Estimating model of sedentary behavior with tri-axial accelerometer in elementary school children

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Abstract Several recent studies reported that a lack of moderate to vigorous physical activity (MVPA) in combination with a high degree of sedentary behavior (SB) is associated with health problems including overweight and obesity in children, as well as psychosocial stress. Therefore, it is important that methods are developed to objectively evaluate both MVPA and SB. The aim of this study was to redevelop the existing equation for estimating SB to improve its accuracy. Healthy boys (n = 42) and girls (n = 26) attending primary school were invited to participate in this study. Participants were asked to perform 2 SB tasks, which were desk work and Nintendo DS, 2 light intensity activities such as sweeping up and clearing away, and higher intensity activities such as sweeping up and throwing a ball, with a few minutes of recovery time between tasks. The tasks and activities were performed in order of PA intensity (lower to higher). All participants wore a triaxial accelerometer on their waist. In addition, they wore a facemask connected to a Douglas bag to gather respiratory gas samples while performing each activity. First, we proposed the two linear regression equations (TL), including an equation for SB, and another equation for light or higher intensity activities with a fixed intercept of 0.9. Moreover, we redeveloped a quadratic polynomial (QP) equation that takes into account all activities. Both models were demonstrated to improve the accuracy of estimations of PA (about 0.2 to 0.3 METs), including SB (about 1.0 METs) other than sweeping up and wiping floor, compared to the existing model.

Keywords : sedentary behavior, accelerometer, elementary school children

Introduction

Although current guidelines recommend that children engage in at least 60 minutes of moderate-to-vigorous intensity physical activity (MVPA) every day, many children globally do not meet this goal¹⁾. MVPA declines with age during childhood and preadolescence, with a greater decline observed in girls than in boys²⁾. Many studies have reported that sufficient MVPA contributes to improvements in depressive tendency³⁾, academic achievement⁴⁾, physical fitness⁵⁾, and a reduction in obesity from

childhood to adolescence⁶⁾.

In Japan, the prevalence of MVPA remains unclear because methods for objective measurement of physical activity (PA) have not been established. Therefore, we proposed a new algorithm for assessing MVPA using an accelerometer in primary school children⁷⁾. The developed algorithm includes two predictive equations for locomotive activity and nonlocomotive activity. The equation for locomotive activity can evaluate both ambulation and running, while the equation for nonlocomotive activity is good at estimating irregular motions associated with daily activities, such as sweeping, clearing away, and throwing a ball. This algorithm has previously been used in investi-

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gative studies such as the validation of MVPA with questionnaire⁸⁾, the contribution of types of physical education to MVPA⁹⁾, and comparisons of MVPA during the school year and summer vacation¹⁰⁾.

Recently, a number of researchers have focused their efforts on evaluating sedentary behavior (SB), which is defined as any waking behavior characterized by an energy expenditure (EE) of ≤ 1.5 metabolic equivalents (METs) while in a sitting, reclining or lying posture¹¹⁾. A lack of MVPA in combination with a high degree of SB is associated with health problems including overweight and obesity in children¹²⁾, as well as psychosocial stress¹³⁾. While it is important to develop methods to objectively evaluate both MVPA and SB, our previously proposed equation for nonlocomotive activity likely overestimates predicted METs for SB. In particular, an intensity of PA around 1.3 METs was regarded as more than 1.5 METs by the existing equation⁷⁾.

The primary aim of the present study was to redevelop the existing equations to improve the accuracy for estimating SB without losing MVPA accuracy. In addition, we propose converting equations from the outputs (adult METs) of the Active style Pro¹⁴⁾ to evaluate METs in children, because there was a significant difference in energy cost between adults and children^{15,16)}, and the Active style Pro provides the predicted values only for adults.

Materials and Methods

Participants

Healthy boys (n=42) and girls (n=26) attending primary school were invited to participate in this study via a public advertisement (Table 1). This study was conducted according to the guidelines of the Declaration of Helsinki, and all procedures involving human participants were approved by the Ethical Committee of the National Institute of Health and Nutrition (No.20080312-1).

Procedures

To avoid diet-induced thermogenesis, the children visit-

ed the laboratory in the morning, three hours after breakfast. After anthropometric measurements were taken, participants were asked to rest for 30 minutes, and then the resting (seated in a chair) metabolic rate was measured for 7 minutes as previously reported^{17,18)}. Next, the children performed PA a total of 6 times for approximately 3 to 7 minutes, which included a steady-state period (Table 2). Two SB tasks, which were desk work and Nintendo DS, and 2 light intensity activities such as sweeping up and clearing away were first performed in order of PA intensity (lower to higher) with a few minutes of recovery time between tasks. Then, after enough rest, participants performed higher intensity activities such as sweeping up and throwing a ball. All participants wore a triaxial accelerometer⁷⁾ on their waist, tightly attached with a belt, while performing each activity. Before the start of the experiment, the accelerometers were synchronized using a wave clock as a reference^{14,19)}. The EE of each activity was calculated based on oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) using Weir's equation²⁰⁾. To calculate METs, EE during each activity was divided by the measured value of the metabolic rate of the participant when seated in a chair.

Indirect calorimetry

Respiratory gas samples were analyzed using the Douglas bag method, in which each participant was fitted with a facemask and allowed to breathe into a Douglas bag. Participants performed calibration tasks with the aid of an assistant who held either the 50 L or 100 L-sized Douglas bag. The assistant opened a cock of the Douglas bag to collect the expired gas as the steady-state period finished, and then closed it when the measurement finished without hindrance. The concentrations of oxygen and carbon dioxide within the bag were analyzed by a mass spectrometer (ARCO-2000; Arco System Inc., Kashiwa, Japan).

Improvement of existing model

We reported a prediction model⁷⁾ to evaluate METs in children using primary data collected in 2009. This study

Table 1. Physical characteristics of participants

		Boys (42)		Girls (26)	
		Mean	SD	Mean	SD
Age	(yrs)	10.0	1.7	9.0	1.8
Height	(cm)	140.5	11.5	134.4	12.6
Weight	(kg)	33.9	9.9	29.8	8.2
BMI	(kg/m ²)	16.8	2.6	16.1	2.1

BMI: body mass index, SD: standard deviation

Table 2. Description of calibration tasks

Tasks	Content of activity	Intensity	Steady state (min)	Gathering expired gas (min)*
Desk work	handwriting letters at a desk	sedentary	3.0	4.0
Nintendo DS	playing Nintendo DS with sitting on the floor	sedentary	3.0	3.0
Sweeping up	sweeping floor (about 17 m ²) while moving	light	3.0	3.0
Clearing away	placing books from floor onto a bookshelf	light	3.0	3.0
Wiping floor	wiping down floor with a cloth in a squatting position	moderate	3.0	2.0
Throwing a ball	playing catch with a large ball with a partner consecutively	moderate	3.0	3.0

* We collected expired gas for 1 to 4 min after steady state for 2 or 3 min.

re-analyzed these data to improve the existing model. We first developed two linear equations (TL) model from the existing equation for nonlocomotive activity⁷⁾ by separating SB, i.e., writing letters while seated in a chair and playing a portable game console (Nintendo DS) while sitting on the floor. Practically, we proposed the equation for SB including the desk work and Nintendo DS, and then another equation for light or higher intensity activities based on sweeping up, clearing away, wiping floor and throwing a ball. We fixed the intercept at 0.9 in the equation for SB. Second, we also revised the existing linear equation for nonlocomotive activity to a quadratic polynomial (QP) with a fixed intercept of 0.9 according to a previous study²¹⁾. We assumed the METs while awake and without movement to be 0.9, based on the intercept of the regression line for METs and accelerations. In principle, the ratio of EE between sitting quietly and lying quietly should typically fall in the range of 0.9 to 1.0, when assessing PA by accelerometer. Practically, previous studies reported that the ratio of EE while sitting quietly to EE while lying quietly in both adults^{14,22)} and in children¹⁵⁾ could be around 0.9.

Statistical Analysis

Statistical analysis was performed with JMP version 8.0 for Windows (SAS Institute, Tokyo, Japan). All results are reported as mean $\pm$ standard deviation (SD). One-way analysis of variance (ANOVA) was used to compare measured METs and predicted METs using the existing model and predicted METs using the two procedures (TL and QP) in the present study. If there was a statistically significant difference between variables, a post-hoc test by Tukey HSD was performed to compare the difference between variables. Single regression and quadratic polynomial analysis were used to convert adult's METs into children's METs in the current study. $P < 0.05$ was considered statistically significant.

Predicted METs using the existing model were simply based on a single linear relationship between synthetic acceleration of three dimensions and measured METs using the Douglas bag method⁷⁾. We also carried out multiple regression analysis with a stepwise method to examine the effects of weight, age and gender, and then analysis of covariance to assess the interaction (age $\times$ gender) on the measured METs in the previous study⁷⁾. As a result, age and gender were significant variables, while the interaction was not significant. There were no significant differences in predicted METs between single regression model and multiple regression model including variables of age and gender.

Results

The first model exhibits two linear regression equations (TL), including an equation for sedentary activities of desk work and playing Nintendo DS with a fixed

intercept of 0.9, and another equation for sweeping up, clearing away, wiping floor, and throwing a ball (Fig. 1). In addition, the point of intersection between the equation for light or higher intensity activities and the equation for sedentary is 58mG, which was set as the boundary value for distinguishing the two equations. The second model is a quadratic polynomial (QP) equation, which takes into account all activities (Fig. 2). Two linear regression equations can be expressed as in equation (1) and (2):

$$y = 0.0275x + 0.9 \text{ (sedentary behaviors: } \leq 58\text{mG)} \quad (1)$$

$$y = 0.009x + 1.9789 \text{ (light or higher intensity activities: } > 58\text{mG)} \quad (2)$$

where y denotes measured METs, x is integrated acceleration.

The quadratic polynomial equation is expressed in equation (3):

$$y = -0.00003x^2 + 0.0209x + 0.9 \text{ (all activities)} \quad (3)$$

where y denotes measured METs, x is integrated acceleration.

We compared each METs obtained from the TL and QP equations with the METs measured during each episode of PA (Table 3). There were significant differences among METs in all episodes of PA for each equation (desk work: F value = 96.2, $P < 0.001$; Nintendo DS: F = 213.0, $P < 0.001$; sweeping up: F = 7.8, $P < 0.001$; cleaning away: F = 4.9, $P < 0.01$; wiping floor: F = 30.8, $P < 0.001$; throwing a ball: F = 8.1, $P < 0.001$), and then the post-hoc test was adopted to compare the difference between METs for each equation. As a result, there was no significant difference in METs obtained for desk work (absolute difference: -0.03, 95% CI [confidence interval]: -0.08 to 0.10, $P = 0.14$) using the TL equations and cleaning away using the TL equations (absolute difference: 0.02, 95% CI: -0.18 to 0.23, $P = 0.99$) and using the QP equation (absolute difference: -0.08, 95% CI: -0.28 to 0.12, $P = 0.73$) when comparing the measured METs. In addition, absolute and percent differences in desk work, playing Nintendo DS, cleaning away, and throwing a ball were improved using

Fig. 1 Relationship between integrated acceleration and measured METs using two regression equations.

- Upper solid line: equation including circle plots (o) of sweeping up, clearing away, wiping floor and throwing ball (light or higher intensity activities: > 58 mG)
- Lower solid line: equation including triangle plots (Δ) of desk work and playing Nintendo DS with fixed intercept (0.9) (sedentary behaviors or light intensity activities: ≤ 58 mG)
- Dotted line: existing equation⁷⁾
- The point of intersection between the equation for light or higher intensity activities and the equation for sedentary denotes 58 mG

Fig. 2 Relationship between integrated acceleration and measured METs using a quadratic polynomial equation.

- Solid line: quadratic polynomial equation including sedentary activities and light or higher intensity activities with fixed intercept (0.9)
- Dotted line: existing equation⁷⁾

the TL and QP equations compared to the existing equation. On the other hand, the estimated accuracy of METs for sweeping up and wiping floor, as evaluated by the TL and QP equations, were not improved compared to the existing equation (Table 3).

We proposed the following conversion equation with cubic polynomial (4) from the outputs of the Active style Pro to evaluate METs in children:

$$Y = -0.0057X^3 + 0.0184X^2 + 0.7636X + 0.135 \quad (4)$$

where Y is children's METs, X is the outputs (METs of lifestyle activity) of the Active style Pro.

We also proposed the following two conversion equations (5) and (6) from the outputs of the Active style Pro to evaluate METs in children:

Nonlocomotive activity:

$$s = 0.7367t + 0.2317 \text{ (outputs of the Active style Pro for sedentary behavior or light intensity activities: } \leq 2.5 \text{ METs)} \quad (5)$$

$$s = 0.4529t + 1.3552 \text{ (output of the Active style Pro for light or higher intensity activities: } > 2.5 \text{ METs)} \quad (6)$$

where s is children's METs, t is the output (METs) classified into "lifestyle activity" by the Active style Pro. The point of intersection between the equation for light or higher intensity activities and the equation for sedentary, that is 58mG, is 2.5 METs, based on the relationship between synthetic acceleration and METs in the Active style Pro. In addition, when using the following conversion equation of locomotive activity (7) based on the previous study⁷⁾, we can more accurately estimate children's PA considering the type and intensity of PA.

Locomotive activity:

$$a = 0.6237b + 0.2411 \quad (7)$$

where a is children's METs, b is the output (METs) classified into "locomotive activity" by the Active style Pro.

Discussion

In this study we sought to redevelop the previously proposed equation for accurate evaluation of SB without impairing the estimate accuracy in MVPA in elementary school children. As described above, the existing equation with an intercept of 1.21⁷⁾ is inappropriate for the

Table 3. Comparison of differences obtained using each of the various equations

Activities	Measured value	Existing equation (Hikihara et al., 2014)		Two regression equations		Quadratic polynomial equation		One-way analysis of variance
		Absolute difference	% difference	Absolute difference	% difference	Absolute difference	% difference	
Desk work	1.2 ± 0.1	0.2 ± 0.1	17.5 ± 15.0	-0.03 ± 0.1	-2.5 ± 12.6	-0.1 ± 0.1	-7.2 ± 10.6	E > M, T > Q
Nintendo DS	1.1 ± 0.1	0.2 ± 0.1	17.9 ± 9.1	-0.1 ± 0.1	-4.4 ± 10.9	-0.1 ± 0.1	-8.0 ± 9.5	E > M > T > Q
Sweeping up	3.0 ± 0.6	0.1 ± 0.5	5.8 ± 14.6	0.4 ± 0.5	15.5 ± 18.4	0.4 ± 0.5	14.6 ± 19.6	T, Q, E > M
Clearing away	3.1 ± 0.6	-0.3 ± 0.4	-6.5 ± 12.8	0.02 ± 0.6	3.9 ± 18.4	-0.1 ± 0.6	0.02 ± 18.8	T, M > E
Wiping floor	4.6 ± 0.8	-0.5 ± 0.8	-9.0 ± 18.9	-0.8 ± 0.8	-13.7 ± 17.1	-0.7 ± 0.8	-12.3 ± 17.4	M > E, Q, T
Throwing a ball	3.7 ± 0.7	0.5 ± 0.5	14.9 ± 13.4	0.4 ± 0.5	12.0 ± 15.1	0.3 ± 0.5	11.4 ± 16.2	E, T, Q > M

Bold type shows more improvement of accuracy compared with existing equation.

M; measured value, E; existing equation, T; two regression equations, Q; quadratic polynomial equation

A sign of inequality shows $P < 0.05$.

evaluation of SB because the ratio of EE between sitting quietly and lying quietly typically falls in the range of 0.9 to 1.0. Therefore, we proposed two new models (TL and QP) with a fixed intercept of 0.9. Both models demonstrated improved accuracy compared to the previous model among four different activities. SB, such as desk work and Nintendo DS, was especially improved by 13 to 15% compared to the existing model without significantly spoiling the accuracy in MVPA. Nevertheless, the prediction accuracy for sweeping and wiping floor, which were classified in MVPA, tended to slightly decrease, although not significantly. In epidemiology research, it is also important for an accelerometer to be able to classify the intensity of PA, such as SB and MVPA²³⁾. Although the redeveloped models in this study may negatively influence the estimation accuracy of energy cost in two of the investigated activities (sweeping up: 3.0 ± 0.6 METs; wiping floor: 4.6 ± 0.8 METs) as shown in Table 3, there do not appear to be any issues with the evaluation of time of moderate-intensity PA between 3.0 to 6.0 METs, although time of vigorous intensity PA would be underestimated by the QP equation.

Although the Active style Pro produced by Omron Healthcare Co, Ltd exhibits an algorithm for evaluation of METs for adults^{14,24)}, this device cannot be adapted for evaluation of PA in children due to the differences in the relationship of acceleration to METs between adults and children^{15,16)}. In practice, there were large differences in slope and intercept of the relationships between acceleration and METs based on the same methodology between adults and children^{7,14)}. Therefore, we propose the conversion equations with polynomial formula from the outputs of the Active style Pro to evaluate METs in children. As can be seen from Fig. 2, this conversion equation is convenient for estimating PA below 4 METs. However, it could be difficult to estimate more than 4 METs of PA intensity by this polynomial conversion equation, even if there do not appear to be any issues with the evaluation of time of MVPA. Therefore, we also proposed the following two linear conversion equations from the outputs of the Active style Pro to evaluate METs in children. Although this model would resolve the above problem, how to set the point of intersection between the equation for light or higher intensity activities and the equation for sedentary was not always appropriate.

Although epidemiological researchers tend to focus strongly on SB as well as MVPA in children, the different appearances of PA observed across studies have recently been attributed to the algorithms used for evaluating SB and MVPA. Future investigations are needed to determine whether classifying PA intensities in daily activities using our proposed algorithm is appropriate or comparable with direct observation and commonly used devices (e.g., ActiGraph).

Conclusion

This study redeveloped two models to more accurately estimate SB compared to a previous model. The first redeveloped model separates out the equation for SB with an intercept of 0.9 from the equation for estimation of PA of light or higher intensity. The second redeveloped model uses a quadratic polynomial equation with an intercept of 0.9. Both approaches were demonstrated to improve the accuracy of estimating PA (about 0.2 to 0.3 METs), including SB (about 1.0 MET) other than sweeping up and wiping floor, compared to the existing model.

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Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this article.

Author Contributions

All authors conceptualized the study design and protocol, and determined the study institutions. YH, YO, KO and ST collected and assembled the data. YH, CT and ST carried out the analysis and interpretation of data. YH drafted the manuscript. All authors have critically reviewed, revised and approved the manuscript.

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