

Original Research

# Effects of Kettlebell Swing Style and Mass on Female Hip Joint Kinetics

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### Background

Kettlebell (KB) swing exercises, whether performed using shoulder height (SHS) or overhead (OHS) swing variations in therapeutic or strength and conditioning settings, are posterior chain dominant exercises that require hip extension contributions when performed correctly.

### Purpose/ Hypothesis

The primary purpose of this study was to evaluate the effect of swing style (SHS, OHS) and KB mass on hip extension kinematics and kinetics in young adult females. A secondary purpose was to determine the effects of swing style and KB mass on the forces applied to the total body center of mass and KB. It was hypothesized that velocity, power, and work would be greater for the OHS compared to the SHS, as well as for the heavier compared to the lighter KB's.

### Study Design

Crossover study design.

### Methods

Fifteen physically active females performed 15 swings under four conditions, SHS/12kg, SHS/16kg, OHS/12kg, and OHS/16kg, while three-dimensional dominant limb foot, shank, thigh, pelvis, and KB kinematic and ground reaction force (GRF) data were collected.

### Results

KB distance (95%CIDiff: 17.5–25.1 %BH), time (95%CIDiff: 0.067–0.023 s), and peak velocity (95%CIDiff: 0.56–0.74 m·s<sup>-1</sup>) were significantly greater during the OHS ( $p < 0.05$ ). During OHS, significantly greater hip joint peak power (95%CIDiff: 1.6–4.1 W·kg<sup>-1</sup>), work (95%CIDiff: 0.104–0.527), peak velocity (95%CIDiff: 7.6–40.5 °·s<sup>-1</sup>) occurred compared to SHS, although the time and hip angular position of peak velocity and peak power were not statistically different between styles.

### Conclusions

These results may influence choices of KB progressions, suggesting that one may first consider changes in KB mass prior to changing from the SHS style to the OHS style.

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## Level of Evidence

Level 3

### INTRODUCTION

Kettlebells (KB's) are commonly used in strength and conditioning programs to train various aspects of fitness and performance and offer an additional technique for sports rehabilitation practitioners to consider during terminal phases of rehabilitation with patients seeking to return to high activity levels. The kettlebell (KB) is composed of a ball and handle,<sup>1</sup> with a center of mass that extends past the hand. The off-center mass distribution challenges grip, stability, and muscle engagement, and enables a different kind of training compared to traditional dumbbells or barbells.<sup>2</sup> Kettlebells are available in various masses and sizes, allowing for a wide variety of movements such as carries, presses, swings, snatches, cleans, and jerks. Studies have demonstrated that KB training facilitates development of lower body strength and power, endurance, and cardiorespiratory fitness,<sup>3-5</sup> as well as a contribution to a variety of performance training metrics such as the vertical jump,<sup>5,6</sup> and one-repetition maximum strength in the deadlift, squat, and power clean.<sup>3,5,6</sup> Additionally, due to the ability of KB swings to activate the medial hamstrings,<sup>7,8</sup> they have been used in rehabilitation settings to manage pain and musculoskeletal disorders of the lower back<sup>9,10</sup> and in anterior cruciate ligament injury rehabilitation programs.<sup>11,12</sup> In practical application, the integration of KB exercises can enhance rehabilitation and exercise protocols by promoting functional hip extension movement patterns that are crucial for athletes returning to sport.

Popular variations of KB exercises include the shoulder height swing (SHS) and overhead swing (OHS). Both swings are ballistic in nature and involve a rapid cyclical sequence of eccentric and concentric actions of the hip extensor musculature.<sup>3,7,10</sup> Strong and powerful hip extensor muscles are essential to the maintenance of an upright posture and many functional movements (e.g., vertical jump). The sequence of muscle activation begins with active flexion of the hip during the eccentric phase of the swing. This is followed by the concentric swing phase that requires activation of the trunk extensors, abdominal co-contraction for spinal stability, while the gluteal muscles primarily produce the forces needed to elevate the KB to the desired height.<sup>13,14</sup>

Shoulder height kettlebell swings impose large compressive and shear forces on the body.<sup>1</sup> There is an inertial component of the KB that causes higher posterior shear forces in relation to compressive forces.<sup>1</sup> This requires sufficient dynamic spinal stability and is one of the factors that differentiate KB swings from traditional resistance exercises like the back squat or deadlift. Objective evidence concerning the mechanical demands of an exercise,<sup>1</sup> as well as how mechanical demands change with various progressions (e.g., external mass changes),<sup>1,15</sup> is a necessary prerequisite for practitioners to make informed decisions about exercise prescription and progression.<sup>3,5,6,13</sup> Several investigations have used EMG,<sup>7,14,16,17</sup> ground reaction force

(GRF) characteristics,<sup>1,13,18,19</sup> and joint kinetics<sup>1,14,15,18,19</sup> to quantify the mechanical demands of the different KB swing styles and masses, but few have conducted a comprehensive analysis of hip biomechanics that includes consideration of kinematics (e.g., angular distance and velocity) and kinetics (e.g., impulse, work and power). From a specificity of training perspective, understanding the timing and angular positions of peak kinematic and kinetic events is also important. For example, if the timing, angular positions, and event magnitudes are similar between the SHS and OHS swings, then the SHS may be preferred over OHS to lower injury risk while eliciting a similar training stimulus. Each of these characteristics reflect different perspectives of the demands and stimulus imposed on the hip by KB swing exercise and their documentation may better assist practitioners with exercise prescription. In addition to changing the KB load<sup>1,15</sup> KB swing style is an additional mechanism for exercise progression.<sup>19</sup> In their comparison of OHS, SHS, and Indian club swings, Bullock et al<sup>19</sup> reported the SHS and OHS to be mechanically similar despite moderate differences in peak hip flexion, impulse and cycle time. It is important to note that their study used a mixed sex sample in which the males used a 20kg KB and the females used a 12kg KB for the OHS and SHS. However, to date there has not been a direct comparison of KB load effects between the OHS and SHS styles. As males and females appear to demonstrate different responses to kettlebell masses during SHS,<sup>1</sup> studies examining KB load effects need to consider sex. The primary purpose of this study was to evaluate the effect of swing style (SHS, OHS) and KB mass on hip extension kinematics and kinetics in young adult females. A secondary purpose was to determine the effects of swing style and KB mass on the forces applied to the total body center of mass and KB as reflected by GRF and overall KB swing characteristics. It was hypothesized that velocity, power, and work would be greater for the OHS compared to the SHS, as well as for the heavier compared to the lighter KB's. It has also been hypothesized that GRF characteristics (peak, average, and impulse) would be greater with the higher mass. The results of this research can directly inform practitioners on the most effective KB movements and progressions to implement during rehabilitation and performance enhancement programs to maximize patient outcomes while ensuring safety and effectiveness.

### METHODS

#### PARTICIPANTS

Fifteen physically active females ( $29.8 \pm 5.3$  years,  $64.9 \pm 10.5$  kg,  $1.65 \pm 0.07$  m) with a minimum of six months KB swing training experience volunteered to participate in this study.<sup>13,15,19</sup> Prior to data collection, participants were given an overview of the study procedures, signed informed consent documents, and completed demographic

and health history questionnaires related to musculoskeletal injuries and surgeries. All participants were free from any lower extremity, glenohumeral, or spinal pain or injuries that restricted their participation in physical activities within the prior six months. Participants were asked to abstain from vigorous physical activity 24 hours prior to the data collection session. The university's Institutional Review Board approved the study protocol, and all participants were informed of the risks and benefits of testing prior to data collection. A previous investigation examining the effects of KB loads (8kg, 12kg, 16kg) on similar hip joint kinetic variables as the current investigation reported linear effect sizes (Hedges  $g$ ) between 0.91 and 1.11 (median=1.01),<sup>15</sup> which correspond to a Cohen's  $f$  of 0.505. As the primary purpose of the current investigation sought to compare KB swing style differences, a smaller effect size was anticipated than the previously reported KB load effect sizes. Power analysis using G\*Power ( $\alpha=.05$ ,  $\beta=.2$ ,  $f=.45$ ) yielded a minimal sample size of 12; thus 15 participants were targeted to provide an allowance for any data collection or reduction issues (e.g., missing markers, etc.).

## PROTOCOL

This cross-over study was conducted in resistance-trained females experienced with KB swing exercise. In a randomly assigned order, KB swings were performed under four conditions: SHS 12 kg, SHS 16 kg, OHS 12 kg, and OHS 16 kg. These two KB loads were chosen because they have been described as appropriate loads for females.<sup>2</sup> Participants performed one trial under each condition and each trial consisted of fifteen continuous swings. Trials were separated by a 2-minute rest period. Pilot work indicated that 15 swings was a sufficient number of swings to obtain a block of five clean consecutive swings for analysis (i.e. no missing markers) while avoiding the risk of inducing fatigue with too many swings under each condition. Participants were cued to initiate each swing by extending their hips as hard as they could, swinging the KB as fast as they could, and actively pulling the KB back down during the eccentric portion of the swing. Prior to completing the KB swings, each data collection session began with a standardized warm-up consisting of five minutes on an arm ergometer (60-80 rpm), air squats, and 10 repetitions of 4.5 kg KB swings. Next, reflective marker clusters, each with three to five markers in unique asymmetrical and nonlinear patterns, were attached to the participant's left and right feet, shanks, thighs, as well as their sacrum and thorax.

Three-dimensional kinematic data of the reflective marker clusters were captured (100Hz) by a 12 infrared camera system (Vicon, Oxford, UK). Additional marker clusters were secured to the 12kg and 16kg KB. The camera data was streamed into The Motion Monitor acquisition software (IST, Chicago, IL, USA) where it was synchronized with GRF data collected (1000Hz) from two forceplates (AMTI, Watertown, MA, USA), one under each foot. Participant calibration involved digitizing the proximal and distal end of each foot, shank, thigh (distal end), pelvis, and trunk segment (centroid of contralateral points) using calibrated stylus. The hip joint center was established by com-

puting the apex of femoral rotation during a series of circumduction movements.<sup>20</sup> The KB center of mass was also computed relative to the attached cluster by taking the centroid of two antipodal digitized points. Participant mass and height were recorded for the anthropometric computations for locating each segment's center of mass.

Hip flexion/extension joint angles and net joint moments (NJM) using inverse dynamics were computed within The Motion Monitor. Prior to exporting as text files for further data reduction using MATLAB-based scripts (The Mathworks, Inc., Natick, MA, USA), the KB and hip kinematic and NJM data were low pass filtered at 10Hz while the GRF data were low pass filtered at 35Hz. All data were visually examined to verify integrity (i.e., no missing markers, etc.) and five consecutive swings within each set, typically between the 5th and 11th swings, were selected for analysis. The criteria used for swing selection included no missing marker data and the swings completed continuously (no pauses between swings) with similar KB displacements. The start of the concentric phase and end of the eccentric phase for each selected swing was defined by the posterior KB displacement. The concentric-eccentric transition was defined by the maxima of the combined vertical and anterior-posterior KB displacement vector:

$$\sqrt{x_{AP}^2 + x_V^2}$$

where  $x_{AP}^2$  is the anterior-posterior displacement and  $x_V^2$  is the vertical displacement

The hip NJM were normalized to body mass and the polarity was reversed to make extension moments positive. Hip joint angular velocity was computed using the central finite difference method with the angular displacement time series data. Hip net joint powers were computed as the product of the normalized NJM and angular velocity (radians-sec<sup>-1</sup>) and net joint work was computed by integrating the net joint power-time data. Hip NJM impulse (integral of NJM and time), peak power and work were computed for the concentric phase for each of the five selected swings.

In addition, three KB based variables were also computed for the concentric phase of each selected swing: KB travel distance (normalized to body height), concentric swing time, and peak KB vector velocity. KB travel distance and peak velocity were based upon the combined vertical and anterior-posterior KB compositive vector.<sup>15</sup> GRF were summed across the two plates followed by the computation of the combined vertical and anterior-posterior GRF vector. Three GRF variables were computed from the combined vector for the concentric phase of each selected swing: average GRF, peak GRF, and GRF impulse (integral of GRF vector and time).

## STATISTICAL ANALYSIS

Statistical analyses were conducted with IBM SPSS Statistics (Version 27.0. Armonk, NY: IBM Corp). All outcome measures were averaged across the five trials and were examined for normality using QQ plots and Shapiro-Wilk tests. Two factor (style by mass) repeated measures analyses were conducted on all outcome measures. Partial eta squared effect sizes were used to indicate interaction and

**Table 1. Descriptive statistics (means  $\pm$  standard deviation) for the kettlebell swing characteristics variables.**

|                                                      | Overhead Swing  |                 | Shoulder Height Swing |                 |
|------------------------------------------------------|-----------------|-----------------|-----------------------|-----------------|
|                                                      | 12 kg           | 16 kg           | 12 kg                 | 16 kg           |
| Peak velocity ( $\text{m} \cdot \text{s}^{-1}$ )*, † | 4.66 $\pm$ 0.31 | 4.49 $\pm$ 0.24 | 3.96 $\pm$ 0.36       | 3.90 $\pm$ 0.26 |
| Distance (%BH)*                                      | 112.2 $\pm$ 9.3 | 112.6 $\pm$ 8.3 | 91.3 $\pm$ 6.1        | 91.0 $\pm$ 5.3  |
| Concentric swing time (s)*                           | 0.99 $\pm$ 0.16 | 1.01 $\pm$ 0.17 | 0.86 $\pm$ 0.10       | 0.87 $\pm$ 0.10 |

\*Overhead swing significantly greater than shoulder height swing; †12 kg significantly greater than 16 kg

main effect size magnitudes and were interpreted as 0.01, 0.06, and 0.14 for small, medium and large, respectively. Significant interactions were followed by Bonferroni adjusted simple main effect post analyses.<sup>21</sup> Additionally, standardized effect sizes ( $d$ ) were computed using Hedges'  $g$  method, adjusted for small samples.<sup>22</sup> The standardized effect sizes were interpreted as 0.2, 0.6, 1.2, 2.0, and 4.0 for small, moderate, large, very large, and extremely large, respectively.<sup>23</sup> Significance for all inferential statistics was set a priori to  $\alpha < 0.05$ .

## RESULTS

### SWING CHARACTERISTIC RESULTS

Kettlebell travel distance (Table 1) was 23.4% significantly greater for the OHS compared to the SHS ( $p < 0.001$ ,  $d = 2.7$ , 95%CI<sub>Diff</sub>: 17.5–25.1 %BH). Kettlebell travel distance was not significantly influenced by KB mass as evidenced by the interaction ( $p = 0.636$ ,  $\eta^2_p = 0.016$ ) and mass main effect ( $p = 0.970$ ,  $d = 0.01$ ). The concentric swing time was 15.5% greater for the OHS compared to the SHS ( $p = 0.001$ ,  $d = 0.94$ , 95%CI<sub>Diff</sub>: 0.067–0.203s). Kettlebell mass had no significant effect on concentric swing time based on the interaction ( $p = 0.741$ ,  $\eta^2_p = 0.008$ ) and mass main effect ( $p = 0.517$ ,  $d = 0.10$ ). While the style by mass interaction for peak KB velocity was not statistically significant ( $p = 0.057$ ,  $\eta^2_p = 0.235$ ), there was a significant style difference ( $p < 0.001$ ,  $d = 2.1$ , 95%CI<sub>Diff</sub>: 0.56–0.74  $\text{m} \cdot \text{s}^{-1}$ ) with 16.6% greater peak velocity for the OHS and a significant mass difference ( $p = 0.003$ ,  $d = 0.36$ , 95%CI<sub>Diff</sub>: 0.05–0.18  $\text{m} \cdot \text{s}^{-1}$ ) with 2.7% greater peak velocity for the 12 kg KB compared to the 16 kg KB.

### HIP JOINT KINEMATICS

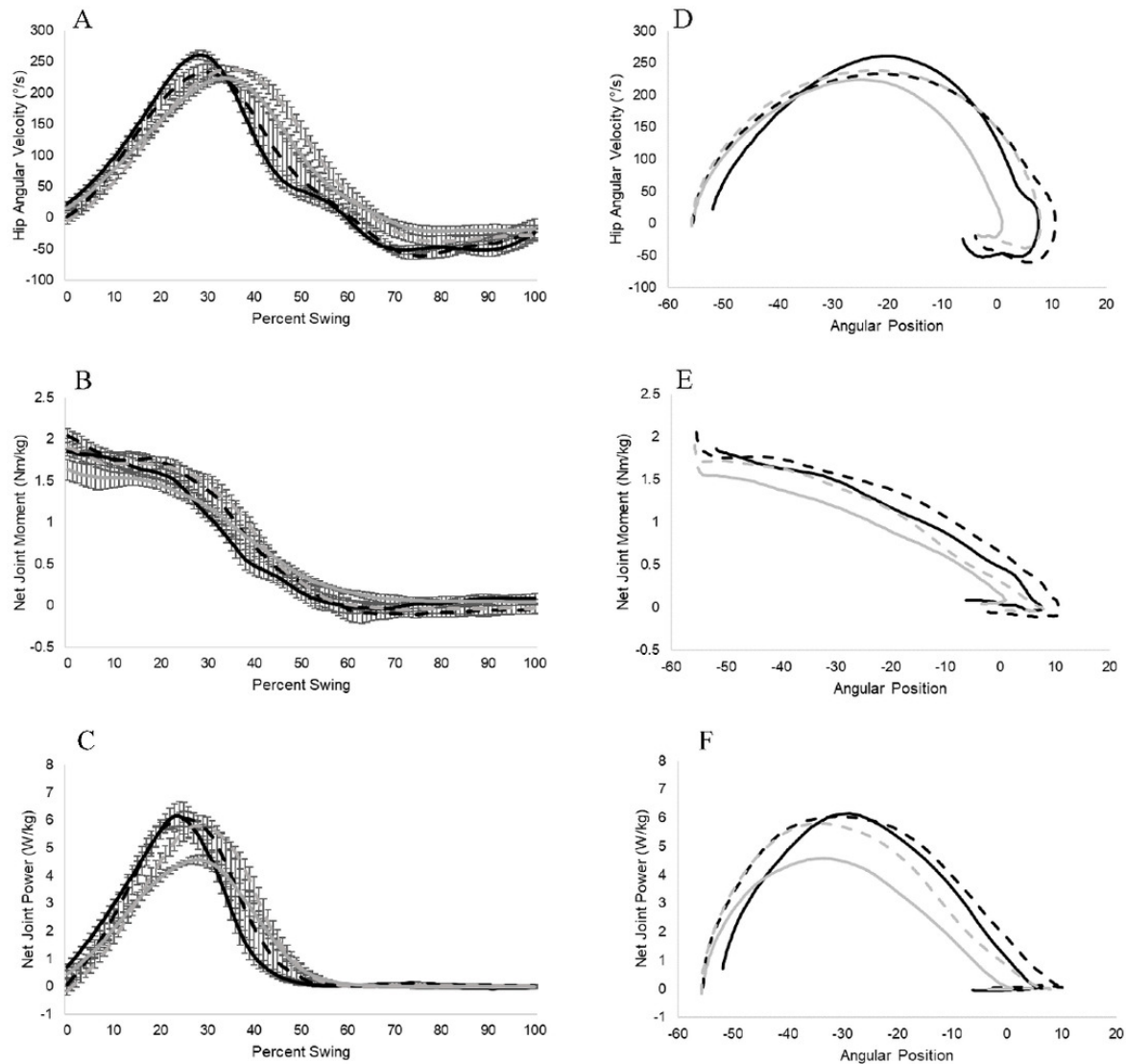
For a randomly chosen participant, hip angular velocity, net joint moments, and net joint power ensemble average graphs against time (percent swing cycle) and angular position are presented in Figure 1. Based on the interaction ( $p = 0.634$ ,  $\eta^2_p = 0.017$ ) and style ( $p = 0.140$ ,  $d = 0.08$ ) and mass ( $p = 0.920$ ,  $d = 0.01$ ) effects, there were no significant differences in the hip angular position at start of the swing (Table 2). At the end of the OHS, the hip was significantly more flexed (95%CI<sub>Diff</sub>: -9.9–4.8°) compared to the SHS ( $p < 0.001$ ,  $d = 1.2$ ). The hip angular distance was 9.8% greater (95%CI<sub>Diff</sub>: 5.5–10.6°) for the OHS compared to the SHS ( $p < 0.001$ ,  $d = 0.44$ ) and the angular distance was 4.1% greater (95%CI<sub>Diff</sub>: 0.8°–6.1°) for the 16kg mass compared to the 12kg mass ( $p = 0.014$ ,  $d = 0.19$ ). The OHS peak hip extension

velocity was 9.7% greater (95%CI<sub>Diff</sub>: 7.6–40.5 °·s<sup>-1</sup>) relative to the SHS ( $p = 0.007$ ,  $d = 0.46$ ). Peak hip extension velocity was not significantly influenced by KB mass based upon the interaction ( $p = 0.460$ ,  $\eta^2_p = 0.040$ ) and mass main effect ( $p = 0.281$ ,  $d = 0.09$ ). The time to reach peak hip extension velocity was not statistically different between the two swing styles ( $p = 0.232$ ,  $d = 0.13$ ) nor was the time to reach peak hip extension velocity significantly influenced by KB mass based upon the interaction ( $p = 0.572$ ,  $\eta^2_p = 0.068$ ) or mass main effect ( $p = 0.358$ ,  $d = 0.12$ ). The angular position of peak hip extension velocity was not statistically different between the two swing styles ( $p = 0.849$ ,  $d = 0.02$ ) nor was the angular position of peak hip extension velocity significantly influenced by KB mass based upon the interaction ( $p = 0.688$ ,  $\eta^2_p = 0.012$ ) and mass main effect ( $p = 0.427$ ,  $d = 0.10$ ).

### HIP JOINT KINETICS

The OHS peak hip extension power (Table 3) was 42.1% greater (95%CI<sub>Diff</sub>: 1.6–4.1  $\text{W} \cdot \text{kg}^{-1}$ ) compared to the SHS ( $p < 0.001$ ,  $d = 0.73$ ) and peak hip extension power was 34.1% greater (95%CI<sub>Diff</sub>: 0.93–5.8  $\text{W} \cdot \text{kg}^{-1}$ ) during the 16kg mass compared to the 12kg mass ( $p = 0.010$ ,  $d = 0.62$ ). The interaction for time to peak hip extension power was not significant ( $p = 0.469$ ,  $\eta^2_p = 0.038$ ). Additionally, neither swing style ( $p = 0.311$ ,  $d = 0.04$ ) nor KB mass ( $p = 0.107$ ,  $d = 0.06$ ) had significant effects on the time to peak hip extension power. There was a significant style by mass interaction ( $p = 0.037$ ,  $\eta^2_p = 0.274$ ) for the angular position of peak power. There were no significant differences in angular position of peak power between the swing styles for either the 12 kg ( $p = 0.062$ ,  $d = 0.25$ ) or 16kg ( $p = 0.655$ ,  $d = 0.03$ ) mass. There was no significant difference between the two masses for the OHS ( $p = 0.197$ ,  $d = 0.16$ ). In contrast, during the SHS, the hip was significantly more flexed (95%CI<sub>Diff</sub>: -10.2 to -3.3°) at peak power for the 12 kg compared to the 16 kg ( $p = 0.001$ ,  $d = 0.47$ ).

Hip joint work was 21.9% greater (95%CI<sub>Diff</sub>: 0.104–0.527  $\text{J} \cdot \text{kg}^{-1}$ ) for the OHS compared to the SHS ( $p = 0.006$ ,  $d = 0.38$ ). Hip joint work was not significantly influenced by KB mass based upon the interaction ( $p = 0.134$ ,  $\eta^2_p = 0.153$ ) and mass main effect ( $p = 0.117$ ,  $d = 0.37$ ). The interaction for hip impulse was not significant ( $p = 0.527$ ,  $\eta^2_p = 0.029$ ). Additionally, neither swing style ( $p = 0.608$ ,  $d = 0.10$ ) nor KB mass ( $p = 0.259$ ,  $d = 0.31$ ) had significant effects on hip impulse.



**Figure 1.** Ensemble averages of hip angular velocity (A), net joint moment (B), and power (C) against normalized time and hip angular velocity (D), net joint moment (E) and power (F) against hip angular position of five trials for a randomly selected participant completing the concentric portion of overhead swings (black lines) and shoulder height swings (grey lines) with 12 kg (solid) and 16 kg (dashed) kettlebells.

Error bars represent one standard deviation across the five trials.

**Table 2.** Descriptive statistics (means  $\pm$  standard deviation) for the hip joint kinematic and kinetic variables.

|                                            | Overhead Swing     |                    | Shoulder Height Swing |                    |
|--------------------------------------------|--------------------|--------------------|-----------------------|--------------------|
|                                            | 12 kg              | 16 kg              | 12 kg                 | 16 kg              |
| Angular Distance ( $^{\circ}$ )*†          | 88.22 $\pm$ 18.40  | 97.71 $\pm$ 18.09  | 81.21 $\pm$ 16.52     | 83.60 $\pm$ 16.44  |
| Angle End ( $^{\circ}$ )*                  | -8.15 $\pm$ 5.97   | -8.19 $\pm$ 6.94   | -1.79 $\pm$ 5.02      | 0.23 $\pm$ 4.48    |
| Angle Start ( $^{\circ}$ )                 | -80.69 $\pm$ 17.60 | -81.21 $\pm$ 18.03 | -79.56 $\pm$ 16.98    | -79.30 $\pm$ 16.99 |
| Peak Velocity Position ( $^{\circ}$ )      | -34.53 $\pm$ 7.61  | -34.94 $\pm$ 7.73  | -34.31 $\pm$ 6.55     | -35.50 $\pm$ 8.82  |
| Peak Velocity Time (s)                     | 0.31 $\pm$ 0.06    | 0.31 $\pm$ 0.05    | 0.31 $\pm$ 0.08       | 0.32 $\pm$ 0.05    |
| Peak Velocity ( $^{\circ} \cdot s^{-1}$ )* | 271.36 $\pm$ 48.24 | 273.51 $\pm$ 50.26 | 244.71 $\pm$ 43.38    | 252.07 $\pm$ 56.90 |

\*Overhead swing significantly greater than shoulder height swing; †12 kg significantly greater than 16 kg; ‡ 12kg significantly greater than 16kg for shoulder height swing

**Table 3. Descriptive statistics (means  $\pm$  standard deviation) for the hip joint kinetic variables.**

|                                        | Overhead Swing     |                    | Shoulder Height Swing |                     |
|----------------------------------------|--------------------|--------------------|-----------------------|---------------------|
|                                        | 12 kg              | 16 kg              | 12 kg                 | 16 kg               |
| Work ( $J \cdot kg^{-1}$ )*            | 1.54 $\pm$ 0.75    | 1.98 $\pm$ 0.93    | 1.35 $\pm$ 0.71       | 1.52 $\pm$ 0.74     |
| Impulse ( $Nm \cdot s \cdot kg^{-1}$ ) | 0.79 $\pm$ 0.29    | 0.92 $\pm$ 0.34    | 0.79 $\pm$ 0.27       | 0.86 $\pm$ 0.31     |
| PP Position ( $^{\circ}$ )             | -56.54 $\pm$ 14.64 | -54.18 $\pm$ 12.78 | -60.43 $\pm$ 14.98‡   | -53.69 $\pm$ 11.92‡ |
| PP Time (s)                            | 0.27 $\pm$ 0.16    | 0.27 $\pm$ 0.18    | 0.25 $\pm$ 0.16       | 0.27 $\pm$ 0.15     |
| PP ( $W \cdot kg^{-1}$ ) *†            | 7.40 $\pm$ 3.64    | 11.84 $\pm$ 6.63   | 5.62 $\pm$ 2.79       | 7.91 $\pm$ 3.79     |

PP: peak power

\*Overhead swing significantly greater than shoulder height swing; †12 kg significantly greater than 16 kg; ‡12kg significantly greater than 16kg for shoulder height swing

**Table 4. Descriptive statistics (means  $\pm$  standard deviation) for the ground reaction force variables.**

|                        | Overhead Swing    |                  | Shoulder Height Swing |                  |
|------------------------|-------------------|------------------|-----------------------|------------------|
|                        | 12 kg             | 16 kg            | 12 kg                 | 16 kg            |
| Peak GRF (BW)          | 1.99 $\pm$ 0.27†  | 2.02 $\pm$ 0.26  | 1.86 $\pm$ 0.27‡      | 1.97 $\pm$ 0.24  |
| Avg. GRF (BW)*         | 1.25 $\pm$ 0.07   | 1.29 $\pm$ 0.07  | 1.25 $\pm$ 0.06       | 1.32 $\pm$ 0.05  |
| Impulse (BW $\cdot$ s) | 20.75 $\pm$ 3.93† | 21.16 $\pm$ 3.45 | 17.69 $\pm$ 3.95‡     | 20.37 $\pm$ 4.05 |

GRF: ground reaction force, BW: body weight

\*12 kg significantly greater than 16 kg; †overhead swing significantly greater than shoulder height swing for 12 kg; ‡16 kg significantly greater than 12 kg for shoulder height swing

## GROUND REACTION FORCES

There was a significant style by mass interaction ( $p=0.009$ ,  $\eta^2_p=0.398$ ) for peak GRF (Table 4). With the 12 kg mass, the peak VGRF was 7.0% greater (95%CI<sub>Diff</sub>: 0.08–0.20 BW) for the OHS compared to the SHS ( $p<0.001$ ,  $d=0.49$ ), whereas with the 16kg there was no significant difference between swing styles ( $p=0.109$ ,  $d=0.18$ ). While there was no significant difference in peak GRF between masses for the OHS ( $p=0.384$ ,  $d=0.09$ ), the peak GRF was 6.3% greater (95%CI<sub>Diff</sub>: 0.07–0.17 BW) for the 16 kg mass compared to the 12 kg ( $p<0.001$ ,  $d=0.44$ ) during the SHS.

The average GRF was 4.4% greater (95%CI<sub>Diff</sub>: 0.08–0.35 BW) for the 16 kg mass compared to the 12 kg mass ( $p<0.001$ ,  $d=0.88$ ). There were no significant differences between the styles based upon the interaction ( $p=0.131$ ,  $\eta^2_p=0.155$ ) and style main effect ( $p=0.178$ ,  $d=0.19$ ).

There was a significant style by mass interaction ( $p=0.032$ ,  $\eta^2_p=0.289$ ) for GRF impulse. With the 12kg mass, the peak GRF was 14.0% greater (95%CI<sub>Diff</sub>: 1.4–4.8 BW $\cdot$ s) for the OHS compared to the SHS ( $p=0.002$ ,  $d=0.73$ ), whereas with the 16kg there was no significant difference between swing styles ( $p=0.445$ ,  $d=0.20$ ). While there was no significant difference in GRF impulse between masses for the OHS ( $p=0.645$ ,  $d=0.10$ ), for the SHS the GRF impulse was 15.2% greater (95%CI<sub>Diff</sub>: 0.53–4.8 BW $\cdot$ s) for the 16 kg mass compared to the 12 kg ( $p=0.018$ ,  $d=0.63$ ).

## DISCUSSION

With the aim of assisting practitioners to make informed KB swing exercise prescription decisions in their training protocols, this study primarily sought to quantify the magnitude of the differences between the SHS and OHS with re-

spect to KB swing characteristics, hip joint kinematics and kinetics, and GRF characteristics in resistance trained females. KB distance during the OHS was ~25% greater, coupled with ~16% greater time and peak velocity. At the hip joint, the most profound swing style effect was on peak power (~42%) followed by work (~22%) and peak velocity (~10%). Remarkably, the time and angular position of attaining peak velocity and power were similar between the swing styles. This result suggests that the hip movement patterns, and muscle activations are similar between the two styles but the OHS requires greater effort. The GRF peak and impulse were also greater for the OHS compared to the SHS, but the relative changes were substantially less than the hip joint changes. Compared to the swing style differences, there were fewer and smaller magnitude changes associated with a 4 kg KB mass increase. Thus, based on the biomechanical demands identified in the current study, these results may influence choices of KB progressions, suggesting that one may first consider changes in KB mass prior to changing from the SHS style to the OHS style.

Based on the results, both styles are mechanically similar in regard to the hip joint. The starting position for both swing styles occurred at similar degrees of hip flexion. While peak velocity and peak power were higher for the OHS, their location and timing were similar between the two swing styles. These results suggest that the mechanical demands and active musculature are similar between styles. The findings of the current study more closely align with those of McGill and Marshall.<sup>14</sup> Although McGill and Marshall compared single arm swings and single arm snatches, the start and end hip joint positions they reported are like the current SHS and OHS results. Additionally, McGill and Marshall measured EMG activity of the gluteal muscles, which play a critical role in hip extension, and demon-

strated the KB swings promoted gluteal muscle activation. Collectively, these results indicate that both KB swings are appropriate exercise selections for the development of posterior chain power.

It comes as no surprise that the OHS was characterized by a greater overall travel distance and swing time than the SHS based on the KB reaching an overhead versus shoulder height position. The higher peak KB velocity is explained upon the relative change and standardized effect size between the swing styles being greater for the KB travel distance compared to the concurrent increase in swing time. Based on the KB swing trajectory, it is also important to note that KB travel distance and peak velocity were based upon the vertical and anterior-posterior composite displacement vector.<sup>15</sup> This operational definition is different than previous research that just considered vertical displacement<sup>19</sup> or composite displacement for just the propulsion phase of the swing.<sup>13</sup> It is worthwhile to note that the current OHS KB distance and peak velocity are similar to a previous OHS report<sup>15</sup> but slightly less than an investigation considering SHS.<sup>5</sup> The discrepancy with the latter report is likely explained by participant differences (i.e., males versus females), KB masses, and consideration of just the propulsion phase of the swing.

Remarkably, in the current study, both swing styles began with near identical hip positions that were consistent across both KB masses. The statistical results revealed the hip to be more flexed at the end of the OHS compared to the SHS. As illustrated by the example ensemble average graph (Figure 1), towards the end of the OHS, the hip attained ~10° of hip extension, but then returned to a more flexed position by the end of the swing. This pattern of hip motion at the end of the swing was consistent for most participants. The end of the swing was defined by the KB displacement. Thus, the movement back to a slightly flexed position at the end of the OHS can be attributed to a postural stability component that allows the KB to attain an overhead position when the KB displacement vector reached a maximal value. While controlled hip extension can be a beneficial training stimulus, practitioners should be aware that repeated bouts of excessive hip extension coupled with poor form or excessive loading may pose an injury risk to the hip and lower back.

A previous investigation reporting hip kinematics reported females began two-handed<sup>7</sup> SHS with 85.6±9.0° of hip flexion and ended in 10.9±8.1° of hip hyperextension. In contrast, the current SHS results revealed the participants beginning the swings with ~6° less flexion and ending close to neutral hip extension. The difference between these results may be explained by the previous study precisely controlling the start/end position of the KB as well as the swing cadence. Consistent with the current results, an additional previous study using a mixed sex sample with different KB masses reported similar peak hip flexion angles between the OHS and SHS styles at the beginning of the swing<sup>19</sup>; however, the starting hip flexion angle was substantially less flexion (~61°) than either the current or previous study. Like the current study, participants were not restricted in start position or cadence, but the different methods used to

define the start of the swing may explain the starting hip position difference.

Impulse provides insight regarding net torque production over time while work provides insight on torque production through the range of motion. Joint power, the product of torque and angular velocity, reflects the rate at which mechanical energy is being produced. Collectively, the three metrics provide a comprehensive understanding of the training stimulus to the hip extensors. The current results show OHS was associated with greater peak hip extension velocity and power which is likely attributable to greater effort required to swing the KB overhead. A previous report by Bullock et al<sup>19</sup> observed no difference between styles for peak hip extension velocity, moment, or power. It should be noted however, that they utilized a mixed sex population, in which the males used a 20 kg KB and females used 12 kg. On the other hand, Lake and Lauder<sup>3</sup> saw significant increases in velocity as KB mass increased. Their KBs were much heavier (16, 24, and 32 kg) and their population was entirely male.

In contrast to the hip velocity and power, the current results revealed hip impulse to be the same for both swing styles. It is important to recall that the start and end of the interval of interest was defined by the position and velocity of the KB. It is evident upon review of the ensemble average graphs that the role of the hip was predominant in the first ~50% of the swings, with less involvement during the later part of the swing. With the computation of hip impulse being based on the product of NJM and overall concentric phase time, the presumable higher NJM required for the OHS may have been diluted because of the longer concentric phase time.

As mentioned previously, the greater hip angular distance and more flexed terminal hip position during the OHS was attributed to the act of decelerating the KB and regaining stability during the terminal swing phase. As evidenced by the ensemble average graphs, starting hip angular position, and angle of peak power, the hip displacement during the concentric phase was similar between the two styles. As a result, the greater work produced during the OHS can be attributed to a greater average net joint moment compared to the SHS. Thus, the OHS may offer the hip extensor musculature a greater sustained training stimulus through the range of motion utilized in performing KB swings.

As it pertains to mass, significant differences were observed in swing characteristics, other than a small (2.7%) increase in peak velocity for the 12 kg KB during the OHS. Hip angular distance was 4.1% greater for the 16 kg KB than the 12 kg KB. Hip extension velocity, time to reach peak hip extension velocity, and the position of peak hip extension velocity were similar across both masses. Watts et al<sup>15</sup> saw significant linear increases in peak power across 8 kg, 12 kg, and 16 kg masses, which is similar to the increased power and velocity observed in the 16 kg in the current study. This demonstrates that both masses are appropriate exercise selections for the development of posterior chain power, but intensity increases as mass increases.

Analysis of GRF provides a mode to compare the overall mechanical demands of the two swing styles under the two



masses. Like previous research,<sup>3,15</sup> the composite vector of the vertical and anterior-posterior GRF was used. While mass prompted a % increase in mean GRF, there were no mean GRF differences between the swing styles. This result is consistent with Ross et al<sup>18</sup> who reported no significant vertical or anterior-posterior mean GRF forces associated with changes in KB swing height. The peak and impulse GRF results revealed greater values for the OHS compared to the SHS only when swings were completed with the 12 kg KB. This finding suggests the mechanical demand to swing the 12 kg KB to shoulder height is less than the requirements to perform a 12 kg OHS and both swing styles with the 16kg KB. Previous research has also reported similar peak vertical GRF values between the OHS and SHS.<sup>19</sup> The lack of GRF differences between the swing styles is contradictory to previous research documenting a 20% change in swing height was a sufficient stimulus to prompt GRF impulse differences.<sup>18</sup> The discrepancy in impulse results can be attributed to differences in the KB masses used; Ross et al<sup>18</sup> has male participants perform the swings with a 56 kg KB whereas the current investigation used 12 kg and 16 kg KB with female participants.

Additionally, it is worthwhile to note there were more significant results related to swing style compared to KB mass. Of those results that were significant for both factors, the swing style effect size magnitudes were generally larger than the mass effect size magnitudes. This outcome can be attributed to using 12 kg and 16 kg KB with females who regularly performed KB swing training. Thus, biomechanical research utilizing KB with greater mass, particularly when examining experienced individuals, is recommended.

This study has a few limitations. First, this study only considered females. Given the differential effects of KB load between males and females,<sup>1</sup> this limits the ability to speculate if similar results would be attained with males. Furthermore, despite requiring that all participants had at least six months of KB swing training experience, exact training protocols or participants' varying degrees of technique were not controlled for. There is a possibility that hip kinetic patterns change with advancements in KB swing training. Additionally, KB mass was limited to 12 kg and 16 kg and relative strength was not accounted for. The 12 kg KB mass for females has been described as an appropriate starting weight for strength-trained females by Steve Cotter in his book *Kettlebell Training*<sup>2</sup> and 16 kg is a standard prescribed mass for females in high-volume CrossFit workouts and competition. Because the participants were recruited from CrossFit gyms, it is likely that they were accustomed to these KB masses, and they may not have been great enough to stimulate maximal power production. Future studies should consider incorporating greater masses to evaluate their participants under more challenging KB mass conditions.

An additional limitation to the current investigation was only considering the concentric (propulsion) phase of the

swing, defined by the start and end position of the KB. The rationale for limiting the focus on the concentric portion of the KB swing was the similarity of the training stimulus relative to many functional athletic movements such as vertical jump and Olympic style weightlifting. The ensemble graphs illustrate that only about 50% of the swing for both styles involve active propulsion effort by the hip. As mentioned previously, perhaps more subtle swing style outcome measure differences would have been evident if only the active propulsion portion of the swing had been considered. For example, Lake and Lauder<sup>13</sup> defined the propulsion phase based on the peak resultant KB velocity. This study opted to consider the full concentric phase because of the timing and location uncertainty of differences in KB velocity, as well as the underlying hip joint kinetics. Based upon the current results showing similarity in the time and location of hip joint kinetics, future research comparing swing styles has some rationale for limiting consideration to the active propulsion portion of the swing. It is worth noting that altering swing height by 20% of shoulder height had more influence on the eccentric (braking) phase GRF characteristics than the concentric (propulsion) phase.<sup>18</sup> Thus, it is recommended future research consider swing style differences during the eccentric phase of the KB swing.

## CONCLUSIONS

At the hip, the OHS promoted greater peak power, work, and peak velocity compared to the SHS. Interestingly, despite these kinetic differences, the time and angular position of attaining peak velocity and power were not statistically different between the two swing styles. The GRF peak and impulse were also greater for the OHS compared to the SHS, but the relative changes were substantially less than the hip joint changes. Kettlebell mass had fewer and smaller magnitude changes than swing style. In conclusion, the results of the current study may have application regarding choices of KB progressions. Specifically, practitioners may want to first consider changes in KB mass prior to changing from the SHS style to the OHS style.

## CONFLICT OF INTEREST

The authors report no conflicts of interest.

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