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EFFECT OF MOVEMENT VELOCITY ON THE RELATIONSHIP BETWEEN TRAINING LOAD AND THE NUMBER OF REPETITIONS OF BENCH PRESS

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ABSTRACT. Sakamoto, A., and P. J. Sinclair, Effect of movement velocity on the relationship between training load and the number of repetitions of bench press. *J. Strength Cond. Res. 20(3): 523–527. 2006.*—This study investigated the effect of movement velocity on the relationship between loading intensity and the number of repetitions of bench press. Thirteen healthy men (age = 21.7 ± 1.0 years; weight = 76.8 ± 2.5 kg; 1 repetition maximum [1RM] = 99.5 ± 6.0 kg), who were involved in regular weight training, voluntarily participated in the experiment. Subjects performed bench presses on a Smith machine at 5 different intensities (40–80% 1RM), repeated for 4 velocity conditions (slow: 0.15 ± 0.03 $m \cdot s^{-1}$; medium: 0.32 ± 0.07 $m \cdot s^{-1}$; fast: 0.52 ± 0.12 $m \cdot s^{-1}$; ballistic: maximum velocity), which were randomly assigned over 5 experimental sessions after a 1RM test. Velocity significantly changed the relationship between intensity (%1RM) and the number of reps performed ($p < 0.001$), with faster velocities producing a higher number of reps. A significant interaction between intensity and velocity meant that velocity had a much greater effect on repetitions at lower intensities. These results suggest that the benefits of using a stretch-shortening cycle during faster movements outweigh the associated disadvantages from the force–velocity relationship. The practical applications of this study are that, when trainees are assigned a resistance training with specific RM values, the lifted intensity (%1RM) or weights will not be consistent unless velocity is controlled during training.

KEY WORDS. 1 repetition maximum, strength training, force–velocity relationship, stretch-shortening cycle

INTRODUCTION

Weight training has been widely applied to many populations, with benefits including the improvement of strength, power, muscle size (hypertrophy), and muscle endurance (1, 2, 4). Training variables such as training load, the number of sets, resting period, and movement velocity vary depending on which specific goal the performers are aiming at (4). For example, it has been recommended that lifting velocity should be smooth and slow for conventional weight training designed to achieve strength gain or hypertrophy (6, 8). This is to assure a constant muscle activation through the full range of motion and also to maintain a correct lifting technique. On the other hand, for power development usually required by athletes, trainees are instructed to perform the movement with as fast a muscular contraction as possible to train under an event-specific movement velocity and to elicit maximal power output (5, 12, 14).

One repetition maximum (1RM) indicates the maximum weight that can be successfully lifted and is usually assessed to identify one's maximal strength for that exercise (9, 15, 20). Percentage of 1RM (%1RM) is a common way of expressing submaximal training intensity (1, 4, 8). Direct assessment of 1RM, however, may be associated with injury when performed incorrectly (9). Moreover, a 1RM test is time consuming and takes approximately 20 minutes to complete per individual (10). Therefore, if the test is to run through a whole sport team, there will be a significant time requirement. In a study by Chapman et al. (10), a 1RM bench press test for 98 subjects with 3 staff took 6 hours to complete using 5 bench press stations.

Repetitions maximum is an alternate method to identify training intensity or load and is defined as the maximal number of repetitions performed at a given weight (2, 4, 6). For example, 10RM refers to a weight that can be lifted for 10 times successfully through the full range of motion but no more. Several studies have been conducted to identify the relationship between %1RM and the number of repetitions performed using a given submaximal load (3, 9, 10, 12, 15). This relationship can allow an estimation of lifting intensity from the RM, eliminating the need for a direct 1RM test, as well as reducing the associated concerns above. The use of RM values may, therefore, be favored in some practical settings.

Research has shown that the relationship between %1RM and the number of repetitions can be affected by training conditions, sex, or interindividual differences (7, 12, 15). Movement velocity could be another factor that influences the relationship between %1RM and the number of repetitions. According to the force–velocity relationship, maximal force production decreases as the contraction velocity increases (17). Lifters performing a fast movement are therefore experiencing a higher percentage of their maximum force capacity to produce a given force. In addition, more force is required under faster conditions to accelerate the bar, and consequently, the effort will be greater than for slower conditions. It could therefore be predicted that training at a higher velocity may reduce the number of repetitions able to be performed with a given weight.

Alternatively, it is also possible that a faster velocity may increase the number of repetitions performed through use of the stretch-shortening cycle (18). The effect of movement velocity on the relationship between %1RM and the maximal number of repetitions has not, however, been studied to date. If the relationship was affected by movement velocities, changing the velocity of movement would alter the desired loading intensity during a training session. For example, a load of 80 kg may represent 4RM or 5RM, depending on the velocity at which the lift was performed.

TABLE 1. Summary table for subject information.*

	Height (cm)	Weight (kg)	Age (yr)	RT experience (yr)	No. of training (session/wk)	1RM (kg)
Mean	178.3	76.8	21.7	3.9	3.2	99.5
SD	7.1	9.0	3.7	3.0	0.6	21.5

* RT = resistance training; 1RM = 1 repetition maximum.

The purpose of this study was, therefore, to determine the effect of movement velocity on the relationship between intensity (%1RM) and the number of repetitions of bench press. Regression equations to determine relative intensities from the number of repetitions performed were established for each velocity condition. These velocity-specific relationships would allow the estimation of intensity from RMs with different training velocities.

METHODS

Experimental Approach to the Problem

This study used a repeated-measures design to investigate the combined effects of movement velocity and lifting intensity on the number of bench press repetitions able to be performed without cessation. After the determination of 1RM, subjects performed a series of trials using randomly presented combinations of 5 different loads and 4 movement velocities over 5 different testing days. The number of repetitions able to be lifted during each trial served as the dependent variable for this experiment, and the effects of velocity and intensity were analyzed using a two-way analysis of variance (ANOVA). Exponential equations were used to characterize the relationship between intensity and the number of repetitions performed for each velocity condition.

Subjects

Thirteen healthy men who were involved in regular weight training voluntarily participated in this study (Table 1). All participants underwent informed consent procedures according to the guidelines of the University of Sydney Human Ethics Committee.

Equipment

A Smith machine, KOLOSSAL Fitness System (KOLOSSAL, Sydney, Australia), was used in this study. This machine allows only vertical movements of the bar along 2 rails and secures the bar movement especially for the ballistic condition, during which a throwing press was performed with the bar released from the hands. The machine had a bar mass of approximately 13.0 kg, and lubricant spray was applied to the rails to reduce friction force against the bar movement. A string potentiometer (String Pot; SpaceAge Control Inc., Palmdale, CA) was vertically attached to the Smith machine bar to measure the bar displacement over time. Calibration of the potentiometer using 8 data points gave a linear response (r^2 = 1.0) and an absolute error always less than or equal to 1 mm. Displacement data were collected using customized Labview software (National Instruments Corp., Austin, TX), and the velocities of bar movement were calculated during the concentric portion of each lift.

Procedure

The experiment consisted of 6 experimental sessions, with subjects restrained from their own training or any fatiguing exercise for at least 48 hours before the experiment. Before starting each session, subjects were asked to warm up with their own routine for usual training. All lifts were performed with grip widths that were slightly wider than shoulder width. The bar was lowered until touching the chest slightly and then pushed all the way up to full extension of the elbows for every repetition. Unwanted body movement that could affect the performance outcome or be associated with injury (such as exaggerated rebounding of the bar off the chest, arching the lower back, or using an excessively wide or narrow grip) was corrected. During every trial, verbal encouragement was given to the subjects.

Testing Velocity

Four velocity conditions were used in this experiment (slow, medium, fast, and ballistic), with a metronome used to guide the subjects. After pilot testing, the metronome tempo was set to be 85 bpm for slow, 170 bpm for medium, and 250 bpm for fast. Each contraction phase (eccentric and concentric) consisted of 4 beats, thus 4 beats down and 4 beats up. These tempos were equivalent approximately to 2.8 seconds down and 2.8 seconds up (5.6-second lift) for slow, 1.4 seconds down and 1.4 seconds up (2.8-second lift) for medium, and 1.0 second down and 1.0 second up (1.9-second lift) for fast. There was no pause allowed at the transition of contraction phase (from eccentric to concentric or concentric to eccentric). To further assist timing, the researcher's hand was moved up and down alongside the bar at the given tempo so that the lifters could maintain bar velocity by following the hand movement.

For the ballistic condition, subjects were asked to perform the lift with as fast a muscular contraction as possible. The lowering of the bar was executed as fast as possible; however, the subjects were instructed not to voluntarily pull the bar toward themselves. They were also instructed not to "bounce" the bar on the chests excessively, but to maintain a slight touch. The concentric phase did not have a deceleration approaching full extension of the elbows. Rather, subjects were instructed to keep exerting force on the bar so that a throwing bench press was performed to simulate a power training condition. After release of the bar, subjects waited for the bar to land back in their grip with the elbows remaining extended. On landing, subjects recovered the same grip positions, immediately followed by a consequent eccentric phase.

Velocities were chosen so that the slow velocity resembled that recommended for strength or hypertrophy training, medium velocity corresponded to speeds with which lifters felt comfortable during pilot testing, and the fast velocity preserved a consistent difference between speeds. Pilot testing showed that the required velocity for the fast condition exceeded the maximum velocity achieved during the ballistic condition at 80% 1RM. Consequently, the 80% 1RM condition was eliminated for fast velocities.

1 Repetition Maximum Test

On the first day of the experiment, a 1RM test was conducted. For each subject, 1RM was identified within 5

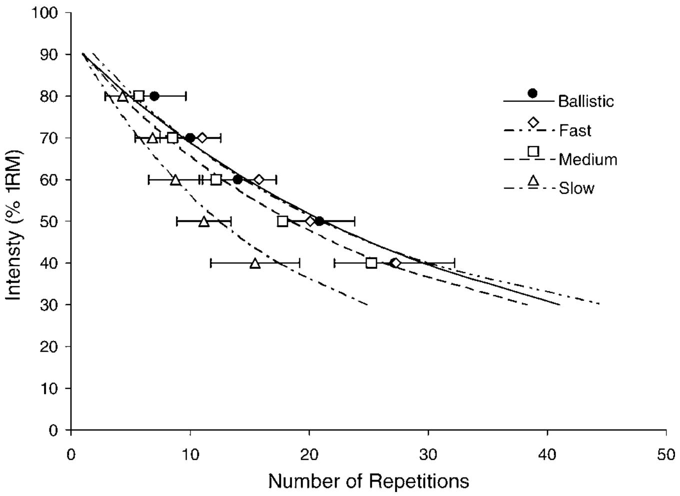

FIGURE 1. The relationship between intensity and the number of reps (mean ± *SD*). Trend lines are based on the regression equations from Table 3. For reasons of clarity, *SD*s for medium and fast conditions are not displayed.

TABLE 3. Regression equations to predict lifting intensity (percent of 1 repetition maximum [%1RM]) from the number of reps.*

Velocity condition	Regression equation	R^2
Ballistic	$y = 8.4204 + 84.2909e^{-0.0332x}$	0.8310
Fast	$y = 18.5896 + 77.1715e^{-0.0427x}$	0.7834
Medium	$y = 15.4593 + 77.8118e^{-0.0438x}$	0.8716
Slow	$y = 13.3629 + 81.4083e^{-0.0639x}$	0.7433

* x = number of repetitions; y = lifting intensity (%1RM); R^2 = correlation between %RM and x.

trials to minimize the fatigue effect. Sufficient rest, at least 5 minutes, was allowed between trials. The initial lifting weight was estimated from their usual training. The weight was increased or reduced by 2.5–5.0 kg after each trial until true 1RM was found with a full range of motion (a lowering of the bar until the bar touched the chest slightly, followed by a successful lift of the bar until full extension of the elbows). After the 1RM test, on the same day, subjects were familiarized with the movement and metronome timing for each velocity condition.

Submaximal Test

From the second day, submaximal tests were performed at 5 testing intensities (40, 50, 60, 70, and 80% 1RM) and at 4 velocities (slow, medium, fast, and ballistic) in a random order over 5 sessions. For each trial, subjects were instructed to continue lifting for as many repetitions as possible until true lifting failure (unsuccessful full extension of the elbows). As fatigue built up, subjects became unable to follow the given tempo successfully; however, the subjects were further encouraged to attempt to keep with the given tempo as much as they could until exhaustion. A rest period of approximately 5 to 10 minutes was given between trials.

Statistical Analyses

Repeated-measures ANOVA was used to identify the main effect of each independent variable and interaction. SPSS version 10.0 (SPSS, Inc., Chicago, IL) was used for all statistical comparisons, and the 0.05 level adopted for statistical significance. For those cases violating the assumption of equal variance between cells, significance was established using the Greenhouse-Geisser procedure (19). Only intensities of up to 70% 1RM were considered for the main effects and interaction because the fast condition did not include 80% 1RM.

Velocity failure was considered to have occurred when the velocity of 2 successive lifts fell more than 1 *SD* below the mean velocity for all lifts within a trial. Velocity failure repetitions were counted by summing the second and all subsequent lifts after velocity failure until true lifting failure. Under the ballistic condition, velocity failure repetitions were disregarded because the velocity was not controlled.

RESULTS

Figure 1 shows the relationship between intensity and the maximum number of reps at different velocity conditions. Two-way ANOVA revealed that the main effect of velocity was significant ($p < 0.001$), and the number of repetitions was higher with faster velocities at any given intensity. Pairwise comparisons, however, indicated that there was no significant difference between the ballistic and fast conditions. The main effect of intensity was significant ($p < 0.001$), with a higher number of repetitions being performed at lower intensities. There was a significant interaction between velocity and intensity ($p < 0.001$), with faster velocities producing more repetitions at lower intensities, whereas velocity had little effect at higher intensities (Figure 1). Table 2 shows mean ± *SD* bar velocities ($m \cdot s^{-1}$) from the concentric portion of the 4 velocity conditions. For all velocity-controlled trials, the velocity failure condition removed lifts after speed fell more than 1 *SD* below the mean for 2 successive lifts. The velocity failure criteria were not applied to the ballistic condition, resulting in a larger variance for these trials.

Table 3 lists exponential regression equations to predict lifting intensity (%1RM) from the number of reps lifted for each velocity condition. The actual number of reps and loading intensity (%1RM) calculated by these regression equations are summarized in Table 4.

Table 5 shows the mean numbers of velocity failure

TABLE 2. Mean ± *SD* of bar velocities ($m \cdot s^{-1}$) from the concentric phase of each velocity and intensity combination.*

Velocity condition	Intensity (%1RM)				
	40	50	60	70	80
Ballistic	0.68 (0.17)	0.59 (0.16)	0.49 (0.14)	0.41 (0.12)	0.32 (0.11)
Fast	0.57 (0.10)	0.55 (0.09)	0.52 (0.08)	0.41 (0.07)	NA
Medium	0.35 (0.07)	0.34 (0.06)	0.32 (0.06)	0.30 (0.05)	0.29 (0.05)
Slow	0.16 (0.03)	0.15 (0.03)	0.16 (0.03)	0.15 (0.03)	0.14 (0.02)

* NA = not applicable; %1RM = percentage of 1 repetition maximum.

TABLE 4. Summary table for percentage of 1 repetition maximum (%1RM) and the number of repetitions of this study.*

Repetitions	Slow	Medium	Fast	Ballistic
1	90†	90†	93†	90
2	85†	87†	89†	87
3	81†	84†	86†	85
4	76	81†	84†	82
5	73	78	81†	80
6	69	75	78†	77
7	65	73	76†	75
8	62	70	73†	73
9	59	68	71†	71
10	56	66	69	69
11	54	64	67	67
12	51	61	65	65
13	49	59	63	63
14	47	58	61	61
15	45	56	59	60
16	43	54	58	58
17	41	52	56	56
18		51	54	55
19		49	53	53
20		48	51	52
21		46	50	50
22		45	49	49
23		44	47	48
24		43	46	46
25		41	45	45
26		40	44	44
27			43	43
28			42	42
29			41	41
30			40	40

* The relationship is listed down to the minimum intensity of this study (40% 1 repetition maximum [1RM]).

† Assumes that the target velocity representing each velocity condition is maintained when the intensity exceeds the maximum testing intensity of this study (80% 1RM, and 70% 1RM for fast).

TABLE 5. Number of velocity to failure repetitions at the end of each trial (mean ± *SD*).*

	Intensity (%1RM)				
Velocity	40	50	60	70	80
Fast	0.9 (0.8)	0.8 (0.9)	1.9 (1.2)	2.2 (1.0)	—
Medium	0.2 (0.4)	0.6 (0.7)	0.7 (0.5)	0.9 (0.9)	1.2 (0.9)
Slow	0.0 (0.0)	0.3 (0.6)	0.5 (0.9)	0.2 (0.4)	0.0 (0.0)

* %1RM = percentage of 1 repetition maximum.

repetitions for each condition, with faster and heavier intensity conditions producing a significantly greater number of velocity failure repetitions ($p < 0.001$). To test their effect on the relationship between velocity and lifting ability, statistical methods were repeated with the velocity failure repetitions subtracted from the number of lifts counted under each condition. Removing the velocity failure repetitions did not change the overall effect of velocity and intensity on the number of reps performed. The main effects of velocity and intensity, and the interaction between the two, remained significant ($p < 0.001$), with overall trends remaining similar to those shown by Figure 1.

DISCUSSION

This study clearly showed that the relationship between intensity and the number of repetitions was affected by movement velocity and that a faster velocity resulted in more repetitions being performed. The associated disadvantages with faster velocity (i.e., the requirement of a higher force output to achieve a greater acceleration of the bar despite lowered maximal force output capacity according to the force–velocity relationship) did not reduce the number of repetitions. Faster velocities resulted in a greater number of velocity failure repetitions, indicating that the above disadvantages made it difficult for the subject to maintain a high velocity. Reanalyzing the data after excluding the velocity failure repetitions did not, however, change the finding that repetitions were reduced at lower velocities.

The benefit with faster velocity in terms of the number of repetitions may be attributed to the use of a stretch-shortening cycle (11, 18). An alternate explanation may come from previous studies reporting that, during high-velocity lifts, especially with relatively light loads, large accelerations are achieved at the beginning of the concentric phase (11, 13, 16). On the other hand, relatively large percentages of time are spent in deceleration over the final stage of the contraction accompanied by a reduction of agonist electromyographic activity. Consequently, high forces are generated only through a very small range of movement. This smaller requirement of muscle activity at the end of concentric phase, and perhaps at the beginning of the eccentric phase (encouraged muscle pump), could also have attributed to the higher number of repetitions at faster velocity in this study.

The ballistic condition did not show a further increase in the number of repetitions beyond that of the fast condition. Throwing bench presses have previously been associated with greater force and power output than nonthrow lifts, together with a smaller reduction in force output at the end of the concentric phase (11, 16). This would be expected to increase the rate of fatigue during ballistic conditions. Faster contractions, however, would be expected to enhance the benefits of stretch-shortening cycle. Furthermore, the release of the bar may have allowed the muscles to be free from tension, thus increasing duration of the relaxation phase. It seems likely that the associated advantages and disadvantages from ballistic movement have balanced out in this study, leaving no further benefit in the number of repetitions above the fast condition.

The results of this study are delimited to a fixed bar path (on a Smith machine), with no pause allowed at the transition between the concentric and eccentric phases. These experimental constraints may have affected the repetition values compared with free weight conditions. Furthermore, these regression equations must also be delimited to the present sex, level of resistance training experience, and type of exercise, because these factors have previously been found to affect the relationship between loading intensity and the number of repetitions (7, 12, 15). The main finding, however, that the number of repetitions are increased when using a higher lifting velocity, should be expected to hold for different exercise types, even if the magnitude of the relationship varies. This study has sufficient statistical power to show with a high degree of confidence ($p < 0.001$) that the number of repetitions was affected by velocity and intensity. Further experimentation with larger subject numbers is required, however, to confirm the reliability of these regression equations.

We observed a slight fatigue effect as each subject performed 4 sets of exercise until lifting failure during each submaximal session. Although a substantial rest was given between sets, some subjects produced a fewer number of reps under a light load than that under heavier when this trial was executed at the end of the session. The order effect was minimized by randomizing the trials, and consequently, we do not believe that this affected our conclusions.

PRACTICAL APPLICATIONS

Trainees should be aware that the maximum repetitions can vary with different movement velocities, with a higher number produced under faster conditions, and that this effect becomes greater with lower intensities. When their training intensity or load is estimated from RM values, they may not actually be training under the intended load. For example, if the desired training intensity is approximately 70% 1RM, one needs to produce 9RM or 10RM under the fast condition according to Table 4. 10RM, however, is equivalent to only 56% 1RM when performed at the slow speed. It can therefore be suggested that the estimation of training intensity from RM values should be carried out using a relationship that has been established under a similar velocity condition. This effect should also be considered in experimental settings where the subjects are assigned to different training load groups. A 6RM group and 10RM group, for example, may be experiencing similar training loads if the former is moving more slowly and the latter is moving fast. Movement velocities should, therefore, be controlled within the same loading group to create better group management.

During dynamic power training, the quality of technique and movement velocity would decrease as fatigue builds up, and this may reduce the effectiveness of power development (4). To combat this effect, the target repetitions could be set fewer than the associated maximum reps (4). The current ballistic condition (until lifting failure) may, therefore, not be a practical situation. If the trainees were, however, aiming at muscular endurance or lactic tolerance as well as power improvement, they could continue the lifting to exhaustion. The relationship between intensity and the number of repetitions under the ballistic condition of this study may be referred to in such a case.

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