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Mirko Brandes, Berit Steenbock, Norman Wirsik

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Corresponding author
Mirko Brandes

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Energy Cost of Common Physical Activities in Preschoolers

Mirko Brandes, Berit Steenbock, and Norman Wirsik

Abstract:

Background: To determine the energy cost of common physical activities in preschoolers and to compare it with the Compendium of Energy Expenditure for Youth (CEEY). Methods: In total, 42 children [age: 4.8 (0.8) y; body mass index: 15.3 (2.0) kg/m2; 22 boys] completed 13 common physical activities covering sedentary to vigorous intensities, while energy expenditure (EE) was measured continuously by indirect calorimetry. Activity-specific metabolic equivalents (AME) were calculated as the EE observed during each single activity divided by the EE during observed rest. Independent *t* tests were applied to analyze differences between boys and girls and between AME and CEEY. Results: No significant differences in AME were observed between girls and boys. Except for playing hide-and-seek, all indoor activities revealed significantly higher energy costs compared with those stated in the compendium. Significant differences in outdoor activities were found for riding a tricycle [5.67 (95% confidence interval, 4.94–6.4) AME vs 6.2 metabolic equivalents, riding a bike, $P < .05$] and for fast walking [5.42 (95% confidence interval, 4.84–6.0) AME vs 4.6 metabolic equivalents, $P < .05$]. Conclusions: Applying the CEEY to preschoolers will lead to a substantial underestimation of EE. Therefore, we recommend that a CEEY for preschool children be developed if measurement of EE is not feasible.

Keywords: energy expenditure, free-play activities, indoor, outdoor

To effectively estimate energy expenditure (EE) of physical activity in children, Ridley et al[1] developed the Compendium of Energy Expenditure for Youth (CEEY). The compendium designates metabolic equivalents (METs) to a broad compilation of everyday activities performed by youth. METs are calculated as the metabolic rate observed for a specific activity divided by the resting metabolic rate. However, only 35% of the METs included in the CEEY are based on measured data in youth. Instead, the majority of MET values were adopted from the adults' compendium and expert opinions.[2,3] In addition, the fact that most of the previous research used highly structured protocols under laboratory settings limits the transfer of the results to free-living behaviors, as is shown by Nilsson et al.[4] Furthermore, the compendium addresses children and adolescents aged 6–18 years, and it is not clear to what extent the published METs can also be applied to preschoolers.[1]

Although some research has been done on predicting EE for different activities in preschoolers, it is, however, limited due to the use of direct observation (and again rigid estimates of METs) as the criterion measurement, as was done in recent calibration studies.[5,6] Therefore, the aim of our study was to measure EE of common physical activities in preschoolers by indirect calorimetry and to assign activity-specific metabolic equivalents (AME) to the physical activities. To this end, data originating from a calibration and validation study with different accelerometer devices and wear positions were used for a secondary analysis. By comparing our data with the CEEY, we aimed to provide a substantiated database for activity-related METs.

Methods

Study Participants and Design

To recruit 3- to 6-year-old children from 4 daycare facilities (kindergartens) in Lower Saxony, Germany, we first contacted the administration of the kindergartens, followed by informing the parents. During a prearranged meeting, we explained the aim and the procedures of the study to the administration as well as parent representatives. We then distributed study information material to all parents and demonstrated the indirect calorimetry to all children during morning circle time. Thereafter, the parents were asked to provide written informed consent. If the parents agreed, their children were allocated to a schedule. Each day, the children scheduled for measurement were approached and asked for verbal agreement. Only if the children agreed, they were included in the study. The final study population comprised 42 apparently healthy, white children aged 4.8 (0.8) years, with an average height of 115 (8) cm, weight of 20.2 (4.2) kg, and body mass index of 15.3 (2.0) kg/m2. Of the 42 children, 22 were boys. All children were able to speak and understand German. The measurements were conducted at the kindergarten using the available indoor and outdoor infrastructure. The children had to fast

for at least 2 hours before measurement, but they were allowed to drink water. The measurement was restricted to 2 children per morning to avoid interference with lunchtime. After assessing height and weight, we measured resting metabolic rate (RMR) during 10 minutes of supine rest in a quiet, dimly lit room. The children lay on a mattress and were provided with a blanket. They were shown a short learning story on a tablet to keep them calm during RMR measurement. We decided on a measurement period of 10 minutes as Borges et al[7] showed that this is an appropriate length of time to achieve steady-state conditions and delineate an optimum abbreviated period to estimate the RMR by indirect calorimetry. The local ethics committee of the Bremen University approved the procedures of the study.

Activities

After estimating RMR, the children performed up to 9 indoor and outdoor activities, starting with the indoor activities. Of the 9 activities, 5 covering light- to vigorous-intensity levels were predetermined by the study protocol (Table 1). The children were requested to add 4 more activities of their choice, only depending on the facilities available at their daycare center. Each activity was performed continuously for at least 3 minutes. If the child refused to perform the activity continuously due to tiredness or motivational reasons, the activity was stopped and excluded from the analysis. The child was then asked to continue with the next activity. The protocol was completely aborted if the child was exhausted or refused to go on. The total duration of the protocol was around 75 minutes for performing the 9 activities, mounting and demounting the devices, changing rooms within the kindergarten, and dressing and undressing for outdoor activities.

For the analysis, we only considered activities that occurred at least 8 times across all children. Table 2 provides an overview of the activities included in this study and the corresponding activities of the compendium included in the comparison. Where different intensity levels were identified in the compendium, the intensity level corresponding to the verbal comments of the researcher was chosen.

Outcome Measures

EE was assessed continuously using a portable, open-circuit indirect calorimetry system (MetaMax 3B; CORTEX Biophysik GmbH, Leipzig, Germany). The system was attached to the children using a pediatric harness. In very lean and small children, adhesive tape was used to help adjust the fit of the harness so that the system would not interfere with the activities. A face mask was secured over the child's nose and mouth using an adjustable nylon harness. A bidirectional turbine, inserted to the face mask, measured the volume of inspired and expired air. A sample tube, connected to the turbine, retrieved expired air samples breath by breath. Air samples were analyzed for oxygen uptake and carbon dioxide production within the sensor

unit of the system. Stable and dry weather conditions enabled sound outdoor measurements. The respective data were transferred to a laptop via telemetry and were available in real time (MetaSoft 3; CORTEX Biophysik GmbH).

The laptop operator used the marker function of the software to identify the beginning and the end of each activity. Each morning, the indirect calorimetry system was calibrated according to the procedure recommended by the manufacturer. The MetaMax 3B has proven at least acceptable validity and reliability in studies with healthy adults,[8] as well as high comparability to other common devices.[9] A 3-point rolling median was applied to erase measurement outliers. RMR was calculated as the minimum of a rolling 1-minute mean during supine rest. To correct for a possible delay between quitting the activity and adding a marker to the software, the last 15 seconds of all 9 activities were cutoff. EE was then calculated as the mean over the last 60 seconds. This time period was chosen based on the assumption that all children reached steady-state conditions after 2 minutes of the specific activity.[10,11] VO_2 was converted to EE (kilocalories per minute) using the equations by Weir.[12] Finally, AME was calculated by dividing the EE observed for each specific activity by the EE measured during supine rest (RMR).

Statistical Analysis

All data are expressed as means with their 95% confidence interval (CI). Differences between boys and girls were analyzed with a 2-sided independent *t* test. One-sample *t* tests were computed to compare computed AME and METs from the CEEY. The significance level was set at $\alpha = .05$.

Results

Twelve different activities that occurred at least 8 times across all children were included in the statistical analysis. Activities such as “seesaw,” “rotary table,” and “digging” were done by less than 5 children and were hence excluded from the analysis. The included activities enabled their differentiation into light- to vigorous-intensity activities quite well, with the lowest AME being observed in drawing [mean (95% CI): 1.89 (1.7–2.1)], a moderate AME in playing with cars [3.1 (2.5–3.6)] and walking [3.6 (3.3–4.0)], and the most vigorous AME in jogging [7.7 (6.7–8.7)]. Similar trends were observed for VO_2 and EE (Table 2).

Significant differences between AME and METs from the compendium were observed for all indoor activities, as well as for the outdoor activities such as “tricycle” and “fast walking” (Table 3). In most activities, AME exceeded compendium METs, except for the activities “hide-and-seek” and “tricycle” (Figure 1). The most prominent difference for indoor activities was found for the activity “cars” (3.05 AME vs 1.6 MET, $P < .05$), and the most prominent difference for

outdoor activities was found for the activity “fast walking” (5.42 AME vs 4.6 MET, $P < .05$). No significant differences between boys and girls were found for any of the evaluated AME.

Discussion

To our knowledge, this is the first study to not only measure energy costs of common activities in preschoolers by indirect calorimetry, expressed in AMEs, but also compare them with the METs given in the CEEY.[1] Noteworthy, we found statistically and clinically significant differences for all indoor activities. For all indoor activities except for “hide-and-seek,” higher AMEs were observed when compared with the compendium, for example, energy costs for playing with “toy cars” were almost double the value stated in the compendium (3.05 AME vs 1.6 METs). The phenomenon persisted when the activities “building,” “toy cars,” and “dolls” were merged into a single activity, as is done within the compendium.

In line with the findings of a previous study by Mackintosh et al,[13] we also observed significant differences between the preschoolers and the compendium during fast walking (5.42 AME vs 4.6 METs).[13] Although Mackintosh et al[13] included children aged 11.4 (0.3) years, an older population compared with our study population, their results do indicate that the energy cost of fast walking is underestimated in the compendium. This could then be even more pronounced in preschool children, as suggested by our data.

Regarding toy play, tricycle riding, and walking, the EE observed in our study compares well to the findings of Grossek et al,[14] who investigated these activities in 11 children aged 3–6 years. Furthermore, the “tag” activity in our study revealed a similar EE as seen in the “running and soccer” task measured by Byun et al[15] in 28 preschool children. Unfortunately, Byun et al[15] merged the activities playing with blocks, cars, and dolls into one single category. Considering our findings, we found less EE in playing with blocks, but comparable EE in playing with cars and dolls.

Some studies on EE of preschool children have been performed using a whole-room calorimeter. The practical use and reliability of whole-room calorimetry have been demonstrated by Janssen et al.[16] Compared with our findings, oxygen consumption and METs were slightly lower for sedentary behaviors (e.g., in sitting and playing with dolls on the floor).[17,18] We hypothesize that this difference is mainly driven by the limited space and the absence of any interactions with other children in a room calorimeter. Thus, we assume that children consume slightly more energy while playing in their regular environment than in an isolated, artificial area, such as a room calorimeter.

Because some activities, such as “swinging” and “tricycling,” are not listed in the compendium, a similar corresponding activity had to be chosen. For swinging, the corresponding activity was

“playground equipment—light effort” with comparable METs given in the compendium. For tricycling, the most similar activity in the compendium was “riding a bicycle” with moderate effort. The significantly lower energy cost we observed for tricycling compared with that given for riding a bicycle is possibly due to the differences in the physical demands of operating a tricycle. This includes the direct transfer of the muscle power to the front wheel, a lower sitting position and, presumably, a lower velocity.

A recent study addressed the accuracy of a threshold of 1.5 or 2.0 METs to classify children’s activity as sedentary.[19] Pate et al[20] define sedentary behavior as mainly screen-based entertainment (such as watching TV). To distinguish it from light physical activity, they also include activities such as sitting and writing in their definition.[20] The MET of 1.89 (95% CI, 1.70–2.10) we observed for “drawing” in our study therefore supports the setting of a threshold of 1.5 AME for discriminating between sedentary behavior and light physical activity. Further evidence for this threshold is provided by studies using direct (room) calorimetry, such as Janssen et al.[21]

Some limitations of the current study have to be addressed. Unfortunately, we were not able to capture the velocities of the walking tasks, jogging, and tricycling, so we have no descriptive data to compare these activities to other studies. However, as these activities were self-paced, they should be within the range of common velocities of other studies. The fact that the activities lasted at least 3 minutes also prevented very high velocities. In principle, the children could have stopped their activities before the 3 minutes, but the researcher requested them to carry on for at least 3 minutes, so that steady-state conditions could be reached. Hence, the presence of the researcher could have influenced the pace as well as the motivation of the children, and thus the observed energy values. However, we believe that the impact, if any, was minor and affected only the brisk walking, when the researchers had to ensure a higher intensity of the 3-minute period. Furthermore, our study sample only included apparently healthy, white children. Therefore, our findings cannot be generalized to other ethnicities or to children with a chronic condition or disease.

A crucial part of indirect calorimetry remains the measurement of RMR in this very young age group. Several protocols exist, ranging from 10 minutes[22] to 20 minutes.[23] In most cases, the measurement period is truncated, leaving 5–9 minutes of data for calculating RMR.[13,22,23] In our particular study, we have chosen a 10-minute period to minimize the time for keeping the children still and the overall protocol as short as possible. This could potentially lead to a slight overestimation of RMR. Thus, the observed differences in our study may even be slightly larger, except for hide-and-seek. Other studies utilize estimates of RMR, for example, using the Schofield equations.[24] To compare findings from different studies and the absence of RMR measurements in the studies included, McMurray et al[25] referred to Schofield in their

exploration of metrics to express EE in youth as well. To enable a conversion, we provide a table with METs based on Schofield basal metabolic rate (BMR) estimations (Online Supplementary Material 1) as well as the raw data to apply any estimate of RMR and calculations of METs (Online Supplementary Material 2).

Given the differences observed between the measured AMEs in our study and the METs from the compendium, we recommend that a specific compendium for preschool children be developed. Simply extending the compendium for youth to incorporate preschoolers is not practicable as some of the activities included in the compendium for youth are not applicable for preschoolers. Similarly, some activities for preschoolers are not relevant for school-aged children. Furthermore, energy costs calculated based on the compendium would always have to be adapted for preschoolers.

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Tables and figures

Table 1 Overview, Order, and Duration of the Study Procedures

Activity/task	Time, min
Welcoming the child, changing to side room for preparation and RMR measurement	3
Mounting devices (oxygen analyzer and accelerometers) and preparing RMR measurement	12
RMR measurement	10
Finishing RMR measurement and changing room for indoor activities	2
Drawing	5
Break/transition	1
Free choice activity indoors no.1, such as building	3
Break/transition	1
Free choice activity indoors no. 2, such as playing with cars	3
Preparing and dressing for outdoor activities	5
Tag	3
Free choice activity outdoors no. 1, such as tricycling	3
Break/transition	1
Free choice activity outdoors no. 2, such as climbing	3
Break/transition	1
Regular walking	3
Break	1
Fast walking	3
Break	1
Jogging	3
Undressing, demounting devices, saying goodbye, and returning to group room/breakfast	8
Total	75

Abbreviation: RMR, resting metabolic rate.

Table 2 Overview of Indoor and Outdoor Activities

Indoor activities	Outdoor activities
Drawing[a] (n = 41) The child sat down at a table in the group room and chose 1 out of 5 coloring pages with different motifs. (420010, drawing—sitting)	Tag[a] (n = 35) The child chose 2 or 3 friends. The catcher tried to tick one of the runners, if so the former runner becomes the new catcher. A well-defined and plain area was chosen. (342773, playing catch—hard effort)
Building (n = 29) The child moved kneeling and played with toy blocks. (321920, playing with toys/Lego/dolls)	Tricycle (n = 23) The child operated a tricycle on a firm ground, usually made of promenade tiles. (341242, riding a bicycle—moderate effort)
Hide-and-seek (n = 19) The child chose 1 or 2 friends and played hide-and-seek in the group room. (342830, hide-and-seek)	Climbing (n = 23) The child utilized climbing frames, monkey bars, etc, at the playground of the kindergarten. (341902, playground equipment—moderate effort)
Playing with cars (n = 17) The child kneed and scrambled on the ground floor and played with toy cars. (321920, playing with toys/Lego/dolls)	Swinging (n = 8) The child operated the swing at the playground on its own, no pushing, etc, was provided. (341901, playground equipment—light effort)
Playing with dolls (n = 8) The child played with 1 or 2 friends. The children were free to utilize a dollhouse or to play on the floor. (321920, playing with toys/Lego/dolls)	Walking, regular[a] (n = 38) The child walked around the playground with his or her friends and the researcher at his or her own preferred speed. (240052, walking—moderate effort)
	Walking, fast[a] (n = 31) The researcher requested the child to walk fast. The researcher encouraged the child by telling an imaginary journey of a holiday trip, including catching the tram, train, and plane to get to the holiday location. (240053, walking—hard effort)
	Jogging[a] (n = 11) The researcher requested the child to jog together with him or her around on a firm ground at the kindergarten. (341482, running/jogging—moderate effort)

Note. (code, activity) = corresponding code and activity of the Compendium of Energy Expenditure for Youth.[1]
[a]Predetermined activity.

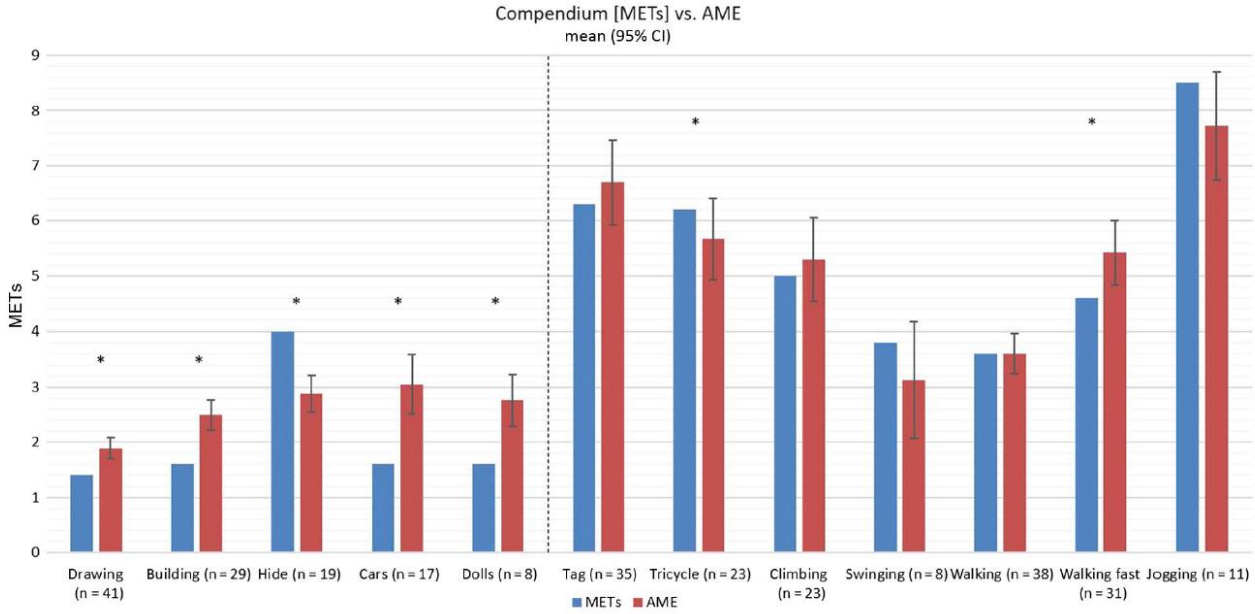
Table 3 VO2, EE, and AME Compared With METs from the Compendium of Energy Expenditure for Youth[1]

	VO_2, mL/min/kg	EE, kJ/min	AME	MET
Indoor activities, mean (95% CI)				
Drawing (n = 41)				
Combined	9.9 (9.2–10.6)	1.8 (1.6–2.1)	1.89 (1.70–2.10)*	1.4
Girls (n = 20)	9.6 (8.6–10.7)	2.0 (1.5–2.4)		
Boys (n = 21)	10.1 (9.2–11.1)	1.7 (1.3–2.1)		
Building (n = 29)				
Combined	12.8 (11.7–14.0)	3.1 (2.7–3.6)	2.50 (2.22–2.77)*	1.6
Girls (n = 14)	12.3 (10.7–14.0)	3.2 (2.5–3.9)		
Boys (n = 15)	13.3 (11.6–15.0)	3.1 (2.4–3.7)		
Hide-and-seek (n = 19)				
Combined	15.2 (13.7–16.7)	4.2 (3.6–4.8)	2.89 (2.56–3.22)*	4.0
Girls (n = 10)	15.0 (12.9–17.1)	4.5 (3.4–5.5)		
Boys (n = 9)	15.5 (13.7–17.3)	3.9 (3.1–4.8)		
Cars (n = 17)				
Combined	15.4 (14.0–16.8)	4.2 (3.5–4.9)	3.05 (2.52–3.58)*	1.6
Girls (n = 5)	15.2 (12.1–18.4)	4.8 (3.1–6.4)		
Boys (n = 12)	15.5 (12.8–18.2)	4.0 (3.2–4.8)		
Dolls (n = 8)				
Combined	14.8 (11.3–18.4)	4.3 (3.1–5.5)	2.76 (2.28–3.23)*	1.6
Girls (n = 6)	15.0 (9.7–20.2)	4.5 (2.8–6.2)		
Boys (n = 2)	14.5 (1.0–28.0)	3.7 (3.4–4.0)		
Outdoor activities, mean (95% CI)				
Tag (n = 35)				
Combined	34.5 (31.9–37.1)	13.8 (12.3–15.4)	6.69 (5.92–7.46)	6.3
Girls (n = 17)	33.5 (29.4–37.6)	13.8 (11.6–16.1)		
Boys (n = 18)	35.4 (31.7–39.1)	13.9 (11.5–16.2)		
Tricycle (n = 23)				
Combined	29.7 (27.1–32.2)	10.9 (9.3–12.5)	5.67 (4.94–6.40)*	6.2
Girls (n = 11)	27.5 (23.8–31.3)	10.1 (7.5–12.8)		
Boys (n = 12)	31.6 (28.0–35.3)	11.6 (9.3–13.8)		
Climbing (n = 23)				
Combined	25.6 (23.8–27.3)	9.4 (8.1–10.7)	5.29 (4.53–6.06)	5.0
Girls (n = 7)	24.2 (20.3–28.2)	9.9 (6.3–13.6)		
Boys (n = 16)	26.1 (24.0–28.3)	9.2 (7.7–10.6)		
Swinging (n = 8)				
Combined	18.2 (11.2–25.1)	5.2 (2.8–7.7)	3.12 (2.08–4.17)	3.8
Girls (n = 3)	14.1 (1.0–30.6)	4.6 (1.4–7.9)		
Boys (n = 5)	20.6 (9.5–31.7)	5.6 (1.1–10.2)		
Walking (n = 38)				
Combined	19.1 (17.4–20.8)	5.9 (5.2–6.6)	3.61 (3.25–3.97)	3.6
Girls (n = 17)	16.6 (13.9–19.3)	5.3 (4.2–6.4)		
Boys (n = 21)	21.1 (19.1–23.0)	6.4 (5.4–7.3)		
Walking fast (n = 31)				
Combined	27.5 (25.0–30.0)	10.1 (8.9–11.3)	5.42 (4.84–6.00)*	4.6
Girls (n = 12)	25.5 (21.7–29.3)	10.2 (8.0–12.3)		
Boys (n = 19)	28.8 (25.4–32.2)	10.0 (8.4–11.6)		
Jogging (n = 11)				
Combined	38.9 (33.0–44.8)	14.5 (12.9–16.0)	7.72 (6.74–8.70)	8.5
Girls (n = 4)	33.1 (13.7–52.4)	15.1 (9.4–20.7)		
Boys (n = 7)	42.2 (38.1–46.3)	14.1 (12.8–15.4)		

Abbreviations: AME, activity-specific metabolic equivalent; CI, confidence interval; EE, energy expenditure; MET, metabolic equivalent.

*$P < .05$ between AME and MET.

Figure 1 – Comparison of METs from the Compendium of Energy Expenditure for Youth[1] and AME of preschoolers.



Dashed line discriminates indoor (left) and outdoor activities (right). AME indicates activity-specific metabolic equivalent; CI, confidence interval; MET, metabolic equivalent.
*$P < .05$.