of upper body strength and function [1,2]. A popular version of the exercise is to see how much weight is lifted one time with proper technique over a full range of motion, commonly known as a one-repetition maximum (1RM). Yet the bench press often provides athletes greater benefit when performed to voluntary failure at submaximal loads. Rather than demand athletes exert maximal force output whereby performance benefits from a high 1RM value, many modern-day sports entail movement of an implement with a modest mass as rapidly as possible using their upper body muscles. Instead athletes in such sports will derive more benefit from exercise done at submaximal loads since it affords greater gains in power, or the ratio of work per unit time which is essential to the demands of modern-day competition [3]. Yet debate exists as to which submaximal resistance best confers power gains; as some advocate lighter (< 50% 1RM), while others heavier (50-75% 1RM) loads [4-7]. High power outputs entail exercise with brief yet intense bursts of effort. Yet demands of an athlete's sport often require sustained power, which involves repetitive efforts of a longer duration done to voluntary failure [8]. The performance of such exercise is impaired by fatigue.

When training for sustained power, such as when bench presses are done at submaximal loads, performance may be impaired by many factors yet none entirely account for losses in force production since fatigue is very specific to a given exercise task [9]. Inorganic phosphate, as well as protonated and deprotonated ammonia, are implicated in numerous muscle fatigue mechanisms that include, but are not limited to, perturbations to crossbridge cycling and intracellular Ca^{+2} kinetics [9-14]. Yet most inorganic phosphate research has focused on in-vitro models, thus it has been largely ignored as a fatigue-inducing metabolite by athletes and coaches [9,11,13,14]. In contrast intracellular lactate and H^+ accrual coincide with pH losses that typify metabolic acidosis and fatigue [15-17]. Among metabolites, lactate and H^+ concentrations undergo perhaps the greatest intra- and extra-cellular changes from exercise [15,18]. Intracellular lactate accrual, such as that incurred from exercise which requires sustained power, impedes Ca^{+2} release from the sarcoplasmic reticulum by nearly 10% [13]. Monitoring changes to lactate is thus an important metabolite associated with fatigue [19,20].

Lactate and H^+ are derived from lactic acid. Due to its pK of 3.8, lactic acid dissociates into lactate and H^+ over the range of intramuscular pH values [21]. An intracellular lactate gain of 70 mmol $\cdot$ kg^{-1} dry weight causes absorption of the majority of H^+ via intramuscular buffers and phophocreatine hydrolysis which offers evidence of a 1:1 lactate-H^+ ratio [22]. Thus

metabolic acidosis byproducts include an elevated blood lactate concentration ([BLa^-]) that parallels the gain in H^+ [19,20]. Strong relationships exist among intramuscular lactate-H^+ accrual and heightened fatigue. Intramuscular lactate rises by up to 40 mmol · L^{-1} from intense exercise, with concomitant gains of up to 25 mmol · L^{-1} in plasma [19,23,24]. Intramuscular pH progressively declines with maximal exercise to as low as 6.5. Such values are most easily achieved with intense repetitive bouts of exercise 30-40 seconds in duration [23]. Such activity also evokes intracellular H^+ increases of up to 54 mmol · kg^{-1} that undermine exercise performance by denaturing phosphofructokinase, competitive inhibition of Ca^{+2} at the troponin C subunit, and by causing crossbridges to remain in their low force state [13,23,25].

The degree of [BLa^-] increase is indicative of the exercise bout's rigor and the workload imposed upon muscles. Without knowledge of the extent to which an athlete's [BLa^-] rises from exercise done at submaximal loads, the ability to design workouts is limited. The bench press-lactate relationship is not linear, meaning a heavier barbell does not assure a commensurate [BLa^-] increase. In fact [BLa^-] peaks from workloads done at supramaximal intensities 30-120 seconds in length [3,16,24,26,27]. The degree of [BLa^-] increase is less a function of barbell mass than other performance measures such as power, and is especially true when repetitions proceed to voluntary failure. The nature of many workout regimens and sports entail exercise done against submaximal loads at supramaximal intensities; thus more knowledge on the workload-lactate relationship aids many athletes such as those who perform the bench press exercise. Many trials examined bench press performance [2,28-30], yet few assessed resultant [BLa^-] changes. This is despite lactate's impact on fatigue when exercise is performed at submaximal loads. One study has assessed the bench press-lactate relationship using untrained subjects (11 men, 4 women) to examine active recovery's role on performance [31].

That study measured [BLa^-] changes from two workouts; one that included active recovery, while the other did not and served as a control condition [31]. Per workout [BLa^-] was measured before exercise, as well as 1.5 and 4.5 minutes after its completion [31]. Yet unlike the prior study, evidence suggests [BLa^-] may peak five minutes post-exercise [3,16,26,27,32]. Furthermore the active recovery study examined performance at only one (65% 1RM) load, thus comparative outcomes from workouts at different submaximal loads were not assessed. Since it is very important to know the extent of lactate accrual in response to such workouts, our study examines exercise performance and [BLa^-] changes from bench presses done at various submaximal loads. We hypothesize 1): workouts will yield differences in exercise performance and [BLa^-] changes, and 2): peak power and the number of repetitions per workout will correlate to amounts of variance for both post-exercise and delta [BLa^-] criterion measures.

Methods

Subjects

Before data collection and in accordance with the Helsinki Declaration, a university-based institutional review board approved all study procedures. To limit variability and best assess inter-load differences, we used a within-subjects design with a larger and more homogeneous sample than prior studies [10,12,30,31]. Thirty healthy men gave written informed consent to participate. Their general characteristics (mean ± sem) were as follows: age 21.0 ± 0.7 years, height 178.3 ± 4.9 cm, body mass 86.8 ± 2.5 kg. They were either scholarship athletes or habitual participants in structured resistive exercise programs. Prior to participation they had 2.6 ± 0.8 years prior bench press experience. Thus each was familiar with the exercise at the start of their project involvement.

Procedures

Subject came to the laboratory four times. Per subject, their visits occurred within a five-week period. Their first visits entailed anthropometric data collection, followed by a 1RM bench press determination. To fulfill within-subjects criteria and to address the question of whether peak power occurs at lighter (< 50% 1RM) or heavier (50-75% 1RM) loads [4-7], their next three visits entailed bench press workouts at one of three (40, 55 or 75% 1RM) levels of resistance. Workout sequence was randomized to limit the chance of an order effect. Per subject, once a workout was completed it was not repeated. For the final three visits, both before and five-minutes after workouts, subjects submitted to [BLa^-] measurements. Per subject, workouts occurred at the same time (1300-1700 hours) of day to limit diurnal variability. They were asked to adhere to their normal diets and refrain from caffeine consumption on days they visited our laboratory.

First visits began with collection of body mass and height data, which were recorded to the nearest 0.1 kg and 0.1 cm respectively, from a calibrated scale (Detecto; Webb City, MO). That visit continued with determination of subject's 1RM load, which was done on a free weight bench press apparatus (Tuff Stuff; Pomona, CA) with an Olympic barbell and plates (Ivanko; Reno, NV). Repetitions occurred as subjects laid supine on the bench while they maintained a bilateral pronated shoulder-width grip on the barbell. Repetitions proceeded from full elbow extension until the barbell descended in a controlled fashion and made contact with the sternum. Horizontal glenohumeral adduction, combined with elbow extension, returned the barbell to its original position to complete each repetition.

Subjects were instructed to move the barbell over a full range of motion and use the "touch-and-go" technique to perform repetitions [28]. Proper technique required subjects keep their hips on the bench, maintain a constant degree of lumbar lordosis, refrain from extraneous body movement and achieve bilateral full elbow extension. Repetitions that did not meet these criteria were excluded from analyses. To limit the risk of injury, 1RM determinations began with a 20-repetition warm-up set. Over successive sets they performed fewer repetitions against progressively heavier loads until a 1RM value was reached. For 1RM determinations, subjects averaged 5.2 ± 1.1 sets and received as much rest between sets as they wished. Their self-selected rest periods averaged 130 ± 45 seconds. First laboratory visits were completed within 30 minutes. All sets were performed with spotters present.

Subject's 1RM bench press values determined the resistance for their final three visits, whereby workouts occurred against one of three (40, 55 or 75% 1RM) loads. Selection of the three relative masses was done to impart a broad range of physiological demands on subject's bench press prowess, elicit varied [BLa^-] responses and identify which submaximal load best elicits the highest power outputs [4-7]. The final three visits began when subjects submitted to pre-exercise [BLa^-] measurements. A spring-loaded lancet was applied to a fingertip on subject's right hands to place a small (~25 µL) blood sample onto a test strip inserted within a calibrated (Accutrend; Hawthorne, NY) analyzer. Operational and calibration procedures of the analyzer followed manufacturer's guidelines. The analyzer quantified [BLa^-] via fluorometric absorbance. Prior research noted a high level of data reproducibility with the current study analyzer [33,34].

The exercise portion of laboratory visits 2-4 began with randomization to a barbell load and a warm-up set at ~15-30% 1RM. Warm-up repetitions occurred at a self-selected pace to ensure fatigue did not impair subsequent exercise sets. Subjects then performed four sets against a constant barbell mass. Per set, they were instructed to perform as many repetitions as possible in good form and to not pace themselves. Affixed to the barbell, an accelerometer (Myotest Inc., Royal Oak MI) measured peak power (PP) for each set. The accelerometer had a cross-axis sensitivity of 2% and collected data at 500 Hz [35]. Prior work reported high levels of accuracy for the device [36,37]. Subjects rested three minutes between sets as such a rest interval may aid force development over successive sets [30]. In addition to the spotter, another member of the research team counted the number of repetitions performed per set; values per workout were summed from the four sets. Per workout, PP and the number of repetitions performed were used for analysis. A post-workout [BLa^-] measurement occurred five minutes after the last set.

Statistical analysis

Prior to our computations, power analyses were conducted to ensure a sufficient sample size was present to perform our ANOVA [38] and multivariate regression [39] tests. Our data set was then examined to ensure all three ANOVA assumptions were met before our statistical computations. PP and the number of repetitions performed were each analyzed with one-way ANOVAs. [BLa^-] values were analyzed with a 3 (load) x 2 (time) ANOVA, with repeated measures for each independent variable. Tukey's post-hoc identified the source of the differences for each of our ANOVA computations. In addition, multivariate regression was used to examine if our PP and the number of repetitions performed could predict the variance of for our two dependent variables. Post-exercise and delta (post-pre exercise) [BLa^-] served as our two criterion measures. An $\alpha = 0.05$ for all analyses.

Results

No subjects were injured through their participation. Absolute 1RM values were 103.8 ± 5.4 kg; 1RM expressed relative to body mass equaled 1.20 ± 0.03 $kg \cdot bodymass^{-1}$. All ANOVA assumptions (normality, independence, homogeneity of variance) were met. With the large effect sizes seen with resistive exercise [40], and α and β values of 0.05 and 0.80, respectively, the current sample enabled detection of significant differences with an equal delineation among type I and II error rates. Power analysis results suggest the sample size was sufficient to proceed with both our ANOVA and multivariate computations [38,39]. PP and the number of repetitions performed results appear in Tables 1 and 2 respectively. PP data analysis results were significant ($P = 0.0009$); post-hoc results revealed a main effect for load (40% 1RM > 75% 1RM). The number of repetitions performed analysis was also significant ($P = 0.0003$); post-hoc results demonstrate a main effect for load (40% 1RM > 55% 1RM > 75% 1RM).

Table 1. *PP values (mean ± sem) in watts*

Load *	40% 1RM	55% 1RM	75% 1RM
	1662 ± 278	1170 ± 133	694 ± 58
Range	133 – 4220	118 – 2430	36 – 2130

*: 40% 1RM > 75% 1RM

Table 2. *Number of correctly performed repetitions (mean ± sem) per workout*

Load *	40% 1RM	55% 1RM	75% 1RM
	97.5 ± 3.6	59.8 ± 2.4	28.5 ± 1.4
Range	52 - 129	28 - 89	14 - 48

*: 40% 1RM > 55% 1RM > 75% 1RM

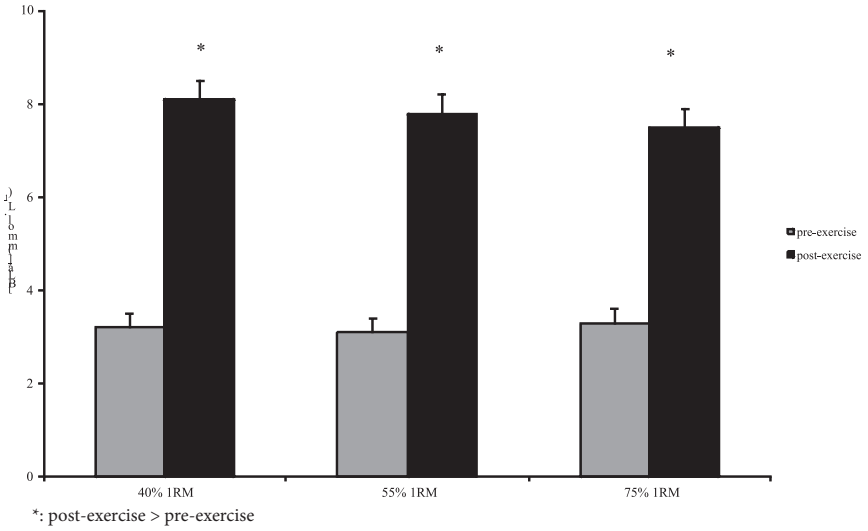

Fig. 1. *Current study [BLa⁻] changes*

Figure 1 displays our [BLa⁻] results, which include a main effect (P = 0.0001) for time (post-workout > pre-workout). Despite the broad range of relative barbell masses used in our study, no inter-load [BLa⁻] differences occurred. Thus while our study saw inter-load differences for both exercise performance measures, such was not the case for [BLa⁻]. Multivariate regression results suggest our exercise performance measures were weak predictors of criterion measure variance. This was true whether post-workout or delta [BLa⁻] was used as a dependent variable.

Discussion

Many possible causes of muscle fatigue exist, yet none explain the decline in force production in their entirety since fatigue is highly specific to the exercise task being performed [9]. The nature of many modern-day sports and workout regimens entail exercise done against submaximal loads at supramaximal intensities to the point of fatigue-induced volitional failure. Resistive exercise workouts done against various loads may induce a variety (sustained power, general conditioning, hypertrophy, etc.) of adaptations when repetitions are done to volitional failure, as occurred in our study. Acute physical changes from such workouts may elevate metabolic acidosis and the [BLa⁻]. The current study's importance identifies the extent to which an athlete's [BLa⁻] rises in response to exercise done against submaximal loads to the point of volitional failure. Since numerous workout regimens and sports operate under a similar exercise paradigm, our results are relevant to a variety of athletes. Our results include a partial affirmation of our hypotheses and warrant explanation in relation to prior research.

Like our study, an active recovery trial measured [BLa⁻] changes from a four-set bench press paradigm whereby each set was performed to voluntary failure [31]. Subjects performed two such workouts, one of which also included active recovery. Results showed active recovery had little effect on post-exercise [BLa⁻] [31]. As compared to our results, the active recovery trial evoked a far lower range (3.88-4.31 μmol · 100 ml^{-1}) of post-workout [BLa⁻] values [31]. Aside from differences in the timing of post-exercise measurements, perhaps the biggest cause for the large post-workout [BLa⁻] discrepancies was the bench press loads for the current and former [31] studies. For the active recovery trial 1RM values were 71.5 ± 7.6 kg, far less than the current study. Thus differences in bench press loads, whereby our exercise bouts generally entailed higher absolute barbell masses and thus greater workloads, evoked a higher post-workout [BLa⁻].

In addition to the active recovery trial [31] and like the current investigation, other studies measured [BLa⁻] changes to resistive exercise performed at different submaximal loads over multiple workouts [10,12]. College-age (n =16) men performed three different squat workouts to assess [BLa⁻] changes [12]. In a randomized sequence subjects performed squat workouts geared toward improvements to each of the following parameters: strength, hypertrophy and muscular endurance. With similar volumes of work performed per workout, the muscular endurance exercise bout, which entailed more repetitions done against lighter loads, yielded greater [BLa⁻] increases than the strength workout (35). Another study employed ten healthy men who submitted to [BLa⁻] measurements before, during and immediately after two different leg press workouts [10]. Each workout entailed three sets. Resistance per workout was maintained at subjects' 5RM or 15RM load. Post-workout [BLa⁻] values were each significantly higher after the 15RM, versus the 5RM, exercise bout [10]. Thus our [BLa⁻] results concur with prior trials that showed high-repetition resistive exercise done against relatively modest loads led to higher increases in the metabolite than workouts done against heavier loads [10,12].

Current power analysis results suggest, particularly with the large effect sizes common to resistive exercise and a within-subjects study design, our sample was large enough to detect [BLa^-] main effects for load and time. While Table 1 and 2 exercise performance measures exhibited main effects for load, such was not the case for our [BLa^-] results. This implies our three submaximal barbell loads were comparable with respect to the degree of lactate accrual, yet there does not appear to be a particularly load where this increase was especially prevalent. The lack of inter-load [BLa^-] differences in the current study is perhaps most attributable to the duration of individual exercise sets, which were somewhat similar for each of our three workouts. In support of this suggestion, the comparative effects of exercise duration on intramuscular lactate accrual were examined from supramaximal cycle ergometry bouts ten and 30 seconds in length [17].

From healthy subjects, vastus lateralis biopsies showed mean lactate values were far less after the ten- (36 mmol · kg dry wt^{-1}), versus the 30-second (61 mmol · kg dry wt^{-1}) cycle ergometry bout and demonstrate greater metabolite accrual from the longer ride and concurs with research that notes supramaximal exercise 30-120 seconds in duration yield the largest [BLa^-] increases [15-17,24,26,27]. Done to voluntary failure, the duration of our sets from each workout were likely long enough to induce substantial lactate accrual, hence the time effect seen in Figure 1. Yet the inter-load duration of each workout's four sets were similar enough to elicit non-significant [BLa^-] differences among our workouts. A combination of barbell mass-exercise duration for our three workouts likely led to comparable [BLa^-] increases. More research is warranted to note if significant inter-load [BLa^-] differences may be produced from workouts done against submaximal loads.

Table 1 shows the 40% 1RM load produced the highest mean PP value, which concurs with prior work [4,5,8]. This likely occurred since velocity, a key component of power, was highest at the 40% 1RM load. Maximal power outputs have been expressed over a broad range (10-70% 1RM) of submaximal loads for different resistive exercises [41]. Yet prior research notes bench press power peaks at 30-45% 1RM loads [8], which is in agreement with our results. Chronic training interventions that compared gains in power also noted a somewhat similar outcome [42]. Gains in power were compared after 12 weeks of elbow flexor training done against four different loading (0, 30, 60, or 100% of peak isometric force) conditions with no crossover. Untrained men in each group performed ten contractions three times per week for 12 weeks. With power tests done before and after the intervention, greater gains occurred to the 30% (+26.1%) group, followed by the 100% (+22.4%), 60% (+21.7%) and 0% (+13.8%) groups. Post-hoc results showed significant inter-load (30% > 60%, 0%) effects. Thus our results are somewhat like those from the chronic training study, as both saw higher power outputs from exercise done at a comparable percentage of subject's submaximal loads [42].

While our Table 1 results show the 40% 1RM load elicited the highest PP, that same load also produced the greatest range of values. This level of data variability contributed to the weak prediction capacity of PP to act as a correlate to the post-exercise and delta [BLa^-] variance in our multivariate analyses. Resistive exercise performance, particularly for workouts that entail dynamic high-speed movements, elicit more data variability [43]. Greater variability may also be inherent to the type of variable measured from our accelerometer [35]. For instance had the accelerometer measured average, rather than peak, power our variability would likely be less and the current exercise performance-lactate relationship strengthened. Increases in movement velocity, such as for the current 40% 1RM barbell load, inherently yield more variability [43-45]. Thus while the higher movement velocity at the aforementioned load evoked higher PP values, it may have contributed to the weak exercise performance-lactate relationship in our study.

In addition to the large data variability, it should also be noted a restriction with respect to the type of subjects from whom our data were collected may have contributed to our non-significant multivariate regression results. The implications of a restricted range on multivariate results include a smaller variance for the affected variable [38]. In turn, this underestimates the actual correlation for the population under inquiry as compared to if there were no range restriction [38]. With respect to the current study, our sample homogeneity of cannot be ruled out as a contributing factor to the lack of statistical significance in our multivariate regression results despite the variability of our PP values. Thus in addition to our PP variability, sample homogeneity may have contributed to the lack of significance in our examination of the bench press-lactate relationship. Nonetheless our study contributes to the understanding of changes to [BLa^-] values when the bench press exercise is performed against submaximal loads to volitional failure.

Declaration of interest

The authors report no conflicts of interest.

Acknowledgements

We wish to thank our subjects for their participation. Support was provided by a University of Tulsa Faculty Research Grant. JF Caruso, NM Olson, ST Taylor and AG Barbosa are participants in the TURC (Tulsa Undergraduate Research Challenge) Program at The University of Tulsa.

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Accepted: September 4, 2013
Published: September 27, 2013

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A – Study Design
B – Data Collection
C – Statistical Analysis
D – Data Interpretation
E – Manuscript Preparation
F – Literature Search
G – Funds Collection