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Original research

Equating accelerometer estimates among youth: The Rosetta Stone 2

Keith Brazendale[a,*], Michael W. Beets[a], Daniel B. Bornstein[a], Justin B. Moore[b], Russell R. Pate[a], Robert G. Weaver[a], Ryan S. Falck[a], Jessica L. Chandler[a], Lars B. Andersen[c,d], Sigmund A. Anderssen[d], Greet Cardon[e], Ashley Cooper[f], Rachel Davey[g], Karsten Froberg[c], Pedro C. Hallal[h], Kathleen F. Janz[i], Katarzyna Kordas[f], Susi Kriemler[j], Jardena J. Puder[k], John J. Reilly[l], Jo Salmon[m], Luis B. Sardinha[n], Anna Timperio[l], Esther M.F. van Sluijs[o], On behalf of the International Children's Accelerometry Database (ICAD) Collaborators

[a] *University of South Carolina, Department of Exercise Science, USA*
[b] *University of South Carolina, Department of Health Promotion, Education, and Behavior, USA*
[c] *University of Southern Denmark, Department of Sport Science and Clinical Biomechanics, Denmark*
[d] *Norwegian School of Sport Science, Norway*
[e] *Ghent University, Department of Movement and Sports Sciences, Belgium*
[f] *University of Bristol, Centre for Exercise, Nutrition and Health Sciences/School of Social and Community Medicine, UK*
[g] *University of Canberra, Centre for Research and Action in Public Health, Australia*
[h] *Federal University of Pelotas, Brazil*
[i] *University of Iowa, Department of Health and Human Physiology, USA*
[j] *University of Zürich, Epidemiology, Biostatistics and Public Health Institute, Switzerland*
[k] *University of Lausanne, Service of Endocrinology, Diabetes and Metabolism, Switzerland*
[l] *University of Glasgow, Division of Developmental Medicine, UK*
[m] *Deakin University, School of Exercise and Nutrition Sciences/Centre for Physical Activity and Nutrition Research, Australia*
[n] *Technical University of Lisbon, Faculty of Human Movement, Portugal*
[o] *University of Cambridge, MRC Epidemiology Unit, UK*

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ABSTRACT

Objectives: Different accelerometer cutpoints used by different researchers often yields vastly different estimates of moderate-to-vigorous intensity physical activity (MVPA). This is recognized as cutpoint non-equivalence (CNE), which reduces the ability to accurately compare youth MVPA across studies. The objective of this research is to develop a cutpoint conversion system that standardizes minutes of MVPA for six different sets of published cutpoints.
Design: Secondary data analysis.
Methods: Data from the International Children's Accelerometer Database (ICAD; Spring 2014) consisting of 43,112 Actigraph accelerometer data files from 21 worldwide studies (children 3–18 years, 61.5% female) were used to develop prediction equations for six sets of published cutpoints. Linear and non-linear modeling, using a leave one out cross-validation technique, was employed to develop equations to convert MVPA from one set of cutpoints into another. Bland Altman plots illustrate the agreement between actual MVPA and predicted MVPA values.
Results: Across the total sample, mean MVPA ranged from 29.7 MVPA min d^{-1} (Puyau) to 126.1 MVPA min d^{-1} (Freedson 3 METs). Across conversion equations, median absolute percent error was 12.6% (range: 1.3 to 30.1) and the proportion of variance explained ranged from 66.7% to 99.8%. Mean difference for the best performing prediction equation (VC from EV) was −0.110 min d^{-1} (limits of agreement (LOA), −2.623 to 2.402). The mean difference for the worst performing prediction equation (FR3 from PY) was 34.76 min d^{-1} (LOA, −60.392 to 129.910).
Conclusions: For six different sets of published cutpoints, the use of this equating system can assist individuals attempting to synthesize the growing body of literature on Actigraph, accelerometry-derived MVPA.

* Corresponding author.
E-mail address: brazendk@email.sc.edu (K. Brazendale).

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1. Introduction

Accelerometers are widely used for assessing free living physical activity levels of children and adolescents.[1–3] The data typically derived from accelerometers, activity counts, are most commonly processed using a set of calibrated and cross-validated cutpoints.[1,4] The use of cutpoints allows for the data to be distilled into categories of intensity ranging from sedentary to vigorous intensity, with these commonly reported as minutes per day ($\min d^{-1}$).[5] Over the past decade, different sets of cutpoints have been developed for use in studies investigating the activity levels of youth (<18 yrs).[6–8] Thus, even when raw accelerometer count data between or among studies are very similar, the application of different cutpoints for estimating minutes of moderate-to-vigorous physical activity (MVPA) to those raw data offer vastly different estimates of MVPA.[9] Unfortunately, even though studies report physical activity in minutes per day, direct comparison cannot be made across studies employing different sets of cutpoints.

Put simply, activity intensity estimates can differ greatly between studies investigating the same population solely because of the cutpoints chosen by the researchers.[10,11] Bornstein et al. defined this problem as 'cutpoint non-equivalence' (CNE).[12] The overarching limitation inherent in CNE is that direct comparisons across studies measuring physical activity via accelerometry cannot be made since the outcome metric ($\min d^{-1}$) is not equivalent, even though expressed in the same units. Thus, attempts at synthesizing a body of literature, disregarding CNE, leads to distorted and biased conclusions (e.g., combining studies using overly conservative cutpoints with studies using overly generous cutpoints). An example of this issue can be found in the recent Institute of Medicine report "Early Childhood Obesity Prevention Policies" where physical activity recommendations were made for preschool-age children by evaluating studies that provide different estimates of physical activity based on different cutpoints.[13] This scenario substantially impacts the soundness of public health policies and initiatives.

A solution to CNE has been proposed by Bornstein et al. who employed secondary data to devise a conversion system to translate reported MVPA estimates from one set of cutpoints into another.[12] Within the findings, originally disparate estimates of MVPA were able to be compared by using a conversion equation. For instance, comparing three studies that used three different sets of cutpoints reporting 91.2 $\min d^{-1}$, 55.2 $\min d^{-1}$, and 20.8 $\min d^{-1}$ of MVPA was problematic. But after applying the conversion equations the estimates were similar, 59.2 $\min d^{-1}$, 55.2 $\min d^{-1}$, and 58.0 $\min d^{-1}$ of MVPA,[12] and, therefore, logical evaluations could be drawn on daily MVPA between the three studies. Converting activity estimates into the same set of cutpoints for evaluation purposes allows practitioners, policy-makers, and researchers to interpret the abundance of evidence on physical activity levels of populations from a common standpoint.

Currently, there are no universally accepted cutpoints, and with the different methodological approaches to calibration studies,[14,15] discrepancies in MVPA estimates between studies (i.e. CNE) will continue. Bornstein et al.[12] provided a solution to CNE for preschool aged children, therefore, the purpose of this study is to illustrate the use of a conversion system that will translate MVPA ($\min d^{-1}$) produced by one set of cutpoints to an MVPA ($\min d^{-1}$) estimate using a different set of cutpoints for children and adolescents.

2. Methods

This is a secondary data analysis using existing pooled data from the International Children's Accelerometer Database (ICAD, http://www.mrc-epid.cam.ac.uk/research/studies/icad/; Spring 2014). This database was constructed to gather data on objectively measured physical activity of youth from around the world.[16,17] All individual studies went through their own ethics committee approval. The aims, design, study selection, inclusion criteria, and methods of the ICAD project have been described in detail elsewhere.[17] In short, a PubMed search and personal contacts resulted in 24 studies worldwide being approached and invited to contribute data. Inclusion criteria consisted of studies that used a version of the Actigraph accelerometer (Actigraph LLC, Pensacola, FL) in children 3–18 years with a sample size greater than 400.[17] After identification, the principal investigator was contacted, and upon agreement, formal data-sharing arrangements were established. All partners (i.e. contributors of data) consulted with their respective research boards to obtain consent before contributing their data to the ICAD. In total, 21 studies conducted between 1998 and 2009 from 10 countries contributed data to the ICAD. The majority of the studies were located in Europe ($N = 14$), with the United States, Brazil, and Australia contributing 4 studies, 1 study, and 2 studies, respectively.[17] All individual data within the pooled data set were allocated a unique and non-identifiable participant ID to ensure anonymity of data.

For the present analysis, data from all 21 studies on children and adolescents aged between 3 and 18 years were used. These data are comprised of 44,454 viable baseline and repeated measures files from a total of 31,976 participants (female 62.4%). A comprehensive description of the assessment of physical activity is available elsewhere.[17] Across all studies, Actigraph accelerometers were waist-mounted,[17] and all children with a minimum of 1 day, with at least 500 min of measured accelerometer wear time were included. The ICAD database epochs varied from 5 s to 60 s, therefore reintegrated 60-s epochs formed the pooled ICAD database.[17] Although the reintegration procedure may slightly over or underestimate MVPA,[18] it is commonly accepted when handling different epoch lengths.[19,20]

In an effort to provide researchers with physical activity data derived from a range of Actigraph cutpoints, the ICAD distilled intensity categories (e.g. sedentary, light, moderate, vigorous) from six commonly used Actigraph cutpoints.[17,21] After receiving the ICAD dataset, a MVPA variable was created for each of the six cutpoints. A breakdown of these cutpoints, along with their corresponding MVPA counts-per-minute can be found in Table 1. The cutpoints used by ICAD, and for analysis in this study, were Pate et al. (PT),[7] Puyau et al. (PY),[8] Freedson equation et al., where the MVPA threshold can be either 3 METs (FR3) or 4 METs (FR4),[22–24] Van Cauwenberghe et al. (VC),[25] and Evenson et al. (EV).[26]

The development and validation of the prediction equations followed a similar procedure previously used by Bornstein et al.[12] Linear and non-linear regression models, accounting for valid days and repeated measures on a single participant (i.e. longitudinal data) were used to develop the conversion equations. Due to the nature of the dataset, access to raw accelerometer count data were not available. However, an additional analysis was run to explore if any fixed effects existed between studies that collected data using 60 s epochs ($n = 14$), and studies employing shorter epochs (e.g. 5–30 s epochs, $n = 7$). A 'leave one out' cross-validation procedure was employed to assess how well each equation performed.[27] In this procedure, each study assumed the role of the validation sample and the remaining 20 studies were used as the derivation sample. This procedure was repeated 21 times until each study had served as the validation sample.

The development of the prediction equations included linear and non-linear terms where appropriate. Furthermore, key covariates were incorporated into the equations where these added significantly to the model including: age (years); gender; and wear time (average wear time per day in minutes). Inclusion criteria for