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THE IMPACT OF VELOCITY OF MOVEMENT ON PERFORMANCE FACTORS IN RESISTANCE EXERCISE

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[1]Human Performance Laboratory, Department of Kinesiology, University of Connecticut, Storrs, Connecticut 06269; [2]Department of Biology of Physical Activity, University of Jyväskylä, Jyväskylä, Finland; [3]Department of Movement Sciences, University of Maastricht, Maastricht, Netherlands. [4]Department of Sport Sciences, Colorado College, Colorado Springs, Colorado 80903; [5]School of Biomedical and Sports Science, Edith Cowan University, Joondalup, Western Australia, Australia.

ABSTRACT. Hatfield, D.L., W.J. Kraemer, B.A. Spiering, K. Häkkinen, J.S. Volek, T. Shimano, L.P.B. Spreuwenberg, R. Silvestre, J.L. Vingren, M.S. Fragala, A.L. Gómez, S.J. Fleck, R.U. Newton, and C.M. Maresh. The impact of velocity of movement on performance factors in resistance exercise. *J. Strength Cond. Res. 20(4):760–766. 2006.*—The purpose of this study was to determine the impact of a very slow (VS) velocity and a self-selected volitional (VOL) velocity at varying intensities on repetition number, peak force, peak power, and total volume in the squat and shoulder press exercises. On separate testing days, 9 resistance trained men (age: 23.9 $\pm$ 2.5 years; height: 174.8 $\pm$ 6.5 cm; body mass: 80.1 $\pm$ 12.4 kg) performed a squat (SQ) and shoulder press (SP) exercise at 60 or 80% of 1 repetition maximum (1RM) at either VOL or VS (10-second eccentric and 10-second concentric actions) velocity for as many repetitions as possible. Force, power, and volume (repetitions $\times$ kg) were also determined. Subjects performed significantly fewer repetitions ($p \leq 0.05$) in the VS exercises (60% VS SQ 5 $\pm$ 1 vs. VOL SQ 24 $\pm$ 2; 80% VS SQ 2 $\pm$ 0 vs. VOL SQ 12 $\pm$ 1; 60% VS SP 4 $\pm$ 1 vs. VOL SP 14 $\pm$ 2; 80% VS SP 1 $\pm$ 0 vs. VOL SP 6 $\pm$ 1). Peak force and power were significantly higher at the VOL speed (peak force [in newtons]: 60% VS SQ 564.4 $\pm$ 77.3 vs. VOL SQ 1229.0 $\pm$ 134.9 N; 80% VS SQ 457.3 $\pm$ 27.9 vs. VOL SQ 1059.3 $\pm$ 104.7 N; 60% VS SP 321.6 $\pm$ 37.8 vs. VOL SP 940.7 $\pm$ 144.8 N; 80% VS SP 296.5 $\pm$ 24.7 vs. VOL SP 702.5 $\pm$ 57.7 N; and peak power [in watts]: 60% VS SQ 271.2 $\pm$ 40.1 vs. VOL SQ 783.2 $\pm$ 129.1 W; 80% VS SQ 229.3 $\pm$ 49.5 vs. VOL SQ 520.2 $\pm$ 85.8 W; 60% VS SP 91.3 $\pm$ 21.9 vs. VOL SP 706.6 $\pm$ 151.4 W; 80% VS SP 78.1 $\pm$ 19.8 vs. VOL SP 277.6 $\pm$ 46.4 W). VOL speed elicited higher total volume than the VS velocity. The results of this study indicate that a VS velocity may not elicit appropriate levels of force, power, or volume to optimize strength and athletic performance.

KEY WORDS. volume, force, power, maximal strength, strength training

INTRODUCTION

Success of a resistance training protocol relies on the manipulation of the acute variables to maximize outcome measurements (i.e., force and power). The effects of manipulating the acute variables (volume, exercise selection, exercise order, loading/intensity, and speed of muscle action) are well documented in terms of long-term training goals (e.g., muscular strength, muscular endurance, power) (12, 13, 14, 19, 30). For instance, maximal strength is best achieved with lower repetitions and higher load, e.g., 80–100% of 1 repetition maximum (1RM) with a repetition range of 1–5, while muscular endurance is best achieved with lighter loads and higher repetitions (12, 30). While it is also known that training for maximal power requires a high velocity at a moderate load (12, 30), the acute effects of manipulating velocity in a resistance training bout are less known, especially when the speed of the exercise is drastically reduced.

Keeler et al. (16) compared a Nautilus exercise protocol, which utilized a 2-second concentric action, 1-second pause, and 4-second eccentric action in each repetition, to a slower movement protocol utilizing a 10-second concentric and 5-second eccentric repetition phase time. After 10 weeks of training, the Nautilus training group made significantly greater gains in 1RM strength in all exercises compared with the slow movement group. These results were seen in the absence of any changes in body composition. In a study by Hunter et al. (15) comparing the metabolic cost of a slow full body training program with traditional movement velocity resistance training, investigators concluded that a traditional program with repetitions performed at a volitional speed elicited significantly higher energy expenditure, heart rate, and blood lactate responses than the slower movement speed protocol. Thus, the efficacy of using a slower speed protocol for short-term resistance training appears to be inferior to conventional velocity repetitions. However, no study to date has examined possible reasons for the lack of efficacy with slow velocity training.

None of the above studies measured the influence of a drastically reduced velocity training protocol on the acute outcome variables of a resistance training bout, such as force, power, and volume. Furthermore, no study has compared these outcome variables between a slow and conventional velocity of movement resistance exercise protocol. Repetition number per set, volume of work, force, and power production are measurable variables of a resistance training protocol, and are important because they can be manipulated to produce an optimal stimulus for strength development (30).

Repetition number is an important variable because it has been documented that the intensity of the loading (as a percentage of 1RM) has an effect on the number of repetitions that can be performed (termed the repetition continuum) (13, 14). It is ultimately the number of repetitions that can be performed at a given intensity that will determine the effects of training on strength development (e.g., 1 to 6 repetition maximum range for maximal strength, 8 to 12 repetition maximum range for muscular hypertrophy) (12, 13, 30). However, the effects of manipulating velocity on repetition range in a resistance training bout with accepted loading (i.e., 80% for maximal strength development and 60% for muscular endurance) are less known, especially when the speed of the exercise is drastically reduced.

Thus, the primary purpose of this investigation was to compare the effects of a slower velocity resistance exercise protocol (10-second concentric action and 10-second eccentric action) with a conventional resistance exercise protocol using a self-selected velocity exercise movement. In order to contrast and compare these 2 dramatically different resistance exercise protocols, the number of repetitions performed to failure, total volume of work, and peak force and power production for each repetition was documented. A secondary purpose was to document the physiological and perceptual responses to each resistance exercise protocol by measuring blood pressure and ratings of perceived exertion (RPE). The research hypothesis was that the intentional reduction in the speed of movement with a given resistance will result in a reduced performance capability as measured by volume, force, power, and RPE.

METHODS

Experimental Approach to the Problem

In order to test the experimental hypotheses that the intentional reduction in the speed of movement with a given resistance will result in a reduced performance capability, 9 men were recruited to participate in the investigation. Subjects were asked to perform a squat and a shoulder press exercise at different percentages of their 1RM and at different speeds of movement. A Smith machine was used to provide for greater consistency and control over the movements performed. Over the course of the 4 protocol sessions, the subjects performed the 2 exercises at 60 and 80% of 1RM at a self-selected volitional (VOL) movement velocity and at a very slow (VS) movement velocity (consisting of 10-second concentric and 10-second eccentric repetition). The self-selected movement velocity was individually determined; subjects were asked to perform the lifts at the same speed they would utilize in training. The 10–10 VS movement velocity was chosen because it is the current recommendation in lay literature for slow lifting protocols. To examine the physiological and perceptual effects of the different treatments, blood pressure, RPE, force, power output, and volume were measured during each exercise testing session.

Subjects

Nine healthy men were recruited to participate in the study. Resistance trained subjects with at least 1 year of experience with both the shoulder press and squat exercises were recruited; each subject was familiar with both exercises. Prior training experience in these lifts was thought to be important to ensure that learning effects did not influence the results. Before participating, subjects were briefed on the potential risks and benefits of study participation, they signed a written informed consent, and they provided a medical health history in accordance with the policies and procedures of the University of Connecticut's Internal Review Board for Use of Human Subjects in Research. Individuals who smoked, had a history of endocrine disorders, or had any orthopedic injuries were excluded during the screening process. In addition, height, body mass, and body fat percentage (via Jackson-Pollock skinfold caliper measurement) were obtained during the familiarization session. Subjects were all recreationally trained men, mean age 23.9 ± 2.5 years, mean body mass 80.1 ± 4.1 kg, and mean height 174.4 ± 1.9 cm. Percent body fat as measured by skinfold calipers was 9.4 ± 1.5%. Mean squat 1RM was 133.1 ± 8.5 kg and mean shoulder press 1RM was 69.3 ± 3.5 kg.

Procedures

Subjects were asked to come to the laboratory for familiarization to remove learning effects, for a 1RM testing visit, and for individual experimental protocol visits. A matched and balanced randomization block was used to eliminate order effects in the study. During the familiarization visit, the participants were instructed on how to properly time the VS lift (10-second eccentric and 10-second concentric action) with the use of a metronome. Participants warmed up on both exercises using a self-selected velocity. Participants were then given the opportunity to practice the squat and shoulder press exercise at 60 and 80% of 1RM until they could smoothly perform the concentric and eccentric portions of both exercises at the prescribed movement speed. Exercise technique and form as normally defined for these 2 exercises were carefully monitored by the investigators.

Protocol

Protocol visits were randomized and a minimum of 72 hours separated each testing session. All sessions were standardized for time of day for each participant. Participants were instructed to consume the same diet before testing on each of the protocol days, and this was verified with dietary and activity logs. Blood pressure and RPE were measured while at rest, and before and after each protocol exercise set. In addition, power, work, and ground reaction force for the squat and shoulder press exercises were measured using the Kistler Quattro Jump (Model 9281b; Kistler Instrument Corp., Amherst, NY) interfaced with the Ballistic Measurement System (BMS; Fitness Technology, Adelaide, Australia).

Each protocol day consisted of performing a squat and a shoulder press exercise on the Smith machine for as many repetitions as possible at either 60 or 80% of 1RM at 1 of 2 movement velocities (VS or VOL). The squat exercise was performed to a parallel depth on each repetition with proper form (i.e., no rounding of the lower back). For the shoulder press, subjects were seated with no back support and their feet remained flat on the floor. The subjects began the exercise with arms fully extended overhead, lowered the bar to the upper chest, and then extended the arms overhead. Grip was standardized between testing protocols. For each exercise, the protocol was terminated when the subject could no longer perform any more repetitions, VS movement speed was compromised, or exercise technique was compromised by improper form (i.e., leaning back on the shoulder press or not going to the prescribed knee angle on the squat, with thigh parallel to the floor).

Experimental Protocol

On arrival to the laboratory, subjects were asked to sit quietly for 10 minutes, and then resting systolic and diastolic blood pressures were obtained, via blood pressure cuff and stethoscope. Subjects then pedaled on the cycle ergometer for 5 minutes at 50 watts (W) and performed a limited dynamic full-body stretching routine.

The warm-up protocol for both exercises consisted of 10 repetitions at 40% of 1RM, 5 repetitions at 50% of 1RM, and 1 repetition at 60% of 1RM, all at volitional speed. If the protocol for that day was 80% of 1RM, additional warm-up sets of 1 repetition at 70% and 1 repetition at 80% were performed. Warm-ups were designed in this manner because during pilot testing, participants reported that a single warm-up repetition at volitional speed with the protocol weight was helpful to mentally prepare for the VS movement at such a high intensity. In pilot testing, when the subjects did not perform a warm-up and went immediately into the protocol weight at a VS speed, they were unable to perform a repetition at 80% of their 1RM.

A metronome was used in the VS protocol to help maintain a proper pace. The BMS was used to collect vertical force data from the plate and linear displacement from a cable-extension transducer (Model PT5A; Celesco, Chatsworth, CA) while the subjects were lifting on the Smith machine, allowing the variables of work, power, and velocity to be measured. The BMS was used in all lifts to determine the speed of movement, and served as a post-protocol check to ensure subjects maintained a constant rate of movement during the VS lifts.

Systolic and diastolic blood pressures were taken via auscultation with a standard cuff and stethoscope. The same technician obtained all blood pressure measurements. RPE was measured via Borg's rating of perceived exertion scale at rest and before and after every protocol exercise was performed. Scores ranged from 6 (no exertion at all) to 20 (maximal exertion). The same instructions on using the scale were read to each subject at the start of the first testing session.

Statistical Analyses

The data from the investigation are presented as mean $\pm$ 1 *SD*. The statistical analyses were undertaken by using SPSS software for Windows (version 13.0; SPSS, Inc., Chicago, IL). Assumptions for linear statistics were tested prior to the use of analysis of variance (ANOVA), and if any underlying assumption was violated, were transformed to $\log_{10}$ data and reanalyzed to see if assumptions were met. All linear assumptions were met with this procedure for use of linear statistics. The statistical analyses of the data set were accomplished using two-way ANOVA with repeated measures. In the case of the ANOVA showing significant differences, pair-wise comparisons were evaluated with a Fisher's Least Significant Difference (LSD) post-hoc test. Intraclass correlation coefficients (ICC) for reliability of the dependent measures ranged from 0.88 to 0.95. Statistical power was calculated using nQuery Advisor software (Statistical Solutions, Saugus, MA). For the *n* size used, statistical power ranged for the variables examined in this investigation from 0.80 to 0.87. The criterion for significance was set at an alpha level $p \leq 0.05$ for this investigation.

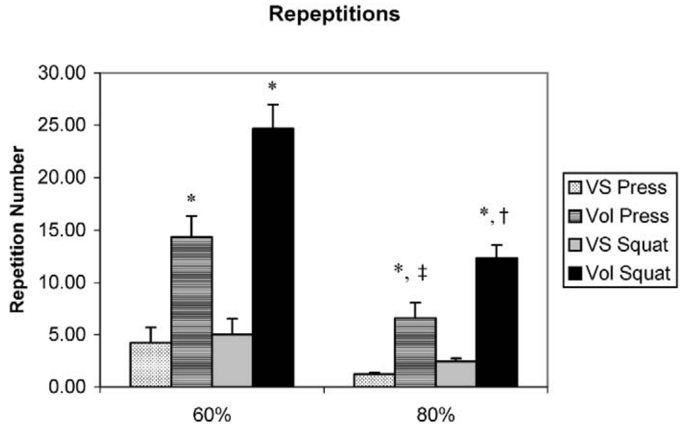

FIGURE 1. Responses (mean $\pm$ *SD*) of the number of repetitions to very slow (VS) and volitional (VOL) velocities in the shoulder press and squat exercises at different percentages of the 1 repetition maximum. * Significantly different ($p < 0.05$) from corresponding VS exercise and intensity. † Significantly different ($p < 0.05$) from 60% VOL squat exercises. ‡ Significantly different ($p < 0.05$) from 60% VOL shoulder press exercises.

RESULTS

In general, the primary findings of this investigation demonstrated that the VS exercise protocol performed at the same load relative to 1RM as the VOL exercise resulted in fewer repetitions, lower force and power outputs, less total volume of work performed, and higher rating of perceived exertion when expressed as a ratio to volume. These data indicate that there are dramatic differences in the biomechanical and physiological responses of these 2 protocols and that the use of these 2 methods in training would result in dramatically different training adaptations.

Significant differences were demonstrated in the number of repetitions performed between a 60% and an 80% VS shoulder press and a VOL shoulder press (Figure 1). Significant differences in the number of repetitions performed were also demonstrated between a VS and VOL squat at 60 and 80% of 1RM (Figure 1).

Interestingly, the total time for all of the VOL speed repetitions to be completed was less than that for the corresponding VS sets. However, only the total time between the VS and VOL speed shoulder press at 60% of 1RM was actually significant (55.56 $\pm$ 32.83 seconds vs. 33.92 $\pm$ 4.88 seconds).

Significant differences were seen in peak force between VS and VOL movement velocity exercises at both intensities for the squat exercise and shoulder press (Figure 2).

Significant differences were demonstrated in peak power between VS and VOL movement velocity repetitions for both intensities and exercises (Figure 3).

Significant differences were demonstrated in the volume of exercise (sets $\times$ repetitions $\times$ resistance) between the 2 repetition speeds (Figure 4).

No significant differences in RPE were demonstrated for either exercise, and no treatment effects were observed. At 60% postexercise RPE for the shoulder press was 15.8 $\pm$ 0.4 for VS and 16.2 $\pm$ 0.4 for VOL. At 80% postexercise RPE for the shoulder press was 15.0 $\pm$ 0.7 for VS and 15.4 $\pm$ 0.4 for VOL. At 60% postexercise RPE

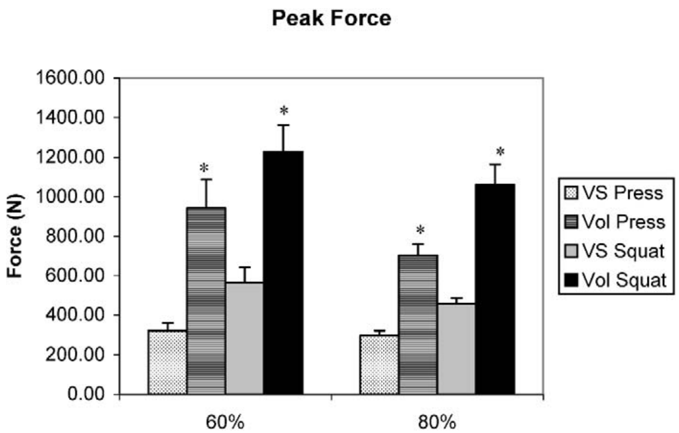

FIGURE 2. Responses (mean ± *SD*) for peak force in very slow (VS) and volitional (VOL) repetition velocities in the shoulder press and squat exercises at different percentages of the 1 repetition maximum. * Significantly different ($p < 0.05$) from corresponding VS exercise and intensity.

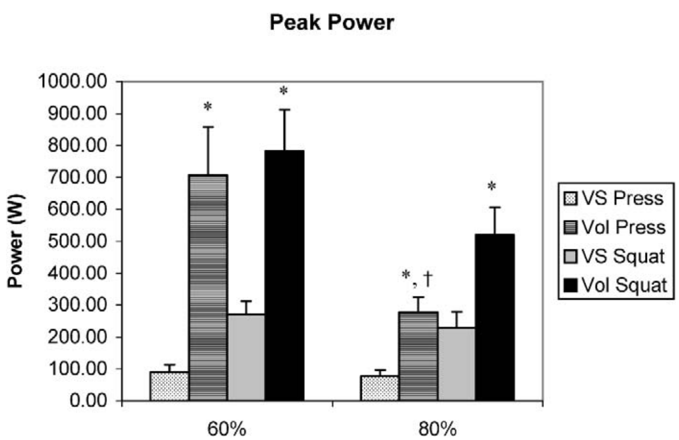

FIGURE 3. Responses (mean ± *SD*) for peak power in very slow (VS) and volitional (VOL) repetition velocities in the shoulder press and squat exercises at different percentages of the 1 repetition maximum. * Significantly different ($p < 0.05$) from corresponding VS exercise and intensity. † Significantly different ($p < 0.05$) from 60% VOL shoulder press exercices.

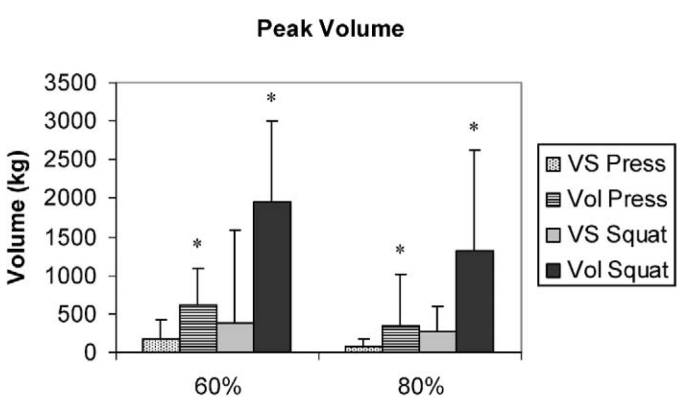

FIGURE 4. Responses (mean ± *SD*) for peak volume (kg) in very slow (VS) and volitional (VOL) repetition velocities in the shoulder press and squat exercises at different percentages of the 1 repetition maximum postexercise. * Significantly different ($p < 0.05$) from corresponding VS exercise and intensity.

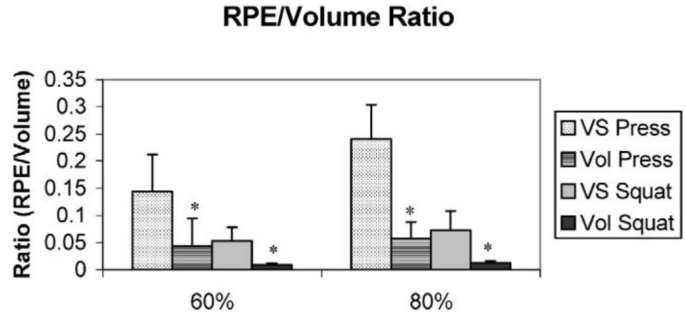

FIGURE 5. Responses (mean ± *SD*) of ratings of perceived exertion (RPE) to volume for very slow (VS) and volitional (VOL) velocities in the shoulder press and squat exercises at different percentages of the 1 repetition maximum postexercise. * Significantly different ($p < 0.05$) corresponding VS exercise and intensity.

for the squat was 15.4 ± 1.2 for VS and 16.6 ± 0.5 for VOL. At 80% postexercise RPE for the squat was 15.9 ± 0.5 for VS and 14.0 ± 1.8 for VOL.

However, when RPE is expressed as a ratio to volume, significant differences were observed between all VS and corresponding VOL movement velocity sets (Figure 5). The VS sets were perceived to be of significantly more effort.

Significant differences were observed in diastolic blood pressure from pre to postexercise for the 80% VS shoulder press. Significant differences were also demonstrated in postexercise systolic blood pressure between 60% VS and VOL movement velocity for the squat exercises with the VS velocity being higher (Table 1).

DISCUSSION

The primary findings of this study demonstrate that a set of volitional movement velocity shoulder press and squat exercises elicit more repetitions and higher peak power, force, and volume at 60 and 80% of 1RM than intentional VS velocity control during a set of repetitions. When viewed as a ratio to the volume of exercise, the VS repetition movement velocity had a significantly higher RPE per volume of work performed. This may indicate why the misperception of greater performance despite an actual reduction in physical performance indices exists.

Hunter et al. (15) had reported that subjects on average could only perform 8 repetitions at 25% of 1RM for various exercises following a self-selected (SS) protocol of a 10-second concentric and a 5-second eccentric repetition phase. In the current study, for both exercises combined, the average repetition range at 80% of 1RM with VS speed was below 2 compared with above 5 for both VOL movement velocity exercises. The resistance load and repetition number have both been shown to be of importance to maximal strength gains and has been the basis of the repetition continuum (30), and that intensity should be set close to 80% of the 1RM range (12, 30). When 4RM is compared with 10RM training in the bench press exercise, the 4RM training group trained at about 85% of their 1RM and the 10RM training group at about 70% of their 1RM (3), validating the repetition continuum theory that for a given load, an accepted number of repetitions should be returned. In the current study, it may be that the VS movement velocity led to low frequency fatigue and subsequent decreased rate of force development, resulting in

TABLE 1. Responses (mean ± *SE*) of blood pressure to very slow (VS) and self-selected volitional (VOL) speed exercise velocities in the shoulder press and the squat exercises pre to post-exercise ($n = 9$).

	Pre-exercise systolic BP	Postexercise systolic BP	Pre-exercise diastolic BP	Postexercise diastolic BP
60% VS press	114.44 ± 4.4	120.33 ± 4.81*	61.22 ± 5.93	62.89 ± 2.79
60% VOL press	112.67 ± 3.54	128.11 ± 5.83	68.67 ± 2.60	59.11 ± 4.16
80% VS press	112.22 ± 4.75	123.56 ± 6.11	71.67 ± 3.41	68.00 ± 4.78†
80% VOL press	119.11 ± 5.83	121.89 ± 5.44	72.56 ± 3.56	65.56 ± 4.80
60% VS squat	116.00 ± 3.37	117.56 ± 5.33	78.44 ± 2.18	58.89 ± 3.81
60% VOL squat	119.78 ± 4.86	137.33 ± 8.82‡	71.33 ± 8.06	55.56 ± 3.50
80% VS squat	120.67 ± 2.54	127.78 ± 4.73	77.11 ± 2.03	59.44 ± 3.43
80% VOL squat	120.44 ± 3.14	130.00 ± 5.19	77.44 ± 2.05	61.33 ± 3.49

* Significantly ($p < 0.05$) different from pre-exercise systolic blood pressure (BP) associated with 60% VS shoulder press.
† Significantly different from pre-exercise diastolic BP associated with 80% VS shoulder press.
‡ Significantly different from post-exercise systolic BP associated with 60% VS squat exercise.

a decreased return in repetition number compared with the volitional speed repetitions. Low frequency fatigue occurs during prolonged activities when force from low frequency stimulation decreases, affecting the rate of force development at lower 1RM percentages (4). Thus, it appears that a VS speed of movement will not allow one to train with an appropriate intensity and volume recommended for maximal strength gains.

It may be hypothesized that the decreased number of repetitions when using VS training would be minimized because of increased total time under tension. Time under tension refers to the total time a muscle is performing work, either in the eccentric or concentric portion of an exercise. All VS repetition movement velocity sets were longer in total duration than the volitional movement velocity sets, but only the 60% shoulder press sets had significant time differences. However, it should be noted that manipulation of this particular variable and its affects on strength and athletic performance are, as of yet, unknown.

The results of this study show that volume, as a function of load and repetition number, was significantly reduced in the VS movement velocity compared with the VOL movement velocity. Variation in volume is vital to periodized resistance models for increasing strength levels over time, even when volume is at least partially equated (2, 10, 24). In all VS repetition speed cases, either the load or repetition number must be reduced. Thus, the dramatic reductions in volume of total work that a VS repetition speed produces compared with a VOL repetition speed may not allow for these required variations on an immediate or long-term training basis unless the time factor plays a bigger role than previously demonstrated.

The amount of force produced in the current study was higher in the VOL repetition speed than in the VS repetition speed protocols. The force–velocity relationship dictates that as velocity decreases, force increases (17). However, it is also important to remember that acceleration is a component of force. Thus, it is not surprising that the extremely low measures of acceleration in the VS sets resulted in decreased peak force measurement. This would impact the physiological response on the amount of force per cross-sectional area of muscle, which is important to stimulate training adaptations (29). Force output is also related to the process of motor unit recruitment, motor unit firing frequency, improved synchronization, and required activation for the amount of cross-sectional area of the muscle, all of which are important for optimal changes in strength and hypertrophy with training (26, 27). Fast motor units, such as those necessary for high force production, are optimally trained at maximum or near-maximum forces (28) and with a faster training velocity (5). With such low forces produced, the recruitment of smaller motor units consisting of smaller cross-sectional areas or Type I fibers during the VS protocol may also have allowed asynchronous neural recruitment of motor units. This would prohibit the recruitment and subsequent training adaptations of Type II fibers. However, electromyography was not done in this study, so it is difficult to know the differences in activation levels of the agonists (and possible antagonists as well) between the present protocols and the loads.

Similar to force, power was also significantly higher with the VOL movement velocity for both exercises and intensities. This is explained by the higher movement speeds, which would contribute to the power output (force multiplied by velocity) during each repetition. Resistance training studies have shown that peak power improves significantly at higher velocities compared with slower velocities, even when only small differences in training velocity are examined (7, 21). For instance, Fielding et al. (9) showed that a self-selected fast movement velocity during the concentric portion of lower-body exercises with a 1-second hold (before performing the eccentric phase) and a 2-second eccentric phase elicited greater improvements in peak power compared with a 2–1–2 tempo (2-second concentric and eccentric and 1-second isometric phase between eccentric and concentric phases of a repetition) after 16 weeks of training the leg press and knee extension exercises. Thus, the reduced power output measured during the VS velocities may be so dramatic that any contribution to power improvement might be minimal. When combined with the lower force production during VS type training, the impact on muscle adaptations may be less than optimal.

Another aspect of a VS training protocol that has not had much attention is the lack of a significant stretch-shortening cycle (SSC) between the eccentric and concentric repetition phases due to the slow speed of the repetition. In acute bouts of exercise, power has been shown to be greater in exercises utilizing an SSC due to higher force at the start of the concentric phase, enhancement of potentiation factors, as well as the muscle–tendon interactions due to their elastic properties (1, 15, 16, 29). Furthermore, the SSC is enhanced with increases in force-producing capabilities (17) during the eccentric phase of the repetition movement, and such rapid and forceful lengthening is not a characteristic of a VS repetition (17). The ability to produce higher forces after a period of training utilizing faster velocity movements involves the greater use of the SSC, which plays a role in the increased power output in the volitional speed exercises (6, 7, 17, 22).

The reduced volume of the slower movement velocity becomes critically important when analyzing the RPE data. It had been hypothesized that there would be differences between exercise modalities with VS demonstrating higher RPEs even when intensities were equated. Interestingly, no differences were observed in the absolute ratings of perceived exertion between the 2 treatment conditions. This may well have been due to movement failure as the volitional end point of the set of repetitions during both VS and VOL protocols. However, when RPE was expressed as a ratio to volume of exercise, the VS exercises had significantly higher RPE/volume. Therefore, the perception of exertion during VS training might be postulated to be greater for the amount and quality of exercise accomplished. Also, RPE may have been based on different feedback mechanisms for the 2 movement velocities. For instance, the VS protocol fatigue endpoint may have been correlated to motor unit fatigue, while fatigue in the volitional speed exercises may have been more highly correlated to ATP/creatine phosphate depletion or lactate accumulation in the muscle. Until further investigations are made comparing VS to VOL movement velocity exercises, these suppositions remain speculative.

To date, there is no published literature concerning the effects of VS training on blood pressure response in any population. Blood pressure increases during a resistance training exercise have been demonstrated for both systolic and diastolic measures in healthy individuals (20). Systolic and diastolic responses are correlated with the length of time of a set, utilization of the Valsalva maneuver, and concentric action phases (8, 20, 23, 25). During exercise bouts, subjects in this study were instructed to breathe in a controlled manner, and every attempt was made to eliminate any Valsalva maneuver. Thus, the only significant difference seen in the blood pressure response was an increased systolic measurement in the 60% VS squat exercise compared with the VOL movement velocity. Again, this difference may have been due to the length of time the 60% VS squat protocol took as blood pressure typically increases in a staircase manner with continued time under tension as a set progresses toward volitional failure (11).

Significant differences in the 60% systolic measurement and 80% diastolic measurement were seen before and after the VS shoulder press exercise. However, it is also possible that the duration of the overhead exercise added to the stress of cardiovascular flow of blood against gravity.

In summary, the results of this investigation demonstrated that volitional speed repetitions in the shoulder press and squat exercises elicit a higher number of repetitions, a higher volume of exercise, and a higher peak power and peak force at 60 and 80% of 1RM compared with intentional VS velocity repetitions. Since manipulation of acute training variables is important to obtaining the highest possible peak power and force to optimize muscular performance and tissue adaptations (32), it appears that a VS protocol may not be an optimal form of training for such purposes.

PRACTICAL APPLICATIONS

Force, power, repetition number, movement speed, and volume measures are becoming increasingly important in the evaluation of physical fitness for various populations. However, the results of this investigation show that VS training may not be optimal due to the reduced volume (load $\times$ repetition) if the intensity is vital to the neurological recruitment process. Future training studies will need to build on these data to better frame the use of VS resistance exercise as a tool in the exercise prescription process. However, the decreased loading that would be needed with VS training to perform an acceptable repetition number, the hypothesized lower threshold motor unit recruitment pattern, and the limited response in measurable outcomes (i.e., force and power) may make muscular endurance a more viable and realistic goal for use of VS repetition protocols.

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