Youth Energy Expenditure During Common Free-Living Activities and Treadmill Walking

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Background: Energy expenditure (EE) estimates for a broad age range of youth performing a variety of activities are needed. **Methods:** 106 participants (6–18 years) completed 6 free-living activities (seated rest, movie watching, coloring, stair climbing, basketball dribbling, jumping jacks) and up to 9 treadmill walking bouts (13.4 to 120.7 m/min; 13.4 m/min increments). Breath-by-breath oxygen uptake (VO_2) was measured using the COSMED K4b² and EE was quantified as youth metabolic equivalents ($\text{MET}_{y1}:\text{VO}_2/\text{measured resting } \text{VO}_2$, $\text{MET}_{y2}:\text{VO}_2/\text{estimated resting } \text{VO}_2$). Age trends were evaluated with ANOVA. **Results:** Seated movie watching produced the lowest mean MET_{y1} (6- to 9-year-olds: 0.94 ± 0.13) and MET_{y2} values (13- to 15-year-olds: 1.10 ± 0.19), and jumping jacks produced the highest mean MET_{y1} (13- to 15-year-olds: 6.89 ± 1.47) and MET_{y2} values (16- to 18-year-olds: 8.61 ± 2.03). Significant age-related variability in MET_{y1} and MET_{y2} were noted for 8 and 2 of the 15 evaluated activities, respectively. **Conclusions:** Descriptive EE data presented herein will augment the *Youth Compendium of Physical Activities*.

Keywords: sedentary behavior, public health, physical activity, epidemiology

Over 20 years have passed since the introduction of the Compendium of Physical Activities, and the original publication,¹ in conjunction with subsequent updates,^{2,3} have collectively received more than 5000 citations (Web of Science, accessed December 16, 2015). The compendium provides standardized estimates of energy expenditure (EE) across a broad array of activities, represented in absolute terms as metabolic equivalents (METs). MET values contained within the compendium are applicable to adult populations and typically used to describe the metabolic cost of self-reported behaviors in epidemiological research.^{1–3}

More recently, a youth compendium (now referred to as the *Youth Compendium of Physical Activities*) was introduced to catalog EE estimates for children and adolescents.⁴ At present, there remains a need to expand the assembled activities and age ranges represented within the *Youth Compendium of Physical Activities*. Therefore, the primary purpose of this study was to provide descriptive data of measured EE in children and adolescents during common free-living activities and treadmill walking. We also examined the age independence of several candidate EE metrics across the completed activities.

Methods

Participants

A convenience sample of 106 children and adolescents (6–18 years) from Louisiana participated in the study. Participants were

recruited using e-mail advertisements, health fair presentations, and via word-of-mouth. The Pennington Biomedical Research Center Institutional Review Board approved all study protocols. Before participation, informed parental consent and assent were obtained for 6- to 17-year-old participants, and informed consent was obtained for 18-year-old participants. The study was prospectively registered at ClinicalTrials.gov before enrollment began (NCT01989104).

Activities

Participants completed laboratory-based free-living activities and ambulatory treadmill bouts while oxygen uptake (VO_2) was measured. A 4-hour fast (no food or caloric/cafeinated beverages) was required and a 10-minute seated washout period preceded the protocol. Participants then completed 3 seated activities by resting motionless, watching a movie, and coloring in a book. A series of up to 10 ambulatory treadmill bouts (0% grade) followed the seated activities, beginning at 13.4 m/min (0.80 km/h) and increasing in 13.4 m/min increments to a maximum of 134.1 m/min (8.05 km/h). Treadmill testing was terminated following the bout when the participant naturally began running. Participants then completed simulated stair climbing (stepping up-and-down on a 19.69 cm step at 88 bpm), basketball dribbling while ambulating at a self-selected speed (continuous movement around a 12 m course), and jumping jacks (126 bpm). Each activity lasted 5 minutes and was preceded by a 2-minute washout period, except for the transition following the final treadmill bout where a 5-minute washout period was given to ensure VO_2 returned close to resting values before completing the remaining activities.

Measures

Weight and body fat percentage were measured to the nearest 0.1 kg and 0.1%, respectively, using an integrated scale and bioelectrical impedance analyzer (Tanita SC-240; Tanita, Tokyo, Japan). Height was measured shoeless to the nearest 0.1 cm using a stadiometer

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(Harpden; Holtain, Crosswell, United Kingdom). Body mass index (BMI) was calculated by dividing weight by height squared (kg/m^2). Reference data from the Centers for Disease Control and Prevention were used to calculate BMI percentiles.⁵

Respiratory gas concentrations and flow volumes were measured during all activities using the portable COSMED K4b² (COSMED, Rome, Italy). A silicone face mask directed respiratory gases through an external housing where breath-by-breath gas sampling and turbine-based flow volume measurements were taken. Before each testing session, the K4b² was calibrated according to the manufacturer's instructions. Measurements from the K4b² were transmitted wirelessly and saved to a laptop computer.

Recorded breaths within each minute were averaged to yield a minute-by-minute data file. Absolute and mass-specific VO_2 (L/min and $\text{ml}/\text{kg}/\text{min}$, respectively) were calculated. We also computed youth METs (mass-specific VO_2 / resting mass-specific VO_2) as this metric has been shown to provide balance in attenuating the age- and sex-dependence of youth EE estimates across a range of activities.⁶ Youth METs were derived in 2 forms: 1) MET_{y1} : (mass-specific VO_2 / measured resting mass-specific VO_2) and, 2) MET_{y2} : (mass-specific VO_2 / estimated resting mass-specific VO_2). Measured resting VO_2 corresponded to the seated rest testing phase while estimated resting VO_2 was calculated using the Schofield equation (resting EE converted to mass-specific VO_2).⁷ The average value from minutes 4 and 5 of each activity was used for analysis. For all seated activities, average values from minutes 4 and 5 were considered steady-state. Steady-state ascertainment among the remaining activities were evaluated by inspecting the variability of breath-by-breath data from minutes 4 and 5. Minutes with mean absolute VO_2 variability < 10% were deemed steady-state. As treadmill walking was one of the specific foci of this study, we eliminated data from treadmill bouts where running occurred.

Data Analyses

Descriptive statistics were computed to characterize the sample. For each activity, differences in metabolic measures between 4 age categories (6–9, 10–12, 13–15, and 16–18 years) were evaluated using one-way ANOVA. Follow-up pairwise comparisons were conducted using the Tukey-Kramer method. All analyses were performed using R (version 3.2.2). Due to the large number of

hypothesis tests conducted, we conservatively defined statistical significance as $P < .001$.

Results

Of the 1696 possible activity bouts [(106 participants $\times$ 6 free-living activities) + (106 participants $\times$ 10 treadmill bouts)], we excluded 316 treadmill bouts (participant began running or bout was not completed), 18 active free-living bouts (bout was not completed), and 1 bout during seated rest (K4b² malfunction). Of the remaining 1361 bouts, we further excluded data from 152 bouts not meeting our predetermined steady-state criteria. In all, the remaining 1209 bouts available for analysis represented 88.9% of the original non-missing observations.

Descriptive characteristics are presented in Table 1. The mean age was 12.0 ± 3.7 years and 58.5%, 15.1%, and 26.4% of the sample were nonoverweight (BMI < 85th percentile), overweight (85th percentile $\leq$ BMI < 95th percentile), or obese (BMI $\geq$ 95th percentile), respectively. The sample was racially/ethnically heterogeneous as 37.7%, 59.4%, and 2.8% identified as African-American, Caucasian, or other race/ethnicity, respectively. The sample's BMI and race/ethnic characteristics were roughly comparable to previously published state-level estimates in Louisiana (2- to 19-year-old obesity prevalence: 29.0%; race/ethnic distribution—African-American: 32.3%, Caucasian: 64.0%, other race/ethnicity: 3.7%).^{8,9}

Age-group stratified mean values of absolute VO_2 , mass-specific VO_2 , MET_{y1} , and MET_{y2} during the 6 free-living activities are presented in Table 2. Significant age-related differences in absolute VO_2 were observed for all activities, except seated rest and coloring, as age tended to be positively associated with absolute VO_2 . Mass-specific VO_2 also significantly differed across age groups for most of the free-living activities, with the exception of jumping jacks; however, age was inversely associated with mass-specific VO_2 . Less variability in MET_{y1} and MET_{y2} values was observed as significant age-related differences were only noted for stair climbing and jumping jacks with MET_{y1} and seated rest and coloring with MET_{y2} . Age was positively associated with MET_{y1} values among those free-living activities with noted significant differences; however, there did not appear to be any consistent relationship between age and MET_{y2} values across the tested free-living activities.

Table 1 Descriptive Characteristics

Stratification	n	Age (years)	Weight (kg)	Height (cm)	BMI (kg/m^2)	BMI percentile	Percent body fat
Total	106	12.0 ± 3.7	53.8 ± 22.6	152.8 ± 16.6	22.2 ± 6.5	67.2 ± 30.4	25.3 ± 11.0
Boys	53	12.0 ± 3.7	54.4 ± 22.3	154.5 ± 18.5	22.0 ± 5.9	66.9 ± 32.0	22.4 ± 11.2
Girls	53	12.1 ± 3.6	53.2 ± 23.0	151.1 ± 14.5	22.5 ± 7.1	67.5 ± 29.0	28.1 ± 10.0
6–9 y	32 (16B, 16G)	7.6 ± 1.1	34.5 ± 13.1	132.9 ± 8.7	19.2 ± 5.3	66.4 ± 32.7	24.7 ± 9.8
10–12 y	25 (13B, 12G)	11.0 ± 0.8	48.9 ± 12.6	152.0 ± 8.1	21.1 ± 4.7	67.8 ± 31.0	24.7 ± 9.2
13–15 y	26 (12B, 14G)	14.0 ± 0.8	68.0 ± 17.6	163.6 ± 8.6	25.3 ± 5.8	78.7 ± 21.2	29.3 ± 10.7
16–18 y	23 (12B, 11G)	17.0 ± 0.9	69.7 ± 24.4	169.0 ± 8.2	24.4 ± 8.3	54.6 ± 31.8	22.2 ± 13.6
African-American	40 (21B, 19G)	11.7 ± 3.7	56.2 ± 24.6	152.0 ± 16.0	23.5 ± 7.2	76.0 ± 26.7	28.1 ± 11.4
Caucasian	63 (30B, 33G)	12.3 ± 3.7	52.7 ± 21.3	153.5 ± 17.0	21.7 ± 6.0	61.8 ± 32.0	23.6 ± 10.6
Other	3 (2B, 1G)	10.3 ± 3.5	41.8 ± 20.6	147.3 ± 21.5	18.4 ± 3.3	63.4 ± 17.0	21.5 ± 6.2

Note. Values presented as counts and Mean $\pm$ SD. BMI percentiles for each participant were calculated using reference data from the Centers for Disease Control and Prevention growth charts.

Abbreviations: BMI, body mass index.

Table 2 Oxygen Uptake (VO₂) and Youth METs During Common Free-Living Activities

Activity	n	Absolute VO ₂ (L/min)	Min-Max	Mass-specific VO ₂ (ml/kg/min)	Min-Max	MET _{y1}	Min-Max	MET _{y1}	Min-Max
Seated rest									
6–9 y	31	0.24 ± 0.04	0.17–0.33	7.55 ± 1.87 ^a	3.60–10.82	1	–	1.43 ± 0.25 ^a	0.97–1.88
10–12 y	25	0.26 ± 0.05	0.19–0.40	5.63 ± 1.45 ^b	3.57–8.71	1	–	1.33 ± 0.25 ^{ab}	0.88–1.92
13–15 y	26	0.27 ± 0.04	0.17–0.36	4.22 ± 1.17 ^b	2.29–6.53	1	–	1.16 ± 0.22 ^b	0.77–1.54
16–18 y	23	0.29 ± 0.06	0.19–0.40	4.34 ± 1.00 ^b	1.90–6.08	1	–	1.22 ± 0.21 ^{ab}	0.75–1.56
Movie watching									
6–9 y	32 [†]	0.22 ± 0.04 ^a	0.15–0.29	7.08 ± 2.00 ^a	2.76–10.94	0.94 ± 0.13	0.60–1.37	1.34 ± 0.27	0.63–1.97
10–12 y	25	0.25 ± 0.04 ^{ab}	0.17–0.35	5.39 ± 1.38 ^b	3.60–7.78	0.96 ± 0.10	0.70–1.15	1.28 ± 0.25	0.89–1.75
13–15 y	26	0.26 ± 0.05 ^{ab}	0.19–0.36	4.00 ± 1.10 ^b	2.22–6.89	0.96 ± 0.10	0.74–1.20	1.10 ± 0.19	0.79–1.62
16–18 y	23	0.28 ± 0.04 ^b	0.21–0.37	4.27 ± 1.03 ^b	1.88–5.72	0.99 ± 0.13	0.72–1.25	1.20 ± 0.22	0.74–1.60
Coloring									
6–9 y	32 [†]	0.28 ± 0.06	0.18–0.40	8.70 ± 2.37 ^a	3.10–14.40	1.17 ± 0.20	0.68–1.60	1.66 ± 0.34 ^a	0.71–2.36
10–12 y	25	0.31 ± 0.06	0.22–0.41	6.56 ± 1.83 ^b	4.56–10.81	1.17 ± 0.16	0.91–1.49	1.55 ± 0.34 ^{ab}	1.14–2.45
13–15 y	26	0.31 ± 0.06	0.25–0.50	4.83 ± 1.12 ^b	2.64–7.84	1.17 ± 0.18	0.87–1.62	1.33 ± 0.20 ^b	0.94–1.85
16–18 y	23	0.34 ± 0.07	0.23–0.50	5.21 ± 1.25 ^b	2.17–7.02	1.21 ± 0.18	0.90–1.58	1.47 ± 0.30 ^{ab}	0.85–1.99
Stair climbing									
6–9 y	27 [†]	0.77 ± 0.15 ^a	0.50–1.02	23.41 ± 4.00 ^a	17.56–34.78	3.20 ± 0.57 ^a	2.29–4.18	4.51 ± 0.56	3.53–5.70
10–12 y	24	1.02 ± 0.24 ^{ab}	0.39–1.53	21.46 ± 4.56 ^{ab}	10.00–29.47	3.91 ± 0.86 ^{ab}	2.09–5.70	5.11 ± 0.97	2.32–6.91
13–15 y	25	1.28 ± 0.33 ^b	0.67–2.35	18.79 ± 2.99 ^b	13.63–25.50	4.75 ± 1.02 ^b	2.32–6.59	5.29 ± 0.78	3.26–7.00
16–18 y	22	1.22 ± 0.35 ^b	0.71–2.5	18.58 ± 2.74 ^b	13.12–25.44	4.29 ± 0.90 ^b	2.96–6.32	5.22 ± 0.78	3.17–7.21
Basketball									
6–9 y	29 [†]	0.87 ± 0.19 ^a	0.46–1.17	27.06 ± 5.44 ^a	17.81–39.54	3.67 ± 0.71	2.46–5.06	5.16 ± 0.84	3.78–6.99
10–12 y	22	1.05 ± 0.20 ^{ab}	0.69–1.58	22.17 ± 4.40 ^{ab}	15.34–30.74	3.99 ± 0.71	2.80–5.48	5.28 ± 0.83	3.82–6.89
13–15 y	25	1.12 ± 0.23 ^b	0.71–1.91	17.13 ± 3.97 ^{bc}	11.61–24.66	4.09 ± 0.79	2.49–5.95	4.70 ± 0.77	3.51–6.10
16–18 y	19	1.03 ± 0.27 ^{ab}	0.60–1.83	15.78 ± 3.26 ^c	9.78–21.49	3.54 ± 0.69	2.57–4.97	4.41 ± 0.80	3.04–6.11
Jumping jacks									
6–9 y	18	1.08 ± 0.24 ^a	0.64–1.50	34.81 ± 8.12	25.91–55.62	4.60 ± 0.90 ^a	3.03–6.12	6.56 ± 1.18	4.68–9.66
10–12 y	16	1.53 ± 0.38 ^{ab}	0.97–2.48	33.72 ± 7.65	20.31–48.93	5.69 ± 1.40 ^{ab}	3.39–9.19	7.71 ± 1.46	5.06–10.80
13–15 y	15	1.93 ± 0.48 ^b	1.23–3.05	30.19 ± 8.25	18.97–48.39	6.89 ± 1.47 ^b	4.33–9.08	8.23 ± 1.71	5.92–11.70
16–18 y	18	1.94 ± 0.61 ^b	1.15–3.69	31.13 ± 8.79	18.98–52.04	6.82 ± 1.61 ^b	4.77–11.12	8.61 ± 2.03	5.12–13.89

Note. Values presented as Mean ± SD. MET_{y1} = youth metabolic equivalents calculated as mass-specific VO₂ divided by measured resting mass-specific VO₂. MET_{y2} = youth metabolic equivalents calculated as mass-specific VO₂ divided by estimated resting mass-specific VO₂ (using the Schofield equation). Estimated mean resting mass-specific VO₂ values for ages 6–9, 10–12, 13–15, and 16–18 years were 5.19 ± 0.67, 4.20 ± 0.51, 3.60 ± 0.44, and 3.53 ± 0.43 ml/kg/min, respectively. Mean values within each activity and across age groups with different superscript letters are significantly different at *P* < .001.

[†] Sample size is reduced by 1 participant for MET_{y1} data due to missing measured resting VO₂.

Table 3 Oxygen Uptake (VO₂) and Youth METs During Treadmill Walking

Treadmill Speed	n	Absolute VO ₂ (L/min)	Min-Max	Mass-specific VO ₂ (ml/kg/min)	Min-Max	MET _{yl}	Min-Max	MET _{yl}	Min-Max
13.4 m/min									
6–9 y	19	0.40 ± 0.11 ^a	0.27–0.70	12.54 ± 2.55 ^a	8.26–17.58	1.62 ± 0.28	1.18–2.30	2.38 ± 0.33	1.88–3.05
10–12 y	18	0.48 ± 0.08 ^{ab}	0.39–0.68	10.25 ± 2.06 ^{ab}	7.25–14.07	1.86 ± 0.25	1.61–2.63	2.43 ± 0.35	1.80–3.13
13–15 y	23	0.52 ± 0.13 ^{ab}	0.26–0.91	7.96 ± 1.65 ^b	3.72–10.14	1.96 ± 0.34	1.31–2.55	2.19 ± 0.37	1.15–2.78
16–18 y	17	0.56 ± 0.14 ^b	0.35–0.95	8.46 ± 1.19 ^b	6.28–10.64	1.94 ± 0.37	1.34–2.77	2.38 ± 0.29	1.89–3.05
26.8 m/min									
6–9 y	27 [†]	0.45 ± 0.12 ^a	0.28–0.86	13.76 ± 2.73 ^a	8.11–18.55	1.85 ± 0.34 ^a	1.25–2.82	2.62 ± 0.37	1.85–3.48
10–12 y	19	0.56 ± 0.10 ^{ab}	0.42–0.82	11.45 ± 2.23 ^{ab}	8.23–15.84	2.13 ± 0.31 ^{ab}	1.66–2.97	2.77 ± 0.40	2.05–3.52
13–15 y	23	0.62 ± 0.14 ^b	0.44–1.10	9.48 ± 1.56 ^b	6.20–12.25	2.27 ± 0.38 ^{ab}	1.52–3.07	2.58 ± 0.30	1.99–3.27
16–18 y	20	0.66 ± 0.16 ^b	0.39–1.09	9.60 ± 1.89 ^b	6.16–12.52	2.32 ± 0.50 ^b	1.54–3.33	2.72 ± 0.42	2.12–3.55
40.2 m/min									
6–9 y	22 [†]	0.52 ± 0.14 ^a	0.34–0.96	15.12 ± 2.58 ^a	10.17–19.23	2.09 ± 0.37 ^a	1.36–3.13	2.94 ± 0.32	2.32–3.73
10–12 y	17	0.63 ± 0.12 ^{ab}	0.46–0.92	12.49 ± 1.99 ^{ab}	9.55–15.78	2.33 ± 0.34 ^{ab}	1.79–3.08	3.08 ± 0.36	2.38–3.72
13–15 y	22	0.71 ± 0.18 ^{ab}	0.48–1.33	10.78 ± 1.91 ^b	7.26–13.93	2.58 ± 0.51 ^{ab}	1.66–3.72	2.95 ± 0.40	2.33–3.97
16–18 y	21	0.76 ± 0.20 ^b	0.47–1.37	11.30 ± 2.07 ^b	7.59–15.87	2.68 ± 0.56 ^b	1.99–3.98	3.19 ± 0.47	2.53–4.21
53.6 m/min									
6–9 y	22 [†]	0.58 ± 0.11 ^a	0.39–0.78	17.77 ± 3.34 ^a	12.62–24.07	2.37 ± 0.38 ^a	1.49–3.02	3.40 ± 0.42	2.75–4.18
10–12 y	19	0.72 ± 0.13 ^{ab}	0.56–1.12	14.77 ± 2.24 ^{ab}	10.47–17.63	2.72 ± 0.49 ^{ab}	1.95–3.82	3.55 ± 0.38	2.77–4.36
13–15 y	23	0.81 ± 0.20 ^b	0.55–1.45	12.37 ± 2.08 ^b	8.85–15.78	2.95 ± 0.56 ^{ab}	1.88–4.06	3.43 ± 0.48	2.65–4.61
16–18 y	21	0.86 ± 0.24 ^b	0.52–1.56	12.50 ± 1.98 ^b	9.71–15.73	3.05 ± 0.69 ^b	2.34–5.19	3.54 ± 0.45	2.89–4.46
67.1 m/min									
6–9 y	21	0.65 ± 0.14 ^a	0.46–0.90	19.77 ± 3.48 ^a	14.83–27.03	2.69 ± 0.51 ^a	1.74–3.59	3.82 ± 0.48	3.08–4.70
10–12 y	19	0.85 ± 0.17 ^{ab}	0.63–1.29	17.62 ± 2.80 ^{ab}	12.64–24.35	3.24 ± 0.70 ^{ab}	2.21–4.53	4.24 ± 0.54	3.51–5.52
13–15 y	24	0.97 ± 0.22 ^b	0.66–1.66	14.68 ± 2.16 ^b	10.46–18.18	3.53 ± 0.66 ^b	2.27–4.68	4.04 ± 0.50	3.18–5.00
16–18 y	20	0.94 ± 0.26 ^b	0.56–1.81	14.28 ± 2.13 ^b	10.99–18.26	3.31 ± 0.66 ^{ab}	2.45–4.71	4.01 ± 0.54	3.12–4.93

(continued)

Table 3 (continued)

Treadmill Speed	n	Absolute VO ₂ (L/min)	Min-Max	Mass-specific VO ₂ (ml/kg/min)	Min-Max	MET _{y1}	Min-Max	MET _{y2}	Min-Max
80.5 m/min									
6–9 y	16	0.77 ± 0.17 ^a	0.56–1.10	22.68 ± 4.17 ^a	16.88–30.74	3.07 ± 0.61 ^a	1.97–4.23	4.40 ± 0.52	3.55–5.34
10–12 y	20	0.98 ± 0.20 ^{ab}	0.70–1.42	20.35 ± 3.09 ^{ab}	15.71–26.96	3.74 ± 0.80 ^{ab}	2.49–5.53	4.85 ± 0.62	4.05–6.63
13–15 y	24	1.16 ± 0.25 ^b	0.75–1.88	17.22 ± 2.48 ^b	12.06–20.73	4.23 ± 0.74 ^b	2.60–5.50	4.81 ± 0.55	3.65–5.99
16–18 y	19	1.07 ± 0.30 ^{ab}	0.66–2.16	16.61 ± 2.01 ^b	12.92–20.59	3.86 ± 0.83 ^{ab}	2.98–5.60	4.61 ± 0.52	3.65–5.77
93.9 m/min									
6–9 y	10	0.85 ± 0.17 ^a	0.67–1.26	28.01 ± 4.59 ^a	23.19–36.26	3.43 ± 0.72 ^a	2.46–4.79	5.26 ± 0.57	4.52–6.10
10–12 y	20	1.12 ± 0.22 ^{ab}	0.82–1.71	24.37 ± 3.61 ^{ab}	18.76–32.37	4.41 ± 0.94 ^{ab}	3.13–6.43	5.73 ± 0.72	4.77–7.85
13–15 y	21	1.37 ± 0.33 ^b	0.94–2.29	20.50 ± 2.75 ^b	15.58–24.47	5.03 ± 0.85 ^b	3.26–6.39	5.69 ± 0.70	4.13–6.83
16–18 y	20	1.31 ± 0.36 ^b	0.85–2.71	20.40 ± 2.62 ^b	15.36–25.22	4.71 ± 0.99 ^{ab}	3.46–6.87	5.66 ± 0.68	4.66–7.01
107.3 m/min									
6–9 y	4	1.00 ± 0.19	0.75–1.16	32.06 ± 7.49	26.16–43.03	3.99 ± 0.64	3.40–4.88	6.11 ± 1.01	5.05–7.47
10–12 y	12	1.37 ± 0.30	1.03–2.13	28.61 ± 3.04	24.06–35.07	5.37 ± 1.38	3.61–7.83	6.84 ± 0.69	6.09–7.89
13–15 y	19	1.61 ± 0.40	1.17–2.81	24.41 ± 3.96	17.21–32.74	5.95 ± 1.01	4.04–7.85	6.73 ± 0.83	5.33–8.59
16–18 y	16	1.60 ± 0.53	1.07–3.46	24.89 ± 3.72	18.56–32.33	5.58 ± 1.23	4.19–8.75	6.84 ± 0.98	5.54–9.16
120.7 m/min									
6–9 y	0	–	–	–	–	–	–	–	–
10–12 y	2	1.39 ± 0.03	1.37–1.41	29.74 ± 1.25	28.85–30.62	5.79 ± 0.49	5.44–6.14	7.16 ± 0.52	6.80–7.52
13–15 y	6	2.26 ± 0.63	1.75–3.33	32.17 ± 2.93	28.60–35.49	7.43 ± 1.34	5.44–9.31	8.43 ± 0.91	7.50–9.92
16–18 y	6	1.70 ± 0.28	1.25–1.98	26.28 ± 1.14	24.74–28.05	6.31 ± 1.22	5.10–8.24	7.65 ± 0.37	7.18–8.23

Note. Values presented as Mean ± SD. MET_{y1} = youth metabolic equivalents calculated as mass-specific VO₂ divided by measured resting mass-specific VO₂. MET_{y2} = youth metabolic equivalents calculated as mass-specific VO₂ divided by estimated resting mass-specific VO₂ (using the Schofield equation). Estimated mean resting mass-specific VO₂ values for ages 6–9, 10–12, 13–15, and 16–18 years were 5.19 ± 0.67, 4.20 ± 0.51, 3.60 ± 0.44, and 3.53 ± 0.43 ml/kg/min, respectively. Mean values within each treadmill speed and across age groups with different superscript letters are significantly different at $P < .001$.

* Sample size is reduced by 1 participant for MET_{y1} data due to missing measured resting VO₂.

Age-group stratified mean values of absolute VO_2 , mass-specific VO_2 , MET_{y1} , and MET_{y2} during treadmill walking are presented in Table 3. All participants that attempted the tenth treadmill bout (134.1 m/min) began running at this speed; therefore, we restrict our presentation to only those 9 speeds ≤ 120.7 m/min. Absolute VO_2 significantly differed across age groups at all speeds between 13.4 and 93.9 m/min, as age tended to be positively associated with absolute VO_2 . Significant age-related differences were also noted for mass-specific VO_2 at all speeds between 13.4 and 93.9 m/min. However, age was inversely associated with mass-specific VO_2 . Significant differences in MET_{y1} values between age groups were observed at all speeds between 26.8 and 93.9 m/min, as age tended to demonstrate a positive relationship with MET_{y1} . No significant age-related differences in MET_{y2} values were noted across any of the evaluated speeds.

Discussion

The descriptive data we have presented are novel, and we know of no single study which has reported children and adolescents' steady-state EE estimates across the complete set of walking speeds evaluated herein. Moreover, no published studies have reported steady-state EE estimates among children and adolescents 6 to 18 years of age for the specific set of common free-living activities we evaluated. In light of these observations, our comparative discourse is limited. However, these data serve as a needed addition to previous assemblages of children and adolescents' measured EE during various sedentary and physical activities.⁴

Of the candidate EE metrics evaluated herein, the MET_{y2} appeared to be least associated with age, as age-related differences were only observed among 2 of the study's 15 activities. This finding is consistent with previous work by McMurray et al⁶ which demonstrated that the MET_{y2} (using estimated resting VO_2 as the denominator) tended to be less associated with age and sex across a range of activities than absolute, mass-specific, or net VO_2 measures. Interestingly, MET_{y1} demonstrated greater variability across age groups than did MET_{y2} , which is likely attributable to the greater age-related variation in directly measured resting VO_2 (seated rest: 1.90 to 10.82 ml/kg/min) used in MET_{y1} calculations than in estimated resting VO_2 (2.54 to 6.39 ml/kg/min) used in MET_{y2} calculations. Further research is needed to better understand how the formulation of youth METs influences the metric's relationship with children and adolescents' age, sex, body composition, and other physical characteristics.

We have presented estimates of measured steady-state EE during 15 different activities from a diverse sample of youth.

The assembled data herein will inform future pediatric-related epidemiological research and augment the *Youth Compendium of Physical Activities*.

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References

1. Ainsworth BE, Haskell WL, Leon AS, et al. Compendium of physical activities: classification of energy costs of human physical activities. *Med Sci Sports Exerc.* 1993;25(1):71–80. [PubMed doi:10.1249/00005768-199301000-00011](#)
2. Ainsworth BE, Haskell WL, Whitt MC, et al. Compendium of physical activities: an update of activity codes and MET intensities. *Med Sci Sports Exerc.* 2000;32(9, Suppl):S498–S504. [PubMed doi:10.1097/00005768-200009001-00009](#)
3. Ainsworth BE, Haskell WL, Herrmann SD, et al. 2011 Compendium of Physical Activities: a second update of codes and MET values. *Med Sci Sports Exerc.* 2011;43(8):1575–1581. [PubMed doi:10.1249/MSS.0b013e31821ece12](#)
4. Ridley K, Ainsworth BE, Olds TS. Development of a compendium of energy expenditures for youth. *Int J Behav Nutr Phys Act.* 2008;5:45. [PubMed doi:10.1186/1479-5868-5-45](#)
5. Kuczmarski RJ, Ogden CL, Grummer-Strawn LM, et al. CDC Growth Charts: United States. *Adv Data.* 2000; (314):1–27. [PubMed](#)
6. McMurray RG, Butte NF, Crouter SE, et al. Exploring metrics to express energy expenditure of physical activity in youth. *PLoS One.* 2015;10(6):e0130869. [PubMed doi:10.1371/journal.pone.0130869](#)
7. Schofield WN. Predicting basal metabolic rate, new standards and review of previous work. *Hum Nutr Clin Nutr.* 1985;39(Suppl 1):5–41. [PubMed](#)
8. U.S. Census Bureau Population Division. *Annual Estimates of the Resident Population by Sex, Race, and Hispanic Origin for the United States, States, and Counties: April 1, 2010 to July 1, 2014*. Suitland, MD: U.S. Census Bureau; 2015.
9. State of Louisiana Department of Health and Hospitals. *Obesity*. Baton Rouge, LA: Department of Health and Hospitals; 2015.