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Distribution of lower extremity work during clean variations performed with different effort

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Distribution of lower extremity work during clean variations performed with different effort

The purpose of this research was to investigate how lower extremity work was distributed during the pull of cleans performed lifting the barbell to the minimum height required to receive it in a full squat (minimal height clean); or with maximum effort to elevate the barbell as high as possible and receiving it in either a full (maximal effort clean) or partial (power clean) squat. Eight weightlifters screened for proficient technique performed these clean variations at 80% of one repetition maximum. Work performed on the barbell and by the lower extremity net joint moments (NJM) was computed from marker trajectories and ground reaction forces. Total barbell work, lower extremity NJM work, knee extensor work, and knee joint excursion during the second pull was lower in the minimal height clean than the maximal effort and power cleans ($P < 0.05$). This research demonstrates that more knee extensor work is performed in the second pull of maximal effort and power cleans compared to the minimal height clean. The larger knee extensor work performed is due to larger knee joint excursion during the second pull of the maximal effort and power cleans, but not larger knee extensor NJM.

Key Words: Weightlifting, Strength training, Coordination

Introduction

By engaging in regular resistance training, athletes elicit adaptions aimed at improving performance. These adaptions include muscle hypertrophy, increased neural drive, and improved coordination between agonistic, synergistic, and antagonistic muscles (Deschenes & Kraemer, 2002). Exercise execution may influence the amount of mechanical stress exerted on different muscles, which may subsequently affect the adaptions elicited. For example, deep squats require greater relative knee extensor effort, and subsequently results in greater strength adaptions of the knee extensors, compared to shallow squats (Bloomquist et al., 2013, Bryanton, Kennedy, Carey, & Chiu, 2012).

Weightlifting exercises, such as the snatch and clean, are also common multi-joint exercises used in strength training programs (Ebben, Carroll, & Simenz, 2004). These exercises have been purported to improve performance in other multi-joint tasks, such as jumping and landing (Garhammer & Gregor, 1992; Moolyk, Carey, & Chiu, 2013). However, recent research is questioning the effectiveness of weightlifting exercises for eliciting musculoskeletal adaptations and improving performance (Helland et al., 2017). These conflicting results may be due to variations in how the exercises were executed in different research studies. Unfortunately, specific details on how weightlifting exercises are executed in training programs are rarely reported.

The clean and power clean are among the most commonly used weightlifting exercises (Ebben et al., 2004). In these exercises, the barbell is lifted from the ground during the pulling phase and received on the shoulders in a deep (clean) or shallow (power clean) squat (Garhammer, 1984; Stone, Pierce, Sands, & Stone, 2006a). Further, the clean may be executed in different ways with submaximal loads. For example, maximal effort may be exerted during the pull (maximal effort clean), resulting in a relatively large barbell elevation (Bartonietz, 1996). This variation resembles a power clean with the exception that a full, rather than a partial squat, is performed. Alternatively, the barbell may be elevated to the minimal height necessary to receive it in a deep squat (minimal height clean) (Derwin, 1990). Apart from the depth the barbell is received, the clean and power clean are commonly regarded to be the same and expected to elicit similar adaptions, whereas the maximal effort and minimal height cleans are rarely distinguished. However, some clear and potentially important biomechanical differences exist between these variations of the clean exercise. First, since the barbell is received in a shallow squat in the power clean and a deep squat in the clean (Moolyk et al., 2013), the barbell may be lifted to a greater height in the power clean compared to the clean. Second, the vertical ground reaction force normalized to barbell-lifter system mass is greater during the power clean compared to the clean (Häkkinen & Kauhanen (1986). Although other studies have investigated the power clean (e.g. Comfort, Fletcher, & McMahon, 2012; Cormie, McCaulley, Triplett, & McBride, 2007; Hardee), they provide limited insight of the muscular demands required for two reasons. First, only peak variables, such as peak power and force, have been investigated (Comfort et al., 2012; Cormie et al., 2007). However, the existence of one unweighting and two weighting phases in both the power clean and clean is well documented (Enoka, 1979; Souza, Shimada, & Koontz, 2002). Second, these studies employ a point mass model, allowing only the net force acting on the barbell or barbell-lifter system to be quantified, and are therefore not suitable to estimate muscle effort (Chiu, 2017). Finally, no research has compared cleans performed with different effort. However, due to the resemblance between the maximal effort and power clean, it is hypothesized that only small differences exist between these variations.

To lift the barbell, mechanical work is performed to increase the barbell’s gravitational potential and kinetic energies (Garhammer, 1982, 1993). These energy changes result in proportional increases in barbell height and velocity. It is likely that more work will be performed on the barbell in the power and maximal effort cleans compared to the minimal height clean at any given load. Examining how greater work is performed is required to understand the implications for both competitive weightlifters and athletes who utilize weightlifting exercises for strength and conditioning purposes.

The hip extensors, knee extensors, and ankle plantar flexors perform work to elevate the barbell during the three different phases of the pull (Garhammer, 1982). (Enoka, 1979). During the first and last phase, known as first and second pull, respectively, concentric work is primarily performed (Enoka, 1988). In contrast, most of the work performed during the second phase, known as the transition phase, is eccentric (Enoka, 1988). It is not known whether greater work performed on the barbell is uniformly distributed between muscle groups, or across the different phases of the pull. To provide insight into how employing different techniques affect inter-muscular coordination, and ultimately training adaptions, this topic warrants investigation.

The purpose of this study was to compare the work performed within and between different phases of the minimal height clean, maximal effort clean, and power clean. We aimed to quantify the work performed on the barbell during the minimal height clean, maximal effort clean, and power clean, and identify any differences in how the work was distributed between: 1) the different phases of the clean pull, or 2) between the hip extensors, knee extensors, and ankle plantar flexors.

Methods

Participants

A convenience sample (eight males and two females) with minimum one-year experience, who currently or previously competed in weightlifting were recruited from local weightlifting clubs. An *a priori* power analysis for multivariate ANOVA was conducted in G*Power (Faul, Erdfelder, Lang, & Buchner, 2007). A sample size of 10 would allow for detection of withinsubject differences of 0.5 standard deviations (SD) with a power of 0.80 at α-level 0.05. Participants were screened for technical proficiency based on barbell trajectory (further details provided below); only those exhibiting a toward-away-toward barbell trajectory were included for further analysis (*Figure 1*). Participants 3 and 5 were excluded based on their barbell trajectories. Their one repetition maximums (1 RM) were 85 and 120 kg, respectively. Characteristics of the remaining eight participants are shown in Table 1. The study protocol was approved by the University of Alberta Research Ethics Board (Study ID: Pro00057564) and all participants provided written informed consent prior to participation.

***** Figure 1 and Table 1 approximately here *****

Procedures

Participants completed two test sessions with minimum 72 hours between them. In the first session, participants were screened for technical proficiency and their 1 RM clean was established. All warm-up lifts and 1 RM attempts were recorded with a digital camera (D3200, Nikon, Tokyo, Japan) used in video recording mode with 1280 horizontal and 720 vertical pixels capturing 60 frames per second. The 15-55 mm variable lens (Nikon, Tokyo) was set to maximum zoom and the aperture, exposure time, and exposure index rating (i.e. ISO) were set to 5.6, $1 \cdot 500^{-1}$ s, and 800, respectively. The optical axis of the camera was positioned 0.80 m above the ground 15 m from the right end of the barbell (Olympic competition bar, Iron Grip, Santa Ana, CA, USA), capturing a sagittal plane view. An LED-marker was placed on the right end of the barbell (Dæhlin, Krosshaug, & Chiu, 2017).

Participants performed a self-selected warm-up resembling their competition warm-up. Barbell mass increments were decided by participants and rest was provided *ad libitum* between attempts. All participants reached their 1 RM within two to four attempts once exceeding 90% 1 RM. Participants completed a familiarization of the three test conditions after their 1 RM testing. Digital videos were processed using Tracker software (Version 4.91; http://physlets.org/tracker/; accessed October 6, 2015) to examine barbell trajectory, as described by Dæhlin et al. (2017). Horizontal and vertical position coordinates were smoothed using a 5-point moving arc polynomial (Wood, 1982). Participants who did not display a towards-away-towards barbell trajectory were excluded from further analysis. The rationale for excluding these participants is that skilled weightlifters typically exhibit this barbell trajectory (Garhammer, 1985; Kauhanen, Häkkinen, & Komi, 1984); more skilled weightlifters may employ different joint kinetics than lesser skilled weightlifters (Enoka, 1988).

During the second session, participants performed minimal height, maximal effort, and power cleans. Lifts were performed standing on two force platforms (OR6-6, AMTI, Watertown, MA, USA) sampling at 1200 Hz and retro-reflective marker trajectories were recorded by seven optoelectronic cameras (ProReflex MCU240; Qualisys, Gothenburg, Sweden) sampling at 120 Hz. A six-degree of freedom marker set described by Chiu and Salem (2006) was used (*Figure 2*). Briefly, the marker set consisted of 17 calibration markers defining proximal and distal segment ends, and tracking clusters of three (feet) and four markers (legs and thighs) affixed to moulded thermoplastic plates. The proximal calibration markers on the pelvis also served as tracking markers. A retro-reflective marker was placed on each barbell end.

Participants performed a clean specific warm-up consisting of three repetitions (one per condition) at barbell loads approximately 30, 50, and 70% 1 RM. After the warm-up, one repetition in each condition was performed at 80% 1 RM. This load was chosen because it is commonly used in weightlifting training, and as technique is suggested to stabilize around

80% 1 RM (Lukashev, Medvedev, & Melkonian, 1979; Stone, Pierce, Sands, & Stone, 2006b). The order of the three conditions was randomized and a self-selected rest-interval between two and four minutes was allowed between sets, as these rest-intervals are typical for weightlifting competitions. The random order of conditions was repeated three more times, for a total of four sets of one repetition in each condition. The reliability of joint angle and joint moment data (ICC > 0.90) has previously been established for the described methods and marker set (Chiu & Salem, 2006).

***** Figure 2 approximately here *****

Data processing and reduction

Marker data was used to create a rigid body model in Visual 3D (Version 5.00; C-Motion, Germantown, MD). The model consisted of seven rigid bodies representing the pelvis and both thighs, legs, and feet. Marker and force data were filtered using a recursive 4th order low-pass digital Butterworth filter with an 8 Hz cut-off frequency. This cut-off frequency was chosen based on a residual analysis and visual inspection of segment centre of mass acceleration time-curves. Local and laboratory coordinate systems conformed to the right-hand rule with the Z-axis pointing up and Y-axis pointing anteriorly. Joint angles and joint angular velocity were calculated as orientations of the proximal relative to the distal segment using an XYZ Cardan sequence (Chiu, vonGaza, & Jean, 2017; Moolyk et al., 2013). Inverse dynamics was used to calculate net joint moments (NJM) about the ankle, knee, and hip, which were expressed in the distal segments' coordinate system. Segments' inertial properties and centre of mass were determined based on segments having the shape of conical frusta, and mass relative to total body mass using anthropometric data from Dempster (1955). Power at each joint was calculated as the dot product between the local sagittal plane NJM and joint angular velocity; NJM work was computed as the time-integral of power at each joint between events of interest using the trapezoidal rule. The barbell was represented as a point mass by averaging the position of the barbell end markers. Work performed on the barbell between events of interest was computed from changes in the barbell's gravitational potential and kinetic energies as described by Garhammer (1993).

The events of interest were lift-off, first peak knee extension, second peak knee flexion, and peak barbell velocity, which are the temporal events defining the first pull, transition, and second pull phases (Bartonietz, 1996; Garhammer, 1978; Gourgoulis, Aggelousis, Mavromatis, & Garas, 2000). The first pull was defined as lift-off until first peak knee extension; the transition was defined as first peak knee extension until second peak knee flexion; the second pull was defined as second peak knee flexion until peak barbell velocity. NJM work and barbell work performed in the first pull, transition, and second pull were also summed to provide the total work performed during the pulling phase. Joint kinematics were averaged across limbs, while joint kinetics were summed between limbs (Moolyk et al., 2013). All joint kinetics were normalized to body mass, while changes in barbell height were normalized to stature and expressed as a percentage.

Statistical analysis

Statistical analyses were conducted in SPSS v21.0 (SPSS Inc., Chicago, IL). One-way repeated-measures ANOVAs were used to compare the changes in barbell height, work performed on the barbell, and total NJM work between conditions. Multivariate repeated-measures ANOVAs, using the ankle plantar flexors, knee extensors, knee flexors, and hip extensors as multivariate levels, were used to compare the work performed at the ankle, knee, and hip joint between conditions. For NJM and joint angles, the ankle, knee, and hip were used as multivariate levels. NJM and joint angles were only analysed for the phases in which differences in NJM work were significant, due to the mechanical relationship between these variables. Univariate ANOVAs were only considered if the multivariate main effect was significant using Wilk's λ. When univariate ANOVAs were significant, multiple t-tests with Bonferroni correction were used for *post hoc* comparisons. Visual inspection of Q-Q plots indicated normal distribution of the data, and Mauchly's test was used to test for sphericity. If the sphericity assumption was violated, Greenhouse-Geisser corrections were used. Means ± SD and 95% confidence intervals (CI) for mean differences are reported. Typical error was computed as a measure of within-participant variation in each condition. The level of significance was set *a priori* to 0.05.

Results

Typical error ranged between 0.003% and 0.009% for peak barbell height, 0.078 $J \cdot kg^{-1}$ and 0.628 $J \cdot kg^{-1}$ for work performed on the barbell, and 0.003 $J \cdot kg^{-1}$ and 0.551 $J \cdot kg^{-1}$ for NJM work, within conditions.

The minimal height clean (65.1 ± 2.8%) had a lower peak barbell height versus the maximal effort (68.6 ± 1.7%; $P = 0.02$; CI [0.01 0.06]) and power (68.9 ± 2.2%; $P < 0.01$; CI [0.02 0.06]) cleans. Peak barbell height did not differ between the maximal effort and power cleans ($P > 0.05$; CI [-0.01 0.01]).

Less work was performed on the barbell during the pulling phase in the minimal height clean (8.66 ± 1.32 $J \cdot kg^{-1}$) than the maximal effort (9.13 ± 1.40 $J \cdot kg^{-1}$; $P = 0.04$; CI [0.03 0.89]) and power (9.25 ± 1.28 $J \cdot kg^{-1}$; $P = 0.01$; CI [0.15 1.03]) cleans. Work performed on the barbell during the second pull was smaller in the minimal height (2.81 ± 0.75 $J \cdot kg^{-1}$) compared to the power (3.21 ± 0.90 $J \cdot kg^{-1}$; $P = 0.03$; CI [0.06 0.75]; *Figure 3*) clean. Work performed on the barbell was not different between the maximal effort and power cleans in any phase ($P > 0.05$; *Figure 3*).

***** Figure 3 approximately here *****

Total NJM work was strongly correlated to work performed on the barbell in the minimal height ($r = 0.97$, $P < 0.01$), maximal effort ($r = 0.95$, $P < 0.01$), and power ($r = 0.94$, $P < 0.01$) cleans. Total NJM work was lower in the minimal height clean (10.9 ± 1.7 $J·kg^{-1}$) versus the maximal effort (12.0 ± 1.8 $J·kg^{-1}$; $P = 0.03$; CI [0.09 1.96]) and power (12.0 ± 1.9 $J·kg^{-1}$; $P = 0.02$; CI [0.20 1.97]) cleans. A significant multivariate main effect (Wilk's $\lambda = 0.010$) indicated that NJM work performed at the individual lower extremity joints differed. Univariate and *post hoc* tests revealed that both total knee extensor and flexor NJM work was smaller during the minimal height clean (1.8 ± 0.5 $J·kg^{-1}$ and 0.6 ± 0.2 $J·kg^{-1}$, respectively) compared to the maximal effort (2.2 ± 0.7 $J·kg^{-1}$; $P = 0.03$; CI [0.03 0.64] and 0.7 ± 0.3 $J·kg^{-1}$; $P = 0.01$; CI [0.05 0.28], respectively) and power (2.2 ± 0.7 $J·kg^{-1}$; $P = 0.01$; CI [0.09 0.69] and 0.7 ± 0.3 $J·kg^{-1}$; $P < 0.01$; CI [0.12 0.28], respectively) cleans. Moreover, total ankle plantar flexor NJM work was smaller during the minimal height clean (2.6 ± 0.5 $J·kg^{-1}$) compared to the power clean (3.1 ± 0.5 $J·kg^{-1}$; $P = 0.03$; CI [0.05 0.87]), whereas it tended to be significantly smaller compared to the maximal effort clean (3.0 ± 0.6 $J·kg^{-1}$; $P = 0.06$; CI [-0.02 0.87]). Total hip extensor NJM work did not differ ($P > 0.05$) between the minimal height (6.0 ± 1.3 $J·kg^{-1}$), maximal effort (6.0 ± 1.4 $J·kg^{-1}$; CI [-0.28 0.35]), or power (6.0 ± 1.5 $J·kg^{-1}$; CI [-0.28 0.41]) cleans. Differences in knee flexor NJM work occurred during the transition phase, whereas differences in knee extensor and ankle plantar flexor NJM work occurred during the second pull ($P < 0.05$; *Figure 3*). No differences in NJM work occurred during the first pull ($P > 0.05$; *Figure 3*).

Peak ankle plantar flexor, knee extensor, and knee flexor NJM did not differ between conditions in the transition or second pull ($P > 0.05$; *Table 2*). At the end of the transition phase, the knee was more extended in the minimal height clean compared to the maximal effort and power cleans ($P < 0.05$; *Table 3*). At the end of the second pull, there was less ankle plantar flexion in the minimal height clean versus the maximal effort and power cleans ($p < 0.05$; *Table 3*), and the knee was less extended in the minimal height clean versus the maximal effort clean ($P < 0.05$; *Table 3*).

***** Table 2 and 3 approximately here *****

Discussion

The purpose of this study was to compare the work performed within and between different phases of the minimal height, maximal effort, and power cleans. More work was performed during the pull of the maximal effort and power cleans, compared to the minimal height clean. However, the greater work was not uniformly distributed across the lower extremity during these variations. The knee extensors performed more work during the maximal effort and power cleans, compared to the minimal height clean, whereas hip extensor and ankle plantar flexor NJM work, with one exception, remained unchanged.

The distribution of lower extremity work is altered when changing how the clean is executed within the same individual. Changes in NJM work may result from changes in NJM, joint angular excursion, or both. To understand the implications of changes in lower extremity work distribution, it is important to consider the mechanisms responsible for this change. During the maximal effort and power cleans, participants elevated the barbell to a greater height by increasing the knee extensor, and to some degree, ankle plantar flexor work performed during the second pull. The knee flexion and ankle dorsiflexion occurring in the transition prior to the second pull places these joints near the angles where the knee extensors and ankle plantar flexors are strongest (Hahn, Olvermann, Richtberg, Seiberl, & Schwirtz, 2011). Thus, one would expect the knee extensors and ankle plantar flexors to have a large capacity for increasing knee and ankle NJM in the second pull. However, no difference in NJM was observed between the clean variations investigated, which indicates that maximum muscle effort was the same for the three variations. A higher barbell load may be required to increase NJM. Kipp et al. (2011) found that hip extensor and ankle plantar flexor, but not knee extensor NJM increased with increasing barbell load in the clean. The absence of a difference in NJM signifies that lifters may use other strategies than increasing muscular effort to perform more mechanical work.

Although NJMs remained unchanged, joint angular excursion differed between the clean variations investigated. Specifically, knee flexion angles were larger at the beginning and smaller at the end of the second pull during maximal effort and power cleans, whereas ankle plantar flexion angles were larger at the end of the second pull in these variations. Thus, the larger knee extensor and ankle plantar flexor work performed during the maximal effort and power cleans can be attributed to larger joint angular excursions at the knee and ankle in these variations compared to the minimal height clean.

Performing greater knee extensor work during the second pull can elevate the barbell higher. However, a question that arises is whether it is beneficial for competitive weightlifters to exert maximal effort during the clean when submaximal loads are used. Greater barbell elevation will increase the drop displacement – the difference between peak barbell height and barbell height in the deep squat where the barbell is received (Isaka, Okada, & Funato, 1996). While a greater drop displacement allows more time to transition into the deep squat, this contrasts with the mechanics exhibited by elite weightlifters, who have a short drop displacement and fast squat under the barbell (Garhammer, 1993; Kauhanen et al., 1984). Moreover, with a larger drop displacement, the barbell will have a higher downward velocity, increasing the impulse required to stop the barbell from falling.

Another consideration is the cause of the greater knee extensor and ankle plantar flexor work during the maximal effort and power cleans. Larger joint angular excursion during the second pull was responsible for the greater work performed in these variations. This resulted in a more extended position at the end of the second pull. However, Burdett (1982) reported that more skilled weightlifters were less extended at the knee and less plantar flexed at the ankle compared to their less skilled counterparts. Thus, the maximal effort and power cleans resulted in kinematics resembling those of less skilled, rather than more skilled weightlifters.

Although it may be unfavourable for competitive weightlifters to exert maximal effort during submaximal cleans, one may hypothesize that an increase in knee extensor and ankle plantar flexor work is beneficial for individuals using cleans for certain strength and conditioning purposes. However, the larger NJM work resulted from larger joint angular excursions, rather than increases in NJM. This data contradicts research examining clean variations using a point mass model, which has found peak force increases when maximal effort is exerted on the bar (Cormie et al. 2007; Suchomel, Wright, Kernozek, & Kline, 2014). From the current data, it can be hypothesized that the pull portion of these clean variations imposes the same stress on the lower extremity musculature. Consequently, assumptions that greater vertical ground reaction force reflects increased muscle effort and will lead to greater training adaptations may not be valid. Future research should determine whether different variations of the clean results in different muscular adaptions of the knee extensors and plantar flexors.

Although the pull of different clean variations may be hypothesized to impose similar stimuli on the lower extremity muscles, less lower extremity work is performed and smaller knee and hip extensor NJMs occur in the receiving phase of the power clean compared to the clean (Moolyk et al., 2013). Thus, it may be desirable to use power cleans when tapering towards competition or in training periods when the knee extensors and ankle plantar flexors are exposed to considerable training stress in other exercises. Lastly, as no differences were observed between the maximal effort and power clean in any of the measured variables, it appears that the maximal effort variation is redundant.

One limitation of the current study is that only a single barbell load was investigated. Further research is required to examine whether exerting maximal effort to lift a lighter load is similar or different to lifting a heavier load. A second limitation of this research is that only research participants displaying a type of barbell trajectory consistent with the use of a double-knee bend technique were included in the study. Previous research has reported different NJM time series patterns between weightlifters that employ different techniques (Garhammer, 1978). Therefore, the current results may only be generalized to individuals employing the double-knee bend technique. However, this limitation highlights the importance of considering how the clean is performed. The current study found differences in lower extremity mechanics for different methods of executing the clean using the double-knee bend technique. A different technique may alter lower extremity mechanics more. Thus, it is recommended that research using cleans, or similar weightlifting exercises, describe both the technique employed and how the exercise was executed, as these factors may be important to interpret the results.

Conclusions

More knee extensor and ankle plantar flexor NJM work is performed in the maximal effort and power cleans compared to the minimal height clean when using a submaximal load. The greater knee extensor and ankle plantar flexor work results from greater angular excursion at these joints, but no change in NJM.

Disclosure Statement

The authors report no conflicts of interest

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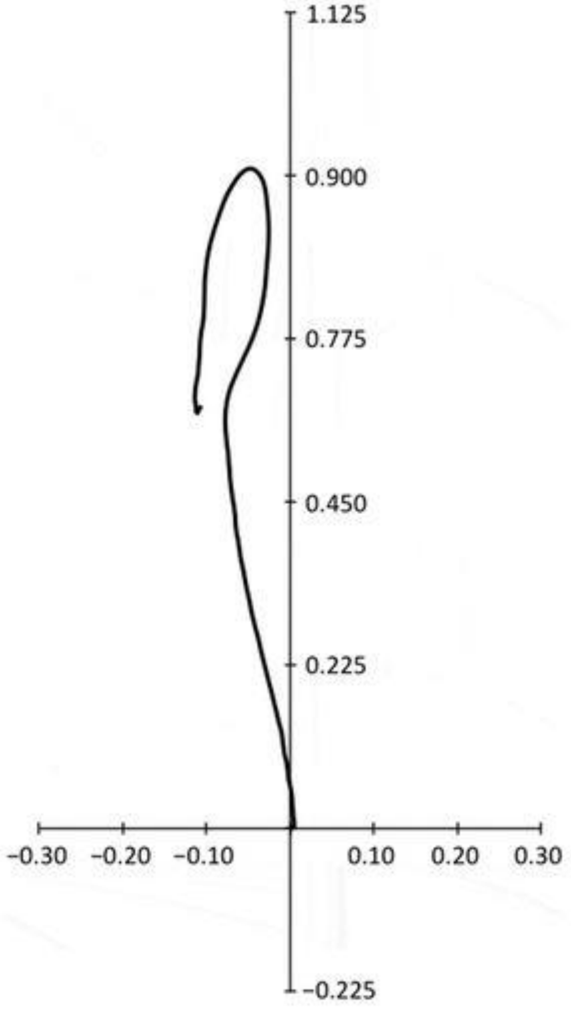


Figure 1**.** The figure shows a representative barbell trajectory from the one repetition maximum clean test. Positive values indicate anterior and up.

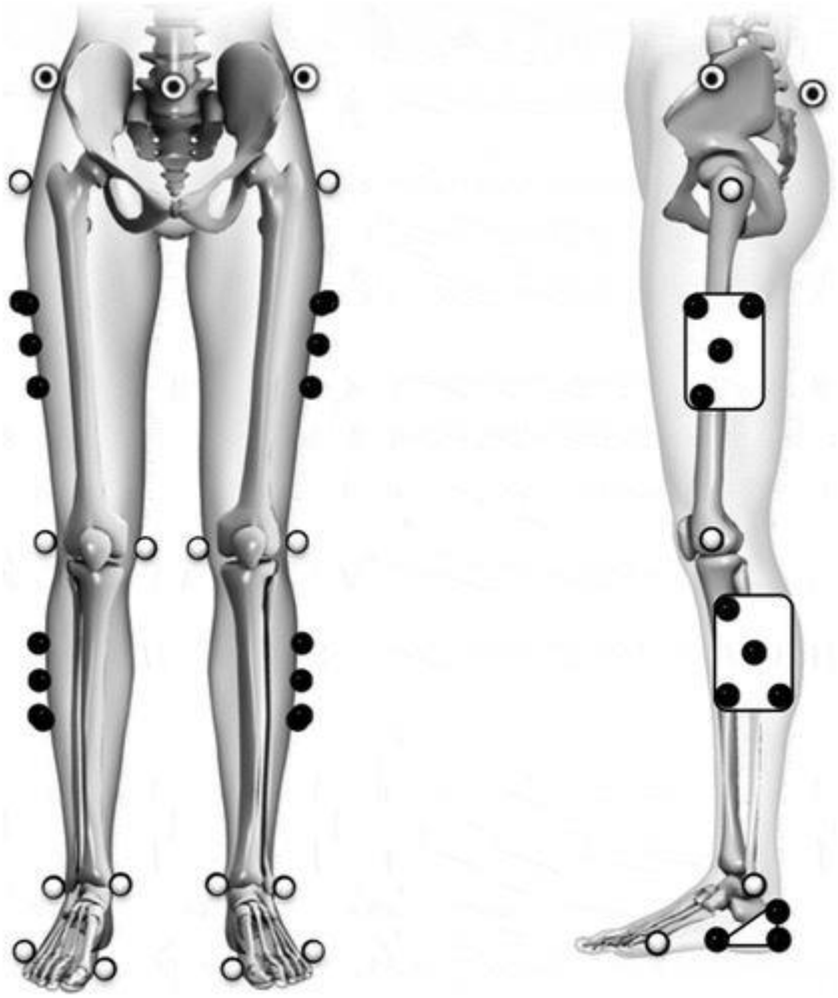
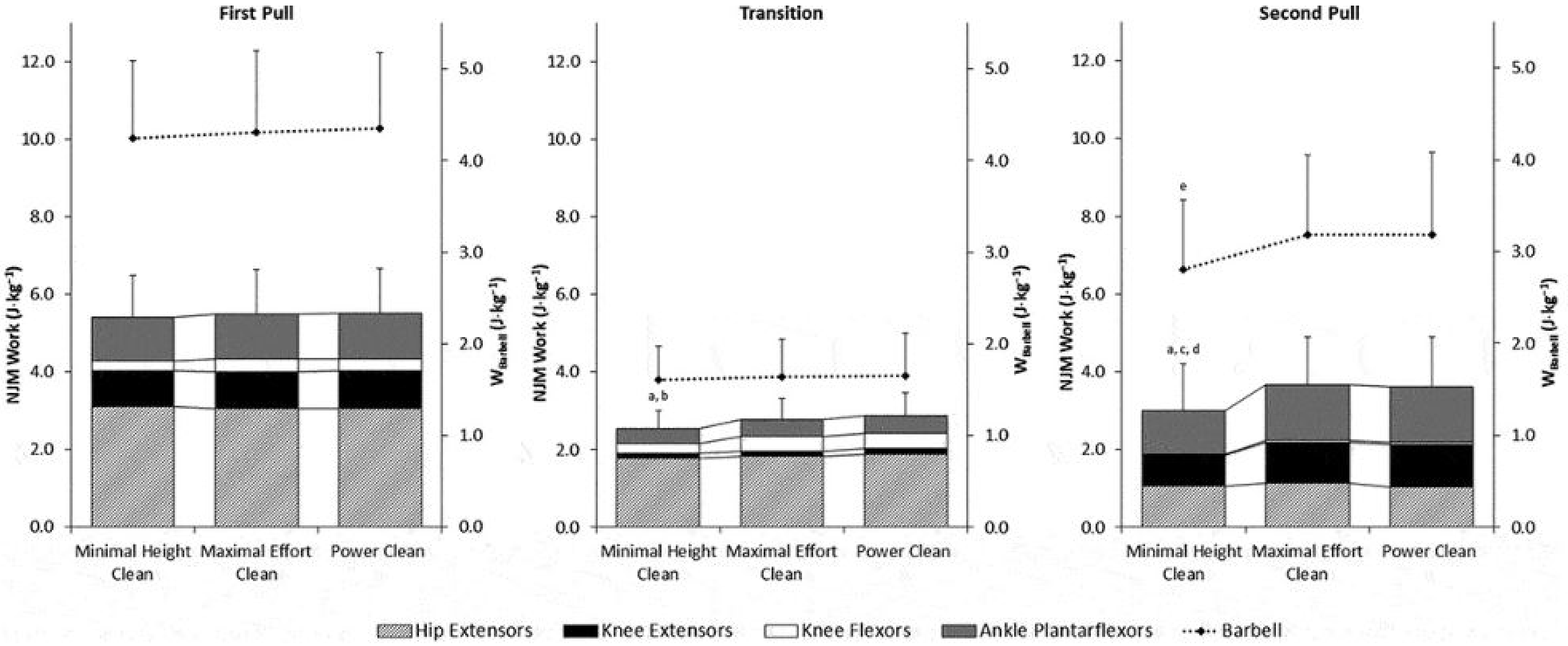


Figure 2. The figure shows a frontal (left panel) and sagittal (right panel) view of the calibration (white) and tracking (black) markers used in the present study. White markers with a black dot served as both calibration and tracking markers. The foot cluster makers are not visible in the frontal plane view.

Figure 3. The figure shows the work performed about the lower extremity joints (stacked bars; left axis) and on the barbell (diamonds; right axis) during the first pull (left panel), transition phase (middle panel), and second pull (right panel) of the minimal height, maximal effort and power cleans.

[a] Total lower extremity NJM work: Minimal height clean < Maximal effort clean = Power Clean, [b] Knee flexor NJM work: Minimal height clean < Maximal effort clean = Power Clean, [c] Knee extensor NJM work: Minimal height clean < Maximal effort clean = Power clean, [d] Ankle plantar flexor NJM work: Minimal height clean < Power clean, [e] $W_{barbell}$: Minimal height clean < Maximal effort clean = Power clean, $W_{barbell}$ = Work performed on the barbell, NJM = Net joint moment



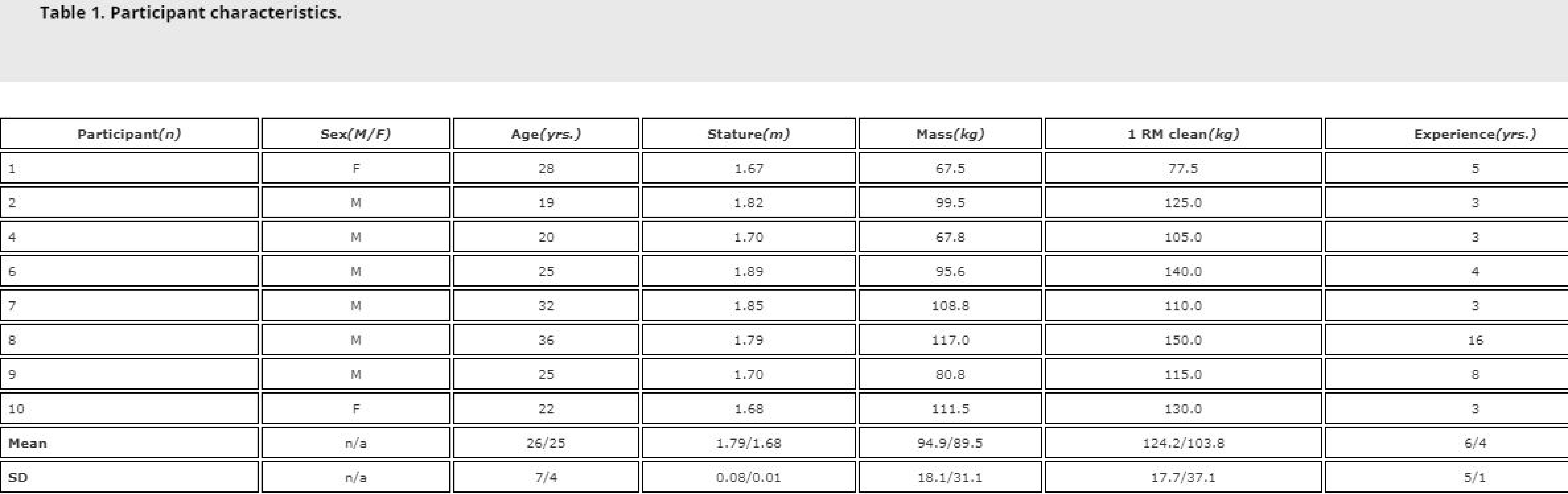


Table 1. Participant characteristics.

Participant(*n*)	Sex(*M/F*)	Age(*yrs.*)	Stature(*m*)	Mass(*kg*)	1 RM clean(*kg*)	Experience(*yrs.*)
1	F	28	1.67	67.5	77.5	5
2	M	19	1.82	99.5	125.0	3
4	M	20	1.70	67.8	105.0	3
6	M	25	1.89	95.6	140.0	4
7	M	32	1.85	108.8	110.0	3
8	M	36	1.79	117.0	150.0	16
9	M	25	1.70	80.8	115.0	8
10	F	22	1.68	111.5	130.0	3
Mean	n/a	26/25	1.79/1.68	94.9/89.5	124.2/103.8	6/4
SD	n/a	7/4	0.08/0.01	18.1/31.1	17.7/37.1	5/1

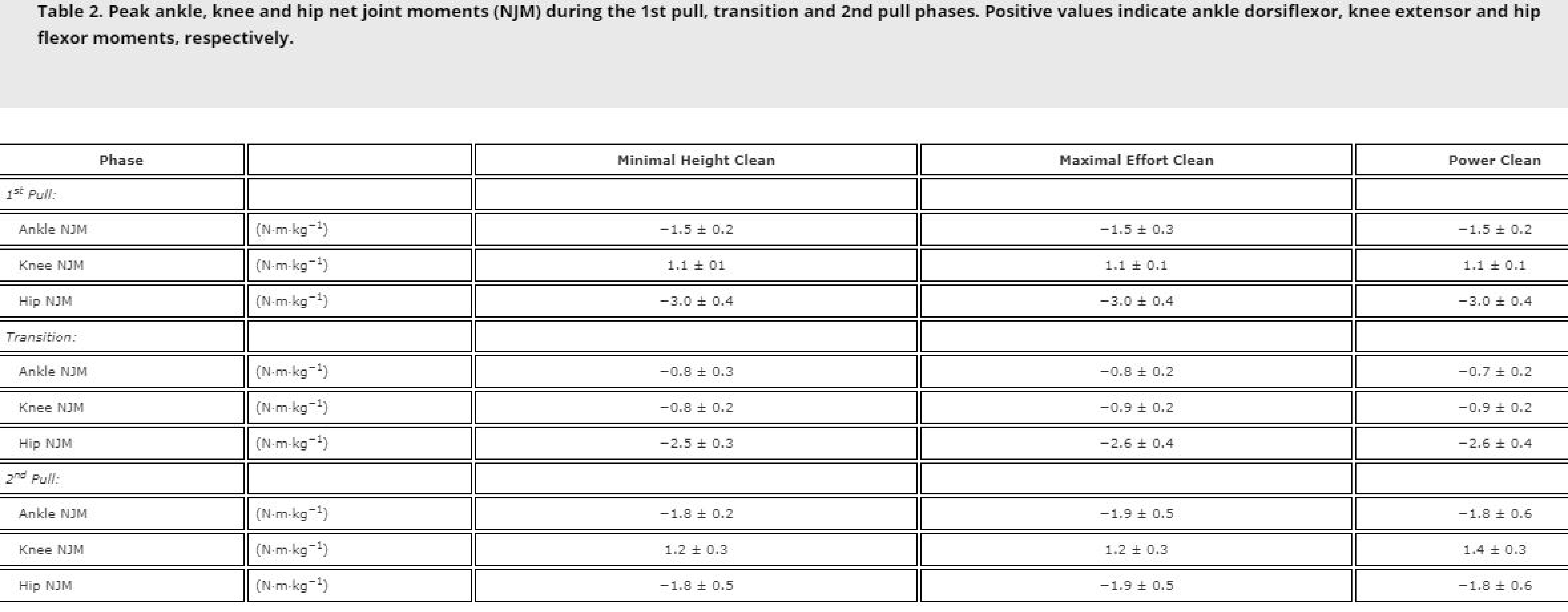


Table 2. Peak ankle, knee and hip net joint moments (NJM) during the 1st pull, transition and 2nd pull phases. Positive values indicate ankle dorsiflexor, knee extensor and hip flexor moments, respectively.

Phase		Minimal Height Clean	Maximal Effort Clean	Power Clean
1st Pull:				
Ankle NJM	(N·m·kg−1)	−1.5 ± 0.2	−1.5 ± 0.3	−1.5 ± 0.2
Knee NJM	(N·m·kg−1)	1.1 ± 01	1.1 ± 0.1	1.1 ± 0.1
Hip NJM	(N·m·kg−1)	−3.0 ± 0.4	−3.0 ± 0.4	−3.0 ± 0.4
Transition:				
Ankle NJM	(N·m·kg−1)	−0.8 ± 0.3	−0.8 ± 0.2	−0.7 ± 0.2
Knee NJM	(N·m·kg−1)	−0.8 ± 0.2	−0.9 ± 0.2	−0.9 ± 0.2
Hip NJM	(N·m·kg−1)	−2.5 ± 0.3	−2.6 ± 0.4	−2.6 ± 0.4
2nd Pull:				
Ankle NJM	(N·m·kg−1)	−1.8 ± 0.2	−1.9 ± 0.5	−1.8 ± 0.6
Knee NJM	(N·m·kg−1)	1.2 ± 0.3	1.2 ± 0.3	1.4 ± 0.3
Hip NJM	(N·m·kg−1)	−1.8 ± 0.5	−1.9 ± 0.5	−1.8 ± 0.6

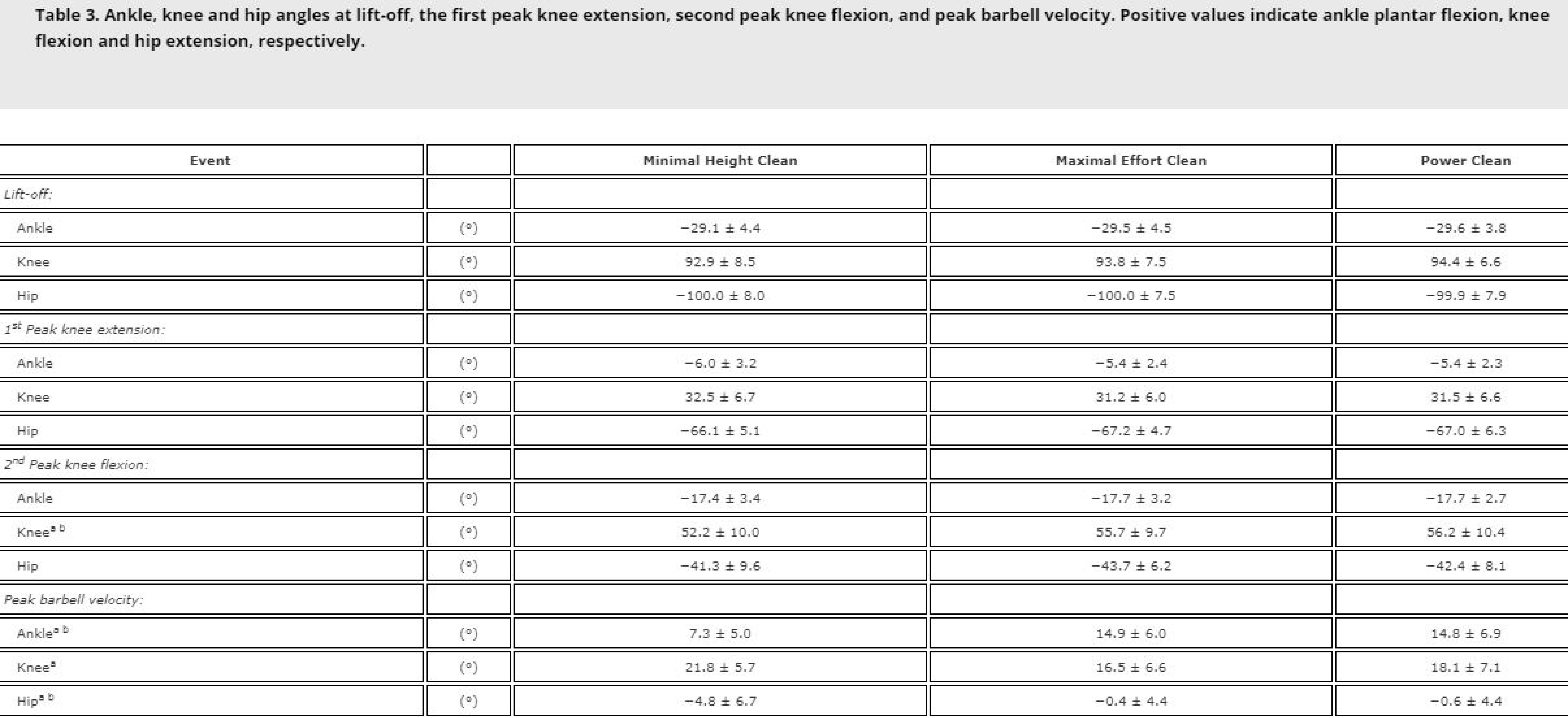


Table 3. Ankle, knee and hip angles at lift-off, the first peak knee extension, second peak knee flexion, and peak barbell velocity. Positive values indicate ankle plantar flexion, knee flexion and hip extension, respectively.

Event		Minimal Height Clean	Maximal Effort Clean	Power Clean
Lift-off:				
Ankle	(°)	−29.1 ± 4.4	−29.5 ± 4.5	−29.6 ± 3.8
Knee	(°)	92.9 ± 8.5	93.8 ± 7.5	94.4 ± 6.6
Hip	(°)	−100.0 ± 8.0	−100.0 ± 7.5	−99.9 ± 7.9
1st Peak knee extension:				
Ankle	(°)	−6.0 ± 3.2	−5.4 ± 2.4	−5.4 ± 2.3
Knee	(°)	32.5 ± 6.7	31.2 ± 6.0	31.5 ± 6.6
Hip	(°)	−66.1 ± 5.1	−67.2 ± 4.7	−67.0 ± 6.3
2nd Peak knee flexion:				
Ankle	(°)	−17.4 ± 3.4	−17.7 ± 3.2	−17.7 ± 2.7
Knee[a b]	(°)	52.2 ± 10.0	55.7 ± 9.7	56.2 ± 10.4
Hip	(°)	−41.3 ± 9.6	−43.7 ± 6.2	−42.4 ± 8.1
Peak barbell velocity:				
Ankle[a b]	(°)	7.3 ± 5.0	14.9 ± 6.0	14.8 ± 6.9
Knee[a]	(°)	21.8 ± 5.7	16.5 ± 6.6	18.1 ± 7.1
Hip[a b]	(°)	−4.8 ± 6.7	−0.4 ± 4.4	−0.6 ± 4.4