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Feasibility of an Activity Protocol for Young Children in a Whole Room Indirect Calorimeter: A Proof-of-Concept Study

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Background: The purpose of this pilot study was to assess the feasibility of a structured activity protocol in a room calorimeter among young children. ***Methods:*** Five healthy children (age 5.2 ± 0.4 y) performed an activity protocol in a room calorimeter, ranging from sedentary to vigorous-intensity activities. Energy expenditure (EE) was calculated from continuous measurements of O_2-consumption and CO_2-production using Weir's formula. Resting EE was defined as EE during the first 30 min of the study where participants were seated while watching television. The children wore an ActiGraph accelerometer on the right and left hip. ***Results:*** The protocol was well tolerated by all children, and lasted 150 to 175 min. Further, differences were seen in both EE and accelerometer counts across 3 of the 4 activity intensities. ***Conclusions:*** It is feasible for young children to perform a structured activity protocol in a room calorimeter enhancing the possibility of conducting future studies to cross-validate existing accelerometer prediction equations.

Keywords: child, validation studies, overweight, obesity, indirect calorimeter

Recent guidelines have highlighted the importance of promoting physical activity among young children.[1] To do this, it is necessary that researchers and practitioners can accurately measure physical activity and free-living energy expenditure in this age group. Valid and reliable instruments are essential to i) better understand the prevalence and patterns of physical activity behavior, ii) determine the factors that may influence physical activity participation, and iii) evaluate the efficacy and effectiveness of physical activity interventions in individuals, and community settings such as preschools.

Due to bias with proxy reports and the subject burden associated with direct observation, accelerometry has become the method of choice for objectively measuring physical activity in free-living children.[2,3] Several equations exist for converting the output from accelerometers into energy expenditure or time spent in varying intensities of physical activity. The most widely used equations[4,5] were developed for older children and adolescents (6–18 y) and may not be valid for younger children because of their differences in resting metabolic rate; poorer economy of movement;[6] and more sporadic and intermittent activity patterns.[7] Recently, 2 equations have been developed for young children[8,9] using different criterion measures (direct observation and portable calorimetry, respectively).

Validating and calibrating accelerometry in children under the age of 6 years, requires several conditions. First, the criterion measure should be able to capture free-living activities that are participated in by these children (a limitation with treadmill exercise). Second, it should be able to differentiate between different intensities of activity and capture these in real time (a limitation of doubly labeled water). Third, it should not be prone to observer bias (as direct observation can be). While there is no single measure that can confidently meet all 3 requirements, the most appropriate appears to be either whole-room calorimetry or portable calorimetry. Although portable calorimetry has been used with children this age[10] its size and weight in proportion to the size and mass of young children raises questions about the extent to which it may: change the movement patterns of young children; limit their ability to undertake certain "usual" movements; and alter the energy cost of movement significantly.

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It appears that whole room indirect calorimetry is the most valid criterion measure of energy expenditure in young children. Furthermore, it allows a young child to be appropriately monitored in an environment where their behavior can be amended if necessary (ie, for safety reasons). Despite this, whole room calorimetry is not undertaken with young children because of a perception that they will be unable to tolerate confinement in and/or be unable to follow a protocol of activities in the calorimeter. It is not clear if a structured activity protocol (incorporating sedentary, light, moderate, and vigorous physical activity) would be feasible for young children to undertake in a room calorimeter. This was the purpose of this study.

Methods

Subjects

A convenience sample of 5 healthy children (3 boys, 2 girls; 83% response rate), mean age 5.2 ± 0.4 y, mean height 113.2 ± 3.61cm, and mean weight 20.6 ± 2.63kg and without any motor pathologies or claustrophobia were recruited from the local community. Before consent, parents and the child visited the calorimeter where the study was explained and an information book (in the form of a children's story with color photos and age-appropriate words) was distributed. Parents were encouraged to read this to their child to familiarize them with the protocol and minimize any stress associated with the unfamiliarity of the calorimeter. If parents were satisfied a time was organized for them to complete the study. Written informed consent was obtained from the parents of each participant and an independent observer. The study was approved by the University of Wollongong Human Research Ethics Committee.

Protocol

A standard breakfast cereal was given to parents and they were instructed to give this to their child at least 1 hour before arriving for the study. Participants and their parents visited the calorimeter early in the morning (approximately 8:30 AM). Before entering it was checked that the child was able to open the door independently to avoid anxiety or a feeling of claustrophobia. Body weight was measured to the nearest 0.1kg using a calibrated electronic scale (Tanita HD646, Tanita Corporation of America, Illinois, USA) and height was measured to the nearest 0.1 cm using a PE87 portable stadiometer (Mentone Educational Centre, Victoria, Australia) and standard procedures.

Once inside the calorimeter (approximately 1.5 hours after consumption of breakfast), participants were instructed to sit on a beanbag and watch television for 30 min. This allowed resting energy expenditure to be measured. Children then adhered to a structured protocol of supervised physical activities (see Table 1), which took approximately 2 hrs to complete. Given that children this age typically do not spend long periods of time engaged in sustained bout of activity, the protocol was designed so each activity changed approximately every 5 min.

Accelerometry. Physical activity was continuously measured using 2 ActiGraph monitors (Model 7164), (ActiGraph, Pensacola). The ActiGraph is a small, lightweight, uni-axial accelerometer detecting accelerations in the vertical plane from 0.05g to 2 g.[10] Each monitor was affixed above the iliac crest of the right and the left hip with an elastic belt and adjustable buckle. Counts were accumulated using 15 sec epochs.

Whole-Room Indirect Calorimetry. Oxygen consumption and carbon dioxide production (paramagnetic O_2 and infrared CO_2 analyzers, Sable System Inc, Las Vegas USA), corrected to STPD, were continuously measured in 1 of the 2 furnished whole room indirect calorimeters (3m × 2.1m × 2.1m) at the University of Wollongong. The room was ventilated with fresh air measured by a solid-state gas sample drying system (Peltier dryer). The analyzers were manually calibrated against a span gas and nitrogen in the morning of each study day. Chamber air was sampled every 2 min. Rates of oxygen consumption and carbon dioxide production were calculated from measured in and outflow and energy expenditure was calculated using Weir's formula.[11] An early childhood education consultant was employed to make the calorimeter aesthetically appealing and to provide a friendly environment for the children. This involved decorating the room like a submarine and adding all necessary equipment and accessories to perform the different activities. Children were in constant view with their parents, and an independent observer and an instructor during the experiment through the glass windows on the walls of the calorimeter and were also able to communicate using a telephone and intercom (see Figure 1).

Data from both the calorimeter and accelerometers were synchronized and captured in real time, allowing them to be matched to the activities. Because there were periods of transition from one activity to the next, this also allowed transition time to be partitioned out of the analyses.

Data from the room calorimeter were downloaded as a Microsoft Excel file. The mean VO_2 and VCO_2 were computed from the raw data output of the calorimeter. Energy expenditure was calculated over 30 minute intervals. Activity related energy expenditure (AEE) was calculated as EE—REE and expressed per kg body mass (kcal/kg/min). Given that the children had the same standard breakfast, approximately 1.5 hours before the start of the measurements, the effect of diet-induced thermogenesis on energy expenditure outcomes was assumed to be minimal.

Data from the ActiGraph were downloaded to Excel files according to the manufacturers' instructions. Accelerometer counts for 4 consecutive 15-second epochs were summed to produce total counts per

Table 1 Protocol of Supervised Physical Activities Performed During the 2.5h in the Calorimeter

Activity	Time (min)
Watching TV (used to measure resting metabolic rate; min 1–30)	30
Sedentary Intensity (min 31–60)	30
Talking on telephone with parents	5
Reading books with a talking cassette	5
Coloring in	10
Sitting on floor and playing with toys	10
Light Intensity (min 61–90)	30
Drawing on a whiteboard	3
Personal grooming (brushing teeth, brushing/combing hair, washing hands/face)	3
Dressing up in costumes	5
Playing a musical instrument (tambourine, guiro, wooden block hand shaker)	5
Mini-golf	5
Cleaning (packing away toys, dusting, sweeping)	5
Slow walking	2
Playing quoits	2
Moderate intensity (min 91–120)	30
Brisk walking on a treadmill (non motorized, metronome set at 80 steps/min)	3
Locomotor movements (walking, skipping, galloping, playing games such as *red light/green light, Simon says,* and *turtle/rabbit*)	3
Shooting a small soft basketball into small ring on wall	2
Animal walks (e.g., like a chicken, kangaroo, bear)	2
Eye toy games (washing windows, catching bubbles)	10
Throwing a tennis ball at a Velcro target on the wall. Points are scored when target is hit.	3
Child bounces and catches a variety of different balls and then throws and catches a scarf	3
Child carries a beanbag up and down set of hard foam gymnastics stairs 10 times	2
Child mimics the actions to the song "Heads, shoulders, knees and toes"	2
Vigorous intensity (min 121–150)	30
Hitting a balloon continuously in the air	5
Circuit (jogging up foam stairs, jumping off, crawling through a standing hoop, and running back. Repeat for 5 min as quickly as possible)	5
Dancing/aerobics (following activities/exercises on DVD)	10
Jogging on child treadmill (non motorized, metronome set at 112 steps/min)	3
Jumping challenges (child jumps in and out of square, using a hoop (similar to skipping with a rope), running up stairs and jumping off, and jumping in a sack around markers on the floor)	7
Grand total	150

minute. Mean counts per minute over each 30 minute interval (sedentary, light, moderate, and vigorous intensity) were calculated for each participant and then averaged for the sample. Because of the small sample size the standard error of the mean (SEM) was used.

Results

Four of the 5 children were able to complete the entire protocol while in the calorimeter. One of the participants did not finish 2 of the vigorous activities due to fatigue. Participants were able to follow all instructions provided through the intercom and none felt anxious, claustrophobic, or terminated the study prematurely.

There was a stepwise linear increase in EE, AEE, and counts/min from sedentary to light and from light to moderate intensity activities (Table 2). However, there was a slight decrease in EE and AEE from moderate to vigorous intensity activities, which probably reflects the fatigue of the participants and their difficulty in maintaining this intensity for 30 min. Individual correlations between AEE ($kcal \cdot kg^{-1} \cdot min^{-1}$) measured by calorimetry and the counts given by the ActiGraphs ranged from 0.86 to 0.99. Overall, AEE significantly correlated with ActiGraph counts ($r = .95$; $P < .01$).

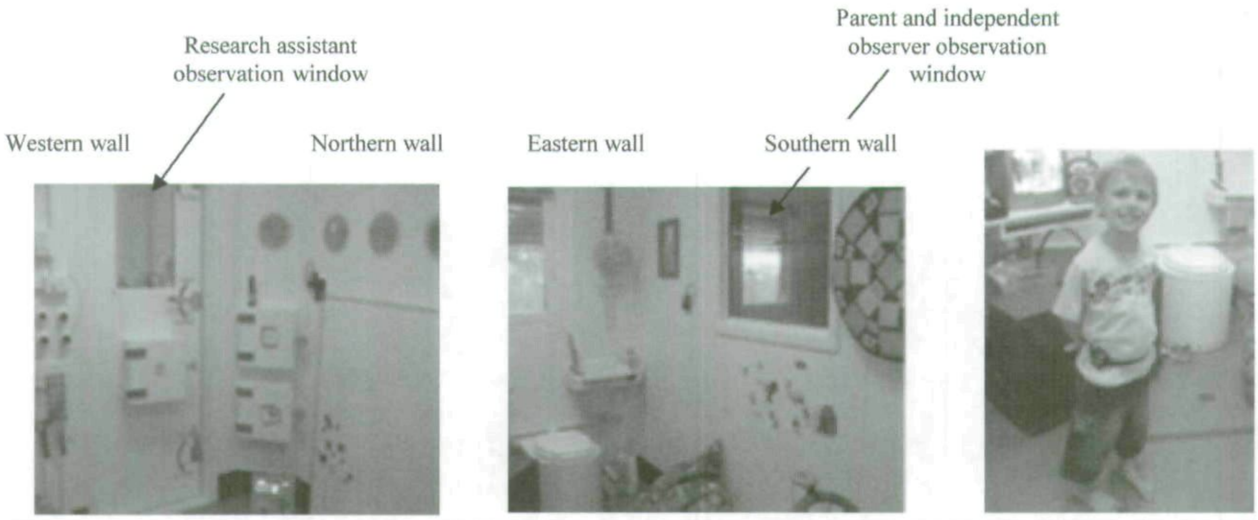

Figure 1 — Set up of the calorimeter.

Table 2 Energy Expenditure and Activity Counts During Physical Activity in the Room Calorimeter[a]

Activity category[b]	EE (Kcal·kg^{-1}min^{-1})	AEE (Kcal·kg^{-1}min^{-1})	ActiGraph (counts/min)[c]
N/A	0.036 ± 0.002	0	47 ± 10.25
Sedentary	0.038 ± 0.002	0.002 ± 0.003	183 ± 27.45
Light	0.046 ± 0.002	0.010 ± 0.003	503 ± 48.80
Moderate	0.072 ± 0.003	0.036 ± 0.004	1897 ± 143.96
Vigorous	0.068 ± 0.005	0.032 ± 0.006	2318 ± 292.30

Abbreviations: N/A, not available; EE, energy expenditure; AEE, activity energy expenditure; REE, resting energy expenditure.
[a] Data are presented as Mean ± SEM.
[b] See Table 1 for specific activities in each category.
[c] This value refers to the mean counts per minute over the entire 30 min period for the whole sample (mean of means).

Discussion

The current study found that it was feasible for young children to complete a 2.5 hr structured activity protocol in a room calorimeter. Further, adherence to the protocol was such that we were able to observe the expected differences in both AEE and accelerometer counts across 3 of the 4 intensities of activity specified in the protocol (Table 2). The major advantage of a room calorimeter is that it allows researchers to use activity protocols reflecting lifestyle activities of young children under controlled laboratory conditions.

The reason for the discrepancy between counts per minute (CPM) and EE/AEE from moderate to vigorous intensity activities is hard to explain. First, it may be that some of the moderate intensity activities (such as bouncing and catching a ball, eye toy games, throwing a ball, shooting a basketball) don't involve a large horizontal displacement of the hip but may still raise EE and AEE considerably. This would result in a lower CPM reading relative to EE and AEE. Second, some of the vigorous activities involve jumping which may overestimate the counts per minute in relation to AEE. For example, jumping challenges, dancing, and jumping in the circuit. This particularly may be the case in the calorimeter where it is not possible to move as freely from one place to another so most of the movement may be in a vertical plane.

Accelerometers have been validated for assessing physical activity in children under laboratory and field conditions.[4] It is recognized that the validation protocol needs to simulate the range of activities in which children typically engage. In the current study, a series of lifestyle activities were performed in the calorimeter. The activities reflected a broad range of gross and fine motor movements as well as the spontaneous, sporadic movements, characteristic of children. Although the activities were selected so they could be performed in the relatively small room, the children enthusiastically completed each one and it is likely that such movements were performed more naturally than if the children had been on a treadmill or wearing a portable calorimeter.[5,8,12,13]

The information booklet, given to the children several days before testing, was essential to properly prepare them for participation in the study. It helped create a balance between feeling relaxed and excited about the study. The familiarization visit to the calorimeter, and the adaptations made to the way the calorimeter was decorated, made the tasks and surroundings more predictable and attractive for the children, which simplified it for the researchers to explain the activities through the intercom. The children felt comfortable in the calorimeter and only one of them did not finish all of the protocol. This was due to the participant feeling fatigued from 2 of the vigorous activities (dancing and jumping) in the last part of the protocol.

Based on the results of this pilot study a suitable activity protocol for follow-up research would be to make the following adjustments: 1) to minimize the large variations in activity counts, further standardizing the way the musical instrument and eye toy activities are played and providing participants with longer time to familiarize themselves with these during the initial visit; and 2) complete the protocol over 2 visits with only the moderate/vigorous completed in the second visit.

Conclusion

Whole room indirect calorimetry has been an important method in the study of energy expenditure and physical activity in older children and adolescents, but has been considered to be impractical for use with younger children. The current study shows that young children can tolerate room calorimetry protocols if properly prepared, and if the calorimeter is adapted to make it more child-friendly. Although the sample size in this study was too small to cross-validate existing accelerometer prediction equations, it does enhance the possibility of room calorimetry as a practical method for young children, particularly for larger methodological studies such as the validation, cross-validation, and calibration of existing accelerometer prediction equations and cut-off points.

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