Biomechanical analysis of the deadlift during the 1999 Special Olympics World Games

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ABSTRACT

ESCAMILLA, R. F., T. M. LOWRY, D. C. OSBAHR, and K. P. SPEER. Biomechanical analysis of the deadlift during the 1999 Special Olympics World Games. *Med. Sci. Sports Exerc.*, Vol. 33, No. 8, 2001, pp. 1345–1353. **Purpose:** Improper lifting techniques may increase injury risks and decrease performance. The aim of this study was to compare and contrast biomechanical parameters between sumo and conventional style deadlifts and between high- and low-skilled lifters who participated in the powerlifting event during the 1999 Special Olympics World Games. **Methods:** Two synchronized video cameras collected 60 Hz of data from 40 subjects. Parameters were quantified at barbell liftoff (LO), when the barbell passed the knees (KP), and at lift completion. **Results:** Compared with the conventional group, the sumo group had a 100% greater stance width, 20% smaller hand width, 10% less vertical bar distance, a more vertical trunk at LO, a more horizontal thigh at LO and KP, a less vertical shank at KP, and greater forefoot abduction. The sumo group generated ankle dorsiflexor, knee extensor, and hip extensor moments, whereas the conventional group produced ankle plantar flexor, knee flexor and extensor, and hip extensor moments. Compared with low-skilled lifters, high-skilled lifters had a 40% greater barbell load, 15% greater stance width (sumo group only), greater knee flexion at LO (conventional group only), greater knee extension at KP, a less vertical shank position at LO (sumo group only), 15% less vertical bar distance, less first peak bar velocity between LO and KP (conventional group only), smaller plantar flexor and hip extensor moment arms at LO and KP, and greater knee extensor moment arms at LO. **Conclusions:** The sumo deadlift may be more effective in working ankle dorsiflexors and knee extensors, whereas the conventional deadlift may be more effective in working ankle plantar flexors and knee flexors. High-skilled lifters exhibited better lifting mechanics than low-skilled lifters by keeping the bar closer to the body, which may both enhance performance and minimize injury risk. **Key Words:** POWERLIFTING, JOINT MOMENTS, JOINT MOMENT ARMS, JOINT ANGLES, SEGMENT ANGLES, KINEMATICS, KINETICS, MECHANICAL WORK

The deadlift is one of three lifts in powerlifting competition. This exercise, which measures overall body strength, begins with the lifter in a squat position, arms straight and pointing down, and an alternating hand grip used to hold a bar positioned in front of the lifter's feet. The deadlift is performed using either a conventional or sumo style (Figs. 1 and 2). The primary differences between these two styles are that the feet are positioned further apart and turned out in the sumo style, and the arms are positioned inside the knees for the sumo style and outside the knees for the conventional style (5).

There are eight known studies that have examined biomechanical variables during the barbell deadlift (1–3,5–8,11). Three studies examined lumbar spinal loads (2,3,6), two studies investigated the effects of intra-abdominal and intra-thoracic pressures (7,8), one study quantified joint and segmental angles (11), and two studies calculated joint and segment angles and joint moments (1,5). However, only three of these studies compared kinematic or kinetic parameters between sumo and conventional deadlifts (3,5,11). Escamilla et al. (5), who conducted the only known three-dimensional (3-D) biomechanical analysis of the deadlift, examined kinematic and kinetic variables between sumo and conventional deadlifts during a national powerlifting competition. These authors found several significant kinematic and kinetic differences between the sumo and conventional deadlifts. They also reported that a two-dimensional (2-D) biomechanical analysis was adequate when analyzing kinematic and kinetic parameters during the conventional deadlift, but a 3-D analysis was needed to accurately calculate these parameters during the sumo deadlift. McGuigan and Wilson (11) performed a 2-D kinematic analysis using male lifters from two regional powerlifting championships. The only significant differences they observed were that the sumo group had a more upright trunk and less hip flexion at liftoff, and the shank range of motion was greatest in the sumo group. Cholewicki et al. (3) quantified lumbar loads and hip and knee moments between the sumo and conventional deadlifts during a national powerlifting championship. They found significantly greater L4/L5 shear forces and moments in the conventional group, whereas hip and knee moments were not significantly different between the two deadlift styles.

In the three known studies that have compared biomechanical parameters between sumo and conventional deadlifts, skilled powerlifters without mental retardation were utilized. There are no known studies that have examined biomechanical parameters for athletes with mental retardation, such as in the

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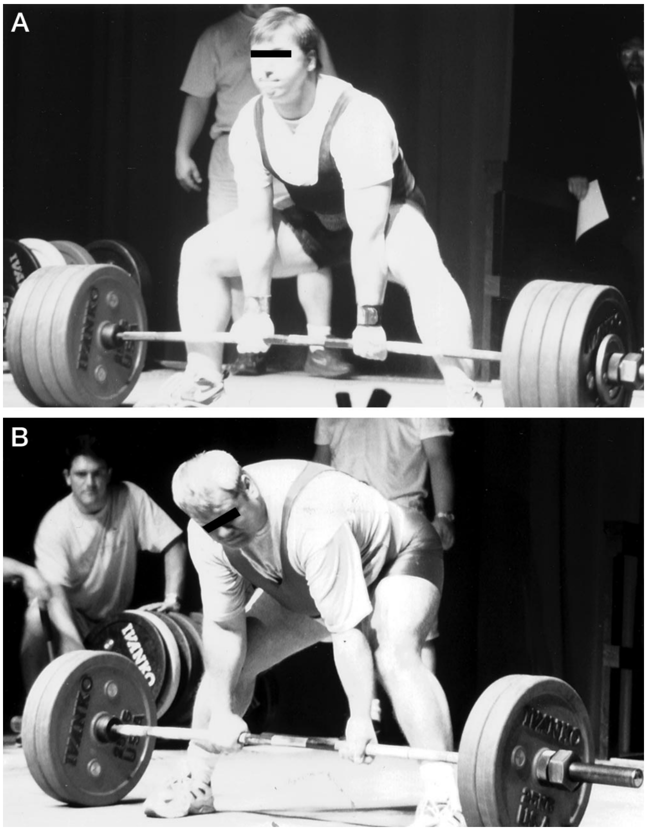

FIGURE 1—High (top)- and low (bottom)-skilled sumo deadlifts.

FIGURE 2—High (top)- and low (bottom)-skilled conventional deadlifts.

Special Olympics powerlifting competition. All participants of the 1999 Special Olympics World Games had varying levels of mental retardation, with an intelligence quotient generally less than 80. Although all powerlifters in the Special Olympics have coaches, most of these coaches are not experts on the proper techniques of performing the deadlift, but rather volunteers who have an interest in supporting athletes with mental retardation. It is believed that results from the current study will aid coaches and volunteers in teaching proper lifting mechanics to powerlifters competing in Special Olympics powerlifting competition.

Since powerlifting is one of the events in Special Olympics competition, it was the purpose of the current study to quantify and compare joint and segment angles, ankle, knee, and hip moments, and ankle, knee, and hip moment arms between sumo and conventional deadlifts during the 1999 Special Olympics World Games. These biomechanical parameters are important because improper lifting mechanics can both increase injury risk and decrease performance. It was hypothesized that significant kinematic and kinetic differences would be found between sumo and conventional deadlifts. In addition, high- and low-skilled lifters were compared with each other for both sumo and conventional deadlifts, with skill level determined by normalized body weight and load lifted. High- and low-skilled lifters performing the deadlift were biomechanically analyzed by Brown and Abani (1) in a study of powerlifters without mental retardation during the 1981 Michigan Teenage Powerlifting Championships. These authors reported several significant kinematic and kinetic differences between low- and high-skilled lifters. It was hypothesized that the high-skilled group would maintain a more erect trunk and generate a smaller hip extensor moment arm and vertical bar distance compared with the low-skilled group.

MATERIALS AND METHODS

Subjects. Over 200 powerlifters from 22 countries participated during the powerlifting competition (squat, bench press, and deadlift) of the 1999 Special Olympics World Games, which was held in Raleigh, NC. Approximately 150–175 of these lifters performed the deadlift. Because most of these lifters were male, the current study was limited to male subjects. Forty male powerlifters, 20 subjects performing the conventional deadlift and 20 subjects performing the sumo deadlift, were randomly selected from the 150–175 lifters to serve as subjects. These 40 subjects, who represented 13 different countries, all wore a one-piece lifting suit during competition. Written informed consent was obtained and approved by the Special Olympics World Games organization committee and by the institutional review board of Duke University Medical Center. Mean age, body mass, body height, and load lifted are shown in Table 1.

TABLE 1. Anthropometric, temporal, and work comparisons (mean ± SD) between sumo and conventional deadlift groups and between high- and low-skilled deadlift groups.

	Sumo Group (N = 20)	Conventional Group (N = 20)	High-Skilled Group (N = 20)	Low-Skilled Group (N = 20)
Age (yr)	24.9 ± 5.5	25.2 ± 4.2	24.8 ± 4.5	25.3 ± 5.2
Body height (cm)	168 ± 8	167 ± 10	154.3 ± 8.5	156.9 ± 9.8
Body mass (kg)	75.7 ± 19.2	76.1 ± 13.0	71.6 ± 13.9	80.3 ± 17.4
Barbell load (kg)	125.5 ± 31.9	137.8 ± 49.3	154.3 ± 41.5[b]	109.0 ± 26.8[b]
Schwartz score (pts)	87.9 ± 20.5	91.9 ± 26.9	109.0 ± 15.4[b]	70.7 ± 11.9[b]
Stance width (cm)[c]	73 ± 12[a]	37 ± 10[a]	58.1 ± 24.3	51.8 ± 18.7
Stance width (% shoulder width)[c]	194 ± 30[a]	93 ± 26[a]	152.2 ± 66.5	134.3 ± 47.5
Hand width (cm)	50 ± 10[a]	63 ± 10[a]	54.7 ± 10.9	57.8 ± 13.3
Total lift time (s)	2.39 ± 0.71	2.36 ± 0.70	2.36 ± 0.66	2.38 ± 0.74
Time from liftoff to knee passing (s)	0.81 ± 0.19	0.74 ± 0.20	0.75 ± 0.16	0.80 ± 0.23
Time at sticking point (s)	1.59 ± 0.31	1.63 ± 0.50	1.58 ± 0.42	1.65 ± 0.42
Total vertical bar distance (% height)	27.7 ± 3.5[a]	30.2 ± 2.3[a]	27.2 ± 2.5[b]	30.7 ± 2.9[b]
Total vertical bar distance (cm)	46.6 ± 4.7[a]	50.6 ± 5.8[a]	45.2 ± 5.2[b]	51.9 ± 6.1[b]
Total mechanical work on bar (J)	338 ± 88[a]	402 ± 103[a]	413 ± 119[b]	328 ± 85[b]

The sumo and conventional groups consisted of both high- and low-skilled lifters combined, whereas the high- and low-skilled groups consisted of both sumo and conventional lifters combined.
[a] Significant differences ($P < 0.01$) between sumo and conventional groups.
[b] Significant differences ($P < 0.01$) between high- and low-skilled groups.
[c] Significant interaction (deadlift style × skill level) ($P < 0.01$).

The Schwartz score, which is used in powerlifting competition to normalize the barbell load to each lifter's body mass, was used to compare relative loads lifted between sumo and conventional groups. The Schwartz score is determined by multiplying the load lifted by a body mass–dependent coefficient. These coefficients range between 1.2803 and 0.4796 for corresponding body masses between 40.9 and 164.5 kg. Therefore, small body mass individuals are assigned a high coefficient, and large body mass individuals are assigned a low coefficient. A complete list of Schwartz coefficients for any given body weight can be found in official powerlifting rulebooks. The Schwartz score was also used to rank from high to low the 20 subjects in the conventional group and the 20 subjects in the sumo group. Subjects with the top 10 Schwartz score rankings in the sumo and conventional deadlift groups were classified as high-skilled lifters, and those with the bottom 10 Schwartz score rankings in the sumo and conventional deadlift groups were classified as low-skilled lifters. Therefore, both the high-skilled and low-skilled groups had a total of 20 subjects. High- and low-skilled sumo and conventional lifters are shown in Figures 1 and 2.

Data collection. Two synchronized gen-locked Peak Performance video cameras (Peak Performance Technologies, Inc., Englewood, CO) were used to collect 60-Hz video data. One camera faced the subject's left side and the other camera faced the subject's right side, with each camera's optical axis forming a 45° angle to the sagittal plane of the lifter. The cameras were positioned approximately 12 m apart and faced perpendicular to each other, with each camera approximately 8 m from the subject. To minimize the effects of digitizing error, the cameras were positioned so that the lifter–barbell system was as large as possible within the viewing area of the cameras.

Approximately 10 flights (two flights per day) of the deadlift competition were videotaped over a 5-d period, with approximately 10–15 lifters in each flight. For each camera view, videotaping began approximately 3 min before a lifter started his lift and ended approximately 2–3 min after the completion of the lift. An event synchronization device (Peak Performance Technologies, Inc.) was used to generate a time code directly onto the video signals, thereby allowing corresponding time-synchronized video frames between the two videotapes to be determined. Before and just after the subjects were videotaped, a 2 × 1.5 × 1-m 3-D calibration frame (Peak Performance Technologies, Inc.), surveyed with a measurement tolerance of 0.5 cm, was positioned and videotaped in the same volume occupied by the lifter–barbell system. The calibration frame was composed of 24 spherical balls of known spatial coordinates, with the x- and z-axes positioned parallel to the ground and the y-axis pointing vertical.

Data analysis. According to the International Powerlifting Federation rules at the time of the current study, a successful deadlift involved the barbell being lifted upward in a continuous motion until the lifter was standing erect with knees locked and the shoulders thrust back in line with the torso. Causes for disqualification included lowering the barbell before the referee's "down" signal at the completion of the lift, any downward movement of the bar once the bar leaves the lifting platform, failure to stand erect with locked knees and shoulders thrust back, any shifting of the feet, and any "hitching," bouncing, or resting of the bar against the thighs during the lift. All deadlift trials analyzed in the current study were in accordance with these International Powerlifting Federation rules.

In powerlifting competition, a lifter is given three attempts during the deadlift to maximize the amount of weight they can lift. A lifter's first attempt is usually submaximal; their second and third attempts are near the maximal weight they are capable of lifting. Therefore, only second and third attempts that were successfully completed (i.e., ruled a "good lift" by at least two of the three judges) were analyzed. Twenty-four of the 40 lifts analyzed were third attempts. The 16 second-attempt lifts were used because the third attempts were unsuccessful due to the lifter attempting a weight that was beyond their one repetition maximum (1 RM), or the lift was disqualified due to a rules infraction. Therefore, it was believed that all lifts analyzed were near each lifter's 1 RM.

Three events were defined during the deadlift. The first event was barbell liftoff (LO), which was defined as the first picture in which the barbell disks on both sides of the bar were no longer in contact with the lifting platform. Because both sides of the bar typically remained symmetrical throughout the lift, the left- and right-side barbell disks left the lifting platform at approximately the same time. Therefore, at LO the lifter was supporting the entire barbell load. The next event was at the instant the bar passed the knees (KP), which was defined as the first picture when the vertical position of the bar was higher than the vertical position of the knees. The last event was lift completion (LC), which occurred when the lifter was in an upright position with the knees and hips fully extended and the shoulders thrust back. At this time, the head judge gave the "down" command, signaling the end of the lift. Total lift time was defined from LO to LC.

A 3-D video system (Peak Performance Technologies, Inc.) was used to manually digitize data for all 40 subjects. A 15-point spatial model was created, comprising the top of the head and centers of the left and right mid-toes, ankles, knees, hips, shoulders, hands, and end of bar. All points were seen in each camera view. Each of these 15 points was digitized in every video field (60 Hz), which was adequate because of the slow movement of the lift (1,3,5,10). Digitizing began 15 video fields (0.25 s) before LO and ended 15 video fields after LC.

A fourth-order, zero-lag Butterworth digital filter was used to smooth the raw data with a cutoff frequency of 5 Hz (4,5,11). Using the direct linear transformation method (15,16), 3-D coordinate data were derived from the 2-D digitized images from each camera view. An average resultant mean square calibration error of 0.3 cm produced an average volume percent error of 0.121.

The origin of the 3-D orthogonal axis system was first translated to the right ankle joint and rotated so that the positive x-axis pointed to the left ankle joint, the positive z-axis pointed anteriorly in the direction the lifter was facing, and the y-axis pointed in the vertical direction (5). The vertical positions of the digitized left and right ankles were within 1 cm of each other. This axes system was initially used to calculate all joint moments, joint moment arms, and joint and segment angles. Because hip flexion and extension during sumo and conventional deadlifts occur primarily in the y-z sagittal plane about the x-axis, hip moments were calculated about the x-axis and hip moment arms were calculated in the z-axis direction. Because the feet were turned approximately 15–25° during the deadlift, ankle and knee flexion and extension occurred in a plane between the y-z sagittal plane and x-y frontal plane established above. Therefore, erroneous moment arm measurements would occur if the above axes system were used for a 3-D analysis, because ankle and knee movements do not occur in the sagittal plane during the sumo deadlift (5). Therefore, the axes system was translated to each ankle joint center and rotated so that the positive z-axis pointed in the direction of the mid-toes, the y-axis pointed vertical, and the x-axis was orthogonal to the y- and z-axes. Hence, for both sides of the body, ankle and knee moments were calculated about the x-axis, and ankle and knee moment arms were calculated in the z-axis direction.

Linear and angular displacements and velocities were calculated for both the left and right sides of the body and then averaged (5). Escamilla et al. (5) have previously demonstrated the symmetrical nature of the deadlift, showing negligible differences between left- and right-side kinematic measurements. Relative knee and hip angles and absolute trunk, thigh, and shank angles were defined in accordance with previous studies (1,5,11). Trunk, thigh, and shank angles were measured relative to the x-z horizontal plane (i.e., relative to a sagittal view of the lifter's right side). Knee angles were measured relative to the thigh and leg segments. Although the hip angle is actually formed between the pelvis and the femur, this measurement cannot accurately be determined without external markers affixed to these segments. Therefore, the hip angle was defined as the relative angle between the trunk (hip to shoulder segment) and thigh (hip to knee segment). As long as the trunk remains rigid and straight, this relative angle approximates the true hip angle. However, during the deadlift the trunk does not remain rigid and straight, because spinal flexion causes the back to round to some extent, especially when maximum weight is used. As the spine flexes during the deadlift, the shoulders drop downward, causing the hip angle measurement to decrease and underestimate its true value. Foot angle was defined as the angle formed between the foot segment and the y-z sagittal plane. Stance width was defined as the linear distance between the left and right ankle centers, and hand width was defined as the linear distance between the left and right hand centers.

Escamilla and colleagues (5) have shown that during the 1 RM deadlift the barbell initially accelerates at LO to a first peak velocity (acceleration phase), then decelerates to a minimum velocity (sticking region), accelerates again to a second peak velocity (maximum strength region), and finally decelerates until LC (deceleration phase). These lifting phases and regions were calculated in the current study.

Because segment and barbell accelerations are very small while lifting maximum or near maximum loads, joint moments can accurately be calculated using quasi-static models (9,10,12–14). Lander et al. (10) found that joint moments varied less than 1% between quasi-static and dynamic analyses during the squat exercise with near maximum loads. Left and right hip, knee, and ankle moments and moment arms were calculated at LO, KP, and LC and then averaged (5). Escamilla et al. (5) have previously demonstrated negligible differences between left- and right-side kinetic measurements. Joint moments and moment arms were calculated relative to the barbell center of mass (COM_{bar}) (5). The geometric center of the barbell represented COM_{bar}. The x-,

TABLE 2. Joint and segment angles (mean ± SD) between sumo and conventional deadlift groups and between high- and low-skilled deadlift groups.

	Sumo Group (N = 20)	Conventional Group (N = 20)	High-Skilled Group (N = 20)	Low-Skilled Group (N = 20)
Liftoff				
Hip (°)	59 ± 9	56 ± 8	59 ± 7	55 ± 10
Knee (°)[c]	121 ± 12	121 ± 12	121 ± 7	120 ± 16
Trunk (°)	16 ± 6[a]	11 ± 7[a]	15 ± 7	12 ± 10
Thigh (°)	143 ± 6[a]	136 ± 6[a]	139 ± 5	140 ± 10
Shank (°)	73 ± 5	74 ± 5	72 ± 4	74 ± 6
Knee passing				
Hip (°)	101 ± 13	101 ± 11	104 ± 11	98 ± 13
Knee (°)	158 ± 10	159 ± 6	162 ± 6[b]	155 ± 7[b]
Trunk (°)	36 ± 8	32 ± 7	36 ± 8	32 ± 8
Thigh (°)	120 ± 6[a]	111 ± 7[a]	115 ± 8	116 ± 8
Shank (°)[c]	74 ± 6[a]	83 ± 4[a]	77 ± 8	80 ± 6
Liftoff to knee passing range				
Hip (°)	42 ± 7	45 ± 9	44 ± 8	43 ± 9
Knee (°)	37 ± 14	38 ± 12	40 ± 9	36 ± 16
Trunk (°)	20 ± 8	21 ± 6	21 ± 7	20 ± 8
Thigh (°)	23 ± 8	25 ± 8	24 ± 6	23 ± 10
Shank (°)	1 ± 6[a]	9 ± 7[a]	5 ± 8	6 ± 7
Minimum bar velocity (sticking point)				
Hip (°)	147 ± 16[a]	157 ± 9[a]	151 ± 8	153 ± 17
Knee (°)	168 ± 6	168 ± 6	169 ± 6	167 ± 6
Trunk (°)	73 ± 11	73 ± 5	74 ± 4	72 ± 11
Thigh (°)	109 ± 7[a]	99 ± 4[a]	105 ± 7	103 ± 8
Shank (°)[c]	69 ± 4[a]	81 ± 4[a]	75 ± 9	75 ± 5
Foot angle (°)	25 ± 6[a]	15 ± 6[a]	20 ± 8	21 ± 8

The sumo and conventional groups consisted of both high- and low-skilled lifters combined, whereas the high- and low-skilled groups consisted of both sumo and conventional lifters combined.

[a] Significant differences ($P < 0.01$) between sumo and conventional groups.

[b] Significant differences ($P < 0.01$) between high- and low-skilled groups.

[c] Significant interaction (deadlift style × skill level) ($P < 0.01$).

y-, and z-position coordinates were calculated for COM_{bar}. Ankle moment arms (MA_{ankle}) were calculated as the distance in the z-axis direction from the ankle joints to COM_{bar}. Ankle moments were the product of MA_{ankle} and barbell weight. Knee moment arms (MA_{knee}) were calculated as the distance in the z-axis direction from the knee joints to COM_{bar}. Knee moments were the product of MA_{knee} and barbell weight. Hip moment arms (MA_{hip}) were calculated as the distance in the z-axis direction from the hip joints to COM_{bar}. Hip moments were the product of MA_{hip} and barbell weight.

Because bar motion primarily occurred in the vertical direction, vertical bar displacement was calculated from LO to LC and normalized by body height. Mechanical work, which was calculated relative to the barbell weight, was the product of the barbell weight and total vertical displacement of COM_{bar}.

A two-factor ANOVA was used to test for main effects of deadlift style (sumo vs conventional) and skill level (high vs low) and to examine the interaction effect (deadlift style × skill level). *Post hoc* comparisons were made using the Tukey test to evaluate the significance between pairwise comparisons. The level of significance used was $P < 0.01$.

RESULTS

Results of anthropometric, temporal, and work comparisons are shown in Table 1. Compared with the conventional group, the sumo group had approximately 100% greater stance width, 20% smaller hand width, and 10–15% less vertical bar distance and mechanical work. Compared with the low-skilled group, the high-skilled group had approximately 40% greater barbell load, 10–15% less vertical bar distance, and 25% greater mechanical work. The ANOVA revealed a significant deadlift style × skill level interaction for absolute and normalized stance widths, which were 20–25% greater in the high-skilled sumo group (80 ± 10 cm and 214 ± 23% shoulder width, respectively) compared with the low-skilled sumo group (67 ± 10 cm and 173 ± 20% shoulder width, respectively). In contrast, there were no significant differences in absolute and normalized stance widths between high- and low-skilled conventional groups.

Results of comparisons of joint and segment angles between sumo and conventional deadlifts are shown in Table 2. Compared with the conventional group, the sumo group had significantly greater vertical trunk position at LO, a significantly greater horizontal thigh position at LO, KP, and minimum bar velocity (MBV), a significantly less vertical shank position at KP and MBV, significantly less movement of the shank from LO to KP, and significantly greater forefoot abduction (i.e., a more turned out foot) throughout the lift. Compared with the low-skilled group, the high-skilled group had significantly greater knee extension at KP. The ANOVA revealed a significant deadlift style × skill level interaction for shank angle at KP and MBV, which was significantly less in the high-skilled sumo group (71 ± 6° at KP and 67 ± 4° at MBV) compared with the low-skilled sumo group (77 ± 6° at KP and 72 ± 3° at MBV). In contrast, there were no significant differences in shank angle at KP or MBV between the high- and low-skilled conventional groups. The ANOVA also revealed a significant deadlift style × skill level interaction for knee angle at LO, which was significantly less in the high-skilled conventional group (118 ± 5°) compared with the

TABLE 3. Select events (M ± SD) between sumo and conventional deadlift groups and between high- and low-skilled deadlift groups.

	Sumo Group ($N = 20$)	Conventional Group ($N = 20$)	High-Skilled Group ($N = 20$)	Low-Skilled Group ($N = 20$)
First peak bar velocity				
Velocity ($m \cdot s^{-1}$)[a]	0.503 ± 0.117	0.536 ± 0.168	0.493 ± 0.138	0.546 ± 0.147
Time occurred (% total time)	34.5 ± 13.3	33.2 ± 15.7	31.6 ± 12.4	36.1 ± 16.1
Vertical bar position (% total vertical bar distance)	48.7 ± 13.8	47.5 ± 18.4	46.8 ± 14.7	49.4 ± 17.6
Minimum bar velocity				
Velocity ($m \cdot s^{-1}$)	0.003 ± 0.046	0.015 ± 0.041	0.016 ± 0.033	0.002 ± 0.052
Time occurred (% total time)	70.0 ± 16.9	70.6 ± 13.4	68.5 ± 14.2	72.1 ± 16.0
Vertical bar position (% total vertical bar distance)	92.4 ± 14.2	95.7 ± 5.0	94.9 ± 5.5	93.1 ± 14.1
Second peak bar velocity				
Velocity ($m \cdot s$)	0.113 ± 0.086	0.091 ± 0.044	0.104 ± 0.061	0.099 ± 0.075
Time occurred (% total time)	78.7 ± 14.7	79.1 ± 13.0	74.8 ± 13.3	82.8 ± 13.3
Vertical bar position (% total vertical bar distance)	96.0 ± 7.5	97.9 ± 3.9	96.9 ± 4.5	97.1 ± 7.1

The sumo and conventional groups consisted of both high- and low-skilled lifters combined, whereas the high- and low-skilled groups consisted of both sumo and conventional lifters combined. There were no significant differences ($P < 0.01$) observed between sumo and conventional groups and between high- and low-skilled groups.
[a] Significant interaction (deadlift style × skill level) ($P < 0.01$).

low-skilled conventional group (123 ± 5°). Knee angle at LO was not significantly different between high- and low-skilled sumo groups.

Select events and lifting phases are shown in Tables 3 and 4. Vertical bar velocity remained low throughout the lift. MVB occurred at 70% of the total lift time and 90–95% of the total vertical bar distance. No significant differences were observed between sumo and conventional groups and between high- and low-skilled groups. The ANOVA revealed a significant deadlift style × skill level interaction for first peak bar velocity between LO and KP, which was approximately 25% less in the high-skilled conventional group ($0.465 \pm 0.133\ m \cdot s^{-1}$) compared with the low-skilled conventional group ($0.607 \pm 0.147\ m \cdot s^{-1}$). In contrast, there was no significant difference in first peak bar velocities between high- and low-skilled sumo groups.

Joint moments and moment arms, which are relative to barbell loads, are shown in Table 5. Positive moment arms are anterior to a joint, producing positive hip flexor, knee extensor, and ankle dorsiflexor load moments. Hip extensor, knee flexor, and ankle plantar flexor resultant muscle moments are needed to counteract these load moments. Negative moment arms are posterior to a joint, producing negative hip extensor, knee flexor, and ankle plantar flexor load moments. Hip flexor, knee extensor, and ankle dorsiflexor resultant muscle moments are needed to counteract these load moments. At LO, KP, and LC, ankle and knee moments and moment arms were significantly different between sumo and conventional groups. The sumo group generated ankle dorsiflexor moments exclusively, whereas the conventional group generated ankle plantar flexor moments exclusively. Although at LO both groups generated knee extensor moments, at KP and LC the conventional group generated knee flexor moments, whereas the sumo group generated knee extensor moments. Although both sumo and conventional groups generated hip extensor moments, hip moments and moment arms were not significantly different between the groups. At LO, the high-skilled group had smaller hip extensor moment arms, larger knee extensor moments and moment arms, and larger ankle dorsiflexor moment arms compared with the low-skilled group. At KP, hip extensor moment arms were smaller in the high-skilled group compared with the low-skilled group. There were no significant deadlift style × skill level interactions.

DISCUSSION

On the average, the total lift time was approximately 2.4 s for both sumo and conventional groups (Table 1), which is similar to the total lift times of 1.9–2.1 s reported by McGuigan and Wilson (11) and 2.4 s reported by Brown and Abani (1). However, 2.4 s is approximately 35–40% less than the 3.6–4.1 s reported by Escamilla et al. (5) and Cholewicki et al. (3). Since the lifters in the studies by Escamilla et al. (5) and Cholewicki et al. (3) were national-level powerlifters, they may have been more experienced than the regional-level lifters in McGuigan and Wilson (11), the teenage lifters in Brown and Abani (1), and the Special Olympic lifters in the current study. A more experienced lifter can better predict their 1 RM in competition compared

TABLE 4. Lifting phases (mean ± SD) between sumo and conventional deadlift groups and between high- and low-skilled deadlift groups.

	Sumo Group ($N = 20$)	Conventional Group ($N = 20$)	High-Skilled Group ($N = 20$)	Low-Skilled Group ($N = 20$)
Acceleration phase (% total time)	34.5 ± 13.3	33.2 ± 15.7	31.6 ± 12.4	36.1 ± 16.1
Sticking region (% total time)	35.5 ± 8.8	37.4 ± 9.1	36.9 ± 6.8	36.0 ± 10.7
Maximum strength region (% total time)	10.0 ± 7.2	8.5 ± 4.3	7.8 ± 3.3	10.7 ± 7.3
Deceleration phase (% total time)	21.3 ± 14.7	20.9 ± 13.0	25.2 ± 13.3	17.2 ± 13.3

The sumo and conventional groups consisted of both high- and low-skilled lifters combined, whereas the high- and low-skilled groups consisted of both sumo and conventional lifters combined.
There were no significant differences ($P < 0.01$) observed between sumo and conventional groups and between high- and low-skilled groups. There were no significant interactions (deadlift style × skill level) ($P < 0.01$).

TABLE 5. Joint moments and moment arms (mean ± SD) between sumo and conventional deadlift groups and between high- and low-skilled deadlift groups.

	Sumo Group ($N = 20$)	Conventional Group ($N = 20$)	High-Skilled Group ($N = 20$)	Low-Skilled Group ($N = 20$)
Moment arms at liftoff (cm)				
Ankle	−4.3 ± 5[a]	6.1 ± 3.7[a]	−0.8 ± 6.3[b]	2.6 ± 7.1[b]
Knee	−13.2 ± 8.0[a]	−3.3 ± 5.2[a]	−10.5 ± 6.9[b]	−6.0 ± 7.1[b]
Hip	27.9 ± 6.2	27.9 ± 5.2	25.9 ± 3.2[b]	29.9 ± 5.9[b]
Moments at liftoff (N · m)				
Ankle	−59 ± 67[a]	83 ± 57[a]	−2 ± 104	27 ± 84
Knee	−170 ± 125[a]	−55 ± 78[a]	−157 ± 108[b]	−68 ± 114[b]
Hip	339 ± 106	370 ± 136	396 ± 131	314 ± 97
Moment arms at knee passing (cm)				
Ankle	−5.2 ± 5.3[a]	2.9 ± 4.0[a]	−2.5 ± 6.0	0.3 ± 6.2
Knee	−4.8 ± 5.4[a]	3.2 ± 3.2[a]	−1.6 ± 6.1	0.0 ± 5.9
Hip	23.5 ± 5.4	21.1 ± 3.6	20.9 ± 3.8[b]	23.8 ± 4.2[b]
Moments at knee passing (N · m)				
Ankle	−68 ± 74[a]	42 ± 60[a]	−31 ± 92	4 ± 80
Knee	−66 ± 80[a]	45 ± 49[a]	−21 ± 96	−1 ± 76
Hip	286 ± 92	281 ± 91	313 ± 82	253 ± 89
Moment arms at lift completion (cm)				
Ankle	−4.2 ± 5.2[a]	4.1 ± 2.7[a]	−1.4 ± 5.8	1.3 ± 5.7
Knee	−7.6 ± 5.7[a]	2.6 ± 3.8[a]	−2.4 ± 6.5	−2.6 ± 7.7
Hip	7.4 ± 2.5	8.3 ± 2.3	7.7 ± 2.1	8.0 ± 2.8
Moments at lift completion (N · m)				
Ankle	−54 ± 68[a]	56 ± 44[a]	−13 ± 89	14 ± 68
Knee	−98 ± 83[a]	38 ± 59[a]	−32 ± 101	−28 ± 99
Hip	92 ± 38	115 ± 73	121 ± 71	86 ± 38

The sumo and conventional groups consisted of both high- and low-skilled lifters combined, whereas the high- and low-skilled groups consisted of both sumo and conventional lifters combined. Positive moment arms are anterior to joint, producing positive hip flexor, knee extensor, and ankle dorsiflexor load moments. Hip extensor, knee flexor, and ankle plantar flexor resultant muscle moments are needed to counteract these load moments. Negative moment arms are posterior to joint, producing negative hip extensor, knee flexor, and ankle plantar flexor load moments. Hip flexor, knee extensor, and ankle dorsiflexor resultant muscle moments are needed to counteract these load moments.
[a] Significant differences ($P < 0.01$) between sumo and conventional groups.
[b] Significant differences ($P < 0.01$) between high- and low-skilled groups.
There were no significant interactions (deadlift style × skill level) ($P < 0.01$).

with a less experienced lifter. Therefore, the subjects in the studies by McGuigan and Wilson (11) and Brown and Abani (1) and those in the current study may have slightly underestimated their 1 RM. This implies that the amount of weight the Special Olympics athletes lifted may be closer to 95% of their 1 RM, which may slightly affect both lifting kinematics and kinetics compared with 1 RM lifting.

Two studies are known to have compared kinematic parameters between sumo and conventional deadlifts (5,11). Whereas McGuigan and Wilson (11) conducted a 2-D kinematic analysis, Escamilla et al. (5) conducted the first 3-D analysis of the deadlift. Escamilla et al. (5) demonstrated that erroneous results occur, especial during the sumo deadlift, from a 2-D analysis of the deadlift. This is because the lower extremities move both in a sagittal and frontal plane during the sumo deadlift. In comparisons of 3-D kinematics between the Special Olympics powerlifters and the elite national powerlifters from Escamilla et al.(5), the national lifters maintained a more vertical trunk and shank and flexed the hips less at LO and KP but had a less vertical trunk, more knee and hip flexion, and a more horizontal thigh at MBV. The latter occurred because MBV occurs at approximately 40–45% of the total lift time in national powerlifters (5,11) but at approximately 70% of the total lift time in the Special Olympics lifters. This implies that the percent time in each of the four lifting phases is different between national and Special Olympics lifters. Compared with the percent total times the Special Olympics lifters spent in each lifting phase (Table 4), the national lifters spent approximately 10–15% less time in the acceleration phase and sticking regions and approximately 10–15% more time in the maximum strength region and deceleration phase. This implies the national lifters are more efficient and effective throughout the deadlift, because spending less time in the sticking region and more time in the maximum strength region enhances the likelihood that a successful lift will occur.

MBV during the deadlift has previously been referred to as the “sticking point” (5). The Special Olympics lifters reached the sticking point at approximately 90% of vertical bar distance (Table 3), compared with approximately 60% of vertical bar distance by the national-caliber lifters in Escamilla et al. (5). Because bar velocity is minimal at the sticking point, this appears to be the most difficult part of the lift and is often where powerlifters fail in their attempt at a successful lift. This implies the most difficult part of the lift for Special Olympic lifters was near LC. In contrast, the sticking point occurred just after KP in national lifters (5). The sticking point phenomenon may be due in part to mechanical principles of skeletal muscle, such as to the length-tension relationship, or to decreasing muscle moment arm lengths from KP to LC.

The lifters in the current study performed the sumo and conventional deadlifts with 5–15% wider stance and hand widths compared with the lifters from Escamilla et al. (5). Since the arms are positioned outside the legs during the conventional deadlift (Fig. 2), a wider stance may force a wider hand width. If the stance widens excessively, the arms are forced to deviate from a vertical position (Fig. 2, bottom), causing the lifter to have to bend over to a greater extent to grip the bar. Optimal arm position is with the arms vertical (Fig. 2, top), because this will decrease vertical bar distance from LO to LC. The wider stance and hand widths may have resulted in the lifters in the current study having 20–25% greater vertical bar distance from LO to LC compared with the lifters in Escamilla et al. (5).

Optimal stance and hand widths also allow the trunk to be in a more vertical position at the beginning of the lift. The wider stance and hand widths in the current study may have compromised good lifting mechanics at LO (Fig. 1, bottom), because the 16 ± 9° and 11 ± 7° trunk positions measured for the sumo and conventional groups, respectively, are considerably less than the 25–33° and 17–24° trunk positions, respectively, reported by other deadlift studies that used skilled elite lifters (1,5,11). The increased forward trunk tilt at LO in the current study resulted in a 10–20° decrease in hip angles compared with several other studies (1,5,11). The increased forward trunk tilt at LO may predispose the spine and back musculature to an increased risk of injury (2,3,6). Cholewicki et al. (3) reported that a more upright trunk at LO resulted in less anterior shear force at the lumbar L4/L5 joint. This was especially true in the conventional group, which had significantly greater forward trunk tilt than the sumo group at LO, since there is approximately 10% greater shear force and moment generated at the L4/L5 joint in the conventional deadlift compared with the sumo deadlift (3).

Escamilla et al. (5) conducted the only known 3-D analysis that quantified ankle, knee, and hip moment arms for sumo and conventional style deadlifts. Compared with the sumo deadlift in the current study, at LO, Escamilla et al. (5) reported 25–30% smaller hip moment arms, 30–35% greater knee moment arms, and three times greater ankle moment arms. This implies that the national lifters from Escamilla et al. (5) used their hip extensors less and their knee extensors and ankle dorsiflexors more compared with the Special Olympic lifters. These hip, knee, and ankle moment arm differences occurred because the national lifters maintained the barbell mass closer to the body compared with the Special Olympics lifters. As the center of mass of the barbell load moves closer to the body in the sumo deadlift, hip moment arms and moments decrease and ankle and knee moment arms and moments increase. In the sumo deadlift, the greater the feet turn out (i.e., forefoot abduction), the closer the barbell can be positioned to the body. The national lifters were able to keep the barbell closer to the body partially because they had 17° greater forefoot abduction compared with the Special Olympics lifters. This implies that a forefoot abduction of 40–45° may be optimal in the sumo deadlift in minimizing hip moment arms and moments. The smaller hip moment arms and moments that result by keeping the barbell mass closer to the body also result in smaller L4/L5 joint moments and shear forces (3). This implies that the Special Olympics lifters may increase their risk of injury to the low back by keeping the barbell mass further away from the body. In addition, performance may also be compromised, since increasing hip and L4/L5 moments may also result in less weight being able to be lifted. However, performance is also dependent on the knee and ankle moments and moment arms that are generated, which increase as hip moments and moment arms decrease.

During the sumo deadlift, the ankle dorsiflexors, knee extensors, and hip extensors were primarily responsible for causing or controlling ankle, knee, and hip movements, respectively. During the conventional deadlift, the ankle plantar flexors, knee flexors, and hip extensors were primarily responsible for causing or controlling movements at the ankles, knees, and hips, respectively. From these data, it is hypothesized that the lower-extremity muscles involved during the conventional deadlift are the hamstrings, gluteus maximus, gastrocnemius, and soleus, and the lower-extremity muscles involved during the sumo deadlift are the gluteus maximus, hamstrings, quadriceps, and tibialis anterior. Electromyography should be used during these two deadlift styles to test these hypotheses.

At KP and LC during the conventional deadlift, small knee extensor moments were generated by the barbell center of mass, which attempts to extend the knees. This occurred because the barbell center of mass was slightly anterior to the knee joint. To counteract this knee extensor moment, increased activity from the knee flexors is needed to generate the knee flexor moment needed to control the rate and extent of knee extension. This is one reason it is hypothesized that the hamstrings are more active and the quadriceps less active during the conventional deadlift compared with the sumo deadlift. Because the knee flexors are also hip extensors, they attempt to extend the hip and flex the knee simultaneously. In contrast, because the barbell center of mass is posterior to the knee axis during the sumo deadlift, a large knee extensor moment is needed to counteract the large knee flexor moment generated by the barbell load. This implies that the quadriceps may be more active during the sumo deadlift compared with the conventional deadlift.

In comparisons of high- and low-skilled lifters, it was surprising that not more significant kinematic differences were observed. From the 21 kinematic variables in Table 2, only knee angle at KP was significantly different between high- and low-skilled groups. Brown and Abani (1) conducted the only other deadlift study that compared biomechanical variables between high- and low-skilled lifters, with their teenage subjects performing the conventional deadlift. Unlike the current study, at LO, these authors reported significant differences in shank, thigh, hip, and knee angles between high- and low-skilled lifters. However, their results were the same as the current study at KP, with generally no significant differences occurring.

From LO to KP, high-skilled lifters have demonstrated lower peak bar velocities compared with low-skilled lifters (1,5), which is in agreement with peak bar velocity data from the current study. The greater first peak bar velocity in low-skilled compared with high-skilled conventional lifters is probably due to differences in body position between these groups. At LO, lifters often attempt to minimize hip and trunk flexion and knee extension in order to better utilize hip and thigh musculature. For example, if the knees extend prematurely and excessively at LO, the lifter will be in a position to perform what is referred to as a "straight-leg" deadlift, which occurs when the knees are at or near full extension. This position may result in a decrease in quadriceps activity and effectiveness, an increase in hamstring activity (17), and an increase in erector spinae activity due to the spine being in a more bent and rounded position. This places the lumbar spine in a more vulnerable position, with a higher risk of injury (3). The low-skilled conventional lifters in the current study had greater knee extension at LO compared with the high-skilled conventional lifters. A rapid knee extension and forward trunk tilt can occur near LO if a lifter attempts to "jerk" the weight off the floor. Brown and Abani (1) have reported that low-skilled lifters attempt to "jerk" the weight off the floor at LO, although these authors did not find greater forward trunk tilt and knee extension in low-skilled lifters compared with high-skilled lifters.

The greater vertical bar distance for the low-skilled group compared with the high-skilled group may be one reason why the relative loads lifted by the low-skilled groups were smaller compared with the relative loads lifted by the high-skilled loads, as shown by the Schwartz scores. This greater vertical bar distance for the low-skilled group implies that if the loads lifted were the same for both the low- and high-skilled groups, the low-skilled group would have to perform a greater amount of mechanical work on the bar compared with high-skilled group. However, since the loads lifted were greater in the high-skilled group compared with the low-skilled group, greater mechanical work was performed by the high-skilled group.

The smaller hip extensor moment arms and larger knee extensor and ankle dorsiflexor moment arms imply that the high-skilled group kept the bar closer to the body compared with the low-skilled group. Keeping a weight close to the body during lifting is important in minimizing injury potential, especially to the lower back, because hip and spinal moment arms will decrease. This implies that the low-skilled group may have a higher risk of injury compared with the low-skilled group. Keeping the weight closer to the body also may enhance lifting performance. In addition, ankle, knee, and hip moment arm data suggest that the high-skilled group may use the hip extensors and ankle plantar flexors to a lesser extent and the knee extensors to a greater extent compared with the low-skilled group. An electromyographic study of high- and low-skilled groups may be helpful in testing this hypothesis.

CONCLUSIONS

There were numerous kinematic and kinetic differences observed between sumo and conventional style deadlifts and between high- and low-skilled lifters. The sumo deadlift was performed with a more upright trunk and a wider stance compared with the conventional deadlift, which may decrease injury risk in the sumo deadlift and increase injury risk in the conventional group. The sumo deadlift may be more effective in developing the ankle dorsiflexors and knee extensors, whereas the conventional deadlift may be more effective in developing the ankle plantar flexors and knee flexors. High-skilled lifters exhibited better lifting mechanics than low-skilled lifters by keeping the bar closer to the body, which may both enhance performance and minimize injury risk.

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