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Factors Related to Average Concentric Velocity of Four Barbell Exercises at Various Loads

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Abstract

Fahs, CA, Blumkaitis, JC, and Rossow, LM. Factors related to average concentric velocity of four barbell exercises at various loads. *J Strength Cond Res* 33(3): 597–605, 2019—The resistance exercise load is the primarily determinant of the average concentric velocity (ACV) during a repetition. It is unknown whether individual factors such as training experience or anthropometrics also influence the ACV. Previous research has shown the ACV during the 1 repetition maximum (1RM) varies between exercises, but it is not clear whether ACV is different between exercises at various percentages of the 1RM. This information could provide practical guidelines for trainees using ACV to select training loads. Therefore, the purpose of this study was to determine whether training age, current training frequency, limb length, height, and relative strength are related to ACV at loads between 35 and 100% of the 1RM for the squat, bench press, deadlift, and overhead press. A secondary purpose was to compare the ACV values between the 4 lifts at each relative load. Fifty-one (18 women and 33 men) completed 2 testing sessions in which the squat, bench press, deadlift, and overhead press ACV were measured during a modified 1RM protocol. Average concentric velocity values were significantly different among the 4 lifts ($p < 0.05$) at all relative loads between 35 and 100% 1RM except for 55% 1RM ($p = 0.112$). Generally, compared at the same relative loads, the overhead press exhibited the greatest ACV followed by the squat, bench press, and deadlift (in order). In addition, relative strength level was inversely related to ACV at maximal loads (≥95% 1RM) for the squat, bench press, and deadlift while height was positively related to ACV at moderate loads (55% 1RM) for all lifts ($p < 0.05$). These results suggest that the load-velocity profile is unique for each of these exercises, and that velocity ranges used for exercise prescription should be specific to the exercise. A trainee's relative strength and height may be a primary influence on the ACV.

Key Words squat, bench press, deadlift, velocity-based training, resistance training

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33(3)/597–605

Journal of Strength and Conditioning Research

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Introduction

It is well established that the force a muscle is able to produce is inversely related to the speed of contraction (3). This inverse relationship is also apparent between the magnitude of a load lifted and the average concentric velocity (ACV) of a resistance exercise repetition (14). Because the relationship between load and ACV is strong and linear (8), ACV has been used for prediction of the 1 repetition maximum (1RM) for a variety of resistance training exercises (6,10,15,19,21,22). In addition, the use of the ACV for resistance training prescription, known as velocity-based training (VBT), has been recommended (18).

With the potential of using velocity as a metric to determine training loads for specific adaptations, velocity zones corresponding to different training outcomes have been proposed (16). For example, if training for absolute strength, it is recommended to train with loads that allow for completion of all repetitions in a set to have an ACV of 0.15–0.35 $m \cdot s^{-1}$, whereas if training for accelerative strength, it is recommended to train with loads corresponding to an ACV of 0.45–0.75 $m \cdot s^{-1}$ (16). These velocity zones are not exercise-specific, however, and do not account for individual factors that may also affect the ACV. There is a need for more research to provide recommendations that are both exercise-specific and individualized. Most of the data on the ACV are reported from the 1RM in which the ACV varies considerably between exercises. For example, the ACV reported during a 1RM is 0.16 ± 0.04 $m \cdot s^{-1}$ for the bench press (10), 0.30 ± 0.04 $m \cdot s^{-1}$ for the squat (6), and 0.14 ± 0.05 $m \cdot s^{-1}$ for the deadlift (12). However, only one study has directly compared ACV values between different exercises within the same sample of subjects. Helms et al. found that 1RM-squat ACV (0.23 ± 0.05 $m \cdot s^{-1}$) was greater compared with the deadlift 1RM ACV (0.14 ± 0.05 $m \cdot s^{-1}$), which was greater than bench press 1RM ACV (0.10 ± 0.04 $m \cdot s^{-1}$)

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Warm Up Set	% Estimated 1RM	Reps
1	30-40%	2-3
2	40-50%	2
3	60-70%	1-2
4	70-80%	1
5	80-85%	1

Figure 1. Warm-up sets.

Actual %1RM	ACV Designation
90-99%	95%ACV
80-89%	85%ACV
70-79%	75%ACV
60-69%	65%ACV
50-59%	55%ACV
40-49%	45%ACV
30-39%	35%ACV

Figure 2. ACV values. ACV = average concentric velocity.

in a group of powerlifters (12). In addition, many of the studies that include ACV as a primary outcome have had subjects perform the resistance exercise using a Smith machine (6,8,10,13,14,17,21,22). Although using the Smith machine may reduce movement variability and produce a stronger load-velocity relationship compared with free-weight exercises, it may be less applicable to trainees using ACV as a means to determine loads for free-weight movements. There is a need for more research on the load-velocity profile for free-weight barbell exercise.

Velocity ranges for VBT may also need to be individualized based on an individual's training experience or anthropometrics. It is possible that velocity ranges should be lowered for more experienced trainees because the ACV during a 1RM squat is lower for experienced compared with novice squatters (24). However, this is only based on the ACV at the 1RM; this may not accurately reflect the difference in the ACV between experienced and novice lifters using lower loads during training. Zourdos et al. (24) suggested that a subject's height may influence the ACV, but no such relationship was found between height and 1RM ACV in a group of experienced powerlifters. Another study examined the relationship between femur length and squat 1RM ACV and also found no relationship (7). However, both of these studies used a relatively homogenous sample and only related the 1RM ACV

Table 1. Descriptive characteristics.*

	Squat	Bench press	Deadlift	Overhead press	N	ANOVA *p*
Training age (y)	6.7 ± 3.4†‡	6.8 ± 3.7‡	5.5 ± 3.1§‖	5.4 ± 3.9§‖	52	<0.001
Frequency (d·wk^{-1})	1.5 ± 1.0†‡	1.4 ± 0.9‡	1.1 ± 0.8§	1.1 ± 0.9§‖	52	0.003
1RM (kg)	126.0 ± 48.8†‡‖	92.4 ± 42.3†‡§	157.5 ± 52.3‡§‖	62.7 ± 24.8†§‖	51	<0.001
REL 1RM	1.48 ± 0.39†‡‖	1.07 ± 0.36†‡§	1.87 ± 0.47‡§‖	0.73 ± 0.20†§‖	51	<0.001
1RM ACV (m·s^{-1})	0.26 ± 0.08†‖	0.18 ± 0.07†‡§	0.22 ± 0.10§‖	0.24 ± 0.09‖	51	<0.001
95% ACV (m·s^{-1})	0.35 ± 0.09‖†	0.25 ± 0.07‡§	0.27 ± 0.08†§	0.36 ± 0.11†‖	32	<0.001
85% ACV (m·s^{-1})	0.47 ± 0.10†‖	0.42 ± 0.09‡§	0.38 ± 0.09‡§	0.50 ± 0.12†‖	34	<0.001
75% ACV (m·s^{-1})	0.60 ± 0.11†‡	0.56 ± 0.11†‡	0.47 ± 0.08‡§‖	0.65 ± 0.16†§‖	19	<0.001
65% ACV (m·s^{-1})	0.66 ± 0.15†	0.62 ± 0.11	0.57 ± 0.12‡§	0.77 ± 0.15†	9	0.008
55% ACV (m·s^{-1})	0.77 ± 0.13	0.74 ± 0.14	0.67 ± 0.08	0.88 ± 0.22	6	0.112
45% ACV (m·s^{-1})	0.84 ± 0.15†‡	0.89 ± 0.14‡	0.78 ± 0.09§‡	1.11 ± 0.20‡§‖	12	<0.001
35% ACV (m·s^{-1})	0.88 ± 0.19‡	1.02 ± 0.17†	0.84 ± 0.14‡‖	1.19 ± 0.28†§	10	<0.001

*ANOVA = analysis of variance; 1RM = 1 repetition maximum; REL 1RM = relative 1 repetition maximum; ACV = average concentric velocity.
†$p < 0.05$ from deadlift.
‡$p < 0.05$ from overhead press.
§$p < 0.05$ from squat.
‖$p < 0.05$ from bench press.

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Table 2. Correlations for the squat.*

	Femur length	Training age	Frequency	REL 1RM	1RM ACV	95% ACV	85% ACV	75% ACV	65% ACV	55% ACV	45% ACV	35% ACV
Height												
r	0.507	0.147	0.190	0.368	−0.116	0.075	0.181	0.429	0.188	0.668	0.186	0.324
p	<**0.001**	0.299	0.178	**0.007**	0.415	0.622	0.207	**0.006**	0.28	<**0.001**	0.301	**0.047**
N	52	52	52	52	52	46	50	40	35	30	33	38
Femur length												
r	1	**0.289**	0.15	0.129	−0.176	0.093	0.028	0.242	0.155	0.340	−0.059	0.018
p		**0.038**	0.29	0.363	0.211	0.539	0.847	0.133	0.375	0.066	0.745	0.915
N		52	52	52	52	46	50	40	35	30	33	38
Training age												
r		1	0.044	0.160	−0.095	0.253	0.080	0.297	0.192	0.271	−0.151	0.159
p			0.756	0.257	0.501	0.089	0.579	0.062	0.268	0.147	0.403	0.342
N			52	52	52	46	50	40	35	30	33	38
Frequency												
r			1	0.194	−0.220	0.051	0.036	0.121	0.111	0.18	0.075	0.045
p				0.168	0.118	0.734	0.807	0.458	0.524	0.342	0.678	0.787
N				52	52	46	50	40	35	30	33	38
REL 1RM												
r				1	−**0.297**	0.028	0.220	**0.334**	**0.474**	**0.474**	**0.397**	**0.495**
p					**0.033**	0.851	0.125	**0.035**	**0.004**	**0.008**	**0.022**	**0.002**
N					52	46	50	40	35	30	33	38
1RM ACV												
r					1	**0.534**	**0.321**	**0.387**	−0.013	−0.317	0.222	0.155
p						<**0.001**	**0.023**	**0.014**	0.943	0.088	0.214	0.352
N						46	50	40	35	30	33	38

*REL 1RM = relative 1 repetition maximum; 1RM = 1 repetition maximum; ACV = average concentric velocity.

to anthropometrics. It is unclear whether the ACV at submaximal loads is related to an individual's height or limb length. Investigating the relationships between ACV at submaximal loads and participant's anthropometrics will help clarify the influence of limb length on ACV values and help trainees or coaches understand if ACV values need to be adjusted to account for limb length differences.

The purpose of this study was to determine whether training age, current training frequency, limb length, height, and relative strength are related to the ACV at loads between 35 and 100% 1RM for the squat, bench press, deadlift, and overhead press. A secondary purpose was to compare the ACV values at each relative load between the 4 lifts. We hypothesized that limb length and height would be positively related to the ACV for each lift, whereas relative strength, training age, and current training frequency would be negatively related to the ACV for each lift. We also hypothesized that the ACV values would differ between the lifts across all loads; specifically, ACV values would be greatest for the overhead press followed by the squat, bench press, and deadlift (in order) at each relative load. We chose to use 4 common free-weight barbell exercises to make the results applicable to trainees using the ACV during free-weight exercises.

Methods

Experimental Approach to the Problem

This investigation used a cross-sectional study design. We asked each subject to complete 2 testing sessions. During the first testing session, we measured height, body mass, femur length, and humerus length. We then asked subjects for their training age (years of experience), current (within the last month) training frequency (number of sessions with each lift per week), and estimated 1RM for each lift. After this, the subjects completed the 1RM protocol for either (a) the squat followed by the bench press or (b) the deadlift followed by overhead press. During the second testing session, the subject completed the 1RM protocol each for the remaining 2 lifts. The order of the 2 testing sessions (a and b) was randomized.

Subjects

Fifty-two subjects ($N = 52$; 19 women, 33 men) gave their written informed consent to participate in this study. Age range was 18–33 years. One subject dropped out after the first testing session (circumstances unrelated to the study) completing the squat and bench press testing but not the

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TABLE 3. Correlations for the bench press.*

	Humerus length	Training age	Frequency	REL 1RM	1RM ACV	95% ACV	85% ACV	75% ACV	65% ACV	55% ACV	45% ACV	35% ACV
Height												
r	**0.574**	0.219	**0.399**	**0.565**	−0.151	0.209	0.010	**0.416**	**0.392**	**0.352**	0.318	0.048
p	**<0.001**	0.119	**0.003**	**<0.001**	0.284	0.189	0.949	**0.014**	**0.022**	**0.041**	0.071	0.821
N	52	52	52	52	52	41	48	34	34	34	33	25
Humerus length												
r	1	−0.148	0.083	0.180	−0.056	0.189	0.118	**0.388**	0.2	0.189	0.329	−0.253
p		0.295	0.558	0.203	0.692	0.237	0.425	**0.023**	0.258	0.285	0.062	0.222
N		52	52	52	52	41	48	34	34	34	33	25
Training age												
r		1	**0.382**	**0.327**	−0.198	−0.028	−0.053	0.052	0.208	0.117	0.067	0.269
p			**0.005**	**0.018**	0.160	0.860	0.719	0.770	0.237	0.511	0.713	0.193
N			52	52	52	41	48	34	34	34	33	25
Frequency												
r			1	**0.335**	−0.028	0.036	−0.186	0.185	0.128	0.056	0.215	0.263
p				**0.015**	0.841	0.823	0.206	0.296	0.470	0.755	0.230	0.204
N				52	52	41	48	34	34	34	33	25
REL 1RM												
r				1	−**0.399**	−0.034	−**0.344**	0.137	0.255	0.311	**0.512**	**0.473**
p					**0.003**	0.833	**0.017**	0.441	0.146	0.073	**0.002**	**0.017**
N					52	41	48	34	34	34	33	25
1RM ACV												
r					1	**0.595**	**0.530**	**0.381**	0.159	**0.393**	0.203	**0.468**
p						**<0.001**	**<0.001**	**0.026**	0.37	**0.021**	0.257	**0.018**
N						41	48	34	34	34	33	25

*REL 1RM = relative 1 repetition maximum; 1RM = 1 repetition maximum; ACV = average concentric velocity. Bolded *p*-values signify statistically significant ($p < 0.05$) correlations.

deadlift and overhead press leaving a sample of 51 (18 women and 33 men) for the latter 2 lifts. Subjects ($N = 52$) were 22.5 ± 3.2 years old with an average height of 1.72 ± 0.09 m, body mass of 84.1 ± 22.9 kg, humerus length of 0.345 ± 0.046 m, and femur length of 0.440 ± 0.041 m. Subject characteristics were measured standard deviation. Lindenwood University–Belleville's Institutional Review Board approved this study (approval #00021), and we informed all subjects informed of the benefits and risks of the study before the subjects providing written consent to participate.

Procedures

Anthropometrics. We measured subjects' standing height with a stadiometer (Tanita HR-200; Tanita Corporation, Arlington Heights, IL, USA) and recorded values to the nearest 0.01 m. We measured subjects' body mass with an electronic scale (Tanita BWB-800S Doctors Scale; Tanita Corporation) and recorded values to the nearest 0.1 kg. We measured femur length with the subject in a seated position, and the knee and hip joints flexed at 90°. The length of each femur was measured with a tape measure as the distance from the greater trochanter to the lateral condyle of the femur and recorded to the nearest 0.001 m. Humerus length was measured as the distance between the acromion process and the olecranon process along the posterior aspect of the right arm and recorded to the nearest 0.001 m. A single measurement was taken as a representative value for each measurement similar to previous investigations (7,11). The limb length measurements were taken by more than one investigator throughout the course of this study. The interinvestigator technical error of the measurement (TEM) for femur length was 0.016 m (3.61%), and for humerus length, the TEM was 0.008 m (1.98%).

Training History. Subjects were asked to verbally indicate how many years of experience they have with each of the four lifts to the nearest 0.5 years (training age) and how frequently they currently (i.e., in the last month) performed the each lift to the nearest 0.5 days per week (frequency).

One Repetition Maximum Protocol. For each lift, we used the protocol recommend by Jovanovic and Flanagan (15) to establish the load-velocity profile while completing a 1RM

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Table 4. Correlations for the deadlift.*

	Femur length	Training age	Frequency	REL 1RM	1RM ACV	95% ACV	85% ACV	75% ACV	65% ACV	55% ACV	45% ACV	35% ACV
Height												
r	0.507	**0.286**	−0.069	**0.298**	**−0.33**	−0.136	−0.007	0.11	0.119	**0.460**	0.139	**0.517**
p	**<0.001**	**0.040**	0.625	**0.033**	**0.018**	0.373	0.966	0.461	0.446	**0.005**	0.413	**0.001**
N	52	52	52	51	51	45	46	47	43	36	37	41
Femur length												
r	1	0.240	0.052	0.043	−0.199	−0.054	0.233	−0.062	−0.115	0.223	−0.113	0.030
p		0.087	0.713	0.767	0.162	0.724	0.118	0.679	0.462	0.19	0.504	0.85
N		52	52	51	51	45	46	47	43	36	37	41
Training age												
r		1	**0.282**	0.225	−0.117	0.136	0.138	−0.050	0.216	0.272	−0.043	**0.311**
p			**0.043**	0.112	0.412	0.375	0.36	0.741	0.165	0.108	0.798	**0.048**
N			52	51	51	45	46	47	43	36	37	41
Frequency												
r			1	**0.33**	−0.231	0.036	−0.228	−0.139	−0.095	−0.034	−0.060	−0.113
p				**0.018**	0.103	0.814	0.128	0.352	0.544	0.843	0.722	0.482
N				51	51	45	46	47	43	36	37	41
REL 1RM												
r				1	**−0.489**	**−0.314**	**−0.473**	**−0.290**	−0.209	0.190	0.025	0.212
p					**<0.001**	**0.036**	**0.001**	**0.048**	0.178	0.266	0.883	0.184
N					51	45	46	47	43	36	37	41
1RM ACV												
r					1	**0.799**	**0.608**	**0.381**	**0.48**	0.195	0.154	0.221
p						**<0.001**	**<0.001**	**0.008**	**0.001**	0.254	0.363	0.166
N						45	46	47	43	36	37	41

*REL 1RM = relative 1 repetition maximum; 1RM = 1 repetition maximum; ACV = average concentric velocity.
Bolded *p*-values signify statistically significant ($p < 0.05$) correlations.

testing protocol. We asked subjects to perform all repetitions with maximum velocity during the concentric portion of the lift. We based the loads for each warm-up set on the subjects' estimated 1RM. The warm-up sets were as follows (Figure 1):

We allotted a minimum of 2 minutes of rest between each warm-up set. After the warm-up sets, the subject's actual 1 repetition maximum was determined within 5 attempts. We allotted a minimum of 3-minute rest between each 1RM attempt. We recorded the 1RM as the heaviest load successfully lifted through a full range of motion. We calculated relative 1 repetition maximum (REL 1RM) as by the 1RM divided by body mass. After the first exercise, 3–5 minutes was allotted before warm-ups for the second exercise began.

Load-Velocity Profile. Based on the 1RM testing protocol used, we obtained the 1RM ACV for each subject for each lift ($N = 52$ for the squat and bench press, $N = 51$ for the deadlift and overhead press). However, because the warm-up sets were based on the subject's estimated 1RM, the actual %1RM used during the warm-up sets for each subject varied slightly. We calculated the actual %1RM of each warm-up set and submaximal 1RM attempt and categorized the ACV values as follows (Figure 2):

Because all subjects performed 5 warm-ups sets and between one and five 1RM attempts, this led to a slightly different sample size for each ACV designation for each lift.

Barbell Lifts. A Certified Strength and Conditioning Specialist supervised all lifts to ensure proper form. For the squat, subjects began with the knee and hips in full extension at which point the subject descended with the barbell to proper depth and then returned to the starting position. Proper squat depth for the purposes of this study was a depth at which the crease of the hip was at or below the level of the top of the patella when viewed from the lateral aspect. Taking a step with the bar during the ascent of descent of the squat resulted in a failed attempt, although we allowed elevation of the heel (without moving the entire foot). For the bench press, subjects began in the supine position with the barbell held at arm's length over the chest with the elbows fully extended. The subject lowered the bar to the chest under control at which point they touched their chest

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Table 5. Correlations for the overhead press.*

	Humerus length	Training age	Frequency	REL 1RM	1RM ACV	95% ACV	85% ACV	75% ACV	65% ACV	55% ACV	45% ACV	35% ACV
Height												
r	**0.574**	0.008	0.054	**0.478**	0.093	**0.422**	0.156	**0.36**	**0.48**	**0.477**	0.243	0.112
p	<**0.001**	0.954	0.705	<**0.001**	0.515	**0.003**	0.336	**0.026**	**0.008**	**0.014**	0.204	0.619
N	52	52	52	51	51	47	40	38	29	26	29	22
Humerus length												
r	1	**−0.248**	−0.070	0.012	0.027	0.028	0.169	**0.320**	0.334	**0.391**	0.250	0.018
p		**0.076**	0.623	0.934	0.848	0.850	0.296	**0.050**	0.076	**0.048**	0.190	0.936
N		52	52	51	51	47	40	38	29	26	29	22
Training age												
r		1	**0.279**	0.233	0.122	0.240	0.273	0.009	0.296	−0.040	−0.156	−0.173
p			**0.045**	0.100	0.393	0.104	0.089	0.958	0.119	0.847	0.418	0.441
N			52	51	51	47	40	38	29	26	29	22
Frequency												
r			1	−0.045	−0.027	0.096	0.167	0.037	0.293	−0.239	−0.319	−0.122
p				0.754	0.852	0.519	0.304	0.827	0.123	0.240	0.092	0.589
N				51	51	47	40	38	29	26	29	22
REL 1RM												
r				1	−0.117	0.149	−0.029	**0.322**	**0.526**	0.283	**0.392**	**0.467**
p					0.414	0.317	0.861	**0.049**	**0.003**	0.161	**0.036**	**0.028**
N					51	47	40	38	29	26	29	22
1RM ACV												
r					1	**0.384**	**0.364**	0.296	0.365	0.072	0.063	0.420
p						**0.008**	**0.021**	0.071	0.052	0.726	0.744	0.052
N						47	40	38	29	26	29	22

*REL 1RM = relative 1 repetition maximum; 1RM = 1 repetition maximum; ACV = average concentric velocity. Bolded *p*-values signify statistically significant ($p < 0.05$) correlations.

with the bar and then executed the press until they fully extended their elbows. Any downward movement of the bar during the concentric portion of the bench press resulted in a failed attempt. For the deadlift, the subjects chose their preferred deadlift stance (sumo or conventional stance). With the barbell on the floor, the subject grasped the bar with their hips and knees flexed and executed the lift by extending their knees and hips. We did not permit hitching or supporting the barbell with the thighs during the execution of the deadlift. We considered the deadlift complete when the subject reached full extension with the hips and knees while holding the barbell motionless. The overhead press began with the barbell held at shoulder height, elbows fully flexed, with the subject in the standing position. A strict press was performed with no knee or hip flexion/extension permitted to assist during the execution of the overhead press. We considered the overhead press complete when the subject held the barbell motionless overhead with the elbow fully extended. Similar to the squat, taking a step during the overhead press resulted in a failed attempt. We allowed subjects to use a lifting belt and chalk if they preferred; we did not permit subjects to use elastic wraps of any kind, which may influence the ACV.

Average Concentric Velocity. We placed a Tendo Power and Speed Analyzer–PS 310 Unit (TENDO FitroDyne; Tendo Sports Machines, London, UK), so that the cable was vertical in both the sagittal and frontal planes when the lifter was in the starting position for each lift. For the squat, bench press, and overhead press, we placed the unit next to the rack with the Velcro strap affixed to the bar touching the inside of the bar sleeve. For the deadlift, we placed the unit in the center of the bar between the subject's feet. We recorded the ACV values ($m \cdot s^{-1}$) for all warm-up sets and 1RM attempts. With the performance of multiple reps during some of the warm-up sets, we used the repetition with the greatest ACV for analysis. This device has been shown to be a reliable instrument for the assessment of velocity of barbell exercises (9).

Statistical Analyses

We checked all data for normality using the Shapiro-Wilk test. Although relative strength data and ACV data were normally distributed ($p \geq 0.05$), training age and training frequency were

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not normally distributed ($p \leq 0.05$). Therefore, we used Spearman's Rho for correlational analyses involving training age and training frequency and Pearson's product-moment correlations for all other correlational analyses. We used repeated-measures analysis of variance (ANOVA) tests to compare dependent variables between the 4 lifts. When repeated-measures ANOVA revealed overall differences, we used paired-samples *t*-test as follow-up tests. We set the alpha level at 0.05 for all statistical tests. All data are presented as mean ± *SD* and were analyzed using IBM SPSS (version 24).

Results

Six of the 51 subjects elected to use the sumo stance rather than conventional stance for the deadlift. Independent-samples *t*-tests revealed no difference in either relative strength ($p = 0.365$) or 1RM ACV ($p = 0.301$) between the 2 deadlift styles, and thus, deadlift data were combined for analysis.

Table 1 presents descriptive characteristics for each lift. Squat ACV at the 1RM was the greatest compared with the other lifts. Average concentric velocity values for the squat were lower than the overhead press at loads ≤95% 1RM. Bench press ACV was the lower than for the squat and overhead press at loads ≥95% 1RM but greater than the deadlift ACV at loads ≤85% 1RM. Deadlift ACV was the lowest compared with all the other lifts at loads ≤85% 1RM. Overhead press ACV was greatest compared with the other lifts at all loads ≤95% 1RM.

Tables 2–5 present the correlation matrices for each of the 4 lifts. Notably, relative squat strength was inversely related to 1RM ACV ($r = -0.297$, $p = 0.033$) but positively related to the ACV at loads ≤75% 1RM ($p < 0.05$) (Table 2). Bench press relative strength was also inversely 1RM ACV ($r = -0.399$, $p = 0.003$) as well as at 85% ACV ($r = -0.344$, $p = 0.17$) (Table 3). Deadlift relative strength was inversely related to the ACV at loads ≥75% 1RM ($p < 0.05$) (Table 4). Overhead press relative strength was positively related to the ACV ($p < 0.05$) at loads ≤75% 1RM except for 55% 1RM (Table 5). Neither training age nor training frequency showed consistent relationships with the ACV across the load spectrum for any of the lifts. Humerus length was positively related to the ACV of the bench press at 75% 1RM ($r = 0.388$, $p = 0.023$) as well as to the ACV of the overhead press at loads of 75% 1RM ($r = 0.320$, $p = 0.050$) and 55% 1RM ($r = 0.391$, $p = 0.048$). Femur length was not related to squat or deadlift ACV at any loads ($p > 0.05$). Height was positively related ($p < 0.05$) to the ACV at various loads for each lift.

Discussion

The primary purpose of this study was to determine whether training age, training frequency, anthropometrics, or relative strength were related to the ACV at loads between 35 and 100% 1RM for the squat, bench press, deadlift, and overhead press. A secondary purpose was to compare the ACV values between the 4 lifts across different loads. We observed that relative strength was most strongly related to the ACV, whereas training age and frequency were not related to the ACV for these lifts. Humerus length was related to the ACV values at moderate loads for the upper-body lifts, whereas femur length was not related to the ACV values for the lower-body lifts. Height, however, was related to the ACV at various loads in each of the 4 lifts. This suggests that relative strength, whether inherent to the individual or as an adaptation to strength training, may affect the ACV on an individual basis. In addition, a trainee's height more than specific limb lengths may influence the ACV. These results have implications for trainees using ACV as a basis for their training loads. We also observed differences in ACV values between the 4 lifts at all relative loads. This suggests that trainees using the ACV to determine training loads should use different velocity ranges for each of these lifts.

For the squat, relative strength was most frequently related to the ACV, but height also was positively related to the ACV at some loads. The relationship between relative strength and the ACV suggest that a stronger squatter may need to use higher velocity zones for VBT when using submaximal loads (≤75% 1RM) but lower velocity zones at maximal loads (≥95% 1RM). Thus, the load-velocity profile would have a greater slope (higher velocities at low loads and lower velocities at high loads) for stronger squatters compared with weaker squatter. One reason for this shift may be a greater movement efficiency with lower loads leading to higher velocities as well as a greater ability to achieve a true (heavier) 1RM. Height, but not femur length, exhibited a positive relationship with the ACV at some submaximal loads. This positive relationship may be due to a greater range of motion during the movement. The propulsive phase of a repetition makes up most duration of the repetition at both high (80% 1RM) and low (20% 1RM) loads (23). With a greater overall range of motion, the greater the absolute duration of the propulsive phase, which may lead to a greater overall ACV over the entire repetition.

The ACV during the 1RM squat in our study (0.26 ± 0.08 $m \cdot s^{-1}$) was slightly lower than studies performed using novice squatters (24), recreationally trained men (4,5) and college athletes (7), but slightly higher than in powerlifters (12,24) and strength trained men who could squat at least 150% of their body mass (2). This fits with the idea that 1RM ACV is inversely related to relative strength level and suggests that our sample was relatively strong (relative squat ×1.48 body mass). To our knowledge, only one other study has reported ACV values at various loads for the free-weight squat (4). Our ACV values for the squat are similar at moderate loads (60–80% 1RM) but lower at high loads (≥90% 1RM) (4). The differences in the ACV at high loads may reflect relative strength-level differences between the subjects in each study. However, relative strength level was not reported in the previous study (4).

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For the bench press, height and the ACV were positively related at moderate loads (55–75% 1RM). Humerus length was also significantly correlated with the ACV at 75% 1RM. Similar to the squat, this may be due to a greater overall duration of the propulsion phase during the repetition in taller/longer limbed subjects. Also similar to the squat, bench press relative strength was inversely related to the ACV at maximal loads but positively related to the ACV at lower loads. This again may be due to stronger individuals having a greater movement efficiency and thus faster bar speed at low loads along with the ability to move higher loads at lower speeds. To our knowledge, only 2 other studies have reported the ACV of the free-weight bench press (1,12). Both studies involved subjects with a slightly higher relative strength level (bench press ×1.40 and ×1.34 body mass) compared with our study (bench press ×1.07 body mass). This may explain why these 2 studies also observed lower average bench press 1RM ACVs (0.10 and 0.14 $m \cdot s^{-1}$) compared with our study (0.18 $m \cdot s^{-1}$). Importantly, our study also characterized bench press ACV during the submaximal loads. Bench press ACV varied considerably across loads compared with the other lifts; it exhibited the lowest ACV at near-maximal and maximal loads (≥95% 1RM) compared with the other lifts as well as higher velocities than the squat and deadlift at low loads (≤45% 1RM). Thus, the load-velocity profile for the bench press seems to be unique compared with the other lifts and velocity ranges that may fit other exercises for VBT may not be appropriate for the bench press.

For the deadlift, height was positively related to the ACV at low loads (55 and 35% 1RM) while relative strength was inversely related to the ACV at loads ≥75% 1RM. This suggests that taller athletes, presumably training through a greater total range of motion, should use higher velocity zones when training with low loads. However, relative strength showed the strongest relationship with the ACV, which implies that stronger deadlifters are able to move heavier loads at slower speeds. This suggests that velocity zones may need to be adjusted lower for individuals who are proficient with the deadlift. Only one other study to our knowledge has characterized the ACV of a 1RM deadlift (12). Powerlifters able to deadlift an average of ×2.6 their body mass averaged a 1RM ACV of 0.10 $m \cdot s^{-1}$. Our sample exhibited an average deadlift of ×1.87 body mass and a higher 1RM ACV of 0.22 $m \cdot s^{-1}$. Similar to the squat and bench press, this suggests more proficient deadlifters may be able to move higher loads at lower velocities compared with less-proficient deadlifts. Also of note, the deadlift was consistently the slowest of the 4 lifts at each relative load ≤85% 1RM. This suggest that the velocity ranges used for training purpose would need to be lower for the deadlift compared with the other exercises. The lower ACV values may be attributable to the fact that the concentric phase of the deadlift precedes the eccentric phase and thus eliminates use of the stretch-shortening cycle that could influence the velocity of movement.

For the overhead press, height, humerus length, and relative strength were all positively related to the ACV at moderate loads. This suggests that taller and relatively stronger overhead pressers may need to increase velocity zones for training purposes. Similar to the other exercises, a greater range of motion due to longer limbs may allow for a longer absolute propulsive phase during the lift leading to a greater ACV. In contrast to the other lifts, relative strength was not significantly related to 1RM ACV. Overhead press ACV was consistently the greatest at all submaximal loads compared with the other lifts. This suggests that the velocity zones for the overhead press should be greater compared with the other lifts. To our knowledge, this is the first study to report ACV values for the overhead press.

Our study is the first to characterize and compare ACV values at multiple relative loads between the squat, bench press, deadlift, and overhead press. In addition, we had a robust sample of men and women with a range of training experience and strength, which increases the generalizability of our results to a large population. This also allowed us to compare data at each relative load between 35 and 95% 1RM for all 4 exercises between subjects. Studies have found low reliability of 1RM-squat ACV (2) and more variation in squat ACV at higher loads because of more movement variability (4). Thus, reporting both the 1RM ACV and the ACV during submaximal loads of the squat in this large sample is a strength of our study. Although we showed that height was positively related to the ACV for some exercises at some loads, we can only speculate that it is due to a greater range of motion and overall longer phase of propulsion during the repetition. Future studies should also quantify range of motion to see whether that specifically relates to the ACV. Finally, we acknowledge that the TEM for femur length (3.61%) was above the acceptable range (2.0%) (20). This variability in our measurement may have lessened the observed relationships between ACV and femur length. We recommend future investigations take multiple measurements of limb length and use the average value as the representative value.

The ACV is different at relative submaximal as well as maximal loads between the squat, bench press, deadlift, and overhead press. The ACV for each lift is influenced primarily by relative strength level and height. This implies that velocity zones used for VBT should be individualized for both the trainees as well as based on the exercise performed.

Practical Applications

Our study provides a framework for which trainees and coaches could use as a basis for characterizing velocity zones for the free-weight squat, bench press, deadlift, and overhead press. Specifically, we recommend using the ACV values presented in Table 1 as a general guide for the coach or athlete using ACV to estimate training loads (%1RM) for

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the squat, bench press, deadlift, and overhead press. Given that relative strength level shows the most consistent relationship with the ACV across various loads and lifts, we suggest that strength level is the primary factor to consider in modifying velocity zones for VBT. Specifically, relatively stronger trainees may achieve lower ACV values under high (≥85% 1RM) loads as well as higher ACV values when lifting moderate to light loads (≤75% 1RM) compared with weaker trainees, and this should be taken into account if using ACV to determine training loads. Finally, relatively tall trainees may achieve greater ACV values compared with shorter trainees for a given load, and this should be taken into account if using ACV to determine training loads.

Acknowledgments

The authors thank the students who assisted in data collection for this project and the subjects for their time and effort.

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