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Original Research

Anthropometric Predictors of Conventional Deadlift Kinematics and Kinetics: A Preliminary Study

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ABSTRACT

International Journal of Exercise Science 16(1): 429-447, 2023. The purpose of this preliminary analysis was to determine if there are relationships between anthropometric characteristics (arm length, torso length, thigh length, and shank length) and conventional deadlift (CDL) kinematics and kinetics during a 5 sets of 5 repetitions (5 x 5) CDL routine in resistance-trained males. Eleven males who had experience with the deadlift exercise were included in this analysis (age: 21.5 ± 1.4 y; height: 180.7 ± 5.7 cm; body mass: 89.9 ± 16.0 kg). Anthropometrics were measured by a 3-dimensional optical scanner. The participants underwent a 5 x 5 CDL workout using a self-selected load corresponding to a rating of perceived exertion (RPE) of 8 out of 10. Performance outcomes were measured synchronously using a 3-dimensional 12-camera motion capture system and two force platforms. Outcomes were averaged across all sets and analyzed using multiple linear regression. The selected anthropometric variables were not significantly related to the CDL performance outcomes, except for concentric ankle work. However, in the overall model, anthropometric predictors did not significantly predict ankle concentric work (p = 0.11; R^2 = 0.67; R^2adj = 0.45). Independently, thigh length significantly correlated with ankle concentric work (p = 0.03). In this model, thigh length accounted for 55% of the normalized variance in ankle concentric work. The results from this preliminary study suggest that arm length, torso length, and shank length may not play a clear role in the examined CDL outcomes, but thigh length may be positively correlated with ankle concentric work during a 5 x 5 CDL routine in resistance-trained males.

KEY WORDS: Biomechanics, ground reaction force, barbell velocity, lower body work, rate of force development

INTRODUCTION

The deadlift is one of the most commonly performed exercises to strengthen the lower body and is one of the primary lifts in powerlifting and strongman competitions. Nevertheless, research exploring the deadlift is quite limited compared to other popular exercises like squats and bench press. This may be due to the commonly held belief that deadlifts are more likely to cause injury, particularly to the lower back, compared to other resistance training exercises. While some data indicate that deadlifts may result in more injuries than other exercises in strongman competitors (32), there is no convincing evidence that the deadlift results in more injuries than other exercises across other resistance trained populations. When deadlift injuries do occur, they may be due to poor technique, as observed in novice lifters, or due to very high training volumes, as in strongman competitors.

The deadlift can be performed in many variations. One of the most commonly performed deadlift variations is the conventional deadlift (CDL). In preparation for a CDL repetition, a person stands with their feet roughly hip- or shoulder-width apart and grasps a straight barbell with their forearms positioned lateral to their knees. To complete a repetition, the individual performs simultaneous extension of the hip and knee joints, along with some plantar flexion at the ankle joint, to lift the bar from the floor to the full lockout position (i.e., standing upright with hips and knees fully extended) before returning the bar to the floor. While these basic components are essential for an exercise to be considered a CDL, several positional deviations can exist between individuals or repetitions. For instance, when positioning the body prior to CDL initiation, hip height, grip position and style, the distance between the bar and the shank, and the amount of flexion of the lower and upper back can vary from person to person.

Some individuals select their preferred deadlift style and set-up simply by defaulting to what "feels best." However, some fitness professionals and researchers believe that lifters should choose their "optimal" deadlift style and set-up based on their anthropometrics in order to maximize their deadlift performance. For instance, Hales (2010) contends that those with elongated torsos relative to their arms, short torsos and short arms, and average torsos and short arms should deadlift with a sumo stance rather than a CDL approach (13). However, these claims were not directly tested and should therefore be viewed as speculative and interpreted cautiously.

While the idea that anthropometrics may influence deadlift performance seems intuitive, there is limited research on this topic. Lockie et al. (2018) found that, for the CDL, body height correlated with lift distance (*rho* = 0.53; $p = 0.05$) and mean force (*rho* = 0.59; $p = 0.03$); arm length correlated with peak power (*rho* = 0.54; $p = 0.05$), mean force (*rho* = 0.73; $p < 0.01$), and work (*rho* = 0.58; $p = 0.03$); and leg length correlated with 1RM (*rho* = 0.57; $p = 0.03$), peak force (*rho* = 0.56; $p = 0.04$), mean force (*rho* = 0.59; $p = 0.03$), and work (*rho* = 0.72; $p < 0.01$) in a cohort of 14 resistance-trained men (21). Fahs and colleagues (2019) reported a positive relationship between height and relative 1RM CDL strength, but this relationship was small ($r = 0.29$, $p = 0.03$) (7). Additionally, neither Lockie et al. (2018) nor Fahs et al. (2019) found relationships between lower limb anthropometrics and mean barbell velocity during the CDL (7, 21). However, Ferland et al. (2020) reported that height, arm length, and reach length did not correlate with CDL 1RM, and that forearm length relative to torso length had an inverse relationship with CDL 1RM ($r = -0.46$; $p < 0.05$) when assessing the data from powerlifters and collegiate football players together (8). This finding is surprising, because it would be reasonable to assume having longer forearms relative to the torso would reduce the distance the barbell must travel during a CDL, thus making the lift easier to complete. However, the ratio of total arm length to torso length, or to total height, may be a more appropriate way to determine the contribution of arm length rather than considering forearm length alone. Ferland and colleagues (2020) did find that height (r = -0.41), thigh length (r = -0.52), trunk length (r = -0.36), thigh length relative to height (r = -0.44), lower leg length relative to height (r = 0.46), and thigh length relative to lower leg length (r = -0.53) were correlated with CDL Wilks scores (p < 0.05 for all) when examining powerlifters and football players together (8). Similarly, Cholewa et al. (2019) found that sitting height relative to standing height was positively related to sumo deadlift strength relative to CDL strength, indicating that those with greater CDL strength had relatively shorter trunk lengths; however, this relationship was weak (r = 0.30; p = 0.04) (4).

Due to the limited and somewhat conflicting research, it is difficult to establish the degree to which anthropometric variation affects CDL performance. If strength and conditioning coaches have a better understanding of the implications that anthropometrics may have on CDL performance, they may be able to make more informed decisions on how and when to utilize CDLs in their training programs, as well as appropriate target performance for this exercise. Additionally, health professionals, such as physical therapists, may be able to make more informed decisions on whether to and how to utilize CDLs in their rehabilitation programs if relationships between anthropometrics and joint kinetics during CDL were clearer. Therefore, the purpose of this preliminary analysis was to determine if there are relationships between anthropometric characteristics and CDL kinematics and kinetics during a 5 sets of 5 repetitions (5 x 5) CDL routine in resistance-trained males.

METHODS

Participants

Resistance-trained males were recruited to participate in this study. To be eligible, participants had to be between the ages of 18 and 45 years; have no previous or current injury, condition, or ailment that may affect their ability to perform the deadlift exercise or similar barbell exercises; and had to have participated in resistance training at least 2 times per week for the last 2 years. Additionally, participants had to be able to perform a CDL repetition with a load corresponding to 1.5 times body mass. Due to a lack of relevant input data for the sample estimation, a preliminary power analysis was conducted using a proposed effect size of 0.30, alpha (α) of 0.05, power (1-β) of 0.90, and a correlation among repeated measures of 0.70 using G*Power software. This calculation estimated a need for 12 participants. Although 12 participants were tested, only 11 were included in the present analysis due to data errors for one participant that precluded inclusion (Table 1). Study procedures, benefits, and risks were reviewed with all participants, and written informed consent was obtained before commencing the testing visit. All study procedures were approved by the Institutional Review Board at Texas Tech University (protocol # IRB2019-45). This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (23).

Table 1. Characteristics and anthropometrics of study participants.

	Mean	SD	Min	Max
Age (y)	21.45	1.37	19.00	23.00
Height (cm)	180.73	5.68	171.50	190.00
Body Mass (kg)	89.86	15.99	69.50	132.00
Body Fat (%)	21.67	4.21	17.16	31.41
Arm Length (cm)	62.55	3.23	56.54	67.37
Torso Length (cm)	47.07	4.22	41.96	54.49
Hip Circumference (cm)	109.52	7.09	99.77	124.36
Thigh Length (cm)	46.86	2.73	41.09	50.77
Shank Length (cm)	44.51	2.23	40.99	48.57
Leg Volume (L)	23.26	3.69	18.39	30.57

Protocol

During the testing visit, participants first had their anthropometric measurements assessed by a 3-dimensional optical scanner (Size Stream® SS20, Cary, NC, USA). Limb lengths were then assessed using the software associated with the optical scanner (software version 5.2.7 for Size Stream Studio, scanner version 6.0.0.32). The high reliability of these anthropometric estimates obtained in our laboratory has previously been reported (29). The specific anthropometric variables used in the present analysis were arm length, torso length, thigh length, shank length, hip circumference, and leg volume. Each anthropometric predictor was based on default output from the Size Stream Studio software: arm length was defined as the average of the "Arm Length Left" and "Arm Length Right" variables, torso length was defined as equivalent to the "Half Back Center Tape Measure" variable, thigh length was defined as leg length (average of "Crotch Height" and the average of "Side Back Waist to Floor Left" and "Side Back Waist to Floor Right") minus shank length, shank length was defined as the average of the "UnderKnee Height Left" and "UnderKnee Height Right" variables, hip circumference was defined as equivalent to the "Hip Circumference" variable, and leg volume was defined as the sum of "Leg Volume Right" and "Leg Volume Left." A representative avatar from the 3-dimensional optical scanner is displayed in Figure 1. In addition to anthropometric variables, estimates of body fat percentage from 3D optical scanning were quantified for descriptive purposes using the built-in body fat equation from the Health and Fitness module at the time of data collection (equation date: 10/4/2017) (28).

Before commencing the CDL protocol, 14-mm reflective spherical markers were adhered bilaterally over the acromion process, the medial and lateral aspects of the wrist and elbow, the iliac crest, the anterior and posterior superior iliac spine, the greater trochanter of the left and right leg, the medial and lateral aspects of the knee joint, the base of the second toe, and the medial and lateral malleoli (Figure 2). Additionally, individual markers were adhered over the following locations: C7 and T10 vertebrae, sternum-jugular notch, xiphoid process, and sacrum. Moreover, thermo-plastic shells with 4 non-collinear markers were secured bilaterally over the lateral mid-segment aspects of the upper and lower arm, thigh, and shank. Thermo-plastic cluster shells with 3 non-collinear markers were also placed bilaterally on both heel counters of the participants shoes. Markers and the thermoplastic shells were secured to the body with hypoallergenic adhesive tape and elastic wraps when needed.

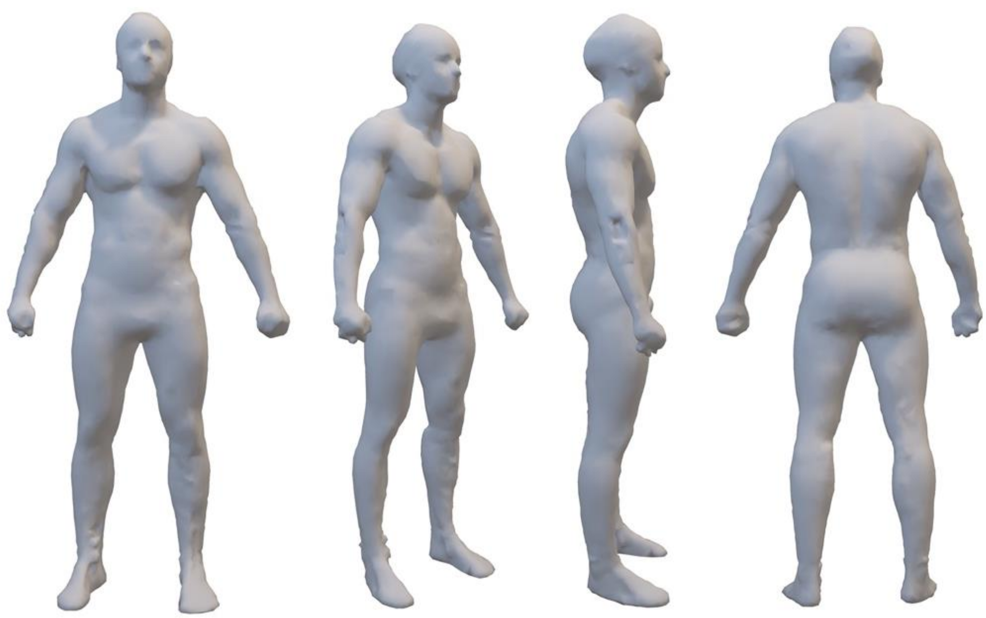

Figure 1. Representative avatar from 3-dimensional optical scanning. Anthropometric variables used as predictor variables in regression models were obtained from these scans.

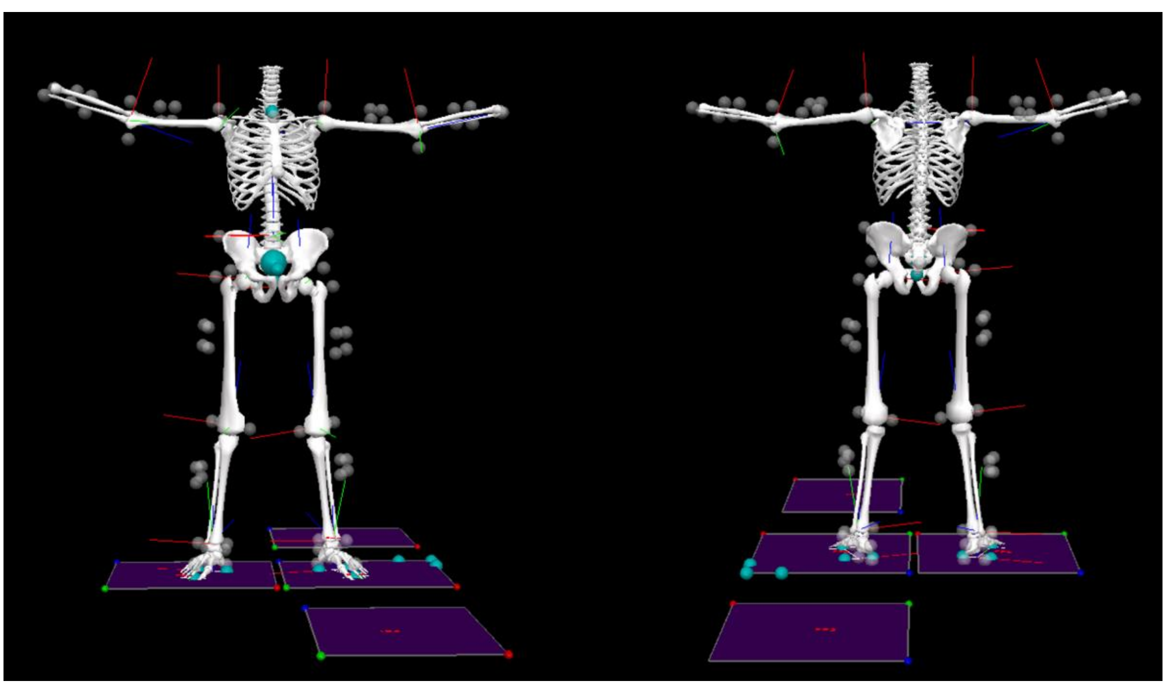

Figure 2. Marker locations used in the present study.

A 12-camera 3-dimensional motion capture system (Vantage v5 cameras; Vicon Motion Systems, Ltd., Oxford, UK) sampling at 200 Hz were used to measure kinematic data. Two 3-dimensional force platforms (OPT464508; Advanced Mechanical Technology, Inc., Watertown, MA, USA) mounted flush with the floor and sampling at 1000 Hz were used to synchronously collect kinetic data. Following a static calibration trial, the markers adhered to the medial and lateral aspects of the wrist and elbow, iliac crest, anterior superior iliac spine, medial and lateral aspects of the knee joint, medial and lateral ankle, and base of the second toe were removed. The remaining markers were retained to track segmental motion.

After completing a warm-up that consisted of 5 minutes of cycling at a self-selected pace and 2-3 minutes of lower body exercises (e.g., bodyweight squats and walking lunges) for a self-selected number of repetitions, the participants began the deadlift protocol. Participants chose their preferred starting position within the CDL style. Participants performed warm-up sets of the CDL exercise while self-selecting their repetitions and incrementally increasing weight during each warm-up set by ~10-20% of their estimated 1RM until reaching a weight that they corresponded to an RPE of 8 on a Borg Category-Ratio (CR-10) scale (31). An RPE of 8 was intended to correspond with participants having 2 repetitions in reserve (RIR) at the conclusion of each set (34). Therefore, if the participants performed deadlifts until concentric failure rather than stopping at rep 5, they would only be able to perform 7 total repetitions with the load they selected for this 5 x 5 CDL protocol. The participants then underwent a 5 x 5 CDL routine using the selected load with 2 to 5 minutes of rest between sets. The mean weight used for the deadlift protocol was 1.41±0.21 times body mass. Participants did not change the weight used for any of the 5 x 5 study protocol sets. Previous research has shown that resistance-trained participants can reliably assess RIR-based RPE when training within close proximity to failure during low-to-moderate-repetition sets (22, 33, 34). All participants performed the 5 x 5 CDL protocol with flat shoes and a double overhand (i.e., pronated) grip. Participants wore their own footwear and were instructed to bring their preferred flat shoes for the deadlift exercise. Grip technique was standardized to a double overhand grip for all participants since previous research has indicated that grip type can affect perceived exertion of a CDL (26) which could have influenced the loads that participants selected for the 5 x 5 CDL protocol. Participants were also not allowed to utilize equipment that may aid CDL performance such as belts and wrist straps. Previous yet limited research has indicated that wearing a belt when lifting a barbell from the floor may alter spine kinetics as compared to performing the same task without a belt (19). Wrist straps were not allowed since previous research has indicated that they may improve CDL performance (5, 18) and alter CDL perceived exertion (18). Furthermore, participants were instructed to pause for a brief moment between all reps to prevent bouncing of the barbell, since previous research has indicated that barbell bouncing may affect joint work and ground reaction force (GRF) during a CDL (20).

A kinematic model was constructed in Visual3D software (version 6; C-Motion, Inc., Germantown, MD, USA) for all trials so that the outcome variables of interest could be processed and assessed. The kinematic model was built using the reflective marker trajectories to include the upper and lower arm, trunk, pelvis, thigh, leg, and foot segments. Hip joint centers were identified as 25% of the intertrochanteric distance (3). All other joint centers were identified as the midpoint of each joint in accordance with the medial and lateral markers adhered around the joint. The raw data were smoothed using a 4th order bidirectional low-pass Butterworth digital filter with a cutoff frequency of 2 Hz for the kinematic data and 50 Hz for the GRF data. These cutoff frequencies were determined by conducting a Fast Fourier Transform on raw pilot data and inspecting the frequency in which the majority of these signals were contained. The filtered data from the force platforms were summed, creating a vertical GRF acting at the total body center of mass.

During piloting, it became clear that the reflective markers would not adhere to the barbell so that barbell velocity could be tracked. Therefore, barbell velocity was estimated from the average vertical center of mass velocity of the forearm segments. Three-dimensional angular positions of the segments and joints were calculated per a Cardan (X-Y-Z) rotation sequence, where X represented the medial-lateral axis, Y represented the anterior-posterior axis, and Z represented the longitudinal axis. The trunk segment angle was defined relative to the laboratory coordinate system. All joint angles were defined as the angle of the distal segment relative to the proximal segment. All angles are presented in agreement with the right-hand rule for rotational polarity. In addition to obtaining joint angles during the concentric and eccentric phases of each repetition, joint angles were also extracted at the time of peak vertical GRF during the concentric and eccentric phases. Net internal moments for the hip, knee, and ankle joints were calculated using Newtonian inverse dynamics. Joint moments were resolved in the coordinate system of the proximal segment of each joint and scaled to the participant's body mass. Joint angular velocities were calculated as the derivative of the joint angular positions with respect to time. Joint angular powers were calculated as the dot product of the joint angular velocities and the net joint moments. The net sum of the joint angular powers of the hip, knee, and ankle joints during the concentric and eccentric phases of each CDL repetition was also calculated. The concentric phase of each repetition was defined as the time when the sum of joint powers was positive as described in previous research (15). Similarly, the eccentric phase of each repetition was defined as the time when the sum of joint powers was negative (Figure 3). Joint angular work of the hip, knee, and ankle joints was obtained by integrating the angular power curves for each joint with respect to time during the concentric and eccentric phases of each repetition. The contribution towards lower extremity total angular work was calculated as the joint angular work of the hip, knee, or ankle joints divided by the sum of angular work of these three joints (16). Peak vertical GRF (PvGRF) was obtained from the sum of vertical GRF data during the concentric and eccentric phases of each repetition, respectively, and was scaled to the participant's body mass. Average vertical rate of force development (RFD) was calculated as the change in vertical GRF divided by the time between the peak GRF magnitudes, scaled to body mass, for the concentric and eccentric phase of each repetition. CDL performance outcomes were averaged across all sets.

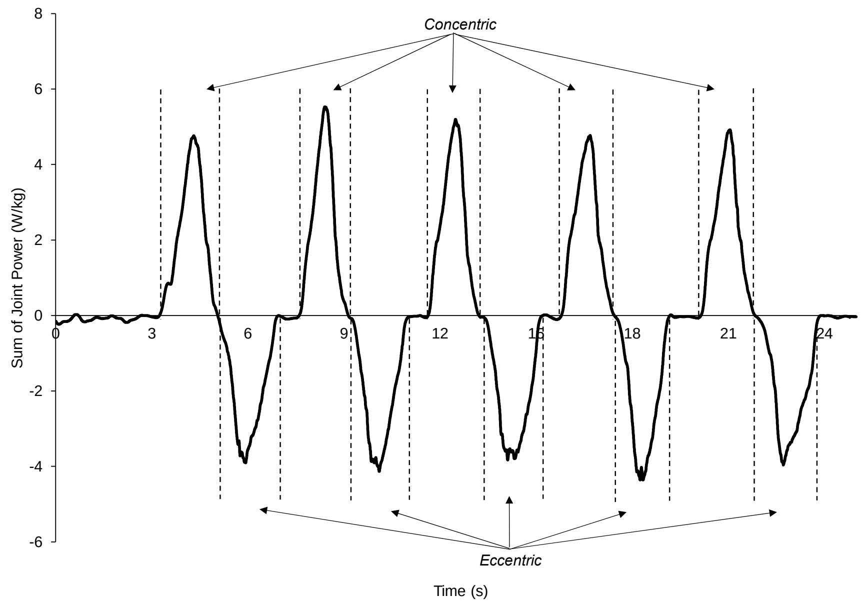

Figure 3. Exemplar representation for the net sum of joint power across five repetitions of deadlift exercise. The data represent five repetitions, beginning in the starting position, after which the first repetition begins with a concentric phase (~3s) and ends with an eccentric phase (~7s). Repetitions two through five then occur with the same pattern. Concentric: Concentric phase of deadlift repetitions, defined as the time during each repetition where the net sum of joint power is positive; Eccentric: Eccentric phase of deadlift repetitions, defined as the time during each repetition where the net sum of joint power is negative.

Statistical Analysis

Six anthropometric predictor variables of interest were originally selected for inclusion in this analysis: arm length, torso length, thigh length, shank length, hip circumference, and leg volume. These variables were selected based on their potential relevance to CDL performance. Other anthropometric variables that may be relevant to CDL performance, such as total body height and body mass, were not included to reduce the likelihood of multicollinearity between predictor variables in the multivariate regression model.

Data analysis was performed using R software (v. 4.0.2) (27). Relationships between the selected predictor variables of interest were examined using the *GGally* package to evaluate potential collinearity issues between the predictor variable (30). Hip circumference was highly correlated with shank length (r = 0.70; $p < 0.05$) and leg volume (r = 0.82; $p < 0.01$). Leg volume was also highly correlated with shank length (r = 0.89; $p < 0.001$). Therefore, to minimize collinearity issues, hip circumference and leg volume were not included in subsequent data analyses.

Multivariate regression and relative importance analysis (RIA) were conducted to determine the relative contribution that each of the predictors had on the outcome variables assessed. Regression was performed using the lm() function of the *stats* package. RIA was performed in the *relaimpo* package using the "lmg" method, which partitions the R^2 values by averaging over orders (11). For completeness, results from the RIA are presented both as normalized (i.e., sum to 100%) and non-normalized (i.e., sum to R^2) values. Skewness, kurtosis, nonlinear link function, and heteroscedasticity of the multivariate regressions were assessed using the *gvlma* package (25), which produces a collective global decision of whether linear regression assumptions are acceptable for a given model. When the global decision indicated that assumptions were not met, a quadratic term was added to address the violation as recommended by Peña and Slate (2006) (25). The global decision for all models indicated assumptions were acceptable, except for the models predicting eccentric knee work, concentric lower body work, and concentric RFD. Adding a quadratic term for shank length resulted in each of these three models demonstrating acceptable assumptions. Both the original models and the models with quadratic terms are presented for completeness.

Regression coefficient estimates, standard errors, and *p*-values were calculated and presented alongside the RIA metrics and overall model performance (i.e., multiple R^2, adjusted R^2, residual standard error, and *p*). Statistical significance was accepted at $p \leq 0.05$.

RESULTS

The selected anthropometric variables were not significantly related to the CDL performance outcomes, except for concentric ankle work (Table 2). Concentric ankle work was significantly related to thigh length ($p = 0.03$). However, in the overall model, anthropometric variables did not significantly predict ankle concentric work ($p = 0.11$; $R^2 = 0.67$; $R^2_{adj} = 0.45$; Table 3). In the model, thigh length accounted for 55% of the normalized variance ($RI_{\%}$) in ankle concentric work, as indicated by the RIA. The correlation between arm length and concentric ankle work was potentially noteworthy ($p = 0.06$; $RI_{\%} = 36\%$), as was the correlation between thigh length and eccentric average barbell velocity ($p = 0.06$; $RI_{\%} = 78\%$). Overall multiple linear regression model performance metrics are displayed in Table 3. Multiple R^2 values for the models ranged from 0.05 to 0.67, with adjusted R^2 values ranging from -0.59 to 0.45. Visualization of the regression model coefficients can be found in Figures 4 and 5. Deadlift performance metrics are contained in Table 4.

After the quadratic term for shank length was added to the models that originally did not meet all assumptions of the global decision (i.e., eccentric knee work, concentric lower body work, and concentric RFD), thigh length was found to be significantly correlated with concentric RFD ($p = 0.02$; $RI_{\%} = 63\%$). Additionally, the relationship between shank length and concentric RFD was potentially noteworthy ($p = 0.06$; $RI_{\%} = 13\%$). However, in the overall model, anthropometric predictors did not significantly predict concentric RFD ($p = 0.15$; $R^2 = 0.73$; $R^2 adj = 0.46$). These results can be found in the Tables 5 and 6, and the visualizations of the regression model coefficients for these results can be found in Figure 6.

Table 2. Results of multiple linear regression analysis.

		Arm Length					Torso Length				
		Est.	*SE*	*p*	*RI (abs)*	*RI (%)*	*Est.*	*SE*	*p*	*RI (abs)*	*RI (%)*
Eccentric	PvGRF (BW)	0.03	0.02	0.33	0.05	10.26	-0.01	0.02	0.56	0.02	3.91
	Average Barbell Velocity (m/s)	0.00	0.01	0.48	0.02	2.93	0.00	0.00	0.36	0.07	12.83
	Lower Body Work (N · m/kg)	0.02	0.09	0.80	0.06	28.26	0.00	0.06	0.98	0.00	0.23
	Hip Work (N · m/kg)	0.04	0.08	0.62	0.11	39.57	0.00	0.05	0.94	0.00	0.39
	Knee Work (N · m/kg)	0.00	0.02	0.85	0.00	6.88	0.00	0.01	0.80	0.01	19.92
	Ankle Work (N · m/kg)	-0.02	0.01	0.11	0.24	46.08	0.00	0.01	0.93	0.01	1.63
	RFD (BW/s)	0.01	0.04	0.81	0.01	3.01	-0.02	0.03	0.42	0.09	46.28
Concentric	PvGRF (BW)	0.04	0.03	0.26	0.08	15.22	-0.02	0.02	0.36	0.06	10.91
	Average Barbell Velocity (m/s)	0.01	0.01	0.44	0.15	49.78	0.00	0.01	0.72	0.01	4.01
	Lower Body Work (N · m/kg)	0.04	0.09	0.68	0.01	4.93	-0.01	0.06	0.90	0.00	0.34
	Hip Work (N · m/kg)	0.02	0.08	0.86	0.02	9.57	0.00	0.05	0.95	0.00	0.14
	Knee Work (N · m/kg)	-0.01	0.02	0.68	0.02	43.15	0.00	0.01	0.93	0.00	0.91
	Ankle Work (N · m/kg)	0.03	0.01	0.06	0.24	35.77	-0.01	0.01	0.57	0.01	1.42
	RFD (BW/s)	-0.02	0.15	0.89	0.01	1.30	-0.04	0.09	0.70	0.02	3.91
		Thigh Length					Shank Length				
		Est.	*SE*	*p*	*RI (abs)*	*RI (%)*	*Est.*	*SE*	*p*	*RI (abs)*	*RI (%)*
Eccentric	PvGRF (BW)	0.00	0.03	0.93	0.04	8.64	-0.08	0.04	0.08	0.37	77.20
	Average Barbell Velocity (m/s)	-0.01	0.01	0.06	0.40	77.67	0.01	0.01	0.35	0.03	6.56
	Lower Body Work (N · m/kg)	-0.05	0.09	0.65	0.02	10.99	0.11	0.13	0.42	0.13	60.52
	Hip Work (N · m/kg)	-0.03	0.09	0.73	0.01	4.83	0.11	0.12	0.41	0.15	55.20
	Knee Work (N · m/kg)	0.01	0.02	0.59	0.05	70.18	0.00	0.03	0.93	0.00	3.01
	Ankle Work (N · m/kg)	-0.03	0.01	0.10	0.24	44.55	0.01	0.02	0.66	0.04	7.74
	RFD (BW/s)	-0.02	0.04	0.70	0.04	21.17	-0.04	0.06	0.56	0.06	29.54
Concentric	PvGRF (BW)	-0.03	0.03	0.44	0.15	28.56	-0.08	0.04	0.13	0.23	45.31
	Average Barbell Velocity (m/s)	0.00	-0.01	0.99	0.00	1.02	0.01	0.02	0.51	0.14	45.18
	Lower Body Work (N · m/kg)	0.12	0.09	0.26	0.15	56.57	-0.14	0.13	0.32	0.10	38.17

Hip Work (N · m/kg)	0.07	0.09	0.43	0.06	24.32	-0.14	0.12	0.29	0.16	65.97
Knee Work (N · m/kg)	0.00	0.02	0.98	0.00	10.11	0.01	0.03	0.67	0.02	45.83
Ankle Work (N · m/kg)	0.04*	0.01	0.03	0.37	54.55	-0.01	0.02	0.63	0.06	8.27
RFD (BW/s)	-0.30	0.15	0.10	0.39	91.86	0.03	0.21	0.89	0.01	2.92

* Indicates $p < 0.05$. PvGRF: Peak vertical ground reaction force, BW: body weight, RFD: rate of force development, RI: relative importance.

Table 3. Overall performance of regression models.

	Variable	Multiple R^2	Adjusted R^2	RSE	*p*
Eccentric	PvGRF (BW)	0.48	0.13	0.21	0.35
	Average Barbell Velocity (m/s)	0.52	0.20	0.04	0.29
	Lower Body Work (N · m/kg)	0.21	-0.32	0.75	0.80
	Hip Work (N · m/kg)	0.28	-0.21	0.69	0.69
	Knee Work (N · m/kg)	0.07	-0.55	0.17	0.98
	Ankle Work (N · m/kg)	0.53	0.22	0.11	0.27
	RFD (BW/s)	0.20	-0.33	0.35	0.82
Concentric	PvGRF (BW)	0.52	0.19	0.25	0.29
	Average Barbell Velocity (m/s)	0.30	-0.16	0.09	0.64
	Lower Body Work (N · m/kg)	0.26	-0.24	0.74	0.72
	Hip Work (N · m/kg)	0.24	-0.26	0.69	0.75
	Knee Work (N · m/kg)	0.05	-0.59	0.18	0.99
	Ankle Work (N · m/kg)	0.67	0.45	0.12	0.11
	RFD (BW/s)	0.42	0.04	1.21	0.44

PvGRF: Peak vertical ground reaction force, BW: body weight, RFD: rate of force development, RSE: residual standard error.

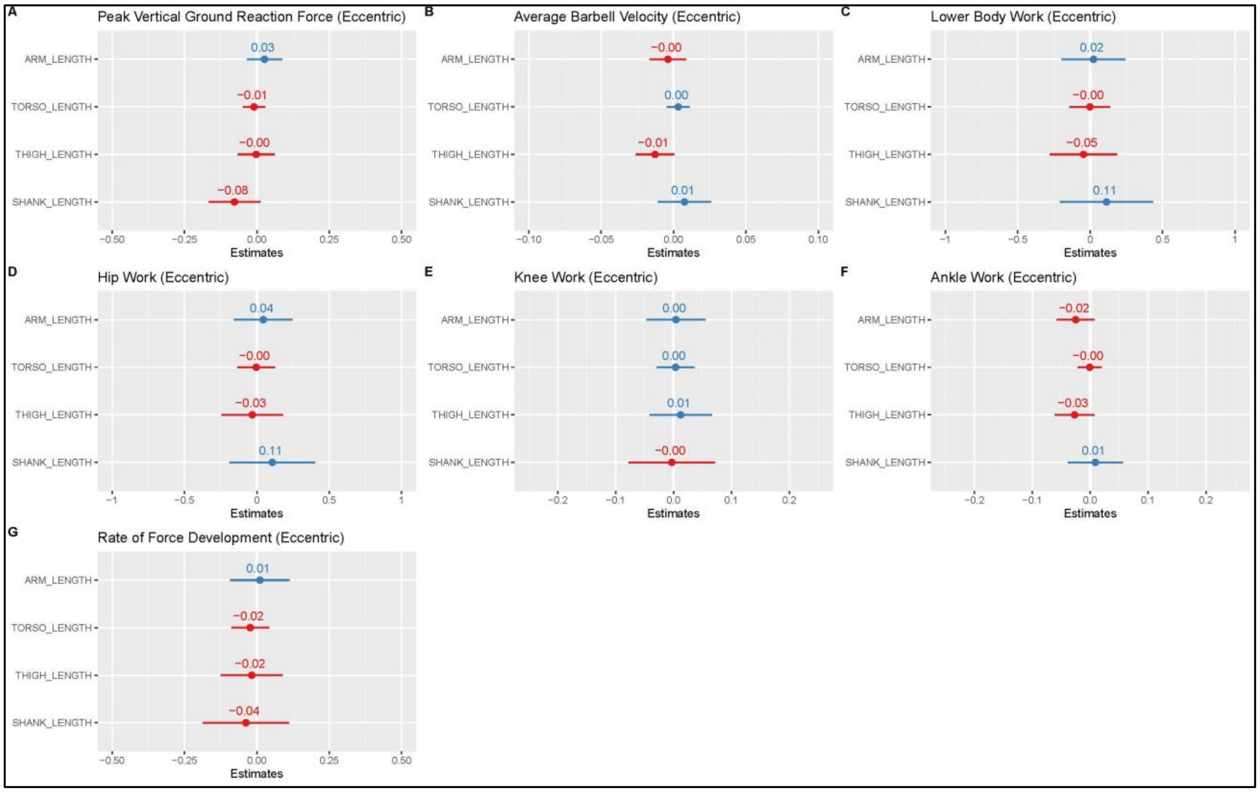

Figure 4. Model coefficients for eccentric conventional deadlift performance outcomes.

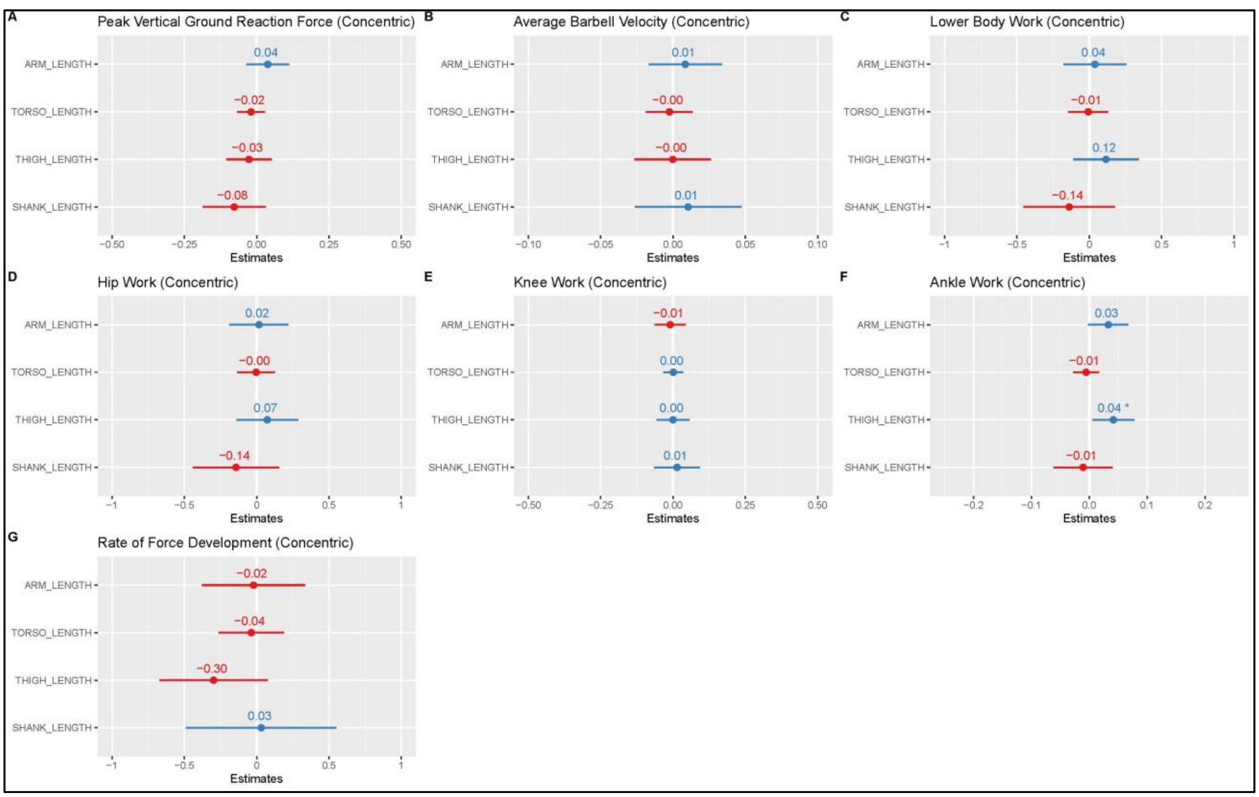

Figure 5. Model coefficients for concentric conventional deadlift performance outcomes. * Indicates $p \leq 0.05$

Table 4. Deadlift performance of study participants.

	Mean	SD	Min	Max
CDL Weight for 5 x 5 (kg)	125.41	20.48	102.27	152.27
CDL Weight for 5 x 5 relative to BM	1.41	0.21	1.15	1.73
Eccentric PvGRF (BW)	2.74	0.22	2.42	3.08
Eccentric Average Barbell Velocity (m/s)	-0.40	0.05	-0.48	-0.32
Eccentric Lower Body Work (N · m/kg)	-3.14	0.65	-4.27	-2.04
Eccentric Hip Work (N · m/kg)	-2.99	0.63	-3.87	-2.16
Eccentric Knee Work (N · m/kg)	0.02	0.14	-0.21	0.22
Eccentric Ankle Work (N · m/kg)	-0.16	0.12	-0.44	-0.02
Eccentric RFD (BW/s)	0.97	0.30	0.49	1.59
Concentric PvGRF (BW)	2.87	0.28	2.50	3.31
Concentric Average Barbell Velocity (m/s)	0.46	0.08	0.33	0.57
Concentric Lower Body Work (N · m/kg)	3.56	0.66	2.22	4.68
Concentric Hip Work (N · m/kg)	3.22	0.62	2.29	4.07
Concentric Knee Work (N · m/kg)	0.06	0.15	-0.24	0.31
Concentric Ankle Work (N · m/kg)	0.28	0.16	0.04	0.59
Concentric RFD (BW/s)	3.99	1.23	2.13	6.29

CDL: conventional deadlift, BM: body mass, PvGRF: peak vertical ground reaction force, BW: body weight, RFD: rate of force development.

Table 5. Multiple linear regression results after addition of quadratic term.

		Arm Length					Torso Length				
		Est.	*SE*	*p*	*RI (abs)*	*RI (%)*	*Est.*	*SE*	*p*	*RI (abs)*	*RI (%)*
Eccentric	Knee Work (N · m/kg)	-0.01	0.02	0.69	0.01	1.55	-0.01	0.01	0.33	0.05	9.04
Concentric	Lower Body Work (N · m/kg)	0.05	0.10	0.65	0.02	5.76	0.01	0.08	0.92	0.00	0.56
	RFD (BW/s)	-0.11	0.12	0.40	0.02	2.32	-0.17	0.09	0.11	0.07	8.93
		Thigh Length					Shank Length				
		Est.	*SE*	*p*	*RI (abs)*	*RI (%)*	*Est.*	*SE*	*p*	*RI (abs)*	*RI (%)*
Eccentric	Knee Work (N · m/kg)	-0.01	0.02	0.70	0.03	6.83	2.23	1.05	0.09	0.21	41.31
Concentric	Lower Body Work (N · m/kg)	0.13	0.11	0.30	0.16	58.12	-2.03	6.06	0.75	0.05	17.86
	RFD (BW/s)	-0.45*	0.13	0.02	0.46	62.64	16.43	6.89	0.06	0.10	13.05
		Shank Length^2									
		Est.	*SE*	*p*	*RI (abs)*	*RI (%)*					
Eccentric	Knee Work (N · m/kg)	-0.02	0.01	0.09	0.21	41.26					
Concentric	Lower Body Work (N · m/kg)	0.02	0.07	0.77	0.05	17.70					
	RFD (BW/s)	-0.18	0.08	0.06	0.10	13.06					

PvGRF: Peak vertical ground reaction force, BW: body weight, RFD: rate of force development, RI: relative importance.

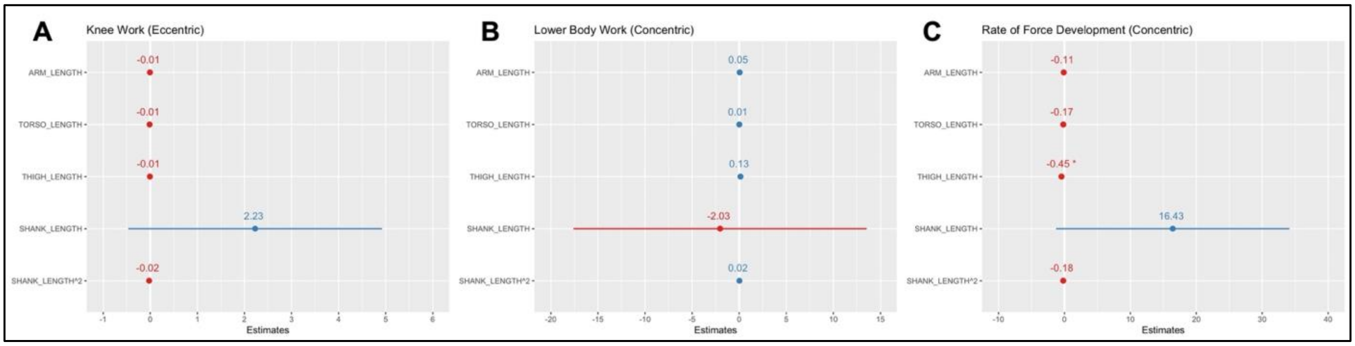

Figure 6. Model coefficients for select CDL outcomes after addition of quadratic term to model. * Indicates $p \leq 0.05$

Table 6. Overall regression model performance after addition of quadratic term.

	Variable	Multiple R^2	Adjusted R^2	*RSE*	*p*
Eccentric	Knee Work (N · m/kg)	0.51	0.02	0.14	0.48
Concentric	Lower Body Work (N · m/kg)	0.27	-0.45	0.80	0.85
	RFD (BW/s)	0.73	0.46	0.91	0.15

PvGRF: Peak vertical ground reaction force, BW: body weight, RFD: rate of force development, RSE: residual standard error.

DISCUSSION

The aim of this preliminary analysis was to determine if there are relationships between relevant anthropometric characteristics and CDL kinematics and kinetics during a 5 x 5 CDL routine in resistance-trained males. The results from this study suggest that the examined anthropometric variables may not be predictive of CDL performance in resistance-trained males completing a 5 x 5 deadlift routine at an RPE of 8. The only predictor variable that significantly correlated with an outcome variable in the original linear models was thigh length, which accounted for 55% of the normalized variance in ankle concentric work. This observation could be due to those with longer thighs experiencing more ankle dorsiflexion when preparing to perform a CDL repetition, and thus requiring more ankle concentric work through plantar flexion during the concentric phase of the lift.

While it was expected that additional predictor variables would correlate with CDL outcomes, the present null results align with some aspects of the limited previous research. For instance, Cholewa et al. (2019) found that the ratios of arm length to height, arm length to sitting height, thigh length to height, lower leg length to thigh length, and lower leg length to height did not correlate with sumo deadlift strength relative to CDL strength (4). Similarly, Ferland et al. (2020) found that several anthropometric predictors such as arm, forearm, thigh, shank, trunk, and reach length were not predictive of 1RM CDL performance when analyzing the data from all of the participants together (8). However, some anthropometric predictors have been shown to correlate with some CDL performance outcomes (4, 7, 8, 21). Interestingly, when stratifying their data into the powerlifter cohort and the American football player cohort, Ferland and colleagues (2020) did find significant relationships between lower leg length and CDL 1RM ($r = 0.48$; $p < 0.05$) and reach length and CDL 1RM ($r = 0.48$; $p < 0.05$) in the powerlifter cohort but not the

American football player cohort (8). This finding may be explained by the fact that powerlifters and American football players tend to differ in body shape and size. As noted by Ferland and colleagues (2020), the average powerlifter was shorter and lighter than the average American football player (8). Given the nuances and divergent findings across these studies, the ability to make clear application is limited at present. Clearly, additional research in distinct populations is needed before definitive conclusions can be made about the degree to which anthropometrics may influence CDL performance.

One reason why our findings regarding torso length and arm length differed from the findings of previous studies could relate to differences in how limb lengths were defined across these studies. For example, Cholewa and colleagues (2019) described torso height as being the distance between the top of the head and the chair in which participants were sitting at the time of measurement, whereas torso height in the present study was assessed as the distance from the back neck point to center back waist point (4). Additionally, Ferland and colleagues (2020) defined arm length as the distance between the lateral posterior apex of the acromion to apex of the olecranon, whereas total arm length in this study was assessed as the straight distance from the shoulder point to the wrist (8). Another source of variation among studies is how limb lengths were measured. For instance, most lab groups manually measured anthropometrics using a tape measure (4, 7, 21). In the present study, anthropometric measurements were assessed by a 3-dimensional optical scanner, and the corresponding limb lengths were measured by the software associated with the optical scanner. While other investigations generally did not report the reliability of anthropometric assessments, we have previously reported the extremely high reliability of assessments conducted via 3-dimensional optical imaging (29). Although this methodological difference may exert a relatively small amount of error, it is possible that additional "noise" due to measurement variation in manual assessments made real but small effects more difficult to observe.

A possible explanation for why most of the anthropometric predictors assessed in the present study did not correlate significantly with most of the CDL performance outcomes may have to do with differences in CDL set-up across participants. It is plausible that many resistance-trained lifters may gravitate towards a CDL set-up and lifting technique that results in similar relative joint work, RFD, and average barbell velocity even when compared to other trained lifters of varying body shapes and sizes. Some set-up preferences that may alter CDL performance are the height of the hips, stance width and toe angle, and grip width and style.

Although the present analysis was considered preliminary *a priori*, there are some key limitations to this study that should be considered. First, the sample size was very small and only included male participants, which makes it difficult to infer if these results would be generalizable to female participants and at the population level. Given that previous research has indicated various anatomical differences may exist between the sexes and across some racial groups, the results of this study may have been different if the sample size was larger, more diverse, and inclusive of female participants (2, 6, 9). In fact, previous research has found differences in peak and average velocities between males and females performing the CDL (17).

Additionally, Lockie and colleagues (2018) found that there were some differences between the sexes in regard to how arm length and leg length influenced CDL mechanics (21). Second, while the participants in the present study were resistance-trained, their CDL strength was modest, which may indicate that these participants were not well trained in this exercise or were not highly trained relative to some other investigations. The external loads used in this study protocol ranged from 102.3 - 152.3 kg (mean ± SD: 125.4 ± 20.5 kg) while the body mass of participants ranged from 69.5 - 132.0 kg (mean ± SD: 89.9 ± 16.0 kg). According to the National Strength and Conditioning Association, this would estimate the average 1RM CDL for participants in this study to be approximately 150 kg, assuming the participants correctly selected a load that corresponded to placing them at an RPE of 8 (12). Thus, participants in this study, on average, could only deadlift approximately 1.7 times their body mass for one repetition. Relative to highly resistance-trained athletes from a variety of sports, this is quite modest. However, the requirement of using a double overhand grip could have limited the strength of participants who were accustomed to using an alternate grip or aids such as lifting straps. Nonetheless, since the participants in this study were not very strong in the CDL exercise, one cannot assume that the results from this study can be extrapolated to those who are highly trained in the CDL. This may help explain why there were differences in results from this study and the study done by Ferland and colleagues (2020), since their participants had an average CDL 1RM of 2 times body mass in the football players cohort and 2.8 times body mass in the powerlifters cohort (8). Third, the present study protocol used a 5 x 5 routine at an RPE of 8, so results from this study may have been different if the protocol's CDL volume, target RPE, or both were altered – or if other exercises were included in the protocol before commencing the CDL. Nevertheless, a 5 x 5 routine is a very popular set-by-rep scheme, and the deadlift exercise is often performed at the beginning of a training session for many lifters.

We have several recommendations for future research examining how anthropometrics may influence deadlift performance. First, researchers should collect detailed background information on the participant's training history so that the relationships between training history and deadlift performance can either formally be considered in the analysis or simply presented in the paper to provide more context to the results. Second, researchers should collect a more diverse sample of participants that includes well-trained participants and female participants, given that anthropometrics may influence CDL performance differently in these populations. Third, researchers could also include a sumo deadlift, trap bar deadlift, or both in a similar study design, given the limited existing research on these popular deadlift variations. Fourth, researchers could utilize a different set-by-rep scheme, target RPE, or both for the deadlift protocol to investigate if anthropometrics influence deadlift performance to a greater extent during higher- or lower-repetition sets, when training closer to failure, or both. Fifth, researchers may want to consider standardizing the definitions of various limb lengths so that the results from future studies can be more directly compared. If not, sufficient description of anthropometric measurements, and the reliability of those measurements within the particular laboratory, should be clearly reported or referenced. Lastly, given the large number of predictor and outcome variables that could be included in a study examining the relationships between anthropometrics and performance outcomes, as well as the variety of statistical techniques that could be used to analyze such results, future researchers should consider pre-registration of their study designs and preliminary analysis plans.

In conclusion, while it is plausible that some anthropometric predictors may influence CDL performance, the results of the present study suggest that arm length, torso length, and shank length may not play a large role in several CDL kinematic and kinetic outcomes, although thigh length may be positively correlated with ankle concentric work during a 5 x 5 CDL routine in resistance-trained males.

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