

Title: Magnitude and relative distribution of kettlebell snatch force-time characteristics

Running Title: Kettlebell Snatch Mechanics

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Abstract

The aim of this study was to compare mechanical output from kettlebell snatch and 2-handed kettlebell swing exercise. Twenty-two men performed 3 sets of 8 kettlebell snatch and 2-handed swing exercise with a 24 kg kettlebell on a force platform. Vertical and horizontal net impulse, mean force, displacement, the magnitude and rate of work performed displacing the kettlebell-and-lifter center of mass (CM), phase durations and impulse ratio (horizontal to resultant) were calculated from force data. The results of repeated measures analysis of variance showed that: 1) vertical CM displacement was significantly larger during kettlebell snatch exercise (22 ± 4 vs. 18 ± 5 cm, $p=0.001$), and

vertical CM displacement was significantly larger than horizontal CM displacement, regardless of exercise (20 ± 3 vs. 7 ± 1 cm, $p<0.0001$); 2) the magnitude (253 ± 73 vs. 3 ± 1 J, $p<0.0001$) and rate of work (714 ± 288 vs. 11 ± 4 W, $p<0.0001$) performed to vertically displace the CM was larger than the horizontal equivalent in both exercises, and the magnitude (5 ± 2 vs. 1 ± 1 J, $p<0.0001$) and rate of work (18 ± 7 vs. 4 ± 3 W, $p<0.0001$) performed to horizontally displace the CM during 2-handed swing exercise was significantly larger than the kettlebell snatch equivalent; 3) this was underpinned by the magnitude of horizontal impulse (29 ± 7 vs. 18 ± 7 N.s, $p<0.0001$) and the impulse ratio (23 vs. 14%, $p<0.0001$). These findings reveal that, apart from the greater emphasis 2-handed swing exercise places on horizontal mechanical output, the mechanical output of the two exercises is similar. Research shows that 2-handed swing exercise improves maximum and explosive strength. These results suggest that strength and conditioning coaches should consider using kettlebell snatch and 2-handed swing exercise interchangeably for the ballistic component of athlete strength and conditioning programs.

Keywords: impulse; power; Hardstyle; asymmetry; resistance exercise

INTRODUCTION

Interest in the relative benefits of including kettlebell exercises, like the 2-handed swing, in athlete and general population training programs has recently increased (2, 9, 10, 11, 12, 13, 15, 18). Research has demonstrated similarities between mechanical output from 2-handed swing exercise, which is illustrated in Figure 1, and back squat and jump squat exercise (10). Specifically, the largest impulse applied to the combined kettlebell-and-lifter center of mass (CM) of $276.1 (\pm 45.3)$ N.s was recorded during 2-handed swing exercise with 32 kg. This was 34% larger than the largest back squat impulse, and 16% larger than the largest jump squat impulse. Furthermore, there were no significant differences between the highest 2-handed swing exercise (3281 ± 970 W) and jump squat (3468 ± 678 W) peak power. This suggests that 2-handed swing exercise could provide a training stimulus sufficient to improve the ability to apply large amounts of force in short periods of time (impulse) and large amounts of force to a moving a mass of interest quickly (power).

Insert Figure 1 about here

Subsequent work by investigators showed that—with relatively light loads (12 to 16 kg)—2-handed swing exercise provided a training stimulus that was sufficient to provide a strength and power training effect (11). Recreational male athletes with limited resistance training experience performed 12 minutes of 30 s 2-handed swing exercise alternated with 30 s recovery twice a week for 6 weeks. Vertical jump performance improved by 13% (20 ± 0.05 cm to 23 ± 0.05 cm), while maximum strength improved by 10% (half squat = 156 ± 22 kg to

174 ± 22 kg), demonstrating the potential of 2-hand swing exercise to provide an effective and relatively time efficient strength and power training protocol. While these investigators (11) did not suggest that kettlebell exercise should, or indeed could, replace traditional resistance exercise, they did suggest that it could be used to provide variety to athlete strength and conditioning programs.

Although 2-handed swing exercise has received research attention, the potential for other popular kettlebell exercises, like the kettlebell snatch, to provide a strength and power training effect have not been studied. The kettlebell snatch is a unilateral exercise that is illustrated in Figure 2, and has been described in detail (17). It begins with the lifter performing a 1-handed swing but concludes with the lifter catching the kettlebell overhead on a locked arm. The aim of 2-handed swing exercise is to project the kettlebell forward, which creates an arc-like trajectory. During kettlebell snatch exercise flexing the elbow joint controls this arc-like trajectory, and greater emphasis is given to vertical displacement of the kettlebell so that it can be caught overhead before the sequence is reversed and repeated.

Insert Figure 2 about here

Proponents of kettlebell snatch exercise suggest that it has the potential to improve what is often referred to as explosive strength. The same load is often used in the 2-handed kettlebell swing and kettlebell snatch assessment portions of popular kettlebell certifications, like the Russian Kettlebell Certification (RKC), with healthy men typically using 24 kg. Therefore, during kettlebell snatch exercise the same load is displaced further with one hand, suggesting that a larger mechanical output is required compared to 2-handed swing exercise. However, the mechanical output from kettlebell snatch exercise has not been established and this

represents a gap in the literature. Addressing this gap by studying force-time curves recorded from kettlebell snatch exercise could, therefore, provide data that will enable strength and conditioning coaches to make informed decisions about the relative merit of including kettlebell snatch exercise in athlete strength and conditioning programs. Therefore, the aims of the current study were to: 1) establish mechanical output from kettlebell snatch exercise; 2) quantify the relative distribution of mechanical output; and 3) compare these data to equivalent data from 2-handed swing exercise. It was hypothesised that greater emphasis would be placed on vertical net impulse to perform more mechanical work to vertically displace the CM further during kettlebell snatch exercise. It was also hypothesized that greater emphasis would be placed on horizontal net impulse to perform more mechanical work to horizontally displace the CM further during 2-handed swing exercise.

METHODS

Experimental approach to the problem

To address the aims of this study a within-subjects repeated measures design was used. Braking and propulsion phase vertical and horizontal ground reaction forces (GRF) were recorded from 22 kettlebell-trained men performing sets of kettlebell snatch and 2-handed swing exercise with a 24 kg kettlebell on a force platform. Dependent variables of vertical and horizontal net impulse, mean force, displacement of the CM, the magnitude and rate of work performed displacing the CM, phase durations, and impulse ratio (the ratio of horizontal to resultant impulse) were obtained from vertical and horizontal forces recorded from a portable force platform, and analysed using repeated measures analysis of variance and paired sample *t* tests.

Subjects

Twenty-two men between the ages of 28 and 41 years (mass: 75.2 ± 14.6 kg; stature: 174 ± 13.5 cm), and with a minimum of 1 year's kettlebell snatch exercise and 2-handed swing exercise experience volunteered to participate. Subjects had been free from lower-body pathology for at least 6 months before data collection. Ethical approval for this study was gained from the institutions ethical review panel. After a thorough explanation of the study aims, protocols, and potential risks, subjects provided written informed consent.

Procedures

Subjects attended a single laboratory based testing session, during which they performed a self-selected warm up followed by three sets of 8 maximum effort kettlebell snatches and 2-handed swings with a 24 kg kettlebell (Dragon Door Kettlebells, Torrance, CA, USA). Exercises were performed in accordance with the technique described by Tsatsouline (17), exercise order was counterbalanced, and subjects rested for three minutes between each set. Subjects attended the laboratory approximately 2 hours post-prandial, having been instructed to avoid heavy resistance exercise for at least 48 hours before testing. Subjects were instructed to perform kettlebell snatch exercise and 2-handed swing exercise with the intention of moving the kettlebell as quickly as possible (using correct technique), and were given verbal encouragement throughout data collection.

Instrumentation

All kettlebell snatch and 2-handed swing exercise were performed on a 101.6 by 76.2 cm portable force platform (AccuPower, AMTI, Watertown, MA, USA) that recorded GRF at 1000 Hz using NetForce software (AMTI, Watertown, MA, USA). All kettlebell snatch exercise began with subjects standing still on the force platform with the kettlebell held at arm's length overhead, and did not begin until the word of command: "go" was given.

Conversely, 2-handed swing exercise began with subjects standing still on the force platform with the kettlebell held in both hands at arm's length in the 'finished deadlift' position, with the kettlebell lightly touching the upper-thighs, and did not begin until the word of command: "go" was given. Subjects were instructed to adopt these positions and stand still for 3 seconds before and after each set. This enabled the recording of a period of quiet standing GRF from which combined kettlebell-and-lifter weight could be obtained. This also enabled removal of drift from the GRF by obtaining the acceleration of the CM, calculating then removing its mean, and repeating this process on the velocity-time curves, then repeating the process on the displacement-time curves, both horizontal and vertical. Net force was obtained by subtracting combined kettlebell-and-body weight from GRF, CM acceleration by dividing net force by combined kettlebell-and-body mass, and CM velocity and displacement, both horizontal and vertical, by integrating the respective acceleration-time and velocity-time curves using the trapezoid rule (4). Work performed by displacing the CM, both vertically and horizontally, was obtained by calculating the area under the respective force-displacement curves, and these were divided by phase duration to yield the respective phase mean power.

Data from the active braking and propulsion phases of both exercises were studied, and these phases were determined from the vertical velocity-time curve. The beginning of the braking phase was identified from the lowest velocity, and continued until velocity changed from negative to positive. This marked the beginning of the propulsion phase, which continued until peak vertical velocity was achieved. Vertical and horizontal impulse from the braking and propulsion phase was calculated as the area under the respective phases of the vertical and horizontal net force-time curves using the trapezoid rule (4). Displacement of the CM during the braking and propulsion phase was calculated as the range of motion between the

lowest and highest position of the CM from the displacement-time curve during these respective phases. Finally, braking and phase durations were also calculated. The impulse ratio parameter was adapted from the force ratio parameter recently used to study force application in sprint performance (14), and was calculated as the ratio of anterior-posterior horizontal to resultant force.

All GRF data were processed in a customized LabVIEW program (National Instruments, Version 10.0, Austin, Texas, USA), which enabled selection of data from the third, fourth and fifth repetition of each set (which were then averaged for further analysis), and identification of braking and propulsion phases. Within session test-retest reliability of the methods used to obtain dependent variables was generally high (intraclass correlation coefficients R values between 0.864 and 0.996).

Statistical Analyses

All data were presented as mean (SD). The dependent variables were vertical and horizontal net impulse, vertical and horizontal displacement of the CM, the magnitude and rate (mean power) of work performed by vertically and horizontally displacing the CM, in addition to phase durations; exercise (kettlebell snatch and 2-handed swing exercise), plane (vertical and horizontal [anterior and posterior]), and phase (braking and propulsion) were the independent variables. Net impulse, work, and mean power, were investigated using a 3-way (exercise by phase by plane) repeated measures analysis of variance. Displacement of the CM (exercise by plane - propulsion phase only) and phase durations (exercise by phase) were investigated using a 2-way repeated measures analysis of variance. Bonferonni corrected planned comparisons were performed where appropriate. All statistical analyses were performed using SPSS (version 17.0; SPSS Inc., Chicago, IL, USA), and an alpha level of $p \leq 0.05$ used

to indicate statistical significance. Effect sizes (ES) were quantified using the scale recently presented by Hopkins et al. (2), where effect sizes of 0.20, 0.60, 1.20, 2.0, and 4.0 represented small, moderate, large, very large and extremely large, respectively.

Insert Figures 3, 4 and 5 about here

Insert Tables 1 and 2 about here

RESULTS

Representative force-time, velocity-time, and displacement-time graphs from kettlebell snatch and 2-handed swing exercise are presented in Figures 3 to 8. Net impulse data are presented in Table 1. Vertical net impulse was significantly larger than the horizontal equivalent, regardless of exercise or phase ($p < 0.0001$, ES = 4.56). There were no significant differences between kettlebell snatch and 2-handed swing exercise vertical impulse ($p = 0.592$, ES = 0.10), but 2-handed swing exercise horizontal impulse was significantly greater than the kettlebell snatch equivalent ($p < 0.0001$, ES = 1.63). Phase significantly affected impulse, but depended on exercise ($p < 0.037$). However, differences between propulsion phase impulse and braking phase impulse during 2-handed swing exercise did not reach the Bonferroni corrected alpha level of $p \leq 0.0004$ ($p = 0.015$, ES = 0.20); there were no significant differences between kettlebell snatch braking and propulsion phase impulse ($p = 0.865$, ES = 0.02).

Insert Figures 6, 7 and 8 about here

Mean (SD) braking and propulsion phase net mean force data are presented in Table 1. Vertical mean net force was significantly larger than the horizontal equivalent, regardless of

exercise or phase ($p < 0.0001$, ES = 3.08). Horizontal 2-handed swing exercise mean net force was significantly larger than the kettlebell snatch equivalent, regardless of phase ($p < 0.0001$, ES = 1.98). However, while differences between the vertical mean net force applied during kettlebell snatch and 2-handed swing exercise approached statistical significance ($p = 0.007$ >Bonferonni corrected $p = 0.004$, ES = 0.71), differences between the horizontal equivalent did not ($p = 0.530$, ES = 0.14). The only effect that phase had on mean net force was that mean net vertical force applied during the braking phase of 2-handed swing exercise was significantly greater than the propulsion phase equivalent ($p = 0.001$, ES = 0.36).

Phase duration data are presented in Table 3. There were no significant differences between kettlebell snatch braking and propulsion phase duration ($p = 0.863$, ES = 0.05). However, kettlebell snatch braking phase duration was significantly longer than the 2-handed swing exercise equivalent ($p < 0.0001$, ES = 1.54). Furthermore, 2-handed swing exercise propulsion phase duration was significantly longer than the braking phase equivalent ($p < 0.0001$, ES = 1.21). Displacement data are presented in Table 4. Vertical displacement of the CM was significantly larger than horizontal displacement of the CM, regardless of exercise and phase ($p < 0.0001$, ES = 6.16). Furthermore, vertical displacement of the CM during kettlebell snatch exercise was significantly larger than during 2-handed swing exercise ($p < 0.0001$, ES = 1.20).

Work data are presented in Table 2. Work performed displacing the CM was significantly affected by exercise, phase and plane ($p = 0.004$). Work performed vertically displacing the CM was significantly greater than the horizontal equivalent, regardless of exercise and phase ($p < 0.0001$, ES = 6.65). Work performed horizontally displacing the CM during 2-handed swing exercise was significantly greater than the kettlebell snatch equivalent ($p < 0.0001$, ES

= 2.02). However, there were no significant differences between the amount of work performed vertically displacing the CM during either kettlebell snatch or 2-handed swing exercise ($p = 0.186$, $ES = 0.23$). A plane effect was found, but did not meet the Bonferonni corrected alpha value of $p = 0.004$, and the ES were below 0.30.

Average power data are presented in Table 2. The power of displacing the CM was significantly affected by exercise, phase and plane ($p = 0.039$). The power of vertically displacing the CM was significantly greater than the horizontal equivalent, regardless of exercise and phase ($p < 0.0001$, $ES = 4.82$). The power of horizontally displacing the CM during 2-handed swing exercise was significantly greater than the kettlebell snatch equivalent, regardless of phase ($p < 0.0001$, $ES = 2.55$). Finally, the power of vertically displacing the CM during the braking phase of 2-handed swing exercise was significantly greater than the propulsion phase equivalent ($p < 0.001$, $ES = 0.28$).

Impulse ratio data is presented in Table 5. Impulse ratio from 2-handed swing exercise was significantly larger than the kettlebell snatch equivalent ($p < 0.0001$, $ES = 2.15$). However, there was no significant difference between braking and propulsion phase impulse ratio, regardless of exercise ($p = 0.192$, $ES = 0.44$).

Insert Tables 3, 4 and 5 about here

DISCUSSION

The aims of this study were to: 1) establish mechanical output from kettlebell snatch exercise; 2) quantify the relative distribution of this mechanical output; and 3) compare these data to equivalent data from 2-handed swing exercise. The main findings of this study show

that: 1) vertical CM displacement was significantly larger during kettlebell snatch exercise, and vertical CM displacement was significantly larger than horizontal CM displacement, regardless of exercise; 2) work performed and power achieved to vertically displace the CM was larger than the horizontal equivalent in both exercises, and that work performed and power achieved to horizontally displace the CM during 2-handed swing exercise was significantly larger than the kettlebell snatch equivalent; 3) this was underpinned by the magnitude of horizontal impulse and the impulse ratio.

Kettlebell snatch requires greater vertical mechanical output

It was hypothesized that a greater emphasis would be placed on vertical net impulse to perform more mechanical work to vertically displace the CM further during kettlebell snatch exercise. The results of the present study led to the rejection of this hypothesis. The CM was vertically displaced 18% further (4 cm, ES = 0.98) during kettlebell snatch exercise. However, there were no significant differences between vertical impulse or the work performed and the power achieved to vertically displace the CM during kettlebell snatch exercise. This appears to be a consequence of the aim of the kettlebell snatch exercise, which is to vertically displace the kettlebell overhead. Significantly larger horizontal impulses were applied during 2-handed swing exercise. This means that although similar vertical impulses were applied during both exercises, the emphasis was on vertical displacement during kettlebell snatch exercise, compared to the emphasis that was placed on horizontal displacement during 2-handed swing exercise.

Kettlebell snatch exercise appears to rely on a more controlled application of force compared to the more aggressive 2-handed swing exercise. This is supported by results from the present

study that show that 2-handed swing exercise braking phase impulse was within 4% of the kettlebell snatch equivalent, and was applied 25% faster ($ES = 1.54$). This suggests that bilateral nature of 2-handed swing exercise affords greater control over the kettlebell, which, in turn, facilitates use of the stretch-shortening cycle (SSC).

Several reasons have been proposed to explain why use of the SSC in movements, like the countermovement vertical jump, enhances performance during the concentric propulsion phase, often significantly (1, 3, 4, 5). It appears that performance enhancement relies on a combination of several factors that include increased active state, generation and use of elastic energy, and that this improves the muscle length-tension relationship (1, 3, 4, 5). It would appear that the net product of these mechanisms results in arrival at the braking-propulsion phase transition immediately preceded by an eccentric braking phase that requires the generation of vertical force that is sufficient to arrest continued negative displacement of the CM, which, in turn is greater than the starting force of non-SSC movement (3, 4). This could go some way to explain how six weeks of 2-handed swing exercise improved vertical jump performance (11), and must be considered by strength and conditioning coaches when they select exercises for athlete strength and conditioning programs.

2-handed swing exercise requires greater horizontal mechanical output

It was also hypothesized that greater emphasis would be placed on horizontal net impulse to perform more mechanical work to horizontally displace the CM further during 2-handed swing exercise. This hypothesis was also rejected. More horizontal impulse underpinned the performance of more work at a greater power output to horizontally displace the CM. However, horizontal displacement of the CM was not significantly greater during 2-handed

swing exercise. In fact, it should be noted that horizontal CM displacement during kettlebell snatch exercise was 25% larger and yielded a moderate to large effect size (2 cm, $ES = 0.99$). This indicates that technique differences between kettlebell snatch and 2-handed swing exercise do not extend to horizontal displacement of the CM. This finding was not expected, but would appear to be underpinned by the rate of horizontal mechanical output during 2-handed swing exercise. The greater control that the bilateral nature of 2-handed swing exercise affords over the kettlebell was discussed above. However, the rate of horizontal mechanical output enables the lifter to perform more work, and achieve higher power outputs horizontally displacing the CM during 2-handed swing exercise. This may have important implications for strength and conditioning coaches looking for plane-specific resistance exercises. The 2-handed swing exercise appears to provide a greater horizontal mechanical demand and could benefit athletes who need to apply relatively large horizontal impulses.

This is the first study to consider the mechanical output of kettlebell snatch exercise, comparing it to 2-handed swing exercise to provide context. It is also the first to study the direction in which vertical and horizontal impulse are applied during both braking and propulsion phases of both exercises. In the present study, impulse ratio describes the ratio between horizontal (anterior and posterior) and resultant impulse. This was based on a method that was recently shown to be significantly related to sprint performance (14). Rather than consider absolute magnitude, it considers technical efficiency, and, as such, could play an important role in the identification of resistance exercises for athletes who need the ability to apply relatively large horizontal impulses (16). The impulse ratio of 2-handed swing exercise reported in the present study matched recently reported sprint performance impulse ratio data (14), and impulse ratios extrapolated from sprint performance force data (impulse ratio of ~20%, 6 and 8). This suggests that the impulse ratio of resistance exercises used to

enhance sprint ability may be more important than initially thought, and that greater thought should be given to plane specific resistance exercise selection (16). For example, it would appear that the impulse ratio of 2-handed exercise might make a useful addition to a strength and conditioning program designed to improve general sprint ability. Conversely, the impulse ratio of kettlebell snatch exercise was about 30% less than typical sprint performance impulse ratios, and about 40% less than the 2-handed swing exercise impulse ratio ($ES = 2.15$). This suggests that kettlebell snatch exercise may provide a more vertical-plane specific training effect.

With the exception of the differences that have already been discussed, the principle difference between kettlebell snatch and 2-handed swing exercise appears to be that kettlebell snatch exercise somewhat paradoxically represents a ballistic exercise that requires similar mechanical output to 2-handed swing exercise. The 2-handed swing exercise is often thought of as being a ballistic exercise. However, comparison of traditional ballistic and non-ballistic resistance exercises indicates that the key difference is a period of active braking that ends the propulsion phase of the exercise prematurely. Similar mechanisms, including forceful contraction of the upper-back, trunk and upper-leg musculature, are employed toward the latter stages of 2-handed swing exercise. This exerts control on the trajectory of the kettlebell, stopping it from being displaced to potentially dangerous positions. Conversely, the kettlebell snatch has a more obvious end point – locked arms overhead.

An obvious limitation to this study was that only one load, the load typically used to assess competency at popular kettlebell certifications, was considered. Investigators recently demonstrated that during 2-handed swing exercise impulse increased linearly with kettlebell

mass from 16 kg to 32 kg (in 8 kg increments, (10)). Therefore, it is possible that kettlebell snatch exercise with different loads could cause changes in mechanical output parameters, like impulse, work and power, and suggests that study of kettlebell snatch exercise with a range of loads could provide greater insight into the exercise. Furthermore, it should be remembered that the kettlebell snatch exercise is a unilateral exercise, and as such it may seem obvious that mechanical output from kettlebell snatch exercise would not exceed mechanical output from 2-handed swing exercise. However, that the mechanical output of the two exercises was largely comparable indicates that any attempt to equalize left and right side training load would double the amount of mechanical work that must be performed.

Two other limitations warrant further consideration, and provide areas for future research. First, these data were obtained from subjects who were relatively well trained in both the kettlebell snatch and 2-handed swing exercise. Therefore, applying these results to subject populations with differing kettlebell exercise experience may not be appropriate. However, it should also be noted the recent research has shown 2-handed swing exercise with relatively light loads (12-16 kg) by relatively untrained subjects (kettlebell exercise specifically and resistance exercise in general) demonstrated significant improvements in maximum and explosive strength after six weeks (11). The final limitation that should be considered is that this study considered mechanical output data derived from ground reaction force. While these data provide useful information about fundamental biomechanical parameters for strength and conditioning practitioners, they are limited to describing the mechanical output of the CM. Future research should consider accompanying motion analysis. This could provide information about kettlebell and joint kinematics and kinetics, and might provide the opportunity to compare mechanical output data from kettlebell and barbell snatch exercise variations.

PRACTICAL APPLICATIONS

The results of this study show that while a larger mechanical output was required to horizontally displace the CM during 2-handed swing exercise, the mechanical outputs of the two exercises were largely comparable. The bilateral nature of 2-handed swing exercise does appear to afford greater control over the kettlebell. Further, research has already shown that 2-handed swing exercise improves maximum and explosive strength. However, the unilateral and overhead nature of kettlebell snatch exercise could afford a greater trunk and shoulder stability training effect, but would require more than twice the lower-body work to achieve this. Therefore, the results of the present study suggest that kettlebell snatch and 2-handed swing exercise could have a positive impact on a wide range of athletic applications, and that strength and conditioning coaches should consider using kettlebell snatch and 2-handed swing exercise interchangeably for the ballistic component of their athlete strength and conditioning programs.

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FIGURE HEADERS

Figure 1. Key positions of 2-handed swing exercise. The subject began with the kettlebell held in 2 hands as if in a deadlift finish position; he hinged at the hip joint, driving the

kettlebell back between his legs until the outside of just above his wrists made contact with the inside upper thighs, at which point the motion was reversed, the object to project the kettlebell forwards to approximately sternum height.

Figure 2. Key positions of kettlebell snatch exercise. The subject began with the kettlebell on his locked-arm overhead, as seen in the final image. From here the kettlebell was lowered, the elbow flexing slightly, and the hip joint hinged, driving the kettlebell back between his legs until the outside of just above his wrists made contact with the inside and upper thighs (the first image). From here the movement was reversed as portrayed by the image sequence.

Figure 3. Vertical and horizontal force-time (vertical force less system weight) curves from representative kettlebell snatch performance (subject body mass = 93.3 kg). The beginning of the braking phase, the end of the braking phase/beginning of the propulsion phase, and the end of the propulsion phase are indicated with dotted lines. The period before the braking phase began, and the after then propulsion phase ended is the lowering and lifting phase momentum sub-phases, respectively.

Figure 4. Vertical and horizontal velocity-time curves from representative kettlebell snatch performance (subject body mass = 93.3 kg). The beginning of the braking phase, the end of the braking phase/beginning of the propulsion phase, and the end of the propulsion phase are indicated with dotted lines. The period before the braking phase began, and the after then propulsion phase ended is the lowering and lifting phase momentum sub-phases, respectively.

Figure 5. Vertical and horizontal displacement-time curves from representative kettlebell snatch performance (subject body mass = 93.3 kg). The beginning of the braking phase, the

end of the braking phase/beginning of the propulsion phase, and the end of the propulsion phase are indicated with dotted lines. The period before the braking phase began, and the after then propulsion phase ended is the lowering and lifting phase momentum sub-phases, respectively.

Figure 6. Vertical and horizontal force-time (vertical force less system weight) curves from representative 2-handed swing exercise performance (subject body mass = 93.3 kg). The beginning of the braking phase, the end of the braking phase/beginning of the propulsion phase, and the end of the propulsion phase are indicated with dotted lines. The period before the braking phase began, and the after then propulsion phase ended is the lowering and lifting phase momentum sub-phases, respectively.

Figure 7. Vertical and horizontal velocity-time curves from representative 2-handed swing exercise performance (subject body mass = 93.3 kg). The beginning of the braking phase, the end of the braking phase/beginning of the propulsion phase, and the end of the propulsion phase are indicated with dotted lines. The period before the braking phase began, and the after then propulsion phase ended is the lowering and lifting phase momentum sub-phases, respectively.

Figure 8. Vertical and horizontal displacement-time curves from representative 2-handed swing exercise performance (subject body mass = 93.3 kg). The beginning of the braking phase, the end of the braking phase/beginning of the propulsion phase, and the end of the propulsion phase are indicated with dotted lines. The period before the braking phase began, and the after then propulsion phase ended is the lowering and lifting phase momentum sub-phases, respectively.

TABLE HEADERS

Table 1. Mean (SD) vertical and horizontal impulse and mean force magnitude and rate (mean power) of work performed displacing the CM vertically and horizontally during kettlebell snatch and 2-handed swing exercise.

Table 2. Mean (SD) work and power of displacing the CM vertically and horizontally during kettlebell snatch and 2-handed swing exercise.

Table 3. Mean (SD) kettlebell snatch and 2-handed swing exercise braking and propulsion phase durations (s).

Table 4. Mean (SD) vertical and horizontal displacement of the CM (m) during kettlebell snatch and 2-handed swing exercise.

Table 5. Mean (SD) kettlebell snatch and 2-handed swing exercise impulse ratios.

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Table 1. Mean (SD) vertical and horizontal impulse and mean force magnitude and rate (mean power) of work performed displacing the CM vertically and horizontally during kettlebell snatch and 2-handed swing exercise.

	Impulse (N.s)				Mean force (N)			
	Kettlebell snatch		2-handed swing		Kettlebell snatch		2-handed swing	
	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal
Braking	103.34*	18.18	99.40*	26.11†	261.11*	43.66	362.43*‡	88.39†
	23.52	9.32	38.19	9.95	62.39	21.93	222.23	32.82
Propulsion	104.62*	17.50	101.84*‡	32.22†‡	271.89*	41.57	291.37*	86.71†
	31.77	12.74	39.52	6.94	106.80	29.85	167.54	24.33

* = Vertical significantly greater than horizontal

† = 2-handed swing value significantly greater than kettlebell snatch value

‡ = Propulsion phase value significantly different to Braking phase value

Table 2. Mean (SD) work and power of displacing the CM vertically and horizontally during kettlebell snatch and 2-handed swing exercise.

	Work (J)				Mean power (W)			
	Kettlebell snatch		2-handed swing		Kettlebell snatch		2-handed swing	
	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal
Braking	270.11*	1.72	233.08*	4.38†	676.25*	4.33	817.01*‡	18.16†
	83.73	1.21	90.54	2.13	201.82	3.05	427.71	8.54
Propulsion	253.55*	0.96	253.11*	4.79†	655.28*	4.15	705.49*	16.82†
	71.18	2.05	88.44	2.22	231.41	4.28	375.52	8.18

* = Vertical significantly greater than horizontal

† = 2-handed swing value significantly greater than kettlebell snatch value

‡ = Propulsion phase value significantly different to Braking phase value

Table 3. Mean (SD) kettlebell snatch and 2-handed swing exercise braking and propulsion phase durations (s).

	Kettlebell snatch	2-handed swing
Braking	0.40†	0.30
	0.07	0.07
Propulsion	0.41	0.39‡
	0.08	0.07

† = Kettlebell snatch value significantly longer than 2-handed swing exercise value

‡ = Propulsion phase value significantly longer to Braking phase value

Table 4. Mean (SD) vertical and horizontal displacement of the CM (m) during kettlebell snatch and 2-handed swing exercise.

	Kettlebell snatch	2-handed swing
Vertical	0.22*†	0.18*
	0.03	0.05
Horizontal	0.08	0.06
	0.02	0.02

* = Vertical significantly greater than horizontal

† = Kettlebell snatch value significantly greater than 2-handed swing value

Table 5. Mean (SD) kettlebell snatch and 2-handed swing exercise impulse ratios.

	Kettlebell snatch	2-handed swing
Braking	14%	21%†
	6%	7%
Propulsion	14%	26%†
	10%	7%

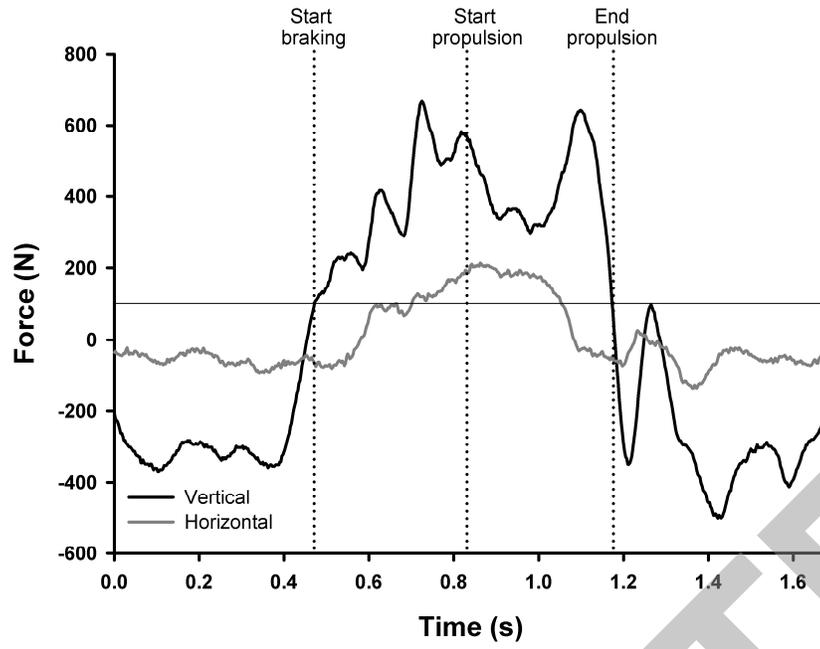
† = 2-handed swing value significantly greater than kettlebell snatch value



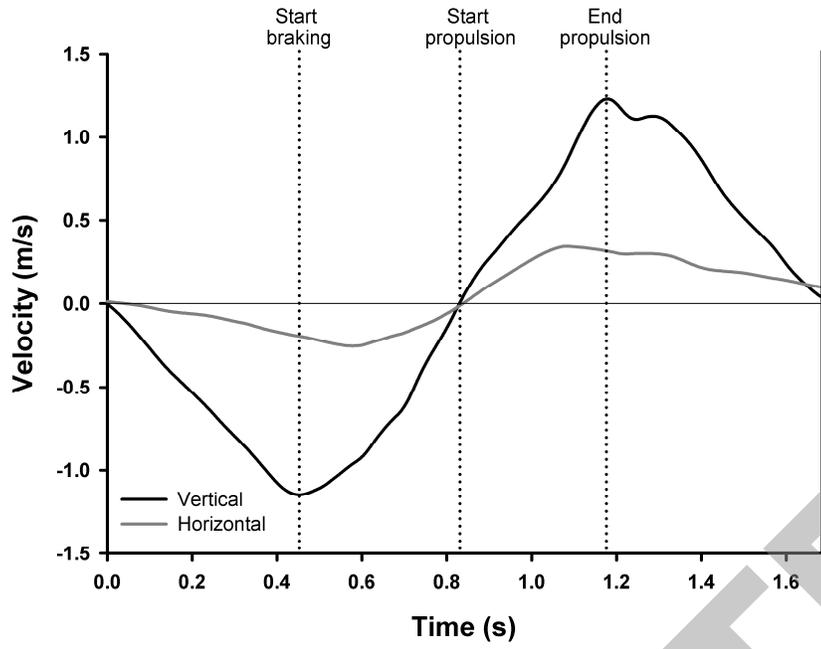
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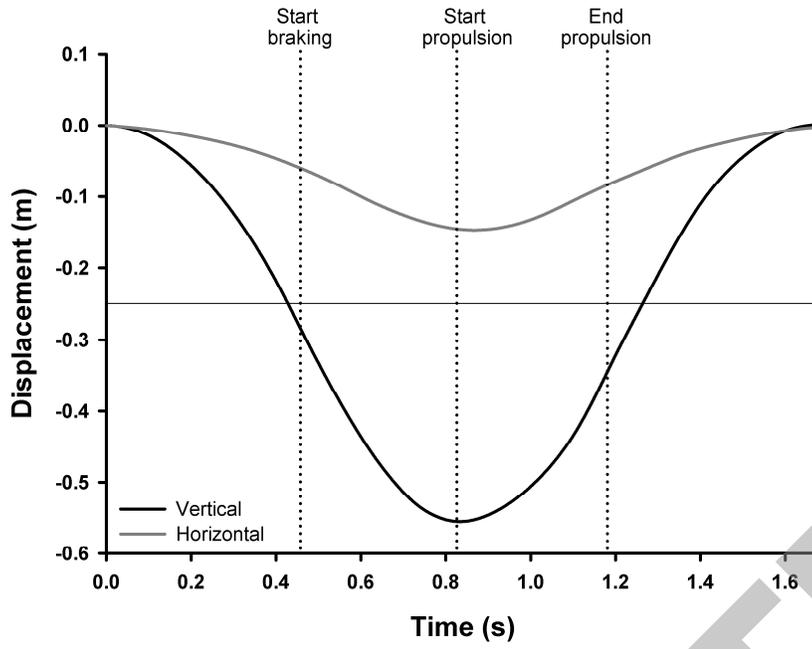


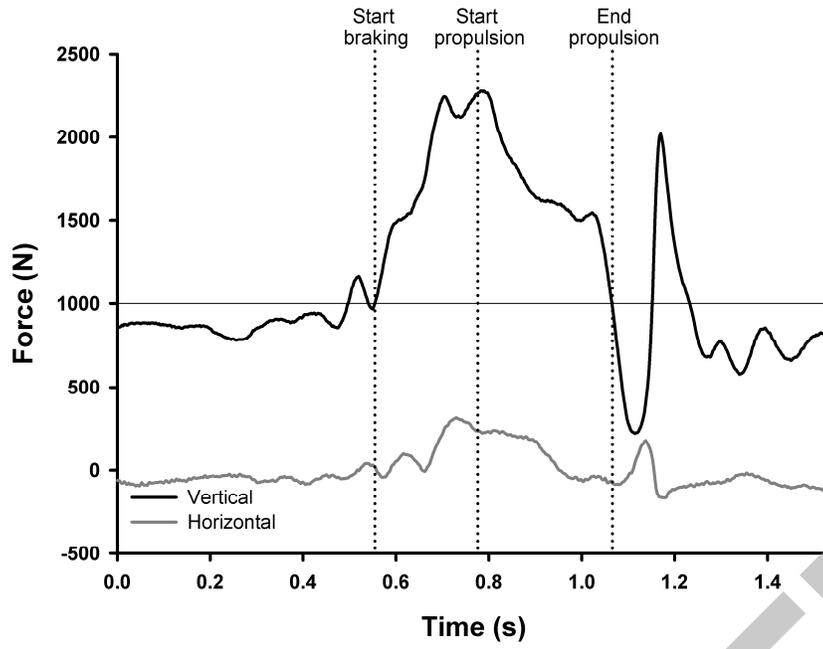
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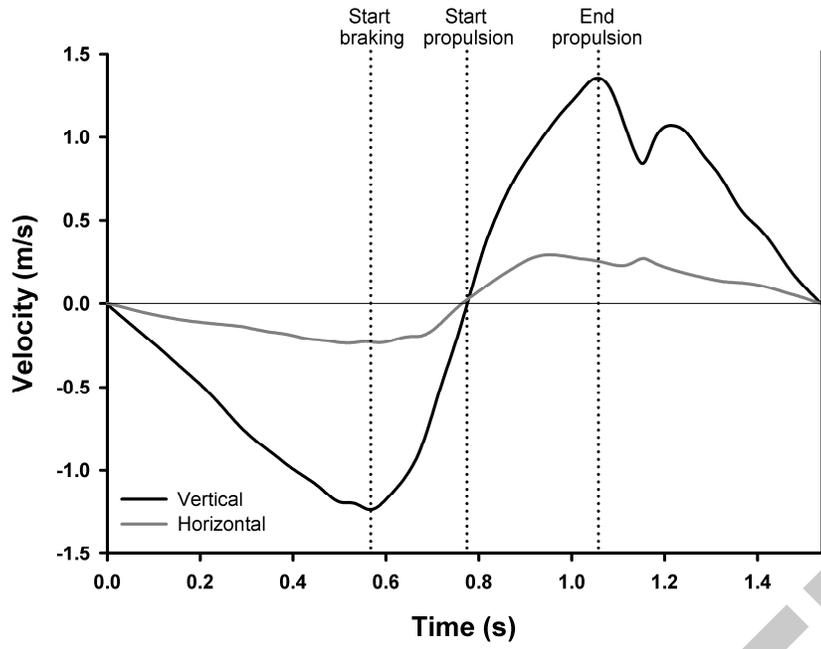
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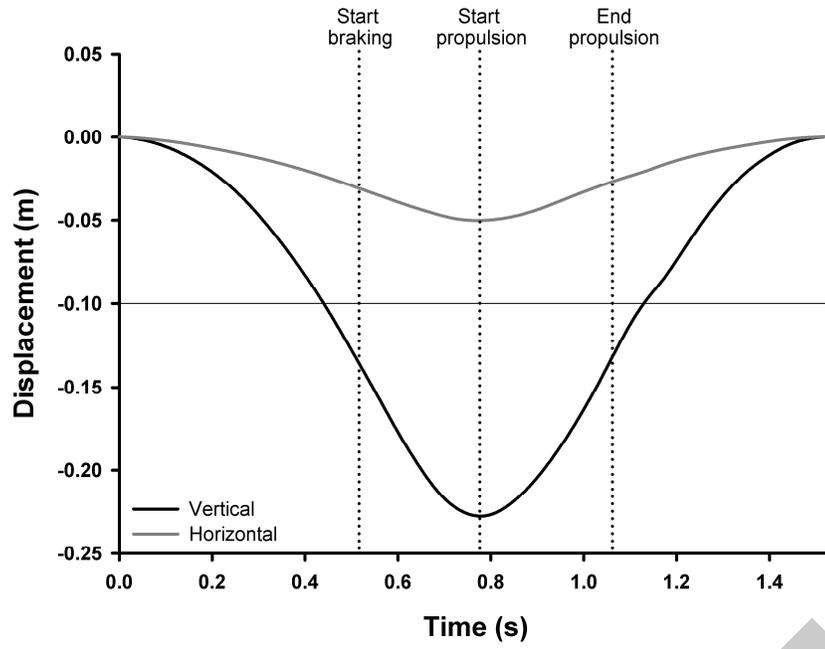




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