How much energy do preschoolers really expend?

Application of advanced statistical methods to predict energy expenditure and physical activity


Children’s Nutrition Research Center
Baylor College of Medicine
Valid and age-appropriate approaches are needed to assess energy expenditure (EE) and physical activity (PA) in preschool children.

Special consideration for this age group
- Growth and maturation may confound associations between EE and its correlates.
- BMR on a weight basis decreases as children mature.
- Activity behaviors and patterns may be distinct in preschool children.
**Li’l Cal Study: Specific Aims**

- **Study Phase I for Model Development**
  - To develop models for the prediction of EE based on accelerometry and heart rate using room calorimetry in preschool-aged children (Development Phase)
  - Cross-sectional time series (CSTS)
  - Multivariate adaptive regression splines (MARS)

- **Study Phase II for Model Validation**
  - To validate the CSTS and MARS models against room calorimetry and doubly labeled water method in independent sample of preschool-aged children (Validation Phase).
Li’l Cal Study Phase I: Design

- Cross-sectional study
- 69 preschool children, ages 3 - 5
- 8-h Protocol for measurement of energy expenditure (EE) and physical activity (PA)
  - Room calorimetry
  - Actiheart and Actigraph GT3X
- 7-day Measurement of free-living TEE and PA
  - Doubly labeled water method
  - Actiheart and Actigraph GT3X
Two small (2.7 x 3m, 19 m³) calorimeters
- Temperature, humidity-controlled chambers (Conviron)
- Paramagnetic O₂ analyzers (Siemens)
- Nondispersive infrared CO₂ analyzers (Siemens)
- Fast response calorimeters
- Data modeled with first-order, linear, differential equation to account for net gas flows and gas accumulation within calorimeter
- Reprocessed with centered derivative formula

Moon JK; J Nutr 125:220-228, 1995
CNRC Standards Laboratory

- CalBench flow calibrator (Sierra Instruments) traceable to National Institute of Standards and Technology (NIST)
- Computerized gas blender (Environics)

Functions

- Calibrate flow meters and gas analyzers
- Validate performance of room calorimeters using gas blends
- Validate performance of metabolic carts
CNRC Room Respiration Calorimeters
<table>
<thead>
<tr>
<th>Activity Type</th>
<th>Activity</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleep</td>
<td>nap after lunch</td>
<td>45-120 min</td>
</tr>
<tr>
<td>Stationary</td>
<td>watching TV</td>
<td>20 min</td>
</tr>
<tr>
<td>Stationary play</td>
<td>coloring</td>
<td>10 min</td>
</tr>
<tr>
<td>Stationary play</td>
<td>video games</td>
<td>10 min</td>
</tr>
<tr>
<td>Stationary play</td>
<td>puzzles</td>
<td>10 min</td>
</tr>
<tr>
<td>Low active play</td>
<td>kitchen/toys</td>
<td>15 min</td>
</tr>
<tr>
<td>Moderate active play</td>
<td>ball toss</td>
<td>15 min</td>
</tr>
<tr>
<td>Moderate active play</td>
<td>active video game</td>
<td>10 min</td>
</tr>
<tr>
<td>Moderate active play</td>
<td>dance/aerobics</td>
<td>2 x 15 min</td>
</tr>
<tr>
<td>Very active play</td>
<td>running in place</td>
<td>6 min</td>
</tr>
</tbody>
</table>
Li’l Cal: Heart Rate and Accelerometers

ACTIHEART

ACTIGRAPh
How much energy do preschoolers really expend?

In the room calorimeter
Room Respiration Calorimetry: Energy Expenditure and HR

Energy (kcal/min)

Heart Rate (bpm)

9:54 10:54 11:54 12:54 13:54 14:54 15:54
Measured Sleeping Metabolic Rate
Predicted Basal Metabolic Rate

Energy Expenditure (kcal/kg/d)
Age (y)

- Measured Sleeping Metabolic Rate
- Predicted BMR (Schofield Equation)
## Metabolic Equivalents for BMR

<table>
<thead>
<tr>
<th>Age Group (y)</th>
<th>VO$_2$ (ml-O$_2$/kg/min)</th>
<th>EE (kcal/kg/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-5</td>
<td>6.8</td>
<td>1.9</td>
</tr>
<tr>
<td>5-8</td>
<td>5.6</td>
<td>1.6</td>
</tr>
<tr>
<td>9-12</td>
<td>4.0</td>
<td>1.2</td>
</tr>
<tr>
<td>13-15</td>
<td>3.5</td>
<td>1.0</td>
</tr>
<tr>
<td>16-18</td>
<td>3.1</td>
<td>0.9</td>
</tr>
<tr>
<td>Adult</td>
<td>3.5</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Mean Energy Cost of Activities

Energy expenditure (kcal/min)

- Sleep
- TV time
- Video games
- Coloring
- Puzzles
- Play
- Active video games
- Active play
- Ball toss
- Running
Physical Activity Ratio (PAR)

$\text{PAR} = \frac{\text{EE}}{\text{BMR}}$
Absolute Energy Cost of Activities

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Energy Expenditure (kcal/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

- Sleep
- TV time
- Play
- Dance/Aerobics
- Run in place
Energy Cost of Activities Adjusted for Weight

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Energy Expenditure (kcal/kg/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>0.05</td>
</tr>
<tr>
<td>5</td>
<td>0.10</td>
</tr>
<tr>
<td>6</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Activities:
- Sleep
- TV time
- Play
- Dance/Aerobics
- Run in place
Activity Energy Expenditure Adjusted for Weight

AEE = EE - BMR

Activity Energy Expenditure (kcal/kg/min)

Age (years)

TV time
Play
Dance/Aerobics
Run in place
Physical Activity Ratio

PAR = EE/BMR

Age (years)

Sleep
TV time
Play
Dance/Aerobics
Run in place
How much energy do preschoolers really expend?

Free-living environment
Doubly Labeled Water Method

DLW is stable isotope method for the measurement of total energy expenditure.

TEE encompasses BMR, TEF, thermoregulation, physical activity and synthetic cost of growth.

DLW method entails oral administration of $^{18}O$ and $^2H$ to estimate VCO$_2$.

Gas isotope ratio mass spectrometry analysis (GIRMS)

Accuracy: $2 \pm 3-9\%$ SD (Schoeller 1991)
## Doubly labeled Water Method

<table>
<thead>
<tr>
<th></th>
<th>3y</th>
<th>4y</th>
<th>5y</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEE (kcal/d)</td>
<td>1088</td>
<td>1258</td>
<td>1385</td>
</tr>
<tr>
<td>TEE (kcal/kg/d)</td>
<td>69</td>
<td>68</td>
<td>66</td>
</tr>
<tr>
<td>PAL (TEE/BMR)</td>
<td>1.31</td>
<td>1.42</td>
<td>1.46</td>
</tr>
</tbody>
</table>

*Mean ±SD*
Moderate-Vigorous Physical Activity (% awake time)

Application of Advanced Mathematical Models for the Prediction of Energy Expenditure from Heart Rate and Accelerometry in Children and Adolescents
Cross-sectional Time Series (CSTS)

- CSTS is a parametric method that examines multiple subjects (cross-sectional) and how they change over the course of time (longitudinal).

- Any series of values of a variable taken at successive times or in a fixed order.

- CSTS is well suited to describe the dynamic series of minute-by-minute EE, taking into account the correlation structure of the data.
Multivariate Adaptive Regression Splines (MARS)

- MARS is nonparametric regression method that approximates a complex, nonlinear relationship by series of spline functions on different intervals of the independent variable.
- A generalization of binary recursive partitioning but overcomes limitations of disjointed, discontinuous functions at subregion boundaries.
- Consideration of the degree of polynomials, the number and locations of knots.
CSTS Model:
Prediction of Energy Expenditure in Calorimeter

Measured TEE
Predicted EE (CSTS AG HR)
Heart Rate
MARS Model:
Prediction of Energy Expenditure in Calorimeter

- Measured TEE
- Predicted EE (MARS AG HR)
- Heart Rate

Time

0.0 0.5 1.0 1.5 2.0 2.5 3.0

1 61 121 181 241

160 140 120 100 80 60 40
CSTS: Prediction Errors for EE

Predicted - measured EE (%) vs. EE measured (kcal/min)

Symbols:
- 3y
- 4y
- 5y
MARS: Prediction Errors for EE
CSTS and MARS: Model Evaluation

- CSTS model for EE
  - Degree of concordance (CCC = 0.94)
  - Mean prediction error for EE was -0.2 ± 7-8.6%

- MARS model for EE
  - Degree of concordance (CCC = 0.95)
  - Mean prediction error for EE was 0.3 ± 4.7-6%

- Bland-Altman plots indicate good agreement and no bias with increasing EE

- Prediction errors were not correlated with gender, age, or BMI status
Conclusions

- CSTS and MARS models based on HR and PA and subject characteristics provides a useful predictive model for EE in preschool children.

- Calibration-free population CSTS and MARS models represents a significant advancement in field methodology for the prediction of EE.

- Models will be validated against doubly labeled water method in free-living preschool children.