Characterisation of the Mechanical Loads and Metabolic Intensity of the CAPO Kids Exercise Intervention for Healthy Primary School Children

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Abstract
Sedentarism is associated with obesity and other chronic diseases at all ages. Increasing physical activity with in-school interventions, focusing on energy expenditure and bone loading reduces risk of a number of costly chronic diseases. The aim of the current study was to characterise the metabolic and musculoskeletal load intensity of the recent successful CAPO Kids exercise intervention. Pre and early pubertal children (10.4 ± 0.5 years old) from the CAPO Kids trial wore an armband sensor to estimate energy expenditure during a 10-minute CAPO Kids session. Eleven participants performed manoeuvres from the session on a force platform to determine vertical ground reaction forces. In total, 28 boys and 20 girls had armband measures and 11 boys and girls undertook GRF testing. The energy expenditure associated with the 10-minute session was 39.7 ± 9.3 kcal, with an average of 4 kcal·min⁻¹. The intensity of physical activity was ‘vigorous’ to ‘very vigorous’ for 34% of the session. Vertical ground reaction forces of the CAPO Kids manoeuvres ranged from 1.3 ± 0.2 BW (cartwheels) to 5.4 ± 2.3 BW (360° jump). CAPO Kids generates adequate load intensity to stimulate positive health adaptations in both metabolic and musculoskeletal systems of pre and early pubertal children.

Key words: Pediatrics; energy expenditure, ground reaction forces, physical activity.

Introduction
Despite our increasing knowledge of the positive impact of physical activity during childhood for long term health, children are becoming less active (Boreham and Riddoch, 2001; Tremblay et al., 2011a). Childhood sedentary behaviour is strongly associated with obesity (Must and Tybor, 2005; Pearson and Biddle, 2011) and is also known to predict overweight in adolescence and adulthood (Guo et al., 2002; Magarey et al., 2003). In addition, sedentary behaviour is related to other chronic metabolic diseases, such as osteoporosis, type 2 diabetes and ischaemic heart disease (Dunstan et al., 2010; Katzmarzyk et al., 2009; Tremblay et al., 2011a). Increasing physical activity participation in school is notionally a very practical method to improve the health of children at the population level (Boreham and Riddoch, 2001). An exercise regime that would effectively improve the health of multiple body systems, however, is yet to be described. For instance, it is well known that increasing the duration of physical activity is an effective strategy to enhance cardiovascular function (Haskell et al., 2007), but not the skeletal system. To stimulate the latter system, short duration, high intensity loading is required (Lanyon and Rubin, 1984).

Exercise prescriptions can be manipulated in terms of frequency (exercise bouts per week), intensity (metabolic and musculoskeletal load), duration (length of exercise bout), and exercise type (Must and Tybor, 2005). The current physical activity recommendation for children includes the accumulation of 60 minutes per day of moderate to vigorous exercise in addition to activities that strengthen bone and muscle on at least three days per week (Janssen, 2007; Strong et al., 2005; Tremblay et al., 2011b; Twisk, 2001). Measures of intensity traditionally focus on cardiovascular or metabolic load and are classified in terms of heart rate and estimates of energy expenditure (EE) (Haskell et al., 2007). Such measures, however, fail to capture characteristics of mechanical intensity that are vital to the musculoskeletal response. In order to identify childhood activities that are broadly beneficial to multiple systems, it is important to know the intensity of both cardiovascular/metabolic load and musculoskeletal load. Furthermore, from a psychosocial standpoint, variety and enjoyment are critically important elements of an exercise program that contribute to uptake and ongoing engagement (Richard et al., 1997).

Accelerometry is a recognised technique to track physical activity in bone and metabolic research (Janz et al., 2003). Accelerometry-derived weight-bearing movements can predict bone mass and density in young children (Janz et al., 2001; Specker et al., 2001). Biomechanical characteristics of weight-bearing exercises are typically estimated by measuring ground reaction forces (GRF) (Prapavessis and McNair, 1999).

The CAPO Kids program was a recent brief and enjoyable in-school exercise intervention designed to improve the musculoskeletal and metabolic health of pre and peripubertal children (Nogueira et al., 2014; 2015). The goal of the program was to simultaneously apply a moderate to vigorous aerobic load and high intensity impact loading. Exercises were based on capoeira, a Brazilian sport that combines martial art, dance and music, presenting a new and interesting activity for the participants. Capoeira was supplemented with high impact activities including a variety of jumps and upper limb loading activities. The program improved bone health and metabolic factors such as waist circumference, resting heart rate and maximal oxygen uptake over a nine-month period (Nogueira et al., 2014; 2015).

The aim of the present study was to characterise the biomechanical and metabolic loads of the CAPO Kids
exercise program, in boys and girls. Those data will allow others to make an informed judgement with regards to the potential of the program to produce metabolic and musculoskeletal benefit or other outcomes.

**Methods**

**Study design and ethical approval**

We conducted a cross-sectional descriptive study of metabolic and mechanical loads experienced by participants in the CAPO Kids trial. Ethical approval was obtained from the Griffith University Human Research Ethics Committee (PES/35/12/HREC), and all participants provided informed consent. Parents had the option to override and decline to consent.

**Participants**

A sample of the Year 5 and 6 primary school children (9.7-11.4 years of age) who were participating in the 9-month CAPO Kids exercise intervention were recruited for the current study. Participants were included if they were healthy, ambulant, and enrolled in the exercise arm of the trial. Participants were excluded if they had a metabolic, endocrine or renal condition; were taking medications known to affect bone, muscle or fat metabolism; were recovering from a serious lower limb fracture or other immobilising injury in the past six months; or were affected by any condition not compatible with short bouts of physical activity. Specific details of school and participant recruitment are available in previous publications (Nogueira et al., 2014; 2015).

Participants were invited to wear a SenseWear Armband (SWA, BodyMedia, Pittsburgh, PA, USA) for the entirety of one CAPO Kids exercise bout in order to have parameters of metabolic intensity measured. The same participants were also invited to attend a single session of testing at the Biomechanics Laboratory at Griffith University in order to have the ground reaction forces (GRF) associated with intervention activities measured on a force platform. Participation in the GRF session was optional. An *a priori* sample size estimate was not conducted.

**Data collection**

**Anthropometrics:** Anthropometric measures included standing and sitting height (portable stadiometer, HART Sport and Leisure, Australia and a 50 cm stool), and body weight (digital scale, Charder MS 3200, CE, Taichung City, Taiwan). Weight was measured in duplicate, while standing and sitting height were determined by a single measure. Body mass index (BMI) was determined from weight and height per the accepted method (BMI = weight-height², kg-m⁻²).

**Maturity:** Maturity was assessed by calculating years to age of peak height velocity (YAPHV), based on an algorithm that includes several anthropometric variables (Mirwald et al., 2002). The algorithm uses the following variables: date of birth, sex, weight, sitting and standing height; and predicts maturity offset as the number of years the participant is from their estimated age of peak height velocity (APHV). YAPHV is calculated by subtracting APHV from chronological age.

**Measurement of metabolic load:** Total energy expenditure (EE) was estimated by the SenseWear Pro Armband monitor (SWA version 7.0; BodyMedia, Pittsburgh, PA, USA), using child-specific algorithms (Calabró et al., 2009). The SWA is a wireless, non-invasive multiple-sensor device that collects data derived from skin temperature, galvanic skin response (electrical conductivity of skin) and heat flux when placed on the left arm (on the triceps brachii, mid-way between shoulder and elbow) (St-Onge et al., 2007). The tri-axial built accelerometers record motion and the total number of steps in an exercise bout. Measures of energy expenditure are calculated using manufacturer software which incorporates user inputted weight, height, sex and age. Physical activity EE is presented in calories (kcal) and in metabolic equivalents (MET), to characterise the ‘metabolic intensity’ of a bout of exercise. The device has been validated for measures of EE in resting and exercise conditions, for adults (Fruin and Rankin, 2004; Jakicic et al., 2004) and children (Arvidsson et al., 2007; Calabró et al., 2009). Participants wore the SWA while resting for ten minutes before each trial, according to manufacturer recommendations. The participant then wore the SWA for a full 10-minute CAPO Kids session (exercises as described in Table 1). Data collection was held during typical CAPO Kids classes.

Data from the SWA were downloaded onto a personal computer and processed using SenseWear software version 7.0. The data includes minute-by-minute values for EE (kcal), intensity (METs) and number of steps according to in-built algorithms (Calabró et al., 2009). Moderate (3.0 to 5.9 METs), vigorous (6.0 to 8.9 METs), and very vigorous activity (> 9.0 METs) (Nader et al., 2008) was categorised by the software, based on a proprietary equation that has been validated to estimate EE in children (Calabró et al., 2009).

**Ground reaction force measures:** Vertical ground reaction force (vGRF) parameters were measured for 11 of the most common jumps and capoeira manoeuvres included in the CAPO Kids intervention trial (Table 1). Vertical GRF, including magnitude of and rate of force application were collected at 1 kHz using two 900 mm x 600 mm strain gauge bridge force platforms (Advanced Mechanical Technology, Inc, MA, USA). Vertical GRF data collection was performed in the laboratory, where the force platforms are located. As all were participants of the CAPO Kids trial at the time and had completed five months of the intervention, they were familiar with and competent in all measured activities. A single investigator (RN) demonstrated each activity prior to participant performance. Participants were instructed to perform each activity barefoot, to simulate the typical CAPO Kids session. Activities were performed in the same order for all participants. After several practice attempts, three consecutive attempts of each activity were executed on the force platform.

GRFs were normalised to bodyweight (BW) and the average peak vGRFs (BW) and rates of force application (BW/s) were calculated for each activity from three successful trials using custom-designed software in Matlab 7.8.0 (The MathWorks, Natick, MA).
Table 2. Participant characteristics (n = 48). Data are means (±SD).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Whole Group</th>
<th>Boys (n = 28)</th>
<th>Girls (n = 20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>10.4 (.5)</td>
<td>10.4 (.5)</td>
<td>10.4 (.5)</td>
</tr>
<tr>
<td>YAPHV (years)</td>
<td>-2.32 (.94)</td>
<td>-3.03 (.44)</td>
<td>-1.39 (.52) **</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>36.3 (7.6)</td>
<td>35.8 (6.9)</td>
<td>37.1 (8.7)</td>
</tr>
<tr>
<td>Standing height (m)</td>
<td>1.43 (.06)</td>
<td>1.43 (.06)</td>
<td>1.43 (.07)</td>
</tr>
<tr>
<td>Body mass index (kg·m⁻²)</td>
<td>17.8 (3.1)</td>
<td>17.5 (2.8)</td>
<td>18.1 (3.6)</td>
</tr>
<tr>
<td>Estimated VO₂ max (ml·kg⁻¹·min⁻¹)</td>
<td>27.5 (7.0)</td>
<td>28.9 (7.8)</td>
<td>25.5 (5.1)</td>
</tr>
</tbody>
</table>

VO₂ max, maximal oxygen consumption; YAPHV, years from age of peak height velocity. *** p < 0.001
Table 4. Vertical ground reaction forces and rates of force application for each CAPO Kids exercise (n = 11). Data are means (±SD).

<table>
<thead>
<tr>
<th>Activity</th>
<th>vGRF (BW)</th>
<th>95% CI</th>
<th>Rate of Application (BW·s⁻¹)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>360° jump</td>
<td>5.4 (2.3)</td>
<td>3.9 - 6.9</td>
<td>132.4 (78.6)</td>
<td>79.6 - 185.2</td>
</tr>
<tr>
<td>Cartwheel</td>
<td>1.3 (.2)</td>
<td>1.1 - 1.4</td>
<td>15.0 (18.7)</td>
<td>2.4 - 27.5</td>
</tr>
<tr>
<td>Ginga</td>
<td>1.4 (.4)</td>
<td>1.1 - 1.7</td>
<td>15.0 (17.3)</td>
<td>2.6 - 27.4</td>
</tr>
<tr>
<td>Handstand</td>
<td>1.4 (.2)</td>
<td>1.2 - 1.5</td>
<td>26.5 (17.5)</td>
<td>14.7 - 38.2</td>
</tr>
<tr>
<td>Hop</td>
<td>4.0 (1.0)</td>
<td>3.3 - 4.7</td>
<td>54.0 (13.7)</td>
<td>44.3 - 63.8</td>
</tr>
<tr>
<td>Hop plus martelo</td>
<td>4.0 (1.2)</td>
<td>3.3 - 4.7</td>
<td>92.4 (74.7)</td>
<td>39.0 - 145.8</td>
</tr>
<tr>
<td>Jump-lunges</td>
<td>1.5 (.6)</td>
<td>1.1 - 1.9</td>
<td>143.6 (144.9)</td>
<td>46.3 - 241.0</td>
</tr>
<tr>
<td>Jump plus martelo</td>
<td>4.8 (1.2)</td>
<td>3.9 - 5.7</td>
<td>121.8 (93.5)</td>
<td>54.8 - 187.8</td>
</tr>
<tr>
<td>Star jumps</td>
<td>2.9 (.7)</td>
<td>2.4 - 3.3</td>
<td>51.8 (24.6)</td>
<td>34.2 - 69.4</td>
</tr>
<tr>
<td>Running</td>
<td>2.7 (.5)</td>
<td>2.4 - 3.0</td>
<td>27.5 (8.7)</td>
<td>21.7 - 33.4</td>
</tr>
<tr>
<td>Tuck jump</td>
<td>5.2 (2.0)</td>
<td>3.8 - 6.6</td>
<td>106.5 (73.9)</td>
<td>81.0 - 132.0</td>
</tr>
</tbody>
</table>

vGRF, vertical ground reaction forces; BW, body weight.

Mechanical measures

Table 4 presents GRF measures including the average of vGRF magnitude and rates of application for each activity performed during the CAPO Kids intervention. The 360° jumps and tuck jumps produced the highest vGRFs (5.4 ± 2.3 and 5.2 ± 2.0 BW, respectively), followed by jump plus martelo (4.8 ± 1.2 BW), and then hop and hop plus martelo (4.0 ± 1.0 and 4.0 ± 1.2 BW, respectively). The smallest vGRFs were recorded during the upper body exercises, cartwheel and handstand (1.3 ± 0.2 and 1.4 ± 0.2 BW, respectively), followed by the ginja and jump-lunge (1.4 ± 0.4 and 1.5 ± 0.6 BW, respectively). The fastest rate of force application was recorded for the jump-lunge (143.6 ± 144.9 BW·s⁻¹) followed by the 360° jump (132.4 ± 78.6 BW·s⁻¹) and the jump plus martelo (121.8 ± 93.5 BW·s⁻¹).

Discussion

Our aim was to determine the metabolic and musculoskeletal load intensity of the CAPO Kids program; an in-school exercise intervention designed to improve the health of pre and early pubertal children. Specifically, our goal was to quantify energy expenditure and vertical ground reaction forces and rates of force application associated with a typical 10-minute intervention session of *capoeira* plus jumping.

We used SenseWear armbands to estimate energy expenditure of children participating in the school-based CAPO Kids exercise intervention program. We found that a single 10-minute bout of the intervention induced an absolute EE of 39.7 ± 9.3 kcal or 5.5 ± 0.9 METs, which represents an average EE of 4.0 kcal·min⁻¹ (moderate intensity). Previous pediatric studies using the validated SWA algorithms to assess physical activity in children have reported EE for a variety of activities (Arvidsson et al., 2007; Calabrò et al., 2009). For instance, the average EE for walking at 4 km·h⁻¹ was 2.5 kcal·min⁻¹ (low intensity), while the average for cycling was 3.0 kcal·min⁻¹ (moderate intensity); both activities being less vigorous than the CAPO Kids intervention (Calabrò et al., 2009). Activities such as basketball, running at 10 km·h⁻¹, and trampolining have been observed to consume more than 7 kcal/min, representing activities performed at a vigorous level (Arvidsson et al., 2007). While the average EE of a single bout of CAPO Kids was only 4.0 kcal·min⁻¹ (moderate intensity), including short periods of rest, 34% of each 10-min session was spent performing activities at a vigorous or very vigorous level, suggesting the CAPO Kids program has the potential to provide a beneficial metabolic stimulus.

The maximal vGRFs produced by participants ranged from 1.3 BW for cartwheels to 5.4 BW for jumps and *capoeira* manoeuvres. The rates of force application varied from 15 BW·s⁻¹ for cartwheels and ginga to around 140 BW·s⁻¹ for jump-lunges and 360° jumps. Although the vGRF data presented represent a range of magnitudes and rates, five of the 11 measured activities produced vGRFs greater than 4.0 BW and six applied forces at more than 90 BW·s⁻¹. Ground reaction forces have been reported for other common activities such as walking, running, and drop jumps from different heights (Weeks and Beck, 2008; McKay et al., 2005), as well as specific high impact sports such as gymnastics and volleyball (Daly et al., 1999, Salci et al., 2004). Low impact activities generally produce lower GRFs, such as walking (i.e. 1.1 to 1.5 BW) and running (i.e. 2.0 to 3.0 BW), whereas high impact activities such as maximal jumping produce higher peak forces (i.e. 3.0 to 5.0 BW) (Weeks and Beck, 2008). Landings from heights above ground level generate even higher peaks that may reach more than 8.0 BW (Fuchs et al., 2002) with peak forces of up to 10.0 BW recorded for elite athletes from high impact sports such as volleyball and gymnastics (Daly et al., 1999, Salci et al., 2004).

Our GRF results were similar to those reported from other in-school pediatric jumping interventions, with beneficial musculoskeletal outcomes (McKay et al., 2005; Weeks et al., 2008). Those studies reported vGRFs between 3.0 and 5.0 BW from jumping activities such as hops, lunges and jump-squats in their intervention programs for children. Thus, the peak forces and rates of force application produced by the CAPO Kids exercises appear to be sufficiently high to be osteogenic.

The upper extremities are relatively unaccustomed to habitual impact loads and, accordingly, there are very few reports of the GRFs associated with upper limb weight-bearing activities. Forearm fractures, however, are highly prevalent in children (Khosla et al., 2003). As the bone response to mechanical loading is site-specific (Bass et al., 2002; Johannsen et al., 2003), it is important to specifically load the upper extremity to achieve adaptive
benefits. We therefore also quantified the loads to which the upper limbs were exposed while weight-bearing during the CAPO Kids program. The upper extremity weight-bearing manoeuvres of handstands and cartwheels in the current study produced vGRFs of 1.3 and 1.4 BW, respectively. Although upper extremity GRFs of gymnasts performing elite level acrobatic movements have been reported up to 3.6 BW (Daly et al., 1999), our values nevertheless represent a large increase in loading to a region of the skeleton that is not typically exposed to weight bearing. Such loading was very simple and feasible for all of the children and may translate to considerable benefits in fracture prevention.

Limitations
For practical reasons, we used a light-weight, non-invasive, portable device to estimate EE, (i.e. armband sensor). We recognise that direct and indirect calorimetry remains the gold standard to estimate energy expenditure. Similarly, highly invasive techniques of direct measurement of bone strain were not feasible in the current cohort. GRFs were the best practical surrogate of musculoskeletal loading, but may not provide an entirely accurate estimate of the precise loads experiences by the skeleton.

Conclusion
We determined the metabolic and musculoskeletal load intensity of the CAPO Kids exercise intervention. We found that the CAPO Kids program has the ability to apply significant load intensity to both the metabolic and musculoskeletal systems of pre and early pubertal children. We conclude that the CAPO Kids program is likely to be an appealing, feasible and effective strategy to load the musculoskeletal and metabolic systems of children via in-school programming.

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References


**Key points**

- Energy expenditure of a single bout of CAPO Kids yields 39.7±9.3 kcal and includes activities performed at a vigorous and very vigorous intensity.

- Mechanical loads associated with CAPO Kids surpass five times bodyweight and more than 140 bodyweights per second.

- CAPO Kids intervention represents a viable approach to stimulate musculoskeletal and metabolic adaptation in children.