

Title: MECHANICAL DEMANDS OF KETTLEBELL SWING
EXERCISE

Running Title: Swing Exercise Mechanics

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Abstract:

The aims of this study were to establish mechanical demands of kettlebell swing exercise, and provide context by comparing them to mechanical demands of back squat and jump squat exercise. Sixteen men performed two sets of 10 swings with 16, 24, and 32 kg, two back squats with 20, 40, 60 and 80% 1RM, and two jump squats with 0, 20, 40, and 60% 1RM. Sagittal plane motion and ground reaction forces (GRF) were recorded during swing performance, and GRF were recorded during back and jump squat performance. Net impulse, and peak and mean propulsion phase force and power applied to the center of mass (CM) were obtained from GRF data, and kettlebell displacement and velocity from motion data. Results of repeated measures analysis of variance showed that all swing CM measures were maximized during the 32 kg condition, but that velocity of the kettlebell was maximized during the 16 kg condition; displacement was consistent across different loads. Peak and mean force tended to be greater during back and jump squat performance, but swing peak and mean power was greater than back squat power, and largely comparable with jump squat power. However, the highest net impulse was recorded during swing exercise with 32 kg (276.1 ± 45.3 N·s vs. 60% 1RM back squat: 182.8 ± 43.1 N·s, and 40% jump squat: 231.3 ± 47.1 N·s). These findings indicate a large mechanical demand during swing exercise, that could make swing exercise a useful addition to strength and conditioning programs that aim to develop the ability to rapidly apply force.

Keywords: Impulse; force; power; resistance exercise

INTRODUCTION

Kettlebell exercise has become increasingly popular over recent years, with many believing that it can simultaneously develop muscular strength, power and endurance, and aerobic fitness (4, 12). The kettlebell swing forms the technical foundation of most other kettlebell exercises, in addition to forming the basis of many kettlebell exercise programs (4, 12). Swing performance, illustrated in Figure 1, is initiated by actively flexing, or

“hinging” the hip joint, restricting knee flexion while the kettlebell is displaced in a downward arc between the knees, until a bottom position, governed by hamstring flexibility and the ability to maintain a neutral spine, is reached (Figure 1 – position “B”). The hips are then extended to reverse the movement, with the intention of displacing the kettlebell in an arc away from the body (Figure 1 – to position “A”), until its momentum is exhausted. The movement is then immediately repeated for the required number of repetitions.

*****Insert Figure 1 about here, please*****

Swing exercise is relatively unique in that performance requires ballistic flexion, followed by ballistic extension of the hip joint, with the largest muscles of the lower-body repeatedly performing potentially large amounts of mechanical work over short periods of time. The ballistic nature of swing exercise, in addition to relatively low technical demands, and use of relatively light loads may make swing exercise a useful addition for strength and conditioning coaches interested in adding variety to the development of rapid lower-body force production in their athletes.

Investigators have begun to quantify the efficacy of kettlebell exercise with mixed results (4, 5, 6, 11). For example, Farrar *et al.* (4) and Fung *et al.* (5) reported considerable aerobic demand during bouts of kettlebell exercise. However, Jay *et al.* (6) reported no significant change in aerobic fitness following an eight-week kettlebell training program. Chiu (1) stated that the stimulus provided by kettlebell exercise is not sufficient to stimulate increases in maximal, reactive, and explosive strength. Nonetheless, Manocchia *et al.* (11) reported significant increases in upper-body and whole-body strength and power, and trunk endurance, following a 10-week kettlebell training program, although details about

their program were not provided. Further, Jay *et al.* (6) reported significant increases in lower-back strength following eight-weeks of kettlebell training. However, the mechanical demands of kettlebell exercises, like the swing, have not been established.

Full understanding of the mechanical demands of different types of resistance exercise is critical if strength and conditioning practitioners are to make informed decisions about the type of resistance exercise that is included in athlete programs. Historically investigators have determined the mechanical demand of resistance exercise by studying peak and mean force or power applied to the barbell or center of mass (CM) of the combined barbell and body system. Further, study of load-power relationships is often used to assess neuromuscular function and govern resistance exercise intensity (7, 10, 14). Knudson (8) has suggested that impulse applied to a mass of interest provides a better indication of the mechanical demands of a movement because it combines both the magnitude and duration of force application.

Therefore, the primary aim of this study was to begin the development of a knowledge base that will strive to quantify the mechanical demands of kettlebell exercise, starting, in this study, with the two-hand kettlebell swing. A secondary aim of this study was to provide context for the mechanical demands of kettlebell swing exercise by comparing them with the mechanical demands of back squat and jump squat exercise.

METHODS

Experimental approach to the problem

To establish the mechanical demands of kettlebell swing exercise, 16 men performed two sets of 10 two handed swings with single 16, 24, and 32 kg kettlebells on a Kistler force platform while a digital camera recorded sagittal plane motion of the kettlebell. Ground reaction force (GRF) data were used to obtain measures of net impulse, peak and mean force and peak and mean power applied to, and peak and mean velocity of the CM, while motion footage was used to obtain measures of displacement and peak and mean velocity of the kettlebell. Horizontal (anterior and posterior) and vertical data were obtained from the third, sixth and ninth repetition of each set to provide an accurate representation of swing performance across each set. Because of the large horizontal component observed in swing exercise, resultant data values were used to quantify mechanical demands and outcomes, and were obtained by calculating the square root of squared and summed horizontal and vertical data. Further, all data were presented as both absolute values and relative to body mass and stature. Descriptive statistics were computed and repeated measures analysis of variance used to determine whether load affected the dependent variables associated with mechanical demand – net impulse, peak and mean force and peak and mean power applied to the CM, and mechanical outcome - displacement and peak and mean velocity of the kettlebell. At the conclusion of kettlebell swing performance maximal back squat strength (one repetition maximum: 1RM) was established. Four to seven days later subjects performed two back squats with 20, 40, 60, and 80% 1RM and two jump squats with no additional load, 20, 40, and 60% 1RM on a Kistler force platform. Context of the mechanical demands of swing exercise was then obtained by comparing them to the mechanical demands of jump squat and back squat exercise using repeated measures analysis of variance.

Subjects

Sixteen physically active men with a minimum of six months kettlebell, back squat, and jump squat exercise experience participated in this study. Their mean (*SD*) physical characteristics were age: 24 (2) years; mass: 90.2 (14.4) kg, and stature: 1.79 (0.04) m. Volunteers had been free of lower-body pathology for at least six months before data collection. Ethical approval for this study was gained from the ethical review panel at the University of Chichester, Chichester, UK. Following a thorough explanation of the study aims, protocols and potential risks, subjects provided written informed consent.

Procedures

Subjects attended two laboratory based testing sessions. During the first session subjects performed a self selected warm up then performed two sets of 10 maximal effort swing exercise with a 16 kg, 24 kg, and 32 kg kettlebell (Jordan Fitness, Cambridgeshire, UK). All swings were performed in accordance with the technique described by Tsatsouline (12), and seen in Figure 1; subjects were instructed to lead with the hips, driving them backwards during the lowering phase, and forward, exerting maximal force as quickly as possible during the lifting phase. Subjects rested for three minutes between each set. The 16, 24, and 32 kg loads were used because they have been recommended as suitable loads for beginner, intermediate, and advanced men respectively (12). During performance, experimenters enforced performance criteria of vertically displacing the kettlebell to a position in line with the sternum through visual inspection of actual performance and analysis of motion footage (immediately post performance). Swing performance that did not meet the above criteria was excluded from the analysis. At the conclusion of swing performance maximal back squat strength (1RM) was assessed with a modified version of the protocol used by Wallace *et al.* (13). Subjects squatted inside a power rack (Pullum Pro-R half power rack, Pullum Sports, Luton, UK) through a range of

motion equivalent to 45% of their leg length, lightly touching the power rack support at the bottom of the movement before performing the propulsion phase of the lift. Subjects performed warm up sets of 10 repetitions with 50% of the estimated 1RM, five repetitions with 70% of the estimated 1RM, three repetitions with 80% of the estimated 1RM, and one repetition with 90% of the estimated 1RM; subjects then performed progressively heavier single lifts until the load could not be lifted for two successive attempts. Subjects rested for three minutes between each set.

Four to seven days later subjects attended a second laboratory based testing session where they were instructed to perform single repetition back squats with 20, 40, 60, and 80% 1 RM, and single repetition jump squats with no additional load (holding a rigid pole in place of the barbell – mass: 0.4 kg), 20, 40, and 60% 1 RM, controlling the descent phase, but performing the propulsion phase as quickly as possible. Subjects performed back squat and jump squat single repetitions until the difference between peak power applied to the CM of two successive lifts with a given load was less than 5% (2). A rest period of three minutes was enforced between each lift. All data were recorded during June, and subjects had not been involved in competitive sport for at least one month. Subjects attended the laboratory, approximately two hours after breakfasting, having been instructed to avoid heavy resistance exercise for at least 48 hours before testing. Subjects were instructed to perform swing, back squat, and jump squat exercise with the intention of moving the load of interest as quickly as possible using correct technique, and were given verbal encouragement to move the load as quickly as possible throughout each session.

Instrumentation

Swing, back squat and jump squat exercise was performed on a Kistler 9281 force platform (Kistler Instruments, Hook, UK) that recorded vertical and anterior-posterior GRF from both feet at 500 Hz. During swing performance a high-speed digital camera (Basler A602fc-2, Ahrensburg, Germany) positioned 5 m to the right and perpendicular to the subject recorded sagittal plane motion of a retro-reflective marker affixed to the centre of the sphere of the kettlebell at 100 Hz after first recording a 1.5 m calibration pole. Kinematic and kinetic data collection was synchronized with an external trigger mechanism. Motion data were interpolated to 500 Hz using Vicon Motus 9.2 software (Vicon – UK, Oxford, UK).

Ground reaction force data were used to obtain measures of CM kinetics and kinematics, specifically horizontal (anterior and posterior) and vertical net impulse and peak and average propulsion phase force and power applied to the CM. Net impulse was calculated by integrating net GRF (GRF – system weight) data using the Trapezoid method, then summing integrated data across the propulsion phase. Horizontal acceleration of the CM was calculated by dividing horizontal GRF by system mass; vertical acceleration by dividing vertical net GRF by system mass. Acceleration data were then integrated to obtain velocity of the CM; power applied to the CM was calculated by multiplying the velocity of the CM by force applied to the CM (GRF).

Motion data were used to obtain measures of kettlebell kinematics, specifically, peak and average propulsion phase resultant velocity of the kettlebell and resultant displacement of the kettlebell. Motion footage of a retro-reflective, spherical marker affixed to the sphere of the kettlebell (Figure 1) was cropped to include 10 frames before the start and after the

end of the 10 repetitions then automatically digitized for all ten repetitions using Vicon Motus 9.2 software (Vicon – UK, Oxford, UK). Raw displacement data were filtered using a low pass Butterworth filter with a cut off frequency of 4 Hz that was selected using residual analysis (15), and differentiated once to obtain velocity of the kettlebell.

Because of the large horizontal component observed in swing exercise, horizontal (anterior and posterior) and vertical data were recorded to obtain resultant values by calculating the square root of squared and summed horizontal and vertical data. Further, all data were presented as both absolute values and relative to body mass and stature. Only the propulsion phase was studied, and this was identified as starting at the lowest resultant kettlebell displacement, ending at peak resultant kettlebell velocity (9 – See Figures 4 and 5).

All motion and GRF data were processed in a customized LabVIEW program (National Instruments, Version 9.0, Austin, Texas, USA), that enabled selection of data from the third, sixth and ninth repetition from each set of swing exercise (which were then averaged for further analysis), and identification of the propulsion phase of swing, back squat and jump squat exercise. Within session test-retest reliability of the methods used to obtain dependent variables was high, with intraclass correlation coefficients (ICC) of between ICC R = 0.92 and 0.99.

*****Insert Figure 2 about here*****

Statistical analyses

All data were presented as mean (*SD*). Descriptive statistics were computed and one-way (load) repeated measures analysis of variance used to determine whether load affected the dependent variables associated with swing exercise mechanical demand – net impulse, peak and mean propulsion phase force and power applied to the CM, and mechanical expression - velocity and displacement of the kettlebell. Further, mechanical demands of swing, jump squat, and back squat exercise were compared using one-way (exercise type) repeated measures analysis of variance. Where appropriate, post hoc analysis was performed using the Holm-Sidak procedure. All statistical analysis was performed using SPSS (version 17.0; SPSS Inc., Chicago, IL), and an alpha of $p \leq 0.05$ was used to indicate statistical significance.

*****Insert Figures 3, 4, and 5 about here*****

RESULTS

Mean (*SD*) data describing the mechanical demand of kettlebell swing exercise, and illustrating comparison of these demands with those of back squat and jump squat exercise are presented in Tables 1 and 2, while the mechanical consequences of these demands are displayed in the form of kettlebell displacement and velocity data in Table 3. The load and exercise effect on absolute net impulse applied to the CM is presented graphically in Figure 2, while graphical illustrations of the forces applied to the CM, and the horizontal, vertical and resultant displacements and velocities of the kettlebell during representative swing performance are displayed in Figures 3, 4, and 5.

*****Insert Tables 1, 2, and 3 about here*****

Tables 1 and 2 show that mechanical demand data recorded during swing performance were maximized during the 32 kg condition, and that differences between the dependent variables recorded during the 16, 24, and 32 kg conditions tended to reach statistical significance. However, mechanical expression data were maximized during the 16 kg condition, during which peak and mean velocity tended to be significantly greater than during the 24 and 32 kg condition. Displacement (both absolute and relative to stature) of the kettlebell remained relatively consistent across all loading conditions.

Results of comparison with the mechanical demands of back squat and jump squat were mixed. In general the largest values of net impulse (both absolute and relative to body mass) applied to the CM were recorded during the 32 kg swing condition, which tended to be significantly greater than the net impulse applied to the CM during back squat and jump squat performance. Peak and mean force applied to the CM during back squat and jump squat performance tended to be significantly greater than peak and mean force applied to the CM during swing performance. Results of the peak and mean propulsion phase power comparison across exercises were varied, with power applied to the CM during the 32 kg condition swing performance tending to be significantly greater than power applied to the CM during back squat performance, but similar to power applied to the CM during jump squat performance.

DISCUSSION

The aims of this study were to establish mechanical demands of kettlebell swing exercise, and to provide context by comparing them to the mechanical demands of back squat and jump squat exercise. The results demonstrated a large mechanical demand during swing

exercise that increased with load, but varied depending on the way in which mechanical demand was quantified.

Peak force, that is the largest instantaneous force applied to a mass of interest, is often used to quantify the ability to express muscle strength. The results of this study showed that, of the three exercises considered, peak force applied to the CM, both absolute and relative to body mass, was maximized during back squat exercise with 80% 1RM (Table 1 and 2). This finding supports recent commentary (1) suggesting that swing exercise may not provide stimulus sufficient to improve maximal strength.

Investigators have suggested that force applied to the mass of interest should be averaged over the propulsion phase because it provides a better indication of the mechanical demand of the exercise across the phase of interest rather than at one specific point (9). However, the results of this study suggested that whether peak instantaneous or average propulsion phase force applied to the mass of interest is used is of little consequence, given that differences observed between peak forces applied to the CM during swing, back squat and jump squat exercise increased when force was averaged across the propulsion phase. The implications of this finding are similar to those described for peak force results, and should be acted on accordingly. Although it is generally accepted that the amount of force applied to the mass of interest during resistance exercise is important, the rate at which mechanical work is performed is believed to have greater relevance to sporting performance.

Power describes the rate at which mechanical work is performed, and can be calculated as the product of the force applied to an object and its velocity. However, some scholars suggest that it is limited as a measure of mechanical demand because it is a scalar quantity (8). As noted previously, study of the load-power relationship is often used to assess neuromuscular function and govern resistance training intensity. Investigators (7, 10, 14) have suggested that the load that maximizes power applied to the resistance of interest presents an optimal load to develop the ability to apply large power outputs to sports specific resistances. Results related to peak and mean power applied to the CM during heavy swing exercise (32 kg) indicated that peak and mean power applied to the CM was significantly greater than equivalent back squat output, and comparable with equivalent jump squat output. It is noteworthy, given similarities in power outputs recorded during jump squat and swing exercise, that investigators have recorded significant increases in both strength and power following periods of resistance training with the resistance exercise load that maximizes power applied to the mass of interest (7, 10, 14). This suggests that swing exercise might make a useful addition to strength and conditioning coaches interested in increasing the ability to apply large power outputs. However, some feel that mechanical power output is a parameter that is both misused and misunderstood (8).

Knudson (8) suggested impulse applied to the mass of interest as an alternative to mechanical power output to potentially improve the way in which mechanical demand of resistance exercise is quantified. In many ways, this makes sound theoretical sense, mainly because as a mechanical parameter impulse is a vector quantity (compared to power, which is a scalar quantity) that describes both the magnitude and rate of force application to a mass of interest. Interestingly, net impulse applied to the CM was

maximized during swing exercise with 32 kg. This was significantly greater than net impulse applied to the CM during back squat with all loads, and jump squat with 0% and 20% 1RM. During jump squat exercise, net impulse applied to the CM was maximized with 40% 1RM, and was 16% less than net impulse recorded during swing exercise with 32 kg. This finding demonstrates that although force applied to the CM is relatively low during swing exercise, it is applied at a greater rate, often significantly, compared to resistance exercises traditionally used to assess and develop lower-body strength and power. This could have important implications for strength and conditioning professionals looking for suitable exercises to include in strength and conditioning programs developed to improve the ability to apply force quickly. However, the unique movement pattern of swing exercise should be considered.

The reader is reminded that mechanical demand was quantified considering resultant mechanical output, combining vertical and horizontal output. Figure 4 indicates the large horizontal component present during swing exercise. This is largely a consequence of the technical demand of the swing, where the kettlebell is actively projected anteriorly by powerful extension of the hip joint. Therefore, the findings of this study should be considered with the large horizontal component in mind, which may lend itself to the mechanical demands of some sporting movements.

Ebben *et al.* (3) recently studied the effect of low-repetition, high load, and high-repetition, low load resistance training on rowing ergometer performance. They found that training responses depended on athlete standard, varsity rowers benefitting from high-load training, novice rowers from high-repetition training. The combination of results regarding

the mechanical demand of swing exercise from the present study, the hip specific nature of swing exercise, and findings presented by Ebben *et al.* (3), suggest that swing exercise offers a potentially useful and movement plane specific exercise for the strength and conditioning process of rowing athletes.

The heaviest swing exercise load studied during the present investigation was 32 kg. Heavier loads can be applied, by using either heavier kettlebells (currently a 48 kg is available), although this might be limited, or by using a custom made handle. Swing exercise with this sort of handle is often referred to as "Hungarian core blaster" exercise and may warrant further research. Specifically, further research should establish the effect of swing training on common measures of neuromuscular function, like maximal strength and power.

To summarize, careful consideration of the results of this study shows that kettlebell swing exercise does not appear to provide a stimulus sufficient to stimulate gains in maximal strength. However, it may make a useful addition to strength and conditioning programs designed to develop the ability to rapidly apply large forces to sports specific resistances.

PRACTICAL APPLICATIONS

This study is the first to quantify the mechanical demand of two-handed kettlebell swing exercise, and the results suggest that while the mechanical demand of kettlebell swing exercise appears to be sufficient to elicit increases in the ability to apply force quickly, it may not be sufficient to elicit increases in absolute maximal strength. Therefore, kettlebell swing exercise could prove a useful addition to strength and conditioning practitioners

interested in developing the ability of their athletes to rapidly apply large forces to sports specific resistances, but movement specificity should be considered carefully.

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FIGURE HEADERS

Figure 1. Key positions during two-hand kettlebell swing performance – A: top position immediately before the lifter flexes, or “hinges” at the hip joint; B: the kettlebell displaces in

a downward arc, passing between the knees while knee flexion is restricted and a neutral lower-back position is maintained; the kettlebell is then projected forward by powerfully extending the hip joint. Careful attention must be paid to maintaining correct body positions throughout.

Figure 2. Mean (*SD*) net impulse applied to the CM during kettlebell swing (KB), back squat, (BS), and jump squat (JS) exercise with different loads.

Figure 3. Horizontal, vertical and resultant force applied to the CM during representative swing performance with 24 kg. Braking and propulsion phases are highlighted with dark grey and light grey, respectively. The vertical force-time curve is obscured by the resultant force-time curve.

Figure 4. Horizontal, vertical and resultant displacement of the kettlebell during representative swing performance with 24 kg. Braking and propulsion phases are highlighted with dark grey and light grey, respectively.

Figure 5. Horizontal, vertical and resultant velocity of the kettlebell during representative swing performance with 24 kg. Braking and propulsion phases are highlighted with dark grey and light grey, respectively.

TABLE HEADERS

Table 1. Mean (*SD*) resultant mechanical characteristics of the CM during kettlebell swing (KB), back squat (BS) and jump squat (JS) exercise with different loads.

Table 2. Mean (*SD*) resultant mechanical characteristics, normalized relative to body mass, of the CM during kettlebell swing (KB), back squat (BS) and jump squat (JS) exercise with different loads.

Table 3. Mean (*SD*) resultant displacement (absolute and normalized relative to stature) and velocity of the kettlebell during swing (KB) performance with different loads.

Table 1. Mean (*SD*) resultant mechanical characteristics of the CM during kettlebell swing (KB), back squat (BS) and jump squat (JS) exercise with different loads.

	Peak Force (N)	Mean Force (N)	Impulse (N·s)	Peak Power (W)	Mean Power (W)
KB 16 kg	1616c (357)	1323c (233)	194bc (49)	2371c (708)	1130bc (324)
KB 24 kg	1678c (373)	1395c (258)	213c (60)	2471c (862)	1219 (424)
KB 32 kg	2005 (351)	1582 (205)	276 (45)	3281 (970)	1683 (303)
BS 20%	1759 (322)	1195 (303)	146abc (28)	1707abc (239)	823c (232)
BS 40%	2054de (473)	1470 (366)	169bc (35)	2162c (412)	943c (255)
BS 60%	2214def (460)	1731de (377)	183c (43)	2192c (504)	983c (252)
BS 80%	2427def (460)	1985def (401)	156abc (44)	1798bc (408)	754bc (195)
JS 0%	1926de (402)	1528 (482)	185c (38)	3468de (678)	1642d (552)
JS 20%	2141def (479)	1881def (448)	208c (35)	3415de (732)	1682de (396)
JS 40%	2334def (540)	2050def (522)	231d (47)	3284de (586)	1529 (398)
JS 60%	2214def (662)	1731def (632)	183d (52)	2192de (694)	983 (487)

* = a: significantly less than 16 kg; b: significantly less than 24 kg; c: significantly less than 32 kg; d: significantly greater than 16 kg; e: significantly greater than 24 kg; f: significantly greater than 32 kg.

Table 2. Mean (*SD*) resultant mechanical characteristics, normalized relative to body mass, of the CM during kettlebell swing (KB), back squat (BS) and jump squat (JS) exercise with different loads.

	Peak Force (N·kg ⁻¹)	Mean Force (N·kg ⁻¹)	Impulse (N·kg ⁻¹ ·s)	Peak Power (W·kg ⁻¹)	Mean Power (W·kg ⁻¹)
KB 16 kg	18.8c (0.5)	15.5bc (0.9)	2.3bc (0.2)	27.7c (5.8)	13.2c (2.4)
KB 24 kg	19.6c (1.4)	16.4c (1)	2.5c (0.3)	28.6c (6.6)	13.9c (2.5)
KB 32 kg	21.5 (1.4)	17.0 (0.3)	3.0 (0.2)	34.9 (7.4)	18.1 (1.8)
BS 20%	20.7d (2.3)	13.9c (1.1)	1.7abc (0.2)	20.2abc (2.8)	9.5c (1.3)
BS 40%	23.9def (2.1)	17.0 (1.4)	2.0bc (0.1)	25.4c (3.2)	10.9c (1.4)
BS 60%	25.8def (2.7)	20.2def (1.4)	2.1c (0.2)	25.5c (3.3)	11.4c (1.5)
BS 80%	28.4def (2.7)	23.2def (1.8)	1.8 (0.4)	21.2bc (4.4)	8.9bc (2.3)
JS 0%	22.5de (2.4)	18.0 (4.7)	2.2c (0.2)	41.3de (8.8)	19.6de (6.7)
JS 20%	24.9def (2.1)	21.8def (1.9)	2.4c (0.3)	40.3de (7.9)	19.7de (3.7)
JS 40%	27.1def (2.3)	23.8def (2.9)	2.7d (0.4)	38.8de (6)	18.1d (4)
JS 60%	25.8def (2.8)	20.2def (3.3)	2.1d (0.4)	25.5de (4.3)	11.4 (3.6)

* = a: significantly less than 16 kg; b: significantly less than 24 kg; c: significantly less than 32 kg; d: significantly greater than 16 kg; e: significantly greater than 24 kg; f: significantly greater than 32 kg.

Table 3. Mean (*SD*) resultant displacement (absolute and normalized relative to stature) and velocity of the kettlebell during swing (KB) performance with different loads.

		16 kg		24 kg		32 kg	
Peak KB Velocity	(m·s ⁻¹)	5.02	(0.79)	4.41a	(0.77)	4.43a	(0.26)
Mean KB Velocity	(m·s ⁻¹)	2.65	(0.42)	2.41a	(0.39)	2.29ab	(0.19)
KB Displacement	(m)	1.31	(0.27)	1.24	(0.33)	1.29	(0.34)
KB Displacement*	(% Stature)	73	(15)	69	(18)	72	(19)

* Normalized displacement calculated by dividing absolute displacement by body stature, and multiplying by 100; a: significantly less than 16 kg; b: significantly less than 24 kg; c: significantly less than 32 kg.

ACCEPTED

Figure 1. Key positions during two-hand kettlebell swing performance – A: top position immediately before the lifter flexes, or “hinges” at the hip joint; B: the kettlebell displaces in a downward arc, passing between the knees while knee flexion is restricted and a neutral lower-back position is maintained; the kettlebell is then projected forward by powerfully extending the hip joint. Careful attention must be paid to maintaining correct body positions throughout.

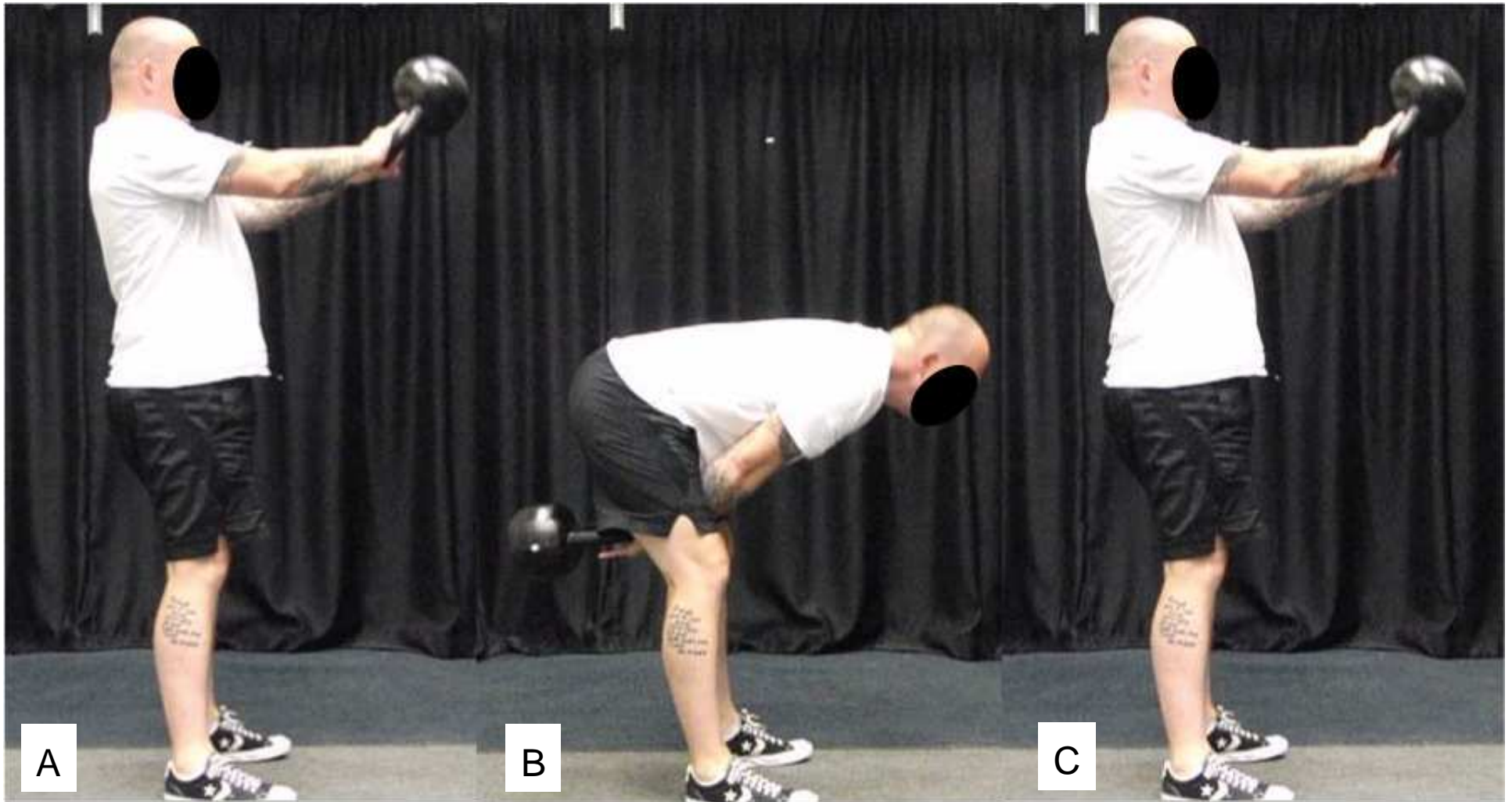
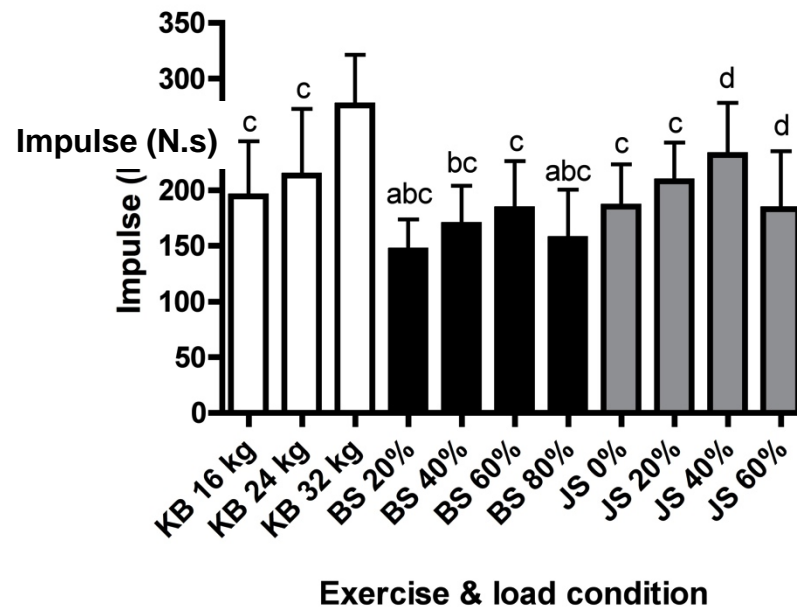


Figure 2. Mean (*SD*) net impulse applied to the CM during kettlebell swing (KB), back squat, (BS), and jump squat (JS) exercise with different loads.



* = a: less than 16 kg; b: less than 24 kg; c: less than 32 kg; d: greater than 16 kg.

Figure 3. Horizontal, vertical and resultant force applied to the CM during representative swing performance with 24 kg. Braking and propulsion phases are highlighted with dark grey and light grey, respectively. The vertical force-time curve is obscured by the resultant force-time curve.

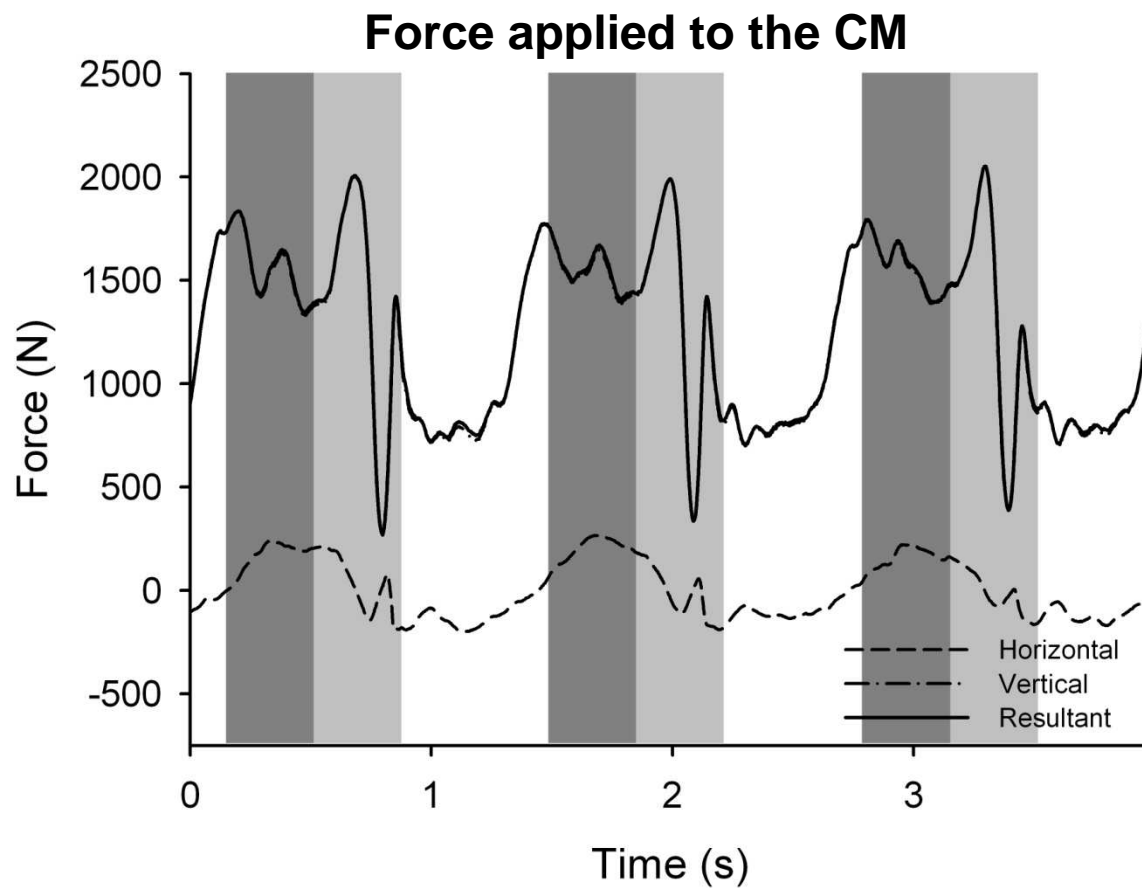


Figure 4. Horizontal, vertical and resultant displacement of the kettlebell during representative swing performance with 24 kg. Braking and propulsion phases are highlighted with dark grey and light grey, respectively.

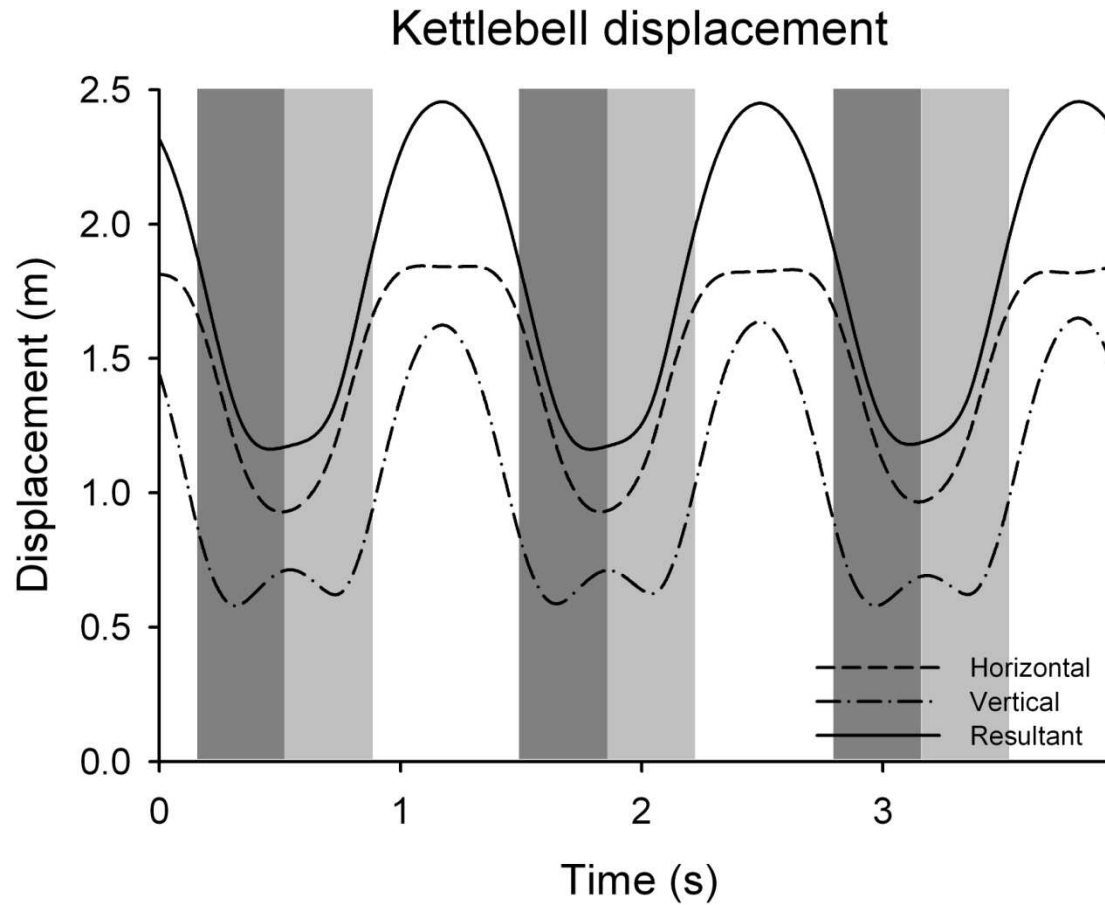


Figure 5. Horizontal, vertical and resultant velocity of the kettlebell during representative swing performance with 24 kg. Braking and propulsion phases are highlighted with dark grey and light grey, respectively.

