Mechanical demands of the two-handed hardstyle kettlebell swing performed by an RKC-certified Instructor

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Abstract

Background. The effects of hardstyle kettlebell training are frequently discussed in the strength and conditioning field, yet reference data from a proficient swing is scarce. The aim of this study was to profile the mechanical demands of a two-handed hardstyle swing performed by a Russian Kettlebell Challenge (RKC) Instructor.

Methods. The subject is a 44-year-old male, body mass 75.6 kg, height 173.5 cm, with 6 years of regular hardstyle kettlebell training since attaining certification in 2013. Two-handed hardstyle swings were performed with a series of incremental weight (8-68 kg) kettlebells. Ground reaction forces (GRFs) were obtained from a floor-mounted force platform. Force-time curves (FTCs), peak force, forward force relative to vertical force, rate of force development (RFD) and swing cadence were investigated.

Results. Data revealed the FTC of a proficient swing were highly consistent (mean SD = 47 N) and dominated by a single force peak, with a profile that remained largely unchanged with 8-24 kg kettlebells. Pearson correlation analyses revealed a very strong positive correlation in peak force with kettlebell weight (r = 0.95), which increased disproportionately from the lightest to heaviest kettlebells; peak net force increasing from 8.36 ± 0.75 $N.kg^{-1}$ (0.85 x BW) to 12.82 ± 0.39 $N.kg^{-1}$ (1.3x BW). There was a strong negative correlation between RFD and kettlebell weight (r = 0.82) decreasing from 39.2 $N.s^{-1}.kg^{-1}$ to 21.5 $N.s^{-1}.kg^{-1}$. There was a very strong positive correlation in forward ground reaction force with kettlebell weight (r = 0.99), expressed as a ratio of vertical ground reaction, increasing from 0.092 (9.2%) to 0.205 (20.5%). Swing cadence exceeded 40 swings per minute (SPM) at all weights.

Conclusion. Our findings challenge some of the popular beliefs of the hardstyle kettlebell swing. Consistent with hardstyle practice and previous kinematic analysis of expert and novice, force-time curves show a characteristic single large force peak, differentiating passive from active shoulder flexion. Ground reaction force did not increase proportionate to bell weight, with a magnitude of forward force smaller than described in practice. These results could be useful for coaches and trainers using kettlebells with the intent to improve athletic performance, and healthcare providers using the kettlebell swing for therapeutic purposes. Findings from this study were used to inform the BELL Trial, a pragmatic clinical trial of kettlebell training with older adults. www.anzctr.org.au ACTRN12619001177145.

Introduction

Kettlebell training has received increasing interest since the first publications in 2009 (Schnettler et al., 2009; Tucker, 2009). Proponents of kettlebell training claim improvements in muscular strength, cardiovascular endurance, explosive power, weight management/fat loss, flexibility, and superior athleticism (Tsatsouline, 2006). Many of the claimed benefits are believed to be attainable from the hardstyle swing, popularised by Pavel Tsatsouline. A hardstyle swing has been proposed to have some kinematic similarities to both a barbell deadlift and countermovement vertical jump (Tsatsouline, 2006), but the kettlebells' shape and offset centre of mass make the kettlebell swing unique, allowing it to be swung between the legs.

National Strength and Conditioning Association (NSCA) standards and guidelines for strength and conditioning professionals state that knowledge of proper technique is a cardinal principle of coaching (NSCA, 2017). There is however, sparce quantitative data of a proficient swing to better understand what McGill and Marshall called "street wisdom" (2012), thus confidence is low that the current body of evidence is representative of a proficient swing. If hardstyle technique is essential for achieving the claimed effects, it must be clearly defined in execution and measurement.

A recent scoping review (Meigh et al., 2019) identified the two-handed hardstyle swing as the most wisely investigated kettlebell technique. More than half of the published studies cited Tsatsouline, however, over 80% of study participants were novices. Among 68 studies, it appeared that only four had been conducted by certified hardstyle Instructors (Back et al., 2016; Jay et al., 2011; Thomas et al., 2014; Wesley & Kivi, 2017) and only one (Back et al., 2016) provided data from hardstyle-certified practitioners. While certification is not necessary to achieve proficiency, certification could be linked to increased accuracy and reliability that a technique will be performed and assessed consistently. Much remains unknown about the proficient hardstyle swing, especially how this may change as a function of kettlebell load. Thus, a kinetic profile of the proficient swing is warranted.

There are distinct kinematic differences between a novice and expert performing a hardstyle swing with a 16kg kettlebell. A kinematic analysis by Back and colleagues (2016) showed that experts used 20° more hip flexion to perform a 'hip hinge', and 19° less shoulder range; the kettlebell being swung upward rather than lifted. A sequence of movements at the hips, pelvis and shoulder during the upswing and downswing phases of a swing cycle was reported, with both sequences reversed between expert and novice. During the upswing, experts lead with the hips followed by the shoulders, whereas novices lead with the shoulders. During the downswing, experts allowed the bell to drop before flexing at the hips, while novices flexed at the hips first and the shoulders followed. At the top of the kettlebells' arc of motion, the experts stood upright in terminal hip and knee extension, but the novices did not. A significant difference in angular velocity at the hips of 223.8°/s between expert (635.5°/s) and novice (411.7°/s), highlights the ballistic nature of a proficient hardstyle swing when performed by experts. As reaction force is a product of mass and acceleration, significant differences in associated ground reaction force (GRF) between expert and novice would be expected.

Lake and Lauder (2012) were the first to quantify the mechanical demands of a two-handed hardstyle swing. With a 24 kg kettlebell, peak force was reported to be 19.6 (1.4) $N.kg^{-1}$, impulse 2.5 (0.3) $N.kg^{-1}.s$, and peak power 28.6 (6.6) $W.kg^{-1}$. Horizontal forward force was subsequently reported to be almost 30% of vertical force (Lake et al., 2014). Contrary to typical hardstyle practice, the start position was described as "standing still with the kettlebell held in both hands at arm's length in the 'finished deadlift' position, with the kettlebell lightly touching the upper thighs". The impact of analysing a swing cycle from standing upright, as opposed to the back or bottom position with the bell between and behind the legs, may be a potential reason that force appears to be *decreasing* throughout the propulsive phase.

McGill and Marshall (2012) included an electromyographic analysis when they conducted a case study of Pavel Tsatsouline performing one and two-handed swings with 32kg. While the surface electromyographic data is interesting, the lack of any kinetic or kinematic data of Tsatsouline's swing makes it somewhat difficult for practitioners to use such information to improve their coaching of the hardstyle kettlebell swing. With this exception, Back and colleagues (2016) remains the only observation of a hardstyle swing performed by a certified Instructor, and the only report of proficient swing kinematics. Prescribing an exercise in the absence of reference standards is challenging for coaches and healthcare providers. This is especially true with athletes for whom improvements in physical performance are crucial, and higher-risk populations with chronic health conditions. Typical resistance training guidelines for intensity, sets, and repetitions, are not used in hardstyle practice, thus reference standards will help to improve the accuracy and reliability of further research using hardstyle techniques and training protocols.

The aim of this exploratory study was to profile the mechanical demands of the two-handed hardstyle swing in a certified Instructor across a range of kettlebell loads. A representative FTC, peak ground reaction force, rate of force development (RFD) and swing cadence are reported. Results were used to inform the BELL trial (www.anzctr.org.au ACTRN12619001177145).

Materials & Methods

Subject

The subject is a 44-year-old male, body mass = 75.6 kg, height = 173.5 cm. He had been training consistently with kettlebells since gaining Instructor certification in 2013, including a period of 20 months (2016/17) running community group kettlebell classes six days a week. The subject was free from injury with no health or medical conditions which would have influenced task performance. Consent was given for the data to be used for scholarly submission, with ethical approval for this study granted by Bond university Human Research Ethics committee (NM03279).

Protocol

Data were collected from the University biomechanics laboratory in a single session. The subject performed two-handed kettlebell swings to chest-height on a floor-mounted force flatform (AMTI, Watertown, NY, USA) recording GRF at 1000 Hz using NetForce software (AMTI, USA). Subject body mass was captured by the force plate from a period of quiet standing. Tri-plantar force variables were obtained from the floor-mounted force platform. The variables of interest were peak GRF, dynamic RFD, and swing cadence. The subject performed a single set of 12 repetitions with each kettlebell, with the middle ten 10 repetitions used for analysis. A custom program (Microsoft Excel, Version 2012) was used to calculate peak force during each swing cycle of the set, with values manually assessed and verified against the corresponding FTC. To obtain peak net force, system weight (body mass + kettlebell weight) was subtracted from the square root of squared and summed data:

$\sqrt{F_z^2 + F_x^2 + F_y^2}$ (F_Z = vertical force, F_Y = horizontal forward force, F_X = medio-lateral force).

The back or bottom position of the swing was used as the start of each swing cycle. Dynamic RFD ($N.s^{-1}$) during hip extension (propulsion) was calculated as the change in GRF during Phase 1 divided by elapsed time and normalised to body mass ($N.\ s^{-1}.kg.^{-1}$), and reported as the mean of 10 swings. Cadence in swings per minute (SPM) was calculated from the average time between the peak force during hip extension in each swing cycle. Rate of perceived exertion (RPE) was captured for the lightest (8 kg) and heaviest (68 kg) weights. Peak force is reported as resultant force unless stated otherwise.

Procedure

Swings were performed as described by the RKC Instructor manual (Tsatsouline, 2013). Data from our laboratory indicated that different shod conditions (flat canvas shoes, trainers/sneakers, Oxford lace-up shoes, barefoot), were unlikely to significantly alter the outcome of the study (Supplementary file A). Swings were thus performed barefoot as recommended. The subject performed a brief self-prescribed mobility drill, with the lighter weights serving as a warm-up for the heavier sets. All sets started and stopped with the kettlebell in a dead-start position on the ground, the feet placed comfortably in the middle of the force platform at a distance roughly equal to the length of the foot behind the bell, as previously described (Thomas et al., 2014). Swings were performed with kettlebells from 8 kg to 68 kg. Weight increased in increments of 2 kg from 8 kg to 24 kg, then in increments of 4 kg from 24 kg to 48 kg, finishing with 56 kg and 68 kg kettlebells. Weights up to 32 kg were Force USA competition kettlebells of standardised dimensions. Kettlebells 36-68 kg were the 'traditional' shape, but due to accessibility issues they were purchased from Force USA (36-40 kg), Aussie Strength (44-48 kg) and Rogue (56-68 kg). The subject was sufficiently rested between sets so that fatigue would not influence any of the outcomes.

The hardstyle swing

Consistent with Wesley (2013) and Thomas and colleagues (2014), the two-handed hardstyle swing is illustrated in Figure 1. Positions in the swing cycle are described as the Start (Fig. 1, A), mid-swing (E) and End (I). The up- and downswing portions of a swing cycle each have two phases. The first phase of the upswing (propulsion) is described by its primary movement; hip extension. The second phase is the *float*. The first phase of the downswing is the *drop*. The final phase in the cycle is described as braking or deceleration, in which the kettlebell returns to its start position. A ballistic movement resulting in periods of float and drop distinguish the hardstyle swing from the double knee bend swing of kettlebell sport.

In the start position, the hips and knees are in terminal flexion (for the exercise), with the kettlebell positioned between the legs and behind the body, mid-forearms in contact with the upper thighs. The trunk is flexed at approximately 45°. Propulsion involves rapid extension of the hips and knees to initiate the bells' forward and upward trajectory. *"The hips drive explosively from the back swing and then there is a momentary float as the kettlebell reaches the apex of the swing"* (Tsatsouline, 2013, p. 48). Propulsion ends when the hips and knees reach terminal extension.

During *float*, the shoulders move through passive flexion until the bell reaches its highest vertical displacement at mid-swing. Throughout *drop*, the hips and knees remain in terminal extension, as the shoulders passively extend, gravity acting on the kettlebell to accelerate it downward. 'Drop' ends when the hips and knees begin to flex, the bell at roughly hip height, and upper arms in contact the ribs. The point at which the person accepts the weight of the kettlebell through the upper limbs, immediately prior to braking, can be described as the 'catch'. Braking is intended to be borne by the lower limbs, predominantly through eccentric action of the hip extensors. *"at the back of the swing you use the elastic power generated to immediately explode the kettlebell up for another rep. There is no need to swing the kettlebell higher than your chest. The movement of the kettlebell is forward and back, not up and down"* (Tsatsouline, 2013, p. 48).

Hardstyle swing – RKC standards (Tsatsouline, 2013)

1. The back must remain neutral. * At the bottom of the swing, the neck should be slightly extended or neutral.
2. The heels, toes and balls of the feet must be planted. The knees must track the toes.

3. The working shoulder must be packed [retracted].
4. During the backswing, the kettlebell handle must pass above knee level.
5. In the bottom position, the working arm must be straight, and elbow locked.
6. There should be no forward movement of the knees or added flexion of the ankles during the upswing.
7. The body should form a straight line at the top of the swing. The hips and knees should be fully extended, and the spine should remain neutral. *
8. Biomechanical breathing should be maintained – exhale when the hips and knees lock out.
9. The abs and glutes should visibly contract at the top of the swing.
10. The kettlebell should float for a moment at the apex of the swing while the hips remain locked out.
11. The hips begin to move back after the upper arm has connected with the ribcage and not before.

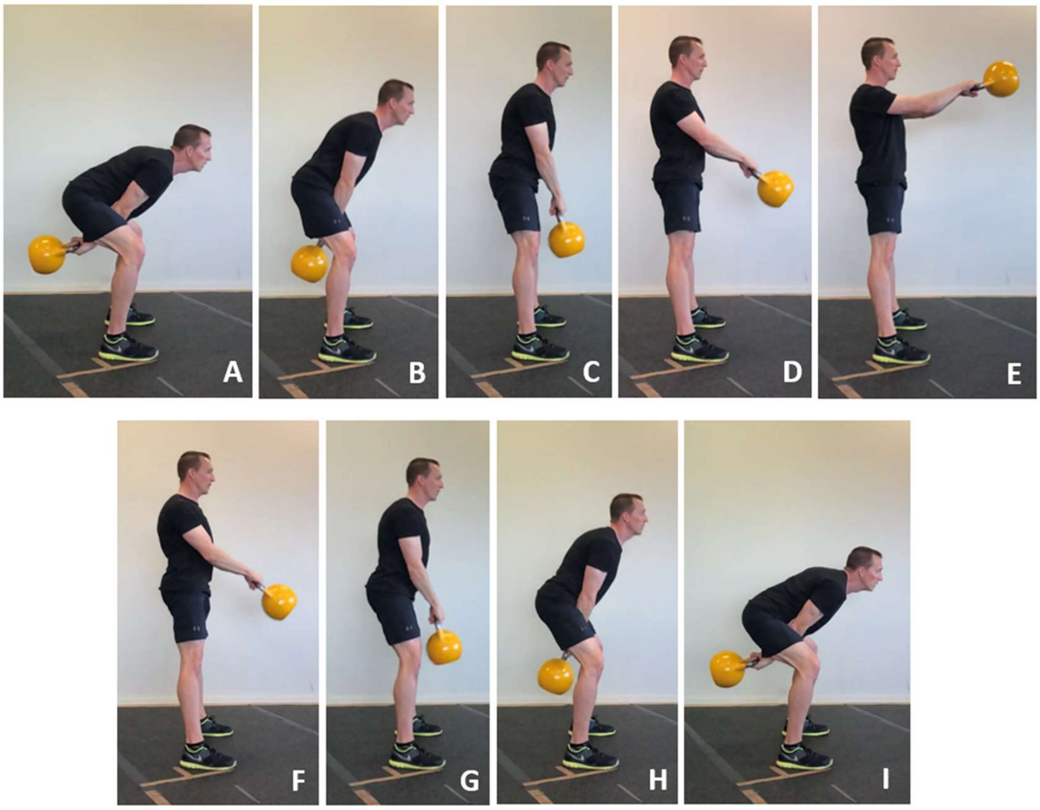


Figure 1. A single two-handed hardstyle swing cycle. A) The Start position of a swing cycle. A-C) Phase 1 - upward *propulsion* of the kettlebell, D-E): Phase 2 - the *float* - passive shoulder flexion with hips and knees in terminal extension, E) *Mid-swing* (top of the swing). E-F): Phase 3 – the *drop* - passive extension of the shoulders with hips and knees in terminal extension, G-I): Phase 4 - *deceleration* (braking) of the kettlebell to the bottom of the swing, I) End of the cycle (bottom of the swing). *: subject has Scheuermann's kyphosis.

Statistical analyses

Measures of centrality and dispersion are presented as mean ± SD. Effect sizes (ES) were calculated and interpreted using Lenhard and Lenhard (2016) and Magnusson (2021). Effect sizes were quantified as trivial, small, moderate, large, very large, and extremely large where ES < 0.20, 0.20-0.59, 0.60-1.19, 1.20-1.99, 2.0-3.99 and ≥ 4.0 respectively (Hopkins et al., 2009). Probability of superiority has been used to illustrate the Cohen's d effect size, representing the chance that a person from group A will have a higher score than a person picked at random from group B. Linear regression was used to calculate the regression coefficients between the independent variable load, and dependent variables force, and cadence. Correlations were investigated using Pearson product-moment correlation coefficient, with preliminary analyses performed to ensure no violation of the assumptions of normality, linearity, or homoscedasticity. Data were analysed and linear regression calculated in SPSS (version 26.0; SPSS Inc., Chicago, IL, USA).

Results

Force-time curves from swings with 8 kg, 16 kg, 28 kg and 68 kg are presented in Fig. 2. Profiles from all kettlebell weights set are shown in Supplementary file B. The FTC of a proficient hardstyle swing is characterised by a tall, single narrow force peak, closely followed by a second distinct force peak of smaller magnitude. The characteristic profile remained consistent from 8-24 kg. It was apparent from the FTC of a 28 kg swing (Fig. 2C), that the subject was unable to maintain the same duration of float and drop, evident by the progressive merging of the two force peaks. A visual change to the braking phase duration was already evident with a 20 kg kettlebell (Supp. file B). With cadence remaining relatively unchanged, the duration of the propulsive phase increased with kettlebell mass, with the duration of float and drop phases decreasing. The braking phase, shown as a relatively horizontal force approximating body mass during swings with a 16 kg kettlebell (Fig. 3A), was almost completely absent in the FTC of a swing with 68 kg (Fig. 3B). Within-set variability between swing cycles remained small regardless of weight and change in FTC.

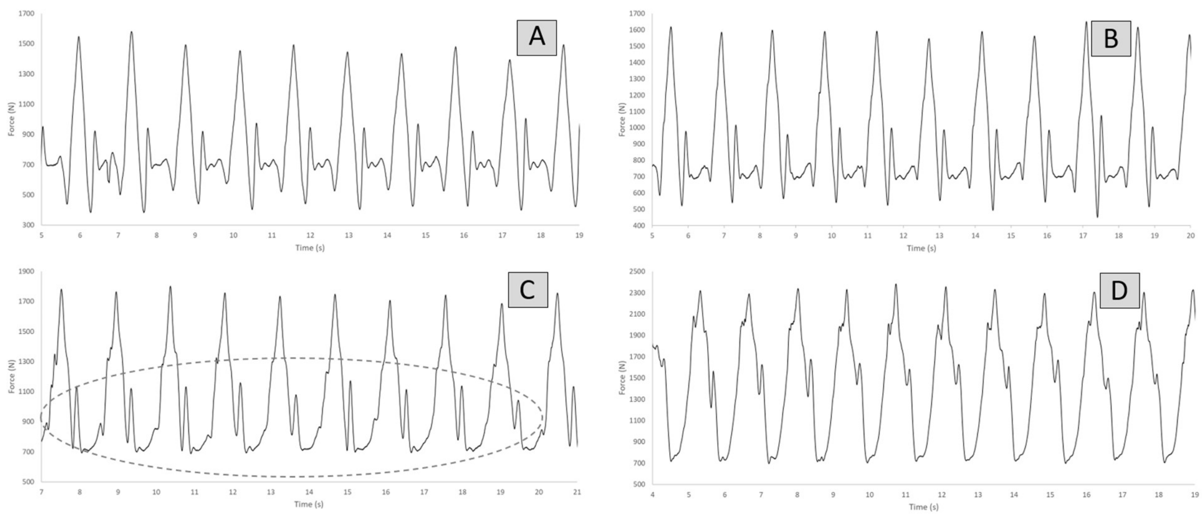


Figure 2. Force-time profiles with (A) 8 kg, (B) 16 kg, (C) 28 kg, (D) 68 kg.

A representative FTC of a single swing cycle with a 16 kg kettlebell is presented in Fig. 3A. Phase location and durations have been approximated. *Start* and *mid-swing* positions can be reached using a metronome at 80 beats per minute (cadence, 40 swings per minute (SPM)), suggesting that the upward and downward portions of the cycle using light to moderate kettlebell weights are approximately equal (47.5% and 52.5% respectively; Fig. 3A). Phase 2 & 3 (*float* and *drop*) accounted for approximately one-third of the swing cycle with a 16 kg kettlebell. Peak ground reaction force (1605.9 ± 29.7) was 2.17x BW during the propulsion phase of the upswing, and less than body mass (741 N) for most of the braking phase. A consistent FTC with light to moderate weights (8-24 kg) showed minimal change in technique. Weights above 24 kg however influenced swing performance, such that the duration of the float and drop phases progressively diminished.

Figure 3B shows the considerably altered FTC with the heaviest kettlebell (68 kg). The elapsed time difference in the presented swing cycles is 0.03s (Fig. 3A = 1.4s, Fig. 3B = 1.46s). Time to peak force (propulsion) with the 68 kg kettlebell however was 0.82s; >2.5x longer than propulsion with the 16 kg kettlebell. This increased the proportion of the propulsive phase in the swing cycle from 22.7% with 16 kg to 56.3% with 68 kg. A 'double-peak' appears to correspond with an accessory effort to move the kettlebell vertically. Movement strategies observed in novices, include active shoulder flexion to 'lift' the kettlebell, and excessive extension of the trunk (Back et al., 2016). The braking phase illustrated in the FTC with 16kg (Fig. 3A), where GRF remains relatively constant, is almost entirely absent with the 68 kg kettlebell (Fig. 3B). Horizontal forward force expressed relative to vertical force, increased from 0.11 (11%) with 16 kg to 0.21 (21%) with 68 kg.

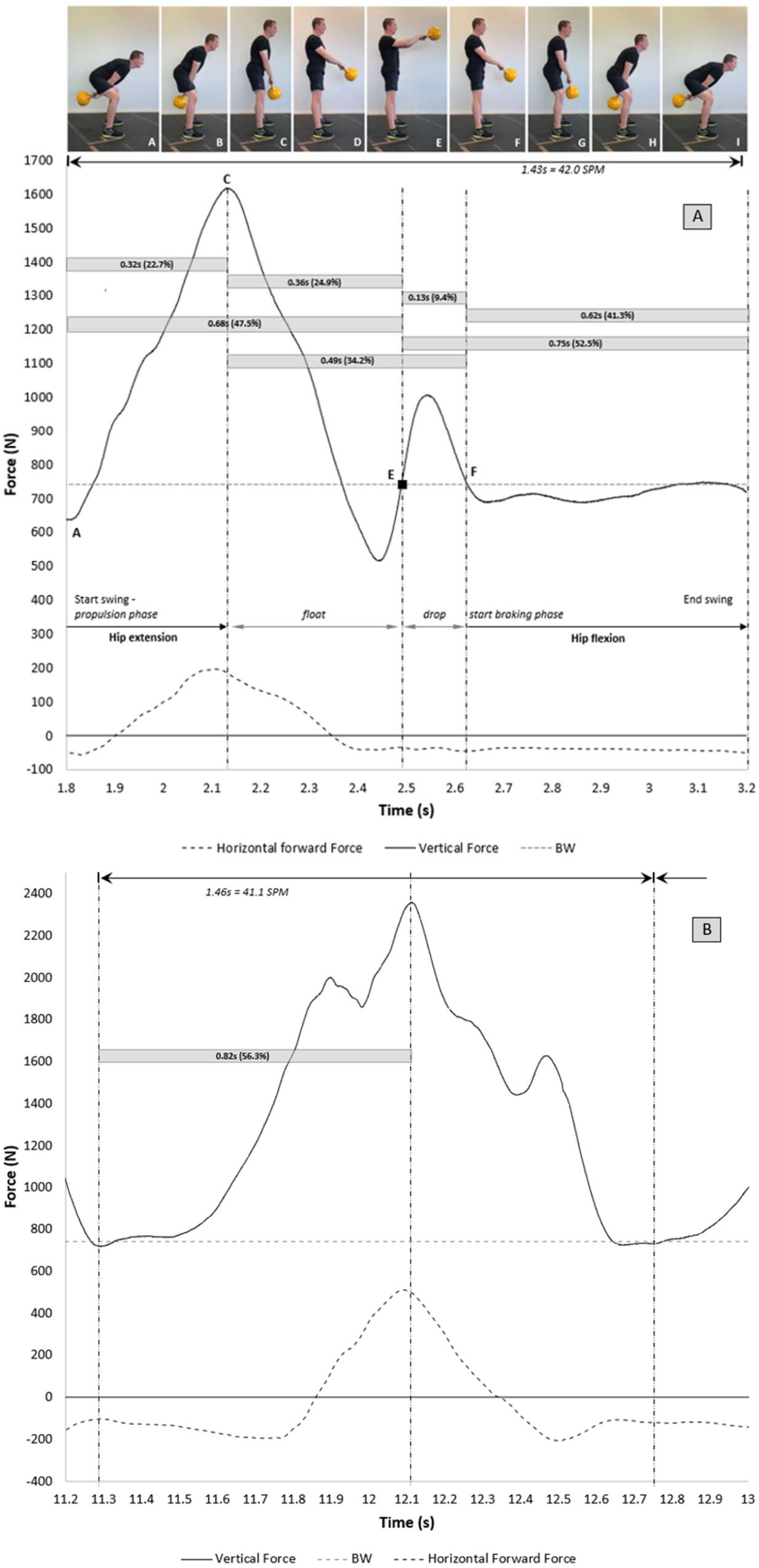
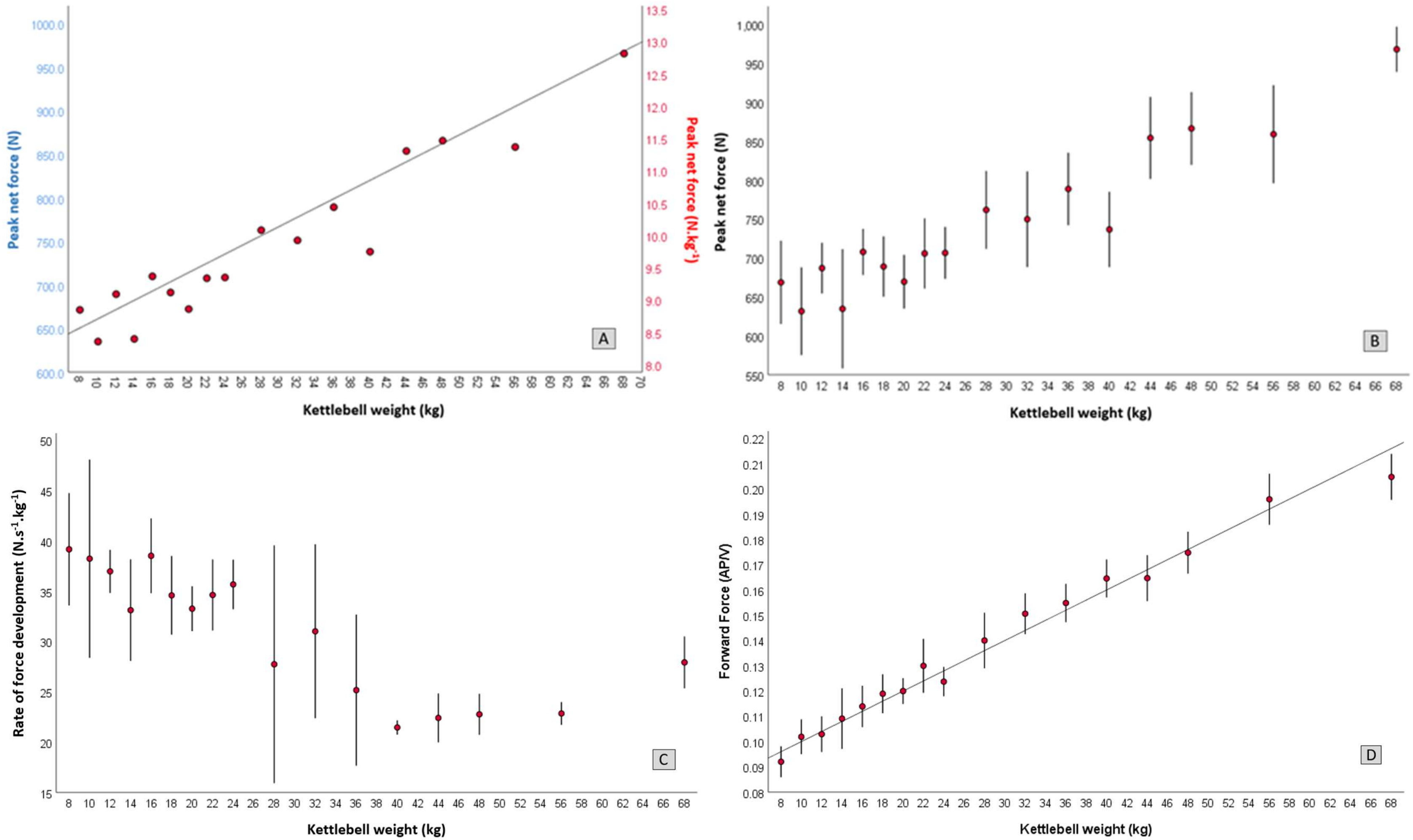


Figure 3. Representative force-time curves of a single two-handed hardstyle swing performed with a 16 kg (A) and 68 kg kettlebell (B). Time and duration of each phase within the 16 kg swing cycle (propulsion, float, drop, braking)

have been approximated from the corresponding sequence of images and kinematic sequence of movements. Force = system weight (body mass (741 N) + kettlebell mass (157 N (16kg), 667 N (68 kg)).

Figure 4A-E show peak force, RFD, forward force, and swing cadence for all kettlebell weights. There was a very strong positive correlation (r = 0.95) in peak net force with kettlebell weight, increasing from 631.8 ± 56.4 N with the 10 kg kettlebell, to 968.4 ± 29.1 N with the 68 kg kettlebell (Fig. 4 A). Normalised to body mass, net force increased from 8.36 ± 0.75 $N.kg^{-1}$ to 12.82 ± 0.39 $N.kg^{-1}$; a 1.5x increase in net force, corresponding with a 8.5x increase in kettlebell weight. Expressed relative to body mass, peak net force increased from 0.85x BW to 1.3x BW. Subject reported RPE (Foster et al., 2001) increased from very, very easy (1/10) with 8kg, to very hard (7/10) with 68kg. There was small within-set variability (SD) in peak force, ranging from 29.1 N with the 68 kg kettlebell, to 76.7 N with the 14 kg (Fib. 4, B), with a mean SD of 47.0 N. Variability in RFD is larger with the 28 kg, 32 kg and 36 kg kettlebells due the change in FTC making the start of hip extension less distinct. There was a strong negative correlation (r = 0.82) in RFD with kettlebell weight, decreasing from 39.2 $N.s^{-1}.kg$ with the 8 kg kettlebell, to 21.5 $N.s^{-1}.kg$ with the 40 kg kettlebell (Fig. 4, C). There was a very strong positive correlation (r = 0.99) in forward force with kettlebell weight, from 0.092 (9.2%) to 0.205 (20.5%) (Fig. 4, D). There was only a weak positive correlation (r = 0.41) in swing cadence with kettlebell weight, increasing from 41.1 SPM with 20 kg to 44.0 SPM with 68 kg. Cadence for all swing sets was higher than the subject's self-reported usual training cadence (40 SPM).


A
Peak net force (N)
Peak net force (N.kg-1)
Kettlebell weight (kg)
B
Peak net force (N)
Kettlebell weight (kg)
C
Rate of force development (N.s-1.kg-1)
Kettlebell weight (kg)
D
Forward Force (AP/V)
Kettlebell weight (kg)

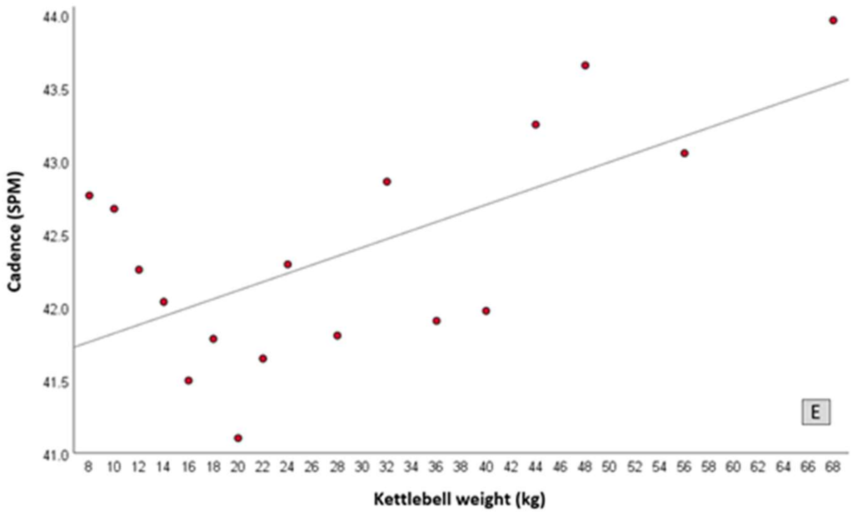


Figure 4. Change in force variables and swing cadence with increasing kettlebell weight. A: peak net force, B: variability in peak net force, C: rate of force development, D: ratio of forward horizontal force to vertical force (A = anterior, V = vertical), E: swing cadence (SPM).

Force variables and cadence with increasing kettlebell weight for the most frequently used and commonly commercially available weights (8 to 32 kg), are presented in Table 1 and Figure 5. Linear regression equations are presented in Table 2.

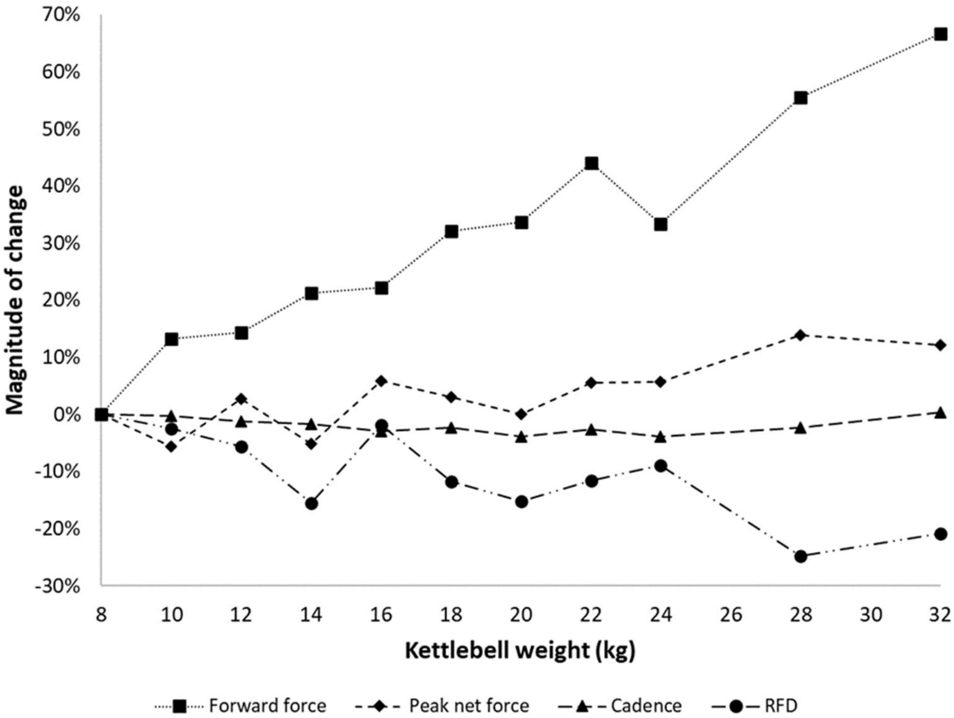


Figure 5. Magnitude of change with increasing kettlebell weight, from 8 kg to 32 kg.

Table 1: Force variables and cadence with increasing kettlebell weight for the most frequently used and commercially available weights (8 to 32 kg).

Kettlebell weight (kg)	Peak force			RFD	Net peak force			Net RFD	Force (AP/V)	Cadence (SPM)
	(N)	(N.kg^{-1})	(BW)	(N.s^{-1}.kg^{-1})	(N)	(N.kg^{-1})	(BW)	(N.kg^{-1}.s^{-1})		
8	1488.3 (53.6)	19.7 (0.7)	2.01 (0.07)	2960.5 (422.0)	668.8 (53.6)	8.85 (0.7)	0.90 (0.07)	39.2 (5.6)	0.09 (0.006)	42.8
16	1605.9 (29.7)	21.25 (0.4)	2.17 (0.04)	2911.4 (281.3)	708.0 (29.7)	9.37 (0.4)	0.96 (0.04)	38.5 (3.7)	0.11 (0.008)	41.5
24	1683.1 (33.4)	22.27 (0.4)	2.27 (0.05)	2696.6 (186.2)	706.7 (33.4)	9.35 (0.4)	0.95 (0.05)	35.7 (2.5)	0.12 (0.006)	41.1
32	1804.9 (61.5)	23.89 (0.8)	2.44 (0.08)	2344.2 (653.5)	750.0 (61.5)	9.93 (0.8)	1.012 (0.08)	31.0 (8.6)	0.15 (0.008)	42.9

Results reported as means (SD). BW = bodyweight. A/V = ratio of anterior (forward) horizontal to vertical GRF.

There was a very strong positive correlation between kettlebell weight and peak force, and kettlebell weight and forward force. For each 1 kg increase in kettlebell weight, peak net force increased by 12 to 16.5 $N.kg^{-1}$ and forward force by 2% to 3%. There was a strong negative correlation between kettlebell weight and RFD; for each 1 kg increase in kettlebell weight, RFD decreased by 11 to 39 $N.s^{-1}$. Swing cadence remained relatively stable at 42.0 ± 0.6 SPM.

Table 2: Linear regression equations for peak net GRF, RFD, and forward force relative to vertical force, where x = kettlebell mass in kg.

Peak net force (N)	$y = 1350 + 14.3x$, $r = 0.98$ ($p < 0.01$), CI [12.0, 16.6]
Peak net force ($N.kg^{-1}$)	$y = 8.1 + 0.6x$, $r = 0.98$ ($p = 0.02$), 95% CI [0.03, 0.09]
RFD ($N.s^{-1}$)	$y = 3112.7 - 25.3x$, $r = -0.81$ ($p = 0.03$), CI [-39.2, -11.4]
RFD ($N.s^{-1}.kg^{-1}$)	$y = 41.2 - 0.34x$, $r = -0.81$ ($p = 0.03$), CI [-0.52, -0.15]
Forward force (A/V)	$y = 0.08 + 0.02x$, $r = 0.97$ ($p = 0.02$), CI [0.02, 0.03]

Discussion

Reliable kinetic reference data enables coaches and healthcare providers to make informed decisions about the potential benefits or risks of an exercise. These data can also provide valuable insights which influence how exercises are coached and tested. A properly designed program using resistance equipment, includes multi-joint exercises such as the kettlebell swing, is individualised, periodised, progressive, and includes appropriate technique instruction (Fragala et al., 2019). A recent review (Meigh et al., 2019) was unable to identify data from a proficient swing for any of these program variables. Results from the present case study provides some insight for coaches and healthcare providers to make more informed decisions about how to use the kettlebell swing for performance enhancement or prescription of therapeutic exercise, where such an exercise might be appropriate.

Peak Force

The magnitude of change in peak force with increasing kettlebell weight was surprisingly small. Quadrupling kettlebell weight from 8 kg to 32 kg, increased peak force by only 81.2 N. Net peak force increased by less than 30% (190 N) between the 8 kg and 56 kg swings. *"If your goal is more force production, swing a heavier kettlebell"* (Tsatsouline, 2013, p. 48) appears to be a somewhat misguided instruction. A strong correlation between GRF and kettlebell weight all the way up to 68 kg was also somewhat surprising. It was anticipated that the rate of increase would drop considerably with kettlebells heavier than 32 kg, but this was not the case.

Lake and Lauder (2012) reported peak force during swings with 16 kg, 24 kg and 32 kg as 18.8 (0.5), 19.6 (1.4) and 21.5 (1.4) $N.kg^{-1}$, respectively. Although absolute difference in mean values between the Instructor in the present study and those reported by Lake were small (range = 2.39 to 2.67 $N.kg^{-1}$), the ES were large to very large (16 kg: $\delta = 4.9$, 24 kg: $\delta = 1.91$, 32 kg: $\delta = 1.71$)

with 88.7% to 100% probability of superiority in favour of the Instructor. These data suggest that proficiency (technique) significantly alters ground reaction with large effect.

With kettlebell weights from 10-20% BW, Levine and colleagues (Levine et al., 2020) reported peak GRF from 1.53 (0.2) to 1.67 (1.7) BW. The ES with comparable weights in the present study, was very large, ranging from $\delta = 2.09$ (8 kg, 10% BW) to $\delta = 2.72$ (12 kg, 15% BW), with a mean probability of superiority >95%. Bullock and colleagues (2017) reported peak vertical force of 0.98 (0.1) BW, however data was not reported as net of system weight. In the present study, vertical GRF was 2.15 (0.1) BW with the same weight kettlebell (20 kg). The ES difference between studies is so unreasonably large, as to suggest that the data (or comparison) is unreliable. If the vertical force reported by Bullock and colleagues was net force, there would be a small effect size difference in favour of the novices (12 kg: $\delta = 0.36$, 20 kg: $\delta = 0.57$). While not impossible, the data from Lake and Lauder (2012) suggests this scenario would be unlikely.

Among male kettlebell sport competitors, Ross and colleagues (2017) reported peak GRF during a 24 kg kettlebell snatch as 2.10 (0.31) BW. In the present study, peak force during the 24 kg swing was 2.27 (0.05) BW. As force is a product of mass and acceleration, the small ES in favour of the swing ($\delta = 0.55$) is most likely explained by the pronounced differences in cadence; 13.9 (3.3) snatches overhead per minute vs 42.3 SPM to chest height. These data appear otherwise comparable, suggesting that proficiency is more likely to influence mechanical demands and its associated effects, than the 'style' of kettlebell training (hardstyle vs Sport). This similarity in GRF also underscores the demands of a unilateral kettlebell exercise (swing, clean, snatch). This highlights an opportunity for coaches and healthcare providers to increase the physiological demand of the swing without increasing the weight.

Rate of force development

Rate of force development, claimed to be a defining feature of the hardstyle swing, is essential for sports performance. It is also an important consideration in rehabilitation and return to sport following injury, and critical for trip and falls prevention (Blazevich et al., 2020). In older adults, RFD may be more important than strength with respect to functional performance and maintaining independence (Kraschnewski et al., 2016; Palmer et al., 2016; Skelton et al., 2002). If the intent of a kettlebell swing is to improve RFD, the findings of this study suggest that even moderate-weight kettlebells (16-24 kg) may be counterproductive, with the lightest weight (8 kg) producing the highest RFD (38.2 $N.s^{-1}.kg^{-1}$). In the present study, swings performed with 40 kg (equal to 50% 10RM), resulted in a 45% reduction in RFD compared to the 8 kg kettlebell.

"When you cannot maintain your explosiveness any longer, it's time to quit." (Tsatsouline, 2013, p. 20). The subject in the present study maintained desirable form up to 68 kg, yet the FTC and relative "explosiveness" had changed considerably. If explosiveness can be characterized by RFD and swing cycle phase duration, and maximising explosiveness is the training goal, we propose

that merging of the force peaks could be used to determine a maximum training weight. In this case, merging of the force peaks was evident with a 28 kg kettlebell. Kettlebell weights under 25% body mass, appear to be most suited for improving RFD in a two-handed hardstyle swing.

Exercise prescription and coaching

Tsatsouline (2006, p. 2) recommends that an average male beginner start with a 16 kg kettlebell, 32 kg kettlebells being reserved for “advanced men”, stating that *“unless you are a powerlifter or a strongman, you have no business starting with a [24kg]”*. Tsatsouline suggests that an average woman should start with an 8 kg kettlebell and a strong woman 12 kg, with most women advancing to 16 kg. Often cited as recommended starting weights for the swing, these are general guidelines for kettlebell training, which includes other exercises such as the military press, goblet squat, snatch and Turkish get-up. A weight most suitable for a swing is unlikely to be the most appropriate for pressing overhead or deadlifting. If the kettlebell swing is to be performed explosively, with the aim to improve muscular power and functional performance, the results of the current study may suggest that slightly lighter loads than recommended by Tsatsouline (2006) might provide the best outcomes for most individuals. However, these recommendations might still need to be changed based on the size and strength of the participant, whereby such loads may be too light for a 110 kg strength athlete but too heavy for a 45 kg septuagenarian with osteoporosis. Choosing the most appropriate weight for a person performing a given kettlebell exercise, should be established at an individual level, with consideration given to factors such as training age, physical capacity and training goals.

“The swing is an expression of forward force projection such as found in boxing or martial arts, like a straight punch.” (Read, 2012). A hardstyle swing is defined by its dominant movement - hip extension. Instruction to drive the hips forward rapidly and aggressively, has translated to a belief that the dominant ground reaction is also in the forward horizontal direction. These data do not support that inference. Contrary to popular commentary, forward force ranged from 9% to 21%, with the median 13%. The difference in magnitude of forward force during swings with a 24 kg kettlebell reported by Lake and Lauder (2012) of 30% to the current study of 12%, cannot currently be explained, with the possible exception of the between study differences in starting position and kettlebell swing proficiency of the participants.

These data suggest that centrifugal force acting on the kettlebell is the result of a predominant (≈85-95%) vertical ground reaction. Training instruction encouraging a movement pattern consistent with a vertical jumping motion, rather than attempting to project the kettlebell forward, are likely to be more effective. Investigation of the influence of technique proficiency on the hammer throw (Murofushi et al., 2007), shows a shift in centre of mass significantly alters the pendular arc of motion, and resultant throwing distance. With similar observations in elite kettlebell sport athletes (Ross et al., 2015), it appears that small changes in technique, are most likely to account for the large differences in GRF observed between expert and notice, highlighting the role and potential value of expert instruction and coaching.

An ideal hardstyle swing can be identified by observing the person's body position at the beginning of the float (Fig. 2D), and end of the drop (Fig. 4F); they should look the same with the direction of bell travel not apparent from the body position. Use of slow-motion video analysis to provide feedback is encouraged as an effective teaching strategy (Beerse et al., 2020). Real-time biofeedback from a force platform could also be a useful tool for coaches and healthcare providers. Previous published FTCs of the hardstyle swing (Lake & Lauder, 2012; Mache & Hsieh, 2016) show a wide multi-peaked force profile, which is inconsistent with the single, narrow force peaks found in the present study. We propose that a multi-peaked FTC is representative of the active shoulder flexion described by Back and colleagues (2016). If phase durations are important and FTC characteristics a reliable indicator of proficiency, a FTC might be helpful in establishing the optimal swing weight.

Proficient hardstyle practitioners perform the swing at a cadence of 40 SPM (Duncan et al., 2015; Thomas et al., 2014; Wesley & Kivi, 2017). The subject in the present study also self-reported a usual training cadence of 40 SPM. The slighter higher mean cadence of 42 SPM in the current study is attributed to the test conditions. While cadence may be intentionally increased or decreased, this is reported to feel "unnatural" (Wesley & Kivi, 2017), requires greater effort (Duncan et al., 2015), and is not recommended. *"Don't confuse a quick and explosive hip drive with manic speed. Pulling the kettlebell down and releasing your hips too soon without allowing the bell to float will give the sense that you are increasing speed, but it will not increase power production"* (Tsatsouline, 2013, p. 48).

To optimise outcomes, prescription of a kettlebell swing should be personalised. Coaches and therapists will need to determine for the individual, if it is necessary or beneficial for kettlebell weight (intensity) to be increased, or whether the same training effect can be achieved with a higher number of repetitions using a lighter weight. Kettlebell swings allow a large volume of work to be performed in a short period of time. If the performance goal is simply to get 'Work' done, heavier kettlebells are an attractive option; what can be achieved in 90s with a 40 kg kettlebell using a 1:1 work:rest ratio of 2x20 reps (1600 kg), would take 9m:30s at the same continuous pace with an 8 kg kettlebell.

The difference in training loading volume between 5 sets of 10 swings with an 8 kg, 16 kg, or 40 kg kettlebell, is a substantial 1,600 kg. The difference in cardiovascular response and effort is also likely to be very high. Results from this study show a disproportionate increase in effort relative to kettlebell weight and the peak net force. Training parameters of exercise, weight, sets, repetitions and work:rest ratio are important variables for prescription, especially for individuals with higher-risk health conditions such as cardiovascular disease. Further research is warranted to help coaches and healthcare providers determine safe and effective parameters for prescribing kettlebell exercises with at-risk populations.

Increasing kettlebell weight or cadence increases cardiovascular response (Wesley & Kivi, 2017) however, a slower cadence can also increase effort (Duncan et al., 2015) as 'swing' and 'drop' becomes a 'lift' and 'lower'. A metronome can be used as an external cue to optimise efficiency in the hardstyle swing. Coaches and healthcare providers should also note that the cardiovascular demand of kettlebell swing is greater than walking (Thomas et al., 2014) and anticipate that heart rate (HR) will increase with continuous swings (Farrar et al., 2010) potentially to a relatively high percentage of HR_{max}. Similar effects may also occur when performing multiple sets of swings with short periods of rest between sets (Wong et al., 2017). The magnitude of these cardiovascular responses may also need to be taken into account when prescribing kettlebell swing training to different individuals, especially clinical patients with compromised cardiovascular and/or respiratory function.

Strengths and limitations

The major strength of this study was the use of a RKC-certified kettlebell instructor as the expert and the large range of kettlebell swing loads and repetitions performed with each load. However, as this paper provides data from one certified kettlebell Instructor, the results cannot be generalised to all Instructors; replication is necessary to increase our confidence in the results. These data are from ground reaction only; concurrent motion capture would elucidate the kinetic and kinematic changes imposed by increasing kettlebell weight. Reliability in calculating RFD from a FTC may also be compromised where the onset of propulsion is not clear; meaning a more reliable standardised measure of calculating RFD is warranted. Ground reaction data from hardstyle swings cannot be generalised to the double knee-bend (kettlebell Sport) or overhead (American) swings which are kinematically different (Del Monte et al., 2020; Mitchell et al., 2015).

Conclusions

The aim of this paper was to profile the mechanical demands of a two-handed hardstyle kettlebell swing, performed by an RKC-certified Instructor. The force-time profile using light to moderate weights, was characterised by a smooth, single narrow force peak, immediately followed by a second peak of smaller magnitude. Small within- and between-set variability was observed, with cadence no less than 40 swings per minute. Flight time accounted for approximately one third of the swing cycle, for weights up to approximately 25% body mass. With increasing weight, propulsion and braking phases increased, evident by progressive merging of the force peaks.

There was a very strong positive correlation between kettlebell weight and peak force, and kettlebell weight and forward force, although magnitude of change was small. For swings performed up to 56kg, peak net force increased by less than 30% than that produced with the 8 kg load. More research is required to determine the potential benefits of performing swings with very heavy kettlebells.

Median horizontal forward force was less than 15%, indicating that the hardstyle swing is an expression of a predominantly vertical ground reaction. Coaching movements consistent with a vertical jump are more likely to be effective than movements intended to project the kettlebell forward. There was a strong negative correlation with rate of force development. Kettlebells under 25% body mass appear to be optimal for developing lower limb power, with the lightest weights resulting in the highest RFD.

Results show that proficiency in hardstyle technique significantly changes ground reaction with large effect. Proficiency should be considered when reporting and interpreting data from novices. Developing a proficient hardstyle swing is likely to be beneficial, where mechanical demands are considered important. Further research is required to better understand the effects of kettlebell weight on outcomes of interests, and prescription variables within a hardstyle program.

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Contributions

NM conducted the study, curated and analysed the data, interpreted the results, conducted the formal analysis, and wrote the original draft. JK, BS and WH supported with ongoing consultation. JK and WH reviewed and provided revisions to earlier versions of the manuscript. All authors read and approved the final manuscript.

Ethics declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Competing interests

The primary author is a Physiotherapist and hardstyle kettlebell instructor, with an online presence as The Kettlebell Physio.

Rights and permissions

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