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Jovana Kasovic

Benjamin Martin

Christopher A. Fahs

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Jovana Kasovic,[1] Benjamin Martin,[1] and Christopher A. Fahs[2]

[1]Department of Exercise Science, Lindenwood University Belleville, Belleville, Illinois; and [2]College of Health Sciences, Logan University, Chesterfield, Missouri

Abstract

fferences between the front and back squat and conventional and sumo deadlift. *J Strength Cond Res* 33(12): 3213–3219, 2019—The average concentric velocity (ACV) of a resistance exercise movement is inversely related to the load lifted. Previous work suggests that different resistance exercises differ in ACV at the same relative load. Currently, there is limited evidence to determine whether the style of exercise (e.g., front or back squat [BS]; sumo-style or conventional-style deadlift) also affects the load-velocity profile or other kinematic variables such as the peak concentric velocity (PCV) and linear displacement (LD). The purpose of this study was to compare the kinematics (ACV, PCV, and LD) between the front squat (FS) and BS as well as between the conventional deadlift (CD) and sumo deadlift (SD). In a randomized order, 24 men and women (22 ± 3 years) performed a 1 repetition maximum (1RM) protocol for the FS, BS, CD, and SD over 4 visits to the laboratory. Barbell kinematics were recorded during all submaximal and maximal repetitions performed during the 1RM protocol using the Open Barbell System. Kinematic data were pooled into categories based on the percentage of the 1RM lifted in 10% increments (e.g., 30–39% 1RM, 40–49% 1RM, etc.) and compared between exercises. Correlations between kinematic data for the FS and BS and for the CD and SD were examined at each relative load. No differences in kinematics were observed between the FS and BS at any load ($p > 0.05$). However, FS and BS ACV was weakly correlated ($r < 0.4$) at high (>80% 1RM) loads. Differences in LD were apparent between the SD and CD at all loads (30–100% 1RM) with the SD having a smaller LD compared with the CD ($p < 0.05$). Average concentric velocity was not different between the SD and CD at the 1RM (0.25 ± 0.09 vs. 0.25 ± 0.06 $m \cdot s^{-1}$; $p = 0.962$) but was different at 80–89% 1RM (0.35 ± 0.08 vs. 0.40 ± 0.07; $p = 0.017$), 70–79% 1RM (0.41 ± 0.08 vs. 0.46 ± 0.06; $p = 0.026$), and 40–49% 1RM (0.66 ± 0.09 vs. 0.77 ± 0.08; $p < 0.001$). In addition, SD and CD ACV values showed no relationships ($p > 0.05$) at any loads except at the 1RM ($r = 0.433$; $p < 0.05$). These results suggest individual load-velocity profiles for the FS and BS as well as for the CD and SD should be used for training purposes.

Key Words: average concentric velocity, velocity-based training, barbell, resistance exercise

Introduction

The inverse relationship between the load lifted during a resistance training exercise and the velocity of movement, average concentric velocity (ACV), is well established and has been used to predict the 1 repetition maximum (1RM) (13,15). The ACV during resistance exercise has also been used for prescribing training, known as velocity-based training (VBT) (16). Typically a range of ACV values may be used for prescribing training loads because there is variability between individuals in ACV at a given load (2). The load-ACV profile may also differ based on the exercise because differences in ACV have been shown at various loads between barbell exercises including the squat, bench press, deadlift, and overhead press (7). Variations in the style of exercise performed may also affect the load-velocity profile.

Several studies have examined the load-velocity relationship in the back squat (BS) performed using a smith machine and shown it to be strong and linear (3,8,15,18) although a similar relationship has been shown for the free weight BS (1,7). However, the load-velocity relationship in the free weight BS may be weaker than the relationship observed with the smith machine BS due to variation in the technique in the free weight BS at high loads (2). For trainees performing other variations of the squat, such as the front squat (FS), the load-velocity profile may be different due to different joint angles and muscle recruitment (22). Studies have documented differences in kinematics between the FS and BS lifts primarily showing the BS elicits more acute hip angle at the bottom of the motion compared with the FS (4,22). Greater quadriceps muscle activity has also been shown in the FS compared with the BS (22), although this has not been found in all studies (10). A comparison between the FS and BS load-velocity profile showed no differences between the FS and BS in a sample of male Division I college baseball players (20). However, the load-velocity profile has been shown to differ between men and women (1), which may be due to differences in strength. Thus, it would be beneficial to coaches and trainees if similar evidence existed comparing the load-velocity profiles of the FS and BS from both male and female trainees.

Previous work has also investigated biomechanical differences between the sumo deadlift (SD) and the conventional-style deadlift (CD). With a greater stance width and slightly more narrow grip width for the SD compared with the CD, there are differences in the amount of mechanical work and stress placed on various joints between the SD and CD (5). Electromyography recorded during the 2 deadlift styles suggests greater knee extensor muscle activity during the SD compared with the CD (6). McGuigan and Wilson (17) provided a thorough description of the kinematic differences between the 2 styles of deadlift in competitive powerlifters during competition; the authors

Address correspondence to Dr. Christopher A. Fahs, christopher.fahs@logan.edu.

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observed that the SD has a shorter range of motion than the CD while both lifts take the same time to complete. These results would suggest that the ACV of the SD would be lower than for the CD at a given load, but this has not been demonstrated at submaximal loads or in trainees other than competitive powerlifters. It is possible that the kinematics of the deadlift may differ between competitive lifters and recreational lifters as the ACV at maximal loads has been shown to be inversely related to relative strength (7) and also lower in experienced lifters compared with novice lifters (23). If differences in ACV exist between the 2 deadlift styles at submaximal loads, this would be important to know for those using VBT for different types of deadlift training. Therefore, the purpose of this study was to compare kinematic differences (ACV, peak concentric velocity [PCV], and linear displacement [LD]) at submaximal and maximal loads between the CD and SD as well as the FS and BS in a sample of men and women. We hypothesized that the BS would elicit greater ACV and PCV values compared with the FS at the same relative load and that the CD would elicit greater ACV, PCV, and LD values compared with the SD at the same relative load. We also hypothesized that men would exhibiter greater ACV and PCV values compared with women for all exercises.

Methods

Experimental Approach to the Problem

Subjects visited the laboratory on 4 occasions. For each visit, subjects were instructed to avoid strenuous exercise with the lower body for 24 hours before testing. During the first visit, the subject's anthropometrics were measured, and the training history was recorded. During this visit and each of the subsequent 3 visits, subjects completed a 1RM protocol for the FS, BS, SD, or conventional deadlift (CD). Each visit was separated by at least 48 hours, and the exercise order was randomized.

Subjects

Twenty-seven subjects gave written informed consent to participate in this study. Owing to circumstances unrelated to the study, 3 subjects only completed only 1 testing session, whereas 1 subject only completed the SD and CD trials leaving a final sample of 24 subjects (15 men and 9 women) for the SD vs. CD comparison and 23 subjects (14 men and 9 women) for the FS vs. BS comparison. Subjects ($N = 24$) were 22 ± 3 years old [age range: 18–35 years] with a body mass of 77.2 ± 13.9 kg and height of 1.73 ± 0.10 m. All subjects were currently training with at least 1 form of the squat (FS or BS) and 1 form of the deadlift (SD or CD), familiar with both styles of each lift, and most subjects had at least 1 year of training experience with both types of squat (18 of 23 subjects) and both types of deadlift (18 of 24 subjects). The Lindenwood University's institutional review board approved this study (approval #00065), and all subjects were informed of the risks and benefits of the study before providing written informed consent (Table 1).

Procedures

Anthropometrics. Standing height was recorded to the nearest 0.01 m with a standard stadiometer (Tanita HR-200; Tanita Corporation, Arlington Heights, IL), and body mass was recorded with a digital scale (Tanita BWB-800S Doctors Scale; Tanita Corporation) to the nearest 0.1 kg. Humerus length was measured with a tape measure as the straight line distance between the acromion process and olecranon process on the right arm and recorded to the nearest 0.01 m. Femur length was measured with a tape measure with the subject seated as the straight line distance between the greater trochanter and lateral epicondyle of the femur and recorded to the nearest 0.01 m.

Training History. Subjects were asked how many years of experience they had performing each of the lifts (training age) and how frequently (training sessions per week) they perform each of the lifts (frequency).

One-Repetition Maximum Protocol. Subjects performed a standardized warm-up on a Monark cycle ergometer (Monark Ergomedic 828 E; Monark, Vargerb, Sweeden) at a self-selected light-intensity (i.e., rating of perceived exertion 9–11 on the Borg 6–20 scale) for 5 minutes. Using the subject's estimated 1RM (e1RM), the loads for the warm-up sets were determined. The subject's e1RM was based on their recent training performance using the %1RM-repetition relationship as a guide (19). If the subject did not have experience with 1 style of deadlift, it was estimated that their 1RM for that style of deadlift would be 5–10% than that of the style of deadlift with which they had experience; if the subject did not have experience with 1 style of squat, it was estimated that their FS 1RM was ~75–80% of their BS 1RM based previous research (22). Following the protocol recommended by Jovanovic and Flanagan (14), warm-up sets consisted of 2–3 repetitions with 30–40% of the e1RM, 2 repetitions with 40–50% of the e1RM, 1–2 repetitions with 60–70% of the e1RM, 1 repetition with 70–80% of the e1RM, and 1 repetition with 80–85% of the e1RM. A minimum of 3 minutes was allotted between warm-up sets. Subjects were instructed to lift with maximal effort and to move the weight as fast as possible on every repetition regardless of the load being lifted, and they were encouraged to maintain consistent technique for each attempt. After the last warm-up attempt, the 1RM was determined as the heaviest load (kg) lifted through a full range of motion. Up to 5 attempts were used to determine the 1RM, and a minimum of 3 minutes rest was allotted between each attempt.

Barbell Lifts. For the FS and BS, the subject began with the hips and knees fully extended and descended until the crease of the hip was level or below the top of the patella when viewed from the side. Completion of a successful repetition required the subject to then return to the standing position with the knees and hips fully extended. Verbal feedback was provided to the subjects during warm-up sets to ensure proper depth; any repetitions that did not reach proper depth were not used in the analysis. For the BS, subjects positioned the bar either over the rear deltoids (low bar) or upper trapezius (high bar) based on personal preference. For the FS, subjects positioned the bar over the anterior deltoids with the arms in either the front rack or crossed-arm position based on

Table 1
Subject characteristics.*

	Men ($n = 15$)	Women ($n = 9$)	p
Age (y)	21 ± 2	22 ± 5	0.335
Body mass (kg)	82.9 ± 13.8	67.7 ± 7.7	0.006
Height (m)	1.78 ± 0.06	1.63 ± 0.06	<0.001
BMI (kg·m^{-2})	25.9 ± 3.7	25.7 ± 4.3	0.924
Humerus length (m)	0.42 ± 0.04	0.37 ± 0.03	0.005
Femur length (m)	0.44 ± 0.04	0.42 ± 0.04	0.427

*BMI = body mass index. Subject characteristics were measured mean ± *SD*.

Table 2
Comparison between the front and back squat.*

	Front squat		Back squat			
	Men	Women	Men	Women	*N*	Lift comparison *p*
Training age (y)	3.3 ± 3.1	4.7 ± 2.8	4.9 ± 3.1	6.3 ± 1.7	23	<0.001
Frequency (d·wk^{-1})	0.6 ± 0.7	0.6 ± 0.7	1.3 ± 0.9	1.4 ± 0.8	23	0.001
One year of experience with exercise (*n*)	11	8	14	9	23	
1RM (kg)	108.6 ± 33.2	61.7 ± 9.7†	131.8 ± 40.7	75.0 ± 12.7†	23	<0.001
Relative 1RM	1.31 ± 0.28	0.91 ± 0.12†	1.59 ± 0.38	1.11 ± 0.18†	23	<0.001
1RM						
ACV (m·s^{-1})	0.32 ± 0.08	0.29 ± 0.08	0.31 ± 0.08	0.25 ± 0.08	23	0.259
PCV (m·s^{-1})	0.68 ± 0.10	0.74 ± 0.21	0.79 ± 0.21	0.73 ± 0.23	23	0.152
LD (m)	0.499 ± 0.078	0.505 ± 0.044	0.527 ± 0.062	0.481 ± 0.093	23	0.732
90–99% 1RM						
ACV (m·s^{-1})	0.36 ± 0.05	0.43 ± 0.16	0.42 ± 0.07	0.26 ± 0.04†	7	0.268
PCV (m·s^{-1})	0.71 ± 0.12	0.81 ± 0.34	0.95 ± 0.18	0.75 ± 0.33	7	<0.001
LD (m)	0.500 ± 0.056	0.494 ± 0.007	0.550 ± 0.065	0.499 ± 0.086	7	0.117
80–89% 1RM						
ACV (m·s^{-1})	0.48 ± 0.09	0.45 ± 0.04	0.50 ± 0.10	0.40 ± 0.03†	16	0.930
PCV (m·s^{-1})	0.86 ± 0.16	0.99 ± 0.16	1.00 ± 0.28	0.99 ± 0.14	16	0.203
LD (m)	0.535 ± 0.047	0.514 ± 0.053	0.562 ± 0.049	0.512 ± 0.080	16	0.326
70–79% 1RM						
ACV (m·s^{-1})	0.58 ± 0.08	0.50 ± 0.08†	0.57 ± 0.11	0.46 ± 0.07†	14	0.390
PCV (m·s^{-1})	1.01 ± 0.13	0.85 ± 0.19†	1.11 ± 0.23	0.83 ± 0.21†	14	0.586
LD (m)	0.559 ± 0.044	0.539 ± 0.049	0.571 ± 0.059	0.517 ± 0.079†	14	0.776
60–69% 1RM						
ACV (m·s^{-1})	0.64 ± 0.10	0.56 ± 0.08	0.67 ± 0.13	0.56 ± 0.07†	9	0.299
PCV (m·s^{-1})	1.06 ± 0.19	0.93 ± 0.26	1.15 ± 0.28	0.95 ± 0.21	9	0.213
LD (m)	0.568 ± 0.057	0.536 ± 0.036	0.592 ± 0.049	0.469 ± 0.051†	9	0.650
50–59% 1RM						
ACV (m·s^{-1})	0.71 ± 0.10	0.65 ± 0.10	0.73 ± 0.11	0.65 ± 0.13	6	0.683
PCV (m·s^{-1})	1.13 ± 0.18	1.04 ± 0.15	1.22 ± 0.21	1.01 ± 0.11	6	0.755
LD (m)	0.566 ± 0.056	0.551 ± 0.052	0.567 ± 0.048	0.575 ± 0.074	6	0.672
40–49% 1RM						
ACV (m·s^{-1})	0.81 ± 0.12	0.67 ± 0.08†	0.83 ± 0.13	0.66 ± 0.13†	13	0.805
PCV (m·s^{-1})	1.26 ± 0.28	1.00 ± 0.12†	1.34 ± 0.26	1.06 ± 0.23†	13	0.327
LD (m)	0.575 ± 0.058	0.546 ± 0.043	0.594 ± 0.037	0.518 ± 0.066†	13	0.988
30–39% 1RM						
ACV (m·s^{-1})	0.82 ± 0.13	0.71 ± 0.10	0.92 ± 0.18	0.62 ± 0.07†	12	0.548
PCV (m·s^{-1})	1.27 ± 0.27	1.05 ± 0.14	1.47 ± 0.25	1.03 ± 0.18†	12	0.060
LD (m)	0.595 ± 0.035	0.561 ± 0.039	0.596 ± 0.074	0.497 ± 0.043†	12	0.484

*1RM = 1 repetition maximum; ACV = average concentric velocity; PCV = peak concentric velocity; LD = linear displacement.
†$p < 0.05$ vs. men.

personal preference. For the CD and SD, the barbell began motionless on the ground. For the CD, grip width was greater than the stance width, and for SD, the grip width was less than the stance width; specific stance and grip width was left to personal preference. Subjects were encouraged to use either the alternate grip (1 palm pronated and the other supinated) or the hook grip for the deadlift; the grip used was same for both deadlift styles within each subject. A full range of motion for the CD and SD was achieved with the subject holding the barbell at arm's length with the hips and knees fully extended. No hitching or supporting the barbell on the thighs during the lift was permitted for either the SD or CD.

Barbell Kinematics. The Open Barbell System (OBS; Squats & Science Labs LLC, Seattle, WA) was attached to the barbell during the 1RM protocol, which recorded the ACV, PCV, and the LD of each repetition. This system uses a cable connected to the barbell similar to the TENDO power and speed analyzer and GymAware systems. Similar to the TENDO power and speed analyzer, this device provides 1-dimensional measurements of velocity and displacement. According the manufacturer, the OBS device calculates kinematic variables every 2.8 mm of displacement during a repetition (21). Although no longer currently available to the public, this device provides a valid measurement of ACV and PCV compared with a 3D motion capture system (9). For the FS and BS, the cable was attached to the sleeve of the barbell, and the unit was placed in a position so that the cable was vertical in the frontal and sagittal plane during the concentric portion of each repetition. For the CD and SD, the unit was placed under the center of the barbell between the subject's feet with the cable attached to the center of the barbell with vertical alignment in the frontal and sagittal plane during each repetition. For the warm-up sets in which more than 1 repetition was performed, the repetition with the greatest ACV was used for analysis.

Load-Velocity Comparison. From the 1RM testing protocol, we obtained kinematic data during the 1RM data on each subject. The load of each warm-up set and each successful 1RM attempt less than the actual 1RM was calculated as a percentage of the actual 1RM and categorized as follows: 30–39%, 40–49%,

Table 3
Comparison between the conventional and sumo deadlift.*

	Conventional deadlift		Sumo deadlift			
	Men	Women	Men	Women	*N*	Lift comparison *p*
Training age (y)	4.2 ± 3.3	5.0 ± 2.4	2.3 ± 2.9	2.8 ± 2.9	24	<0.001
Frequency (d·wk^{-1})	0.9 ± 0.7	1.0 ± 0.8	0.5 ± 0.7	0.5 ± 0.7	24	0.004
One year of experience with exercise (*n*)	15	9	9	8		
1RM (kg)	158.3 ± 38.3	91.7 ± 11.2†	151.7 ± 38.3	90.0 ± 14.4†	24	0.032
Relative 1RM	1.90 ± 0.30	1.37 ± 0.21†	1.81 ± 0.36	1.34 ± 0.21†	24	0.032
1RM						
ACV (m·s^{-1})	0.23 ± 0.05	0.29 ± 0.07†	0.24 ± 0.08	0.27 ± 0.11	24	0.943
PCV (m·s^{-1})	0.45 ± 0.08	0.57 ± 0.09†	0.51 ± 0.56	0.56 ± 0.19	24	0.301
LD (m)	0.549 ± 0.030	0.502 ± 0.052†	0.474 ± 0.050	0.449 ± 0.041	24	<0.001
90–99% 1RM						
ACV (m·s^{-1})	0.29 ± 0.06	0.35 ± 0.08†	0.26 ± 0.06	0.28 ± 0.03	16	0.068
PCV (m·s^{-1})	0.52 ± 0.08	0.71 ± 0.11†	0.53 ± 0.12	0.53 ± 0.19	16	1.000
LD (m)	0.547 ± 0.033	0.512 ± 0.393†	0.480 ± 0.048	0.445 ± 0.038	16	<0.001
80–89% 1RM						
ACV (m·s^{-1})	0.41 ± 0.07	0.37 ± 0.06	0.35 ± 0.08	0.34 ± 0.06	19	0.008
PCV (m·s^{-1})	0.73 ± 0.16	0.79 ± 0.07	0.69 ± 0.15	0.77 ± 0.18	19	0.307
LD (m)	0.571 ± 0.034	0.515 ± 0.029†	0.498 ± 0.055	0.454 ± 0.057†	19	<0.001
70–79% 1RM						
ACV (m·s^{-1})	0.48 ± 0.05	0.44 ± 0.08	0.43 ± 0.08	0.43 ± 0.12	17	0.026
PCV (m·s^{-1})	0.86 ± 0.12	0.91 ± 0.13	0.83 ± 0.12	0.87 ± 0.20	17	0.243
LD (m)	0.577 ± 0.037	0.514 ± 0.043†	0.502 ± 0.058	0.470 ± 0.034	17	<0.001
60–69% 1RM						
ACV (m·s^{-1})	0.56 ± 0.10	0.52 ± 0.08	0.58 ± 0.10	0.47 ± 0.07†	15	0.764
PCV (m·s^{-1})	1.00 ± 0.16	0.97 ± 0.11	1.07 ± 0.16	1.02 ± 0.13	15	0.533
LD (m)	0.567 ± 0.054	0.507 ± 0.037†	0.540 ± 0.069	0.468 ± 0.036†	15	0.015
50–59% 1RM						
ACV (m·s^{-1})	0.66 ± 0.10	0.69 ± 0.09	0.55 ± 0.11	0.57 ± 0.05	11	0.064
PCV (m·s^{-1})	1.17 ± 0.15	1.24 ± 0.11	1.00 ± 0.17	1.04 ± 0.12	11	0.016
LD (m)	0.586 ± 0.045	0.543 ± 0.031†	0.515 ± 0.066	0.487 ± 0.041	11	0.004
40–49% 1RM						
ACV (m·s^{-1})	0.76 ± 0.10	0.72 ± 0.08	0.68 ± 0.08	0.63 ± 0.08	16	<0.001
PCV (m·s^{-1})	1.31 ± 0.18	1.25 ± 0.13	1.17 ± 0.19	1.19 ± 0.14	16	0.002
LD (m)	0.585 ± 0.050	0.540 ± 0.037†	0.549 ± 0.102	0.481 ± 0.029	16	0.008
30–39% 1RM						
ACV (m·s^{-1})	0.76 ± 0.11	0.68 ± 0.08	0.78 ± 0.15	0.71 ± 0.10	13	0.556
PCV (m·s^{-1})	1.33 ± 0.21	1.16 ± 0.21	1.39 ± 0.27	1.23 ± 0.16	13	0.429
LD (m)	0.593 ± 0.053	0.542 ± 0.019†	0.556 ± 0.070	0.504 ± 0.045	13	<0.001

*1RM = 1 repetition maximum; ACV = average concentric velocity; PCV = peak concentric velocity; LD = linear displacement.
†$p < 0.05$ vs. men.

50–59%, 60–69%, 70–79%, 80–89%, and 90–99% 1RM. There were no differences in actual %1RM between the lifts in any category, and the range of actual %1RM was evenly distributed within each category. Kinematic data corresponding to each category were compared between each lift (FS vs. BS and CD vs. SD). Because subjects completed between 1 and 5 1RM attempts and may have over- or under-estimated their actual 1RM, this led to a different sample size for each category.

Statistical Analyses

All data were checked for normality using the Shapiro-Wilk test. When variables were normally distributed, paired-samples *t*-tests (2-tailed) were used to compare ACV, PCV, and LD between the FS and BS and between the SD and CD at each relative load; when variables were not normally distributed, Wilcoxon signed-rank tests were used for analysis. A sample size of 13 ($N = 13$) would provide 80% power to correctly reject the null hypothesis, assuming a mean difference of 0.06 m·s^{-1} between 2 lifts at a relative load with a *SD* of 0.08 m·s^{-1} (effect size of 0.75). All analyses used an alpha level of 0.05. Independent-samples *t*-tests were used to compare men and women in subject characteristics (2-tailed *t*-tests) and for all kinematic variables (1-tailed *t*-tests). Pearson's product-moment correlations were used to examine relationships between demographic variables, relative strength levels, and kinematics measured (ACV, PCV, and LD) at the 1RM for each lift. In addition, correlations were used to compare the relationships between kinematic variables at the 1RM and at 80–89% 1RM for each lift because this was the load at which we had the largest sample size other than the 1RM. Finally, correlations between kinematic variables for the FS and BS and for the CD and SD were examined at each relative load. All data are presented as mean ± *SD*. Statistical analyses were performed using JASP v0.9.0.1 (Amsterdam, the Netherlands).

Results

Table 2 presents the data for the FS and BS. Subjects had more experience (greater training frequency and training age) as well as a greater 1RM for the BS compared with the FS. However, no

Table 4
Correlations between select variables for each lift.*

	1RM ACV	1RM PVC	1RM LD
FS			
Body mass	0.077	−0.009	−0.272
Height	0.114	−0.236	−0.029
Relative strength	−0.120	−0.149	−0.271
80–89% 1RM ACV	0.774†	0.270	0.307
80–89% 1RM PCV	0.522†	0.637†	0.185
80–89% 1RM LD	0.386	0.078	0.638†
BS			
Body mass	0.654†	0.485†	0.161
Height	0.433†	0.185	0.560†
Relative strength	0.225	0.495†	−0.072
80–89% 1RM ACV	0.587†	0.194	0.294
80–89% 1RM PCV	0.314	0.606†	0.174
80–89% 1RM LD	0.198	−0.064	0.723†
CD			
Body mass	−0.260	−0.326	0.437†
Height	−0.402	−0.589†	0.618†
Relative strength	−0.681†	−0.631†	0.153
80–89% 1RM ACV	0.362	0.288	0.319
80–89% 1RM PCV	0.457†	0.533†	0.027
80–89% 1RM LD	0.068	−0.044	0.774†
SD			
Body mass	0.214	−0.010	0.153
Height	0.094	−0.011	0.453†
Relative strength	−0.424†	−0.446†	−0.161
80–89% 1RM ACV	0.547†	0.483†	0.266
80–89% 1RM PCV	0.689†	0.692†	0.264
80–89% 1RM LD	0.377	0.316	0.827†

*1RM = 1 repetition maximum; ACV = average concentric velocity; PCV = peak concentric velocity; LD = linear displacement; FS = front squat; BS = back squat.
†Correlational significant at $p < 0.05$.

significant differences were noted in ACV or LD between the FS and BS at the 1RM or any percentage of the 1RM (Table 2). For the BS, ACV and PCV values were lower for women compared with men at the same relative loads except at the 1RM and at 50–50% 1RM. For the FS, ACV and PCV were lower for women compared with men only at loads of 40–49% and 70–79% 1RM.

Table 3 presents the data for the CD and SD. Subjects' had more experience (greater training frequency and training age) as well as a greater 1RM for the CD compared with the SD. Greater LD was observed for the CD compared with the SD at all loads. Greater ACV was observed at some submaximal loads (40–49%, 70–79%, and 80–89% 1RM) for the CD compared with the SD (Table 3). For the CD, sex differences in LD were observed across all loads with men having greater LD compared with women; men also had lower ACV values at 90–99% 1RM and at the 1RM compared with women. For the SD, LD was greater for men compared with women at loads of 80–89% and 60–69% 1RM, with men showing greater ACV values than women at 60–69% 1RM as well.

Correlations between kinematic variables recorded at the 1RM, subject characteristics, and kinematics recorded at 80–89% 1RM are reported in Table 4. Notable, body mass showed a strong, positive correlation to 1RM ACV and PCV for the BS but not any of the other lifts. Average concentric velocity values at the 1RM and at 80–89% 1RM were strongly related for the FS, moderately related for the BS and SD, and weakly related for the CD. Peak concentric velocity values at the 1RM and at 80–89% 1RM were strongly related for the FS, BS, and SD and moderately related for the CD. Linear displacement values at the 1RM and at 80–89% 1RM were strongly related for the FS, BS, and CD and very strongly related for the SD. For the SD and CD, 1RM ACV was inversely related to relative strength, whereas the correlations between 1RM ACV and relative strength were not as strong for the FS or BS.

Correlations between kinematic variables for the 2 types of squats and 2 types of deadlifts at each relative load are shown in Table 5. Notably, ACV values for the FS and BS showed weak correlations at high loads (>80% 1RM) but moderate-to-strong relationships at lower loads (<80% 1RM). Average concentric velocity values for the SD and CD showed weak correlations at most loads despite moderate to very strong correlations between LD at all loads.

Discussion

The primary findings of this study were as follows: (a) although FS and BS kinematics at the same relative load are not statistically different, ACV values between the FS and BS are weakly related at high (>80% 1RM) loads; (b) LD and ACV values differ between the CD and SD at the same relative load; (c) ACV values are weakly related between the CD and SD at most loads; (d) women generally exhibit lower velocities than men at the same relative load; and (e) kinematics at high loads (80–89% 1RM) and maximal loads (1RM) are strongly correlated for the FS, moderately correlated for the BS and SD, and weakly to moderately correlated for the CD. These findings have implications for those using ACV for prescribing training loads.

Similar to another study comparing the load-velocity profile between the FS and BS (20), kinematics at a given load were not statistically different between the FS and BS. However, examining the relationships between FS and BS kinematics at each relative load, it seems ACV values are not necessarily the same for the FS

Table 5
Correlations between 2 styles of each lift at each relative load.*

	30–39%	40–49%	50–59%	60–69%	70–79%	80–89%	90–99%	1RM
Squat								
ACV	0.522	0.698†	0.584	0.707†	0.699†	−0.312	−0.276	0.303
PCV	0.621†	0.834†	0.696	0.624	0.719†	−0.185	0.609	0.463†
LD	0.601†	−0.004	−0.151	0.057	−0.361	−0.005	−0.309	−0.012
Deadlift								
ACV	0.245	0.361	0.010	0.030	0.307	0.414	0.230	0.433†
PCV	0.489	0.275	0.148	−0.338	0.060	0.525†	0.188	0.327
LD	0.903†	0.570†	0.689†	0.826†	0.694†	0.629†	0.575†	0.586†

*1RM = 1 repetition maximum; ACV = average concentric velocity; PCV = peak concentric velocity; LD = linear displacement.
†Correlation is significant at $p < 0.05$.

and BS at high (>80% 1RM) loads. This is likely due to greater variation in the technique during the squat at high loads, which may contribute to the greater between-subject variability in bar velocity at higher loads (2). Another notable difference between our findings and those of Spitz et al. is the absolute difference in ACV and PCV values between the 2 studies. The subjects in the study by Spitz et al. achieved ACV values >0.50 $m \cdot s^{-1}$ and PCV values all >1.0 $m \cdot s^{-1}$ at all loads 30–90% 1RM for both the FS and BS (20). By contrast, our subject's ACV and PCV values were consistently lower (~0.2–0.4 $m \cdot s^{-1}$) at the same relative loads. One reason for this difference is our sample included both men and women in contrast to all male Division I baseball players studied by Spitz et al. Women have been shown to exhibit lower ACV and PCV compared with men at the same relative load for the BS (1); thus our sample of men and women would be expected to have lower velocity values on average compared with a group of men only. Although there were differences in training age between the FS and BS for our subjects, the results remained the same when analyzing only the subjects who consistently trained (≥1 year experience) with both the FS and BS. Thus, although load-velocity profiles for the FS and BS seem similar averaged within the group, an individual's ACV values are related at moderate loads (<80% 1RM) but not at higher loads (≥80% 1RM) for the FS and BS. Overall, our subjects had an average training age of 5.3 years of barbell training experience. Thus, our results are applicable to those intermediate to advanced trainees who may be using VBT for training prescription.

Previous work investigating differences between the FS and BS has primarily focused on joint angles and muscle activation (e.g., electromyography) of the 2 squat variations (10,22). The similar LD between the FS and BS is not surprising because our criteria for a successful repetition for both lifts involved the crease of the hip reaching a point level or below the top of the patella when viewed from the side. However, LD was weakly to very weakly correlated between the 2 forms of the squat suggesting that our subjects had some horizontal movement in their bar path for at least one form of the squat resulting in some variability in the LD between the 2 squats. Because height exhibited a moderate correlation with 1RM LD for the BS but not with the 1RM LD for the FS, we suggest that more movement variability may have occurred at high loads with the FS.

Similar to previous studies that observed differences in ACV between the squat and deadlift (7,12), we observed that the ACV values for the squat were greater than for the deadlift at the same relative loads. This difference is likely due to the greater velocity achieved following the "sticking point" of the squat compared with the deadlift (11). The novel finding of this investigation is that ACV of the deadlift is also affected by the type of deadlift performed (SD or CD) with the SD eliciting lower ACV values compared with the CD at submaximal loads (e.g., 70–89% 1RM). The differences in LD between the SD and CD may contribute to the differences in the ACV. With a larger LD for the CD compared with the SD, this would allow for a greater velocity to be achieved between the sticking point of the lift and the end LD. In agreement with our findings, previous work has shown a greater bar velocity for the CD compared with the SD in national level powerlifters during competition lifts (5). However, the results of Escamilla et al. (5) demonstrated differences in ACV between the SD and CD at maximal loads, whereas we observed differences in ACV at submaximal loads between the SD and CD. One potential difference for these findings is due to differences in the subjects' characteristics between the studies. Our subjects were relatively young (~22 years old), with a moderate amount of barbell training experience (~5.3 years) and included both men and women. The subjects in the study by Escamilla et al. (5) were older (~47 years) men, competitive masters' powerlifters. Our study expands on our knowledge and provides evidence that kinematic differences exist between the SD and CD at submaximal loads and in populations other than national level powerlifters. The finding of lower ACVs for the SD compared with the CD has implications for trainees using ACV to determine training loads. Based on the weak to very weak relationships between SD and CD ACV values at the same relative load, we suggest that lifters determine separate load-velocity profiles for the SD and CD if using ACV to determine training loads for each exercise. Finally, the fact that the relationships in kinematic variables between 80 and 89% 1RM and 1RM for the SD were stronger compared with those of the CD suggest our subjects had a more consistent movement pattern for the SD compared with the CD.

Our study is not without limitations. We allowed our subjects to use either the high-bar or low-bar position for the BS. This may have influenced the data. However, only 2 subjects elected to use the low-bar position for the BS, and excluding these 2 subjects from the data analysis did not change the findings of the current study. Nonetheless, further studies may wish to examine the specific influence on bar position on BS kinematics as this seems to be an unexplored topic. We also we unable to measure horizontal bar displacement, which may have provided more insight into differences kinematics between the lifts. However, our measures of vertical bar velocity and displacement are useful to those using similar devices for VBT.

Based on our findings, we suggest individuals use separate load-velocity profiles for the FS and BS as well as for the CD and SD if using ACV to determine training loads for each lift in a training plan. Comparing the studies, which have investigated the load-velocity profile for the squat, also suggests that an individual's velocity for a given load is unique and that the data presented in any 1 study may only provide the "average" load-velocity profile for that lift. Examining the sex differences in the load-velocity profile suggest that women, on average, exhibit lower velocities than men at the same relative load. Finally, the relationships between kinematic variables recorded at high (e.g., 80–89% 1RM) and maximal (e.g., 1RM) loads are moderate to strong for these barbell exercises.

Practical Applications

The results of this study can be practically applied by coaches and trainees, in that trainees should obtain separate load-velocity profiles for each lift in a training plan if using ACV as a basis for training loads. For the FS and BS, similar ACV values could be used interchangeably for prescribing moderate load (e.g., <80% 1RM) training, but trainees should not use ACV values interchangeably if training at near-maximal to maximal loads (e.g., >80% 1RM). In addition, trainees using ACV to base training loads for deadlift could assume their ACV values will be lower for the SD compared with the CD, but separate load-velocity profiles should still be developed based on the weak relationships exhibited between SD and CD ACV values at the same relative load.

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