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Title: Equating accelerometer estimates among youth: the Rosetta Stone 2

Article Type: Original Research

Keywords: cutpoints, MVPA, measurement, policy, public health, children

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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 cutpoints, the use of this equating system can assist individuals attempting to synthesize the growing body of literature on Actigraph, accelerometry-derived MVPA.
Attn: Gregory Kolt, Ph.D.
Editor-in-Chief,
Journal of Science and Medicine in Sport

Dear Dr. Kolt,

We would like to have the following original research article titled ‘Equating accelerometer estimates among youth: the Rosetta Stone 2’ to be considered for publication in the Journal of Science and Medicine in Sport under the sub-discipline physical activity and health. We believe this research holds great value and application to the field of physical activity and public health in youth.

The manuscript is a follow-up to the research article titled ‘Equating accelerometer estimates of moderate-to-vigorous physical activity: In search of the Rosetta Stone’ published in your journal, Volume 14, Issue 5, September, 2011. In this, prediction equations were developed for synthesizing accelerometer-derived physical activity estimates of pre-school children. This follow-up manuscript develops prediction equations from a larger sample of children (>30,000) across 10 countries, for children and adolescents (3-18 years) using 6 commonly employed Actigraph accelerometer cutpoints. We believe this to be a worthwhile procedure as “cutpoint non-equivalence” continues to burden the physical activity measurement field, and 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.

The attached manuscript has been submitted solely to this journal, and the findings have not been previously published, posted online, or are under consideration from another journal. As the corresponding/first author on this project, I had full access to all aspects of the research and writing process, and take full responsibility for the paper.

The authors declare that there are no conflicts of interest and no external financial support. I would like to thank you and your editorial staff for taking the time in reviewing our manuscript.

Yours sincerely,

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The authors would like to thank both reviewers for taking the time to consider this manuscript and appreciate the constructive feedback. The authors would also like to express their appreciation for the support given to the manuscript regarding its contribution to the field of physical activity measurement. In consideration of the comments from both reviewers, we believe the subsequent additions have strengthened the manuscript considerably.

Reviewer 1 comments

1- First, how did the authors take into account the potential effect of seasonality in physical activity data collected in the framework of ICAD? In other words, because data from the different countries involved in ICAD may not be collected at the same time, perhaps there are some internal differences to be considered?

   The purpose of this research was to develop a cutpoint conversion system that standardizes minutes of MVPA from a large and diverse sample. The authors view any effect of seasonality as an unmeasured confounder, which would be equally distributed when calculating the mean MVPA min/day from all 21 studies (See table 1.) Secondly, we believe that internal differences that may exist across the different studies can be advantageous to the credibility of the prediction equations generated in terms of their widespread use (i.e. international application), as they are created on a host of conditions as opposed to one setting and/or set of conditions.

2- Second, with the available data, it is possible to evaluate the effect of the reintegration procedure on the results given by the conversion equation. I would suggest that the authors ask for this information in order to address this issue. It may be a real added value of the study. May be there is no effect of the reintegration on the application of the conversion system; but this should be proven and the current manuscript should be used to solve this important issue.

The authors believe that this is a worthwhile pursuit; however, after communication with the ICAD steering committee (e-mail 11/17/2014, 11/24/2014 and 12/02/2014) access to the raw accelerometer data files for each study is not possible.

“... at present we do not have the necessary permission from the contributors of data to give out raw data.” (Member of ICAD Steering committee).

However, of the 21 studies, 14 used 60 second epochs, with the remainder employing either 5 (2 studies), 10, 15 (3 studies), or 30 second epoch. In order to explore if reintegration had any impact, the authors created a dummy variable (0 – 60 second epoch, 1 – Other) and re-ran the analysis. There were no fixed effects when reintegration was taken in to consideration, therefore this was not considered in the final models. However, we agree with reviewer 1 that this must be explored further and have addressed this issue accordingly in the manuscript. (Discussion/limitations: Page 10-Line 182). Amendments have also been made in the methods and results sections.

Methods: Page7- Line 106

“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 second epochs (n=14), and studies using shorter epochs (E.g. 5-30 second epochs, n=7).”

Results: Page8- Line 137

“Additionally, there were no fixed effects between studies that originally used 60 second epochs, and those studies collecting data in shorter epochs, therefore, this was not considered further in any of the models.”
Discussion/Limitation: Page 10- Line 190

“Although an additional analysis confirmed no fixed effects existed between studies that collected data using 60 second epochs and studies employing shorter epochs, the impact the reintegration procedure may hold over conversion equations is still unknown. Further investigation is required into the degree of error surrounding the formation of prediction equations from different epoch lengths, and how that may compromise the generalizability of the conversions.”

3- Finally, some cut-points used in the current study have been developed for preschoolers and should not be extended to schoolchildren and adolescents. For example, the cut-points by Pate et al and that by Van Cauwemberghe et al. Conversely, I disagree completely with the authors as they decided to ignore the cut-points provided by Mattocks et al. and Treuth et al., which should be preferred among adolescents. The reason in support to the exclusion of these cut-points is based on the study by Trost et al., which is highly debatable by itself. The fact that a number of researchers have decided to be true to this study remain unclear, since ROC analysis as well as many other probabilistic approaches are subject to debate. Especially, in ROC analysis, the selection of the classification variable and the way it is then dichotomized, are generally obscure, and may completely influence results. Thus, the authors need to exercise caution in ignoring some cut-points in favour of others. In the revised version of their manuscript; it will be a good idea to test the conversion equation by including the cut-points by Mattocks et al. and by Treuth et al., especially among adolescents. Together with this, they should avoid the use of cut-points developed for preschoolers among adolescents.

We agree with the reviewer that the use of cut-points developed for a specific age range (e.g., preschoolers) and applying them to older (or younger) children is, technically, questionable. However, the application of cut-points, irrespective of the age range they were originally developed, is performed quite extensively in the literature. For instance, Janz et al (2002) used Freedson cutpoints (6-18yrs) to derive MVPA estimates of 4-6yr olds, while Reilly et al has consistently been using Puyau cut-points (developed on 6-16yr olds) for preschoolers (4yr olds).

The inclusion of all cut-points, including those that were originally excluded, is important so that all data can be converted into a single estimate of MVPA, regardless of the cut-point chosen.

After correspondence with some experts in the field, and from a more detailed review of the Trost et al. study (2011), the authors agree with Reviewer 1’s comments and have removed the corresponding statement that supports the discontinued use of Treuth and Mattocks cutpoints (Page 10; Line179).

Ideally, the authors would like to include the Mattocks et al. and Treuth et al. cutpoints. In the e-mail correspondence (11/17/2014, 11/24/2014 and 12/02/2014) with the ICAD steering committee, the cutpoints for Mattocks et al. and Treuth et al. were not developed on this wave of data, and is therefore unattainable at this time. The ICAD steering committee have made it clear that new cutpoints will be made available in their next wave of data stating “We are in the process of running the next wave of ICAD. In this run we will include all previous data and new data. If you would like ‘new’ cutpoints to appear in Wave 2 please email me and The ICAD Steering/Working group can discuss their inclusion.” (Member of ICAD Steering committee). The authors agree that this is a limitation of the current study and has mentioned accordingly in the manuscript (Page 10; Line 179)

“As mentioned previously, the original cutpoints provided by ICAD do not represent the entire range of cutpoints available for use in the field (e.g. Treuth 30, Mattocks 22), however, future iterations of the Rosetta Stone should look to include new prediction equations developed on different cutpoints than those used in this study.”
Reviewer 2 comments

Page 2, Line 6: It’s a little misleading to say regardless of which cut point is used. That statement implies you can use the prediction equations on any cut point derived data set which isn’t true. Suggest revising this sentence.

Revised sentence (Page 2, Line 6)

“The objective of this research is to develop a cutpoint conversion system that standardizes minutes of MVPA across six different sets of cutpoints.”

Page 2, Line 24: The conclusion doesn’t stand alone and seems a bit ambiguous. Clarify what the equating system is and that it is specific to data using certain published ActiGraph cut-points.

Revised sentence (Page 3, Line 24)

“Across 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.”

Page 4, Line 37: I would be careful when using raw accelerometer data as this could be taken to mean raw acceleration data. Suggest changing to raw accelerometer count data.

Revised sentence (Page 4, Line 37)

“Thus, even when raw accelerometer count data between or among studies are very similar…”

Page 7, Line 11: Why did you not consider including number of wear days as a covariate? It would be wise to address the potential impact of days of wear on the accuracy/utility of these equations in the discussion section.

We appreciate this comment; however, there is little reason to believe that the number of days an accelerometer is worn would impact the ability to convert the information collected using one set of cutpoints into another set of cutpoints. We do agree that the number of days is likely to influence the estimate of habitual physical activity, but we believe this would not influence the conversion of activity estimates.

Page 9, Line 154: This section and the data in table 3 nicely illustrate how the equations can be used to equate MVPA between studies using different cut-points. However if one was to attempt to synthesise across studies you are still left with the issue of which cut-point to standardise to i.e. do you convert all data from X to Evenson or from Evenson to X? It would be useful for the reader to include a discussion point here elaborating on this point.

The authors appreciate reviewer 2 bringing up this point. The authors believe that making a recommendation on the best cutpoint to standardize is inappropriate, mainly because the authors did not evaluate the validity of these cutpoints in question, therefore making any recommendation questionable. The underlying use of this conversion system is to give researchers (attempting to synthesize their findings with other research) a viable platform from which MVPA comparisons can be made. At this point, the existence of cutpoint non-equivalence (CNE) is due to researchers continuing to favor a particular cutpoint, and until a universally recommended cutpoint can be agreed upon, or validated, this is unlikely to change (See Page 10- Line 195). What we have done is offer a conversion system where researchers can take a chosen cutpoint of interest and
equate it to other MVPA findings from studies employing a different cutpoint. Being able to synthesize the literature in this way can provide a coherent landscape of where a population stands in terms of MVPA levels.

Bland Altman plots: It looks like agreement is worse for individuals with >100 mins MVPA per day. Was there similar heteroscedasticity in the data for the other equations? If so this issue should be noted in the discussion section

*The authors agree with this observation. The second Bland Altman, which illustrates the worst performing equation (r-squared =0.323) presents a degree of heteroscedasticity. This was also observed during the other poorer-performing prediction equations. The authors have noted this evidence of heteroscedasticity in the discussion section and suggest readers take caution when using some of these prediction equations.*

Added sentence below (Page 9, Line 165)

“It must be noted that a degree of heteroscedasticity can be observed in Figure 1b, where the proportion of variance explained was low (>33%). Rosetta Stone users must interpret their MVPA predictions with caution when using some of the ‘poorer performing’ prediction equations (R² = <60%).”
Equating accelerometer estimates among youth: the Rosetta Stone 2

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On behalf of the International Children’s Accelerometry Database (ICAD) Collaborators

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Tables: 2 (Additional Table 3 added as a supplementary file)

Figures: 1
Title: Equating accelerometer estimates among youth: the Rosetta Stone 2
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.

Keywords: cutpoints, MVPA, measurement, policy, public health, children
Introduction

Accelerometers are widely used for assessing free living physical activity levels of children and adolescents \(^1\text{-}^3\). The data typically derived from accelerometers, activity counts, are most commonly processed using a set of calibrated and cross-validated cutpoints \(^1\text{-}^4\). 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 \((\text{min} \cdot \text{d}^{-1})^5\). Over the past decade, different sets of cutpoints have been developed for use in studies investigating the activity levels of youth \((<18\text{yrs})^6\text{-}^8\). 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 \(^10\text{-}^11\). Bornstein et al., (2011) 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 \((\text{min} \cdot \text{d}^{-1})\) 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. (2011) 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. (2011) 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.

Methods

This is a secondary data analysis using existing pooled data from the International Children’s
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
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. 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. 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 3-18 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. Across all studies, Actigraph accelerometers were waist-mounted, and all children with a minimum of 1 day, with at least 500 minutes of measured accelerometer wear time were included. The ICAD database epochs varied from 5 seconds to 60 seconds, therefore reintegrated 60-second epochs formed the pooled ICAD database. Although the reintegration procedure may slightly over or underestimate MVPA, it is commonly accepted when handling different epoch lengths.

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. 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), Puyau et al. (PY), Freedson equation et al., where the MVPA threshold...
can be either 3 METs (FR3) or 4 METs (FR4)\textsuperscript{22-24}, Van Cauwenberghe et al. (VC)\textsuperscript{25}, and Evenson et al. (EV)\textsuperscript{26}.

The development and validation of the prediction equations followed a similar procedure previously used by Bornstein et al. (2011)\textsuperscript{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 second epochs (n=14), and studies employing shorter epochs (e.g. 5-30 second epochs, n=7). A ‘leave one out’ cross-validation procedure was employed to assess how well each equation performed\textsuperscript{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 these variables were contingent upon a significant increase in the proportion of variance explained (R\textsuperscript{2}), and a reduction in the average error and absolute percent error. Average error (a) and absolute percent error (b) were calculated using the following formulae:

\[
\begin{align*}
(a) & = \sqrt{\frac{\sum (Y - Y_{prime})^2}{(N - 1)}} \\
(b) & = \left[\frac{(Y - Y_{prime})}{Y}\right] \times 100
\end{align*}
\]

Above, “Y” is the actual MVPA value and “Y_{prime}” is the predicted MVPA value from the generated equation\textsuperscript{12}. All equations containing significant demographic variables (e.g. age, gender, wear time) were reported. Finally, Bland Altman plots\textsuperscript{28} were used to illustrate the agreement between the actual MVPA value and the predicted MVPA values. Limits of agreement were calculated as \( \tilde{m} \pm (2 \times \hat{s}) \) where “\( \tilde{m} \)”
is the mean difference between the actual and predicted MVPA, and “ś” is the mean standard deviation.

All statistical analyses were performed using Stata (v.12.1, College Station, TX).

Results

The final ICAD sample consisted of 43,112 files, representing 31,113 children (female 61.5%) between the ages of 3-18 years. Table 1 displays the average MVPA in minutes per day (min.d\(^{-1}\)) for the six sets of cutpoints for the entire sample. Across the six cutpoints, MVPA estimates were from PY 29.65 min.d\(^{-1}\) (± 21.38), VC 47.81 min.d\(^{-1}\) (± 28.52), EV 49.38 min.d\(^{-1}\) (± 29.17), FR4 64.87 min.d\(^{-1}\) (± 47.02), PT 77.55 min.d\(^{-1}\) (± 38.49), and FR3 126.12 min.d\(^{-1}\) (± 75.82). Prediction models with the corresponding proportion of variance explained, average error, and absolute percent error are displayed in Table 2. In total, 61 prediction equations were generated. With the exception of two of these equations (VC from EV, and EV from VC), age contributed significantly to the models, while gender was included in three models (VC from FR3, EV from FR3, and PY from FR3). The third covariate under consideration, wear time, did not contribute significantly to any of the models. Additionally, there were no fixed effects between studies that originally used 60 second epochs, and those studies collecting data in shorter epochs, therefore, this was not considered further in any of the models. Using the best model from each possible conversion, the mean absolute percent error was 12.6%, with 1.3% and 30.1% representing the minimum (VC from EV) and maximum (PY from FR3) percent error, respectively. The proportion of variance explained ranged from 66.7% (FR3 from PY) to 99.8% (VC from EV). Figures 1 (a) and (b) illustrates the best (VC from EV) and the worst (FR3 from PY) prediction equations in the form of Bland Altman plots. The mean difference for VC from EV was -0.110 min.d\(^{-1}\), with -2.623 to 2.402 representing the lower and upper bounds of the limits of agreement (LOA), respectively. The mean difference for FR3 from PY was 34.76 min.d\(^{-1}\) (LOA -60.392 to 129.910).
Discussion

The use of accelerometers provides researchers with a practical, reliable, and valid tool to objectively measure physical activity levels of children and adolescents. Despite these benefits, the widespread use of accelerometers in the field of physical activity measurement has continued to be burdened by CNE\textsuperscript{3,11,29}. The use of different cutpoints has resulted in contrasting estimates of physical activity for children and adolescents, thereby, significantly limiting comparisons of the estimates of physical activity intensity and the prevalence of meeting physical activity guidelines\textsuperscript{9,15,29}.

This study has built on the concept of cutpoint conversion first demonstrated by Bornstein et al. (2011) for preschool-aged children, and provides a solution to the problem of CNE for children and adolescents aged 3-to-18 years. Table 3 (supplementary table) demonstrates the utility and accuracy of this equating system by using previous research that has published MVPA estimates (min.d\textsuperscript{-1}) on two or more cutpoints coinciding with the cutpoints used in this study\textsuperscript{10,25,29}. Recognizing the problem of CNE, Guinhouya et al. examined MVPA of children aged 9 years using FR3 and PY cutpoints\textsuperscript{10}. Of concern, was the difference in the estimate of MVPA between the two sets of cutpoints (113 MVPA min.d\textsuperscript{-1})\textsuperscript{10}. Using the specific conversion equation developed herein for these two cutpoints, the difference is reduced to 7 MVPA min.d\textsuperscript{-1}. In comparison, converting FR3 MVPA in to PY MVPA has taken MVPA estimates from uninformative (141 MVPA min.d\textsuperscript{-1} vs. 28 MVPA min.d\textsuperscript{-1})\textsuperscript{10}, to coherence (21 MVPA min.d\textsuperscript{-1} vs. 28 MVPA min.d\textsuperscript{-1}). It must be noted that a degree of heteroscedasticity can be observed in Figure 1b, where the proportion of variance explained was low (>33%). Rosetta Stone users must interpret their MVPA predictions with caution when using some of the ‘poorer performing’ prediction equations (R\textsuperscript{2} = <60%).

Ultimately, these conversion equations present a practical solution to synthesizing the growing body of literature that reports estimates of youth MVPA using accelerometers to guide public health policy for children and adolescent physical activity recommendations.
A major strength of this study is the diversity and sample size of the data used to derive the conversion equations. The ICAD sample consisted of information on over 30,000 children and adolescents, from 10 different countries, representing 21 studies using waist-mounted Actigraph accelerometers. Although the conversion equations are limited to the six cutpoints used for this study, the cutpoints employed herein are commonly used within the physical activity literature, therefore providing widespread utility of the prediction equations for future research to evaluate their findings. Lastly, the equating system is relatively simple to use and requires commonly published and accessible information (e.g. MVPA min.d⁻¹, age, gender).

On the other hand, there are limitations to this study that need to be considered. As mentioned previously, the original cutpoints provided by ICAD do not represent the entire range of cutpoints available for use in the field (e.g. Treuth, Mattocks), however, future iterations of the Rosetta Stone should look to include new prediction equations developed on different cutpoints than those employed in this study. It must be noted that the cutpoints employed in this analysis were developed with some amount of error, and the prediction equations generated within this study bring an additional degree of error. However, while this error exists, one must consider what is worse - comparing estimates of MVPA that indicate a difference of over 100 min·d⁻¹ between cut points or 7 min·d⁻¹? Also, the 21 studies forming the ICAD database reported epochs ranging from 5 seconds to 60 seconds. The ICAD database reintegrated seven of the 21 studies into 60 second epochs, and research has shown how MVPA data collected in shorter epochs (e.g. 5 seconds) can result in higher estimates of MVPA compared to MVPA data collected in longer epochs. Although an additional analysis confirmed no fixed effects existed between studies that collected data using 60 second epochs and studies employing shorter epochs, the impact the reintegration procedure may hold over conversion equations is still unknown. Further investigation is required into the degree of error surrounding the formation of prediction equations from different epoch lengths, and how that may compromise the generalizability of the conversions.

Conclusion
In summary, this study proposes a solution to CNE by illustrating the use of an equating system that demonstrates acceptable accuracy allowing for comparisons across six different sets of cutpoints used for measuring MVPA in children and adolescents. Until a universally accepted cutpoint can be agreed, researchers will continue to select different cutpoints, and disparities will continue among studies evaluating physical activity levels of similar populations. This considerably impedes efforts to synthesize the growing body of literature on children and adolescents physical activity behavior. Utilizing the equating system gives researchers, practitioners and policymakers the capacity to “paint a better picture” of physical activity levels through which relevant policies can be developed and evaluated.
Practical Implications

- The prediction equations developed within this study allow practitioners to synthesize accelerometer-derived MVPA estimates of children and adolescents between the ages of 3 and 18 years across six commonly used Actigraph cutpoints.

- Converting accelerometer-derived MVPA 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 (e.g. youth of different ages) from a common standpoint.

- With a coherent understanding of the population prevalence of physical activity, policy-makers can evaluate, and potentially reconsider, the realism of policies and standards pertaining to children and adolescents physical activity.
Acknowledgements

We would like to thank all participants of the original studies that contributed data to ICAD.

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The ICAD Collaborators include: Prof LB Andersen, University of Southern Denmark, Odense, Denmark (Copenhagen School Child Intervention Study (CoSCIS)); Prof S Andersen, Norwegian School for Sport Science, Oslo, Norway (European Youth Heart Study (EYHS), Norway); Prof G Cardon, Department of Movement and Sports Sciences, Ghent University, Belgium (Belgium Pre-School Study); Centers for Disease Control and Prevention (CDC), National Center for Health Statistics (NCHS), Hyattsville, MD USA (National Health and Nutrition Examination Survey (NHANES)); Prof A Cooper, Centre for Exercise, Nutrition and Health Sciences, University of Bristol, UK (Personal and Environmental Associations with Children's Health (PEACH)); Dr R Davey, Centre for Research and Action in Public Health, University of Canberra, Australia (Children’s Health and Activity Monitoring for Schools (CHAMPS)); Prof U Ekelund, Norwegian School of Sport Sciences, Oslo, Norway & MRC Epidemiology Unit, University of Cambridge, UK; Dr DW Esliger, School of Sports, Exercise and Health Sciences, Loughborough University, UK; Dr K Froberg, University of Southern Denmark, Odense, Denmark (European Youth Heart Study (EYHS), Denmark); Dr P Hallal, Postgraduate Program in Epidemiology, Federal University of Pelotas, Brazil (1993 Pelotas Birth Cohort); Prof KF Janz, Department of Health and Human Physiology, Department of Epidemiology, University of Iowa, Iowa City, US (Iowa Bone Development Study); Dr K Kordas, School of Social and Community Medicine, University of Bristol, UK (Avon Longitudinal Study of Parents and Children (ALSPAC)); Dr S Kriemler, Institute of Social and Preventive Medicine, University of Zürich, Switzerland (Kinder-Sportstudie (KISS)); Dr A Page, Centre for Exercise, Nutrition and Health Sciences, University of Bristol, UK; Prof R Pate, Department of Exercise Science, University of South Carolina, Columbia, US (Physical Activity in Pre-school Children (CHAMPS-US) and Project Trial of Activity for Adolescent Girls (Project TAAG)); Dr JJ Puder, Service of Endocrinology, Diabetes and Metabolism, Centre Hospitalier Universitaire Vaudois, University of Lausanne, Switzerland (Ballabeina Study); Prof J Reilly, Physical Activity for Health Group, School of Psychological Sciences and Health, University of Strathclyde, Glasgow, UK (Movement and Activity Glasgow Intervention in Children (MAGIC)); Prof. J Salmon, Centre for Physical Activity and Nutrition Research, Deakin University, Melbourne, Australia (Children Living in Active Neighbourhoods (CLAN)); Prof LB Sardinha, Exercise and Health Laboratory, Faculty of Human Movement, Technical University of Lisbon, Portugal (European Youth Heart Study (EYHS), Portugal); Dr LB Sherar, School of Sports, Exercise and Health Sciences, Loughborough University, UK; Dr A Timperio, Centre for Physical Activity and Nutrition Research, Deakin University Melbourne, Australia (Healthy Eating and Play Study (HEAPS)); Dr EMF van Sluijs, MRC Epidemiology Unit, University of Cambridge, UK (Sport, Physical activity and Eating behaviour: Environmental Determinants in Young people (SPEEDY)).


Table 1. Accelerometer cutpoints associated with moderate-to-vigorous physical activity (MVPA) in children and adolescents aged 3-18 years.

<table>
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<th>MVPA Cutpoint</th>
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*Note: All cut-points are presented as counts per minute (CPM).

ᵃ MVPA minutes per day (N = 43,112)
Table 2. Prediction equations to transform estimates of moderate-to-vigorous physical activity (MVPA; min.d\(^{-1}\)) from one set of cutpoints into MVPA (min.d\(^{-1}\)) estimated from another set of cutpoints

<table>
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<tr>
<th>Accelerometer cutpoint MVPA min.d(^{-1})</th>
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<th>Demographics</th>
<th>Leave One Out Cross Validation*</th>
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Table 2. (Continued)
### Prediction Equations

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<td>19.80</td>
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<td>0.5579</td>
<td>-0.0006</td>
<td></td>
<td>0.659</td>
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<td>0.5345</td>
<td>-0.0006</td>
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<td>0.6144</td>
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<td>0.510</td>
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<td>0.946</td>
<td>5.40</td>
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</table>

**Key:**
Prediction equations developed using entire sample (n = 43112)

For example, predicting Freedson (4MET) MVPA min. d\(^1\) using Van Cauwenberghe cutpoints

1 = males, 0 = Females

Average Error calculated using formula: \(\sqrt{\frac{\sum (Y - Y')^2}{N - 1}}\) where Y is the actual value and Y' is the predicted value

Absolute Percent Error calculated using formula: \([\frac{(Y - Y')}{Y}] \times 100\)

One study used as validation, 20 studies as derivation. Repeated until each study served as validation.
Figure 1. Bland Altman plots of best (a) and worst (b) agreement between actual MVPA and predicted MVPA values.

(a) Van Cauwenberghe MVPA predicted from Evenson MVPA. Dashed line signifies mean difference (-0.110 min.d$^{-1}$).

\( R^2 = 99.8\% \)
(b) Freedson (3MET) MVPA predicted from Puyau MVPA (Age not in model). Dashed line signifies mean difference (34.76 min.d⁻¹)
Table 3. Accuracy of the prediction equations using studies that report moderate-to-vigorous physical activity (MVPA) estimates (min.d⁻¹) using two different sets of cutpoints

<table>
<thead>
<tr>
<th>Study</th>
<th>Pre-Conversion Comparison of MVPA (min.d⁻¹)</th>
<th>Post-Conversion Comparison of MVPA (min.d⁻¹)</th>
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<tbody>
<tr>
<td></td>
<td>Cutpoint 1</td>
<td>Cutpoint 2</td>
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<tr>
<td>Guinhouya et al. (2006)</td>
<td>FR3: 141</td>
<td>PY: 28</td>
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<td>Loprinzi et al. (2012)</td>
<td>FR4: 59</td>
<td>PY: 23</td>
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<tr>
<td>Van Cauwenberghe et al. (2011)</td>
<td>VC: 55</td>
<td>EV: 58</td>
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<td>VC: 55</td>
<td>PT: 91</td>
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</tbody>
</table>

Key: FR3, Freedson (3MET); PY, Puyau; FR4, Freedson (4MET); VC, Van Cauwenberghe; EV, Evenson; PT, Pate

a Demographic information reported in studies to convert MVPA estimates: Guinhouya et al, mean age = 9 yrs; Loprinzi et al, mean age = 11 yrs; Van Cauwenberghe et al, mean age = 5.5yrs

b Using specific prediction equation from Table 2