Preventive Medicine 115 (2018) 12–18

Contents lists available at ScienceDirect

Preventive Medicine

journal homepage: www.elsevier.com/locate/ypmed

Associations of volumes and patterns of physical activity with metabolic health in children: A multivariate pattern analysis approach

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ARTICLE INFO

Keywords:
Multivariate pattern analysis
Metabolic risk factors
Pediatric
Childhood
Pre-pubertal
Accelerometer
Bouts
Breaks

ABSTRACT

Physical activity (PA) favorably affects metabolic health in children, but it is unclear how total volumes versus patterns (bouts and breaks) of PA relate to health. By means of multivariate pattern analysis that can handle collinear variables, we determined the associations of PA volumes and patterns with children's metabolic health using different epoch settings. A sample of 841 Norwegian children (age 10.2 ± 0.3 years) provided in 2014 data on accelerometry (ActiGraph GT3X+), using epoch settings of 1, 10, and 60 s and several indices of metabolic health used to create a composite metabolic health score. We created 355 PA indices covering the whole intensity and bout duration spectrum, and used multivariate pattern analysis to analyze the data. Findings showed that bouts of PA added information about childhood health beyond total volumes of PA for all epoch settings. Yet, associations of PA patterns with metabolic health were completely dependent on the epoch settings used. Vigorous PA was strongly associated with metabolic health, while associations of light and moderate PA were weak to moderate, and associations of sedentary time with metabolic health was non-existing. Short intermittent bursts of PA were favorably associated with children's metabolic health, whereas associations of prolonged bouts were weak. This study is the first to determine the multivariate physical activity association pattern related to metabolic health in children across the whole PA intensity and bout duration spectrum. The findings challenge our understanding of PA patterns, and are of major importance for the analysis of accelerometry data.

1. Introduction

Moderate-to-vigorous physical activity (MVPA) has consistently been associated with metabolic health outcomes (i.e., risk factors for cardiovascular diseases) in childhood (Ekelund et al., 2012; Janssen and LeBlanc, 2010; Poitras et al., 2016). Additionally, sedentary time (SED) (Barnes et al., 2012) has received much attention for possibly being detrimental to health beyond overall physical activity (PA) or MVPA (Saunders et al., 2014; Altenburg and Chinapaw, 2015). The majority of pediatric studies investigating relationships between PA and health have restricted their exposure variables to these two (Janssen and LeBlanc, 2010), resulting in a great loss of information and ignoring the possible influence of other PA indices on health outcomes.

Given the potential influence of the patterns (i.e., bouts and breaks) compared to the overall volumes (i.e., total time) of PA and SED in children (Poitras et al., 2016; Saunders et al., 2014; Altenburg and Chinapaw, 2015; Cliff et al., 2016), these indices should be directly compared across the intensity spectrum (Poitras et al., 2016; van der Ploeg and Hillsdon, 2017). Studies that have compared total PA and bouts of MVPA, or sporadic (1–5 min) with longer bouts (≥5 and 10 min) of MVPA, show that these indices perform rather similarly as markers of health in both adults (Wolff-Hughes et al., 2015; Clarke and Janssen, 2014; Loprinzi and Cardinal, 2013) and children (Holman et al., 2011; Mark and Janssen, 2009; Andersen et al., 2006; Stone et al., 2009), although some child studies conclude that bouts add independently to total volumes in terms of explaining variation in fatness (Mark and Janssen, 2009; Willis et al., 2015; Dorsey et al., 2011). The evidence for an influence of SED on metabolic health in children,

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https://doi.org/10.1016/j.ypmed.2018.08.001
Received 12 March 2018; Received in revised form 18 May 2018; Accepted 2 August 2018
Available online 03 August 2018
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beyond MVPA, is weak (Ekelund et al., 2012; Cliff et al., 2016).

While studies have investigated whether sustained bouts (> 1–10 min) of PA are associated with metabolic health, children's PA is characterized by sporadic and intermittent bursts of PA generally lasting < 10 s (Rowlands et al., 2008; Bailey et al., 1995; Sanders et al., 2014). Thus, studies consistently show that SED, vigorous PA (VPA), and MVPA are underestimated, whereas light PA (LPA) is overestimated, when epoch duration increases from 1 to 60 s (Sanders et al., 2014; Vale et al., 2009; Banda et al., 2016; Nettlefold et al., 2016; Froberg et al., 2017). These findings suggest that short epoch settings are recommended. However, using very short epochs might capture small bursts of PA, or "noise", which are not meaningful for health, and thus be counterproductive for increasing knowledge of PA and health. Moreover, different epoch settings for accelerometry will likely cause a substantially altered distribution of PA across different bout durations (Sanders et al., 2014; Nettlefold et al., 2016; Orme et al., 2014), which is crucial to our understanding of PA patterns and the relation to childhood health. There is therefore a need to investigate the influence of PA bouts on metabolic health in childhood across the whole spectrum of durations, both shorter and longer than 1 min. Broadening our understanding in this way merges two lines of research: one focusing on choosing the most optimal epoch setting for measuring PA, and one focusing on whether childhood PA recommendations should include structured exercise training.

Determining the relative importance of PA volumes and patterns is however difficult, given the multi-collinearity among the PA indices. To avoid loss of information and residual confounding (van der Ploeg and Hillsdon, 2017), all indices must be included in the same statistical model. Because common univariate statistical methods (i.e., ordinary least squares regression models) cannot handle highly correlated variables, we need new statistical methods to overcome this shortcoming (Saunders et al., 2016). Multivariate pattern analysis is widely applied in pharmaceutical (Rajalahti and Kvalheim, 2011) and metabolomics studies (Madsen et al., 2010), as well as in other fields of biomedical research, such as treatment and diagnosis of diseases (Rajalahti et al., 2010), with the objective of revealing patterns and important biomarkers among hundreds or thousands of highly interrelated variables. Thus, this statistical approach is well suited to solve the issue of collinearity in accelerometer-derived PA variables.

By means of multivariate pattern analysis, the aim of the present study was to determine the associations of PA volumes and patterns with children's metabolic health, across the intensity and bout duration spectrum, using different epoch settings. This novel statistical approach, as applied to PA accelerometry data, allows addressing questions that have not been possible to answer previously.

2. Methods

2.1. Participants

The present analyses are based on baseline data obtained in fifth grade children from the Active Smarter Kids (ASK) study, conducted in Norway during 2014–2015 (Resaland et al., 2015; Resaland et al., 2016). Sixty schools, encompassing 1202 fifth-grade children, fulfilled the inclusion criteria, and agreed to participate. This sample represented 86.2% of the population of 10-year-olds in the county, and 95.2% of those eligible for recruitment. Later, three schools encompassing 27 children declined to participate. Thus, 1145 (97.4%) of 1175 available children from 57 schools agreed to participate in the study.

Our procedures and methods conform to ethical guidelines defined by the World Medical Association's Declaration of Helsinki and its subsequent revisions. The Regional Committee for Medical Research Ethics approved the study protocol. We obtained written informed consent from each child's parents or legal guardian and from the responsible school authorities prior to all testing. The study is registered in Clinicaltrials.gov with identification number: NCT02132494.

2.2. Procedures

We have previously published a detailed description of the study (Resaland et al., 2015), and provide only a brief overview of the relevant procedures herein.

2.2.1. Physical activity

Physical activity was measured using the ActiGraph GT3X+ accelerometer (Pensacola, FL, USA) (John and Freedson, 2012). Participants were instructed to wear the accelerometer over seven consecutive days, except during water activities (swimming, showering) or while sleeping. Units were initialized at a sampling rate of 30 Hz. Files were analyzed at 1, 10, and 60-second epochs using the KineSoft analytical software version 3.3.80 (KineSoft, Loughborough, UK). Data was restricted to hours between 06:00 and 23:59. In all analyses, consecutive periods of ≥60 min of zero counts were defined as non-wear time (Cain et al., 2013; Chinapaw et al., 2014). We applied wear time requirements of ≥8 h/day and ≥4 days/week to constitute a valid measurement.

We created PA variables to capture volumes and patterns of movement across the intensity spectrum (SED to VPA range). We used the Evenson et al. cut points of 0–99, 100–2295, 2296–4011, ≥4012, and ≥2296 cpm to define SED, LPA, moderate PA (MPA), VPA, and MVPA (Evenson et al., 2008; Trost et al., 2011), respectively. We defined 15 different bout durations between 1 s and ≥60 min: 1 s, 2–4 s, 5–9 s, 10–19 s, 20–29 s, 30–39 s, 40–59 s, 1.0–1.4 min, 1.5–1.9 min, 2.0–2.9 min, 3–4 min, 5–9 min, 10–29 min, 30–59 min, and ≥60 min. All 15 bout durations were used for files analyzed at 1-second epoch, whereas 10-second epoch files were analyzed for 12 bout durations (≥10 s), and 60-second epoch files were analyzed for 7 bout durations (≥60 s). Bouts were further defined without allowing any exceptions (time spent outside of the bouts), and while allowing exceptions of a maximum of 20% of the bout duration (e.g., allowing up to 2 minute drop in intensity below the intensity cut point within a 10-minute bout to account for stopping at right light etc.), to investigate sensitivity to altering the bout definition (please see Supplemental Table 1 for an overview of bout durations and exceptions analyzed). For descriptive statistics, we also reported achievement of the guideline PA level (mean of ≥60 min of MVPA/day).

2.2.2. Metabolic health measures

Aerobic fitness was measured with the Andersen intermittent running test (Andersen et al., 2008), which was performed according to standard procedures. Children ran for as long as possible in a to-and-fro movement on a 20-meter track, touching the floor with one hand each time they turned, with 15-second work periods and 15-second breaks, for a total duration of 10 min. The distance covered was used as the outcome. The test has demonstrated acceptable reliability and validity in 10-year-old children (Aadland et al., 2014). Body mass was measured using an electronic scale (Seca 899, SECA GmbH, Hamburg, Germany), with children wearing light clothing. Height was measured using a portable Seca 217 (SECA GmbH, Hamburg, Germany). Body mass index (BMI) ($kg \cdot m^{-2}$) was calculated. Waist circumference was measured with a Seca 201 (SECA GmbH, Hamburg, Germany) measuring tape 2 cm over the level of the umbilicus. Systolic (SBP) and diastolic blood pressures were measured using the Omron HBP-1300 automated monitor (Omron Healthcare, Inc., Vernon Hills, IL, US). Children rested quietly for 10 min in a sitting position with no distractions before we measured blood pressures four times. We used the mean of the last three measurements for analyses. Serum blood samples were collected from the children's antecubital vein between 08:00 and 10:00 in the morning after an overnight fast. All blood samples were analyzed for total cholesterol (TC), triglyceride (TG), high-density lipoprotein cholesterol (HDL), glucose, and insulin, at the accredited Endocrine Laboratory of the VU Medical Center (VUmc; Amsterdam, the Netherlands). Low-density lipoprotein cholesterol (LDL) was estimated using

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