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

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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.

Cover Letter

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9/30/2014

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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Response to Reviewers

Equating Accelerometer Estimates Among Youth: the Rosetta Stone 2

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.

<u>Reviewer 1 comments</u>

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 ($R^2 = {<}60\%$)."

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

1   **Abstract**

2   **Objectives**: Different accelerometer cutpoints used by different researchers often yields vastly different

3   estimates of moderate-to-vigorous intensity physical activity (MVPA). This is recognized as cutpoint

4   non-equivalence (CNE), which reduces the ability to accurately compare youth MVPA across studies.

5   The objective of this research is to develop a cutpoint conversion system that standardizes minutes of

6   MVPA for six different sets of published cutpoints.

7

8   **Design:** Secondary data analysis

9

10   **Methods**: Data from the International Children's Accelerometer Database (ICAD; Spring 2014)

11   consisting of 43,112 Actigraph accelerometer data files from 21 worldwide studies (children 3-18 years,

12   61.5% female) were used to develop prediction equations for six sets of published cutpoints. Linear and

13   non-linear modeling, using a leave one out cross-validation technique, was employed to develop

14   equations to convert MVPA from one set of cutpoints into another. Bland Altman plots illustrate the

15   agreement between actual MVPA and predicted MVPA values.

16

17   **Results**: Across the total sample, mean MVPA ranged from 29.7 MVPA min.d^{-1} (Puyau) to 126.1 MVPA

18   min.d^{-1} (Freedson 3 METs). Across conversion equations, median absolute percent error was 12.6%

19   (range: 1.3 to 30.1) and the proportion of variance explained ranged from 66.7% to 99.8%. Mean

20   difference for the best performing prediction equation (VC from EV) was -0.110 min.d^{-1} (limits of

21   agreement (LOA), -2.623 to 2.402). The mean difference for the worst performing prediction equation

22   (FR3 from PY) was 34.76 min.d^{-1} (LOA, -60.392 to 129.910).

23

24   **Conclusions**: For six different sets of published cutpoints, the use of this equating system can assist

25   individuals attempting to synthesize the growing body of literature on Actigraph, accelerometry-derived

26   MVPA.

27

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

29

30

Introduction

31

32   Accelerometers are widely used for assessing free living physical activity levels of children and

33   adolescents [1-3]. The data typically derived from accelerometers, activity counts, are most commonly

34   processed using a set of calibrated and cross-validated cutpoints [1, 4]. The use of cutpoints allows for the

35   data to be distilled into categories of intensity ranging from sedentary to vigorous intensity, with these

36   commonly reported as minutes per day (min·d^{-1}) [5]. Over the past decade, different sets of cutpoints have

37   been developed for use in studies investigating the activity levels of youth (<18yrs)[6-8]. Thus, even when

38   raw accelerometer count data between or among studies are very similar, the application of different

39   cutpoints for estimating minutes of moderate-to-vigorous physical activity (MVPA) to those raw data

40   offer vastly different estimates of MVPA [9]. Unfortunately, even though studies report physical activity in

41   minutes per day, direct comparison cannot be made across studies employing different sets of cutpoints.

42   Put simply, activity intensity estimates can differ greatly between studies investigating the same

43   population solely because of the cutpoints chosen by the researchers [10, 11]. Bornstein et al., (2011)

44   defined this problem as 'cutpoint non-equivalence' (CNE) [12]. The overarching limitation inherent in CNE

45   is that direct comparisons across studies measuring physical activity via accelerometry cannot be made

46   since the outcome metric (min·d^{-1}) is not equivalent, even though expressed in the same units. Thus,

47   attempts at synthesizing a body of literature, disregarding CNE, leads to distorted and biased conclusions

48   (e.g., combining studies using overly conservative cutpoints with studies using overly generous

49   cutpoints). An example of this issue can be found in the recent Institute of Medicine report "Early

50   Childhood Obesity Prevention Policies" where physical activity recommendations were made for

51   preschool-age children by evaluating studies that provide different estimates of physical activity based on

52   different cutpoints [13]. This scenario substantially impacts the soundness of public health policies and

53   initiatives.

54   A solution to CNE has been proposed by Bornstein et al. (2011) who employed secondary data to

55   devise a conversion system to translate reported MVPA estimates from one set of cutpoints into another

56   [12]. Within the findings, originally disparate estimates of MVPA were able to be compared by using a

57   conversion equation. For instance, comparing three studies that used three different sets of cutpoints

58   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

59   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],

60   and, therefore, logical evaluations could be drawn on daily MVPA between the three studies. Converting

61   activity estimates into the same set of cutpoints for evaluation purposes allows practitioners, policy-

62   makers, and researchers to interpret the abundance of evidence on physical activity levels of populations

63   from a common standpoint.

64   Currently, there are no universally accepted cutpoints, and with the different methodological

65   approaches to calibration studies [14, 15], discrepancies in MVPA estimates between studies (i.e. CNE) will

66   continue. Bornstein et al. (2011) provided a solution to CNE for preschool aged children, therefore, the

67   purpose of this study is to illustrate the use of a conversion system that will translate MVPA (min•d^{-1})

68   produced by one set of cutpoints to an MVPA (min•d^{-1}) estimate using a different set of cutpoints for

69   children and adolescents.

70

71

72   **Methods**

73   This is a secondary data analysis using existing pooled data from the International Children's

74   Accelerometer Database (ICAD, http://www.mrc-epid.cam.ac.uk/research/studies/icad/; Spring 2014).

75   This database was constructed to gather data on objectively measured physical activity of youth from

76   around the world [16, 17]. All individual studies went through their own ethics committee approval. The

77   aims, design, study selection, inclusion criteria, and methods of the ICAD project have been described in

78   detail elsewhere [17]. In short, a PubMed search and personal contacts resulted in 24 studies worldwide

79   being approached and invited to contribute data. Inclusion criteria consisted of studies that used a version

80   of the Actigraph accelerometer (Actigraph LLC, Pensacola, FL) in children 3-18 years with a sample size

81   greater than 400 [17]. After identification, the principal investigator was contacted, and upon agreement,

82   formal data-sharing arrangements were established. All partners (i.e. contributors of data) consulted with

83   their respective research boards to obtain consent before contributing their data to the ICAD. In total, 21

84   studies conducted between 1998 and 2009 from 10 countries contributed data to the ICAD. The majority

85   of the studies were located in Europe (N=14), with the United States, Brazil, and Australia contributing 4

86   studies, 1 study, and 2 studies, respectively [17]. All individual data within the pooled data set were

87   allocated a unique and non-identifiable participant ID to ensure anonymity of data.

88   For the present analysis, data from all 21 studies on children and adolescents aged between 3-18

89   years were used. These data are comprised of 44,454 viable baseline and repeated measures files from a

90   total of 31,976 participants (female 62.4%). A comprehensive description of the assessment of physical

91   activity is available elsewhere [17]. Across all studies, Actigraph accelerometers were waist-mounted [17], and

92   all children with a minimum of 1 day, with at least 500 minutes of measured accelerometer wear time

93   were included. The ICAD database epochs varied from 5 seconds to 60 seconds, therefore reintegrated

94   60-second epochs formed the pooled ICAD database [17]. Although the reintegration procedure may

95   slightly over or underestimate MVPA [18], it is commonly accepted when handling different epoch lengths

96   [19, 20].

97   In an effort to provide researchers with physical activity data derived from a range of Actigraph

98   cutpoints, the ICAD distilled intensity categories (e.g. sedentary, light, moderate, vigorous) from six

99   commonly used Actigraph cutpoints [17, 21]. After receiving the ICAD dataset, a MVPA variable was

100   created for each of the six cutpoints. A breakdown of these cutpoints, along with their corresponding

101   MVPA counts-per-minute can be found in Table 1. The cutpoints used by ICAD, and for analysis in this

102   study, were Pate et al. (PT) [7], Puyau et al. (PY) [8], Freedson equation et al., where the MVPA threshold

103　can be either 3 METs (FR3) or 4 METs (FR4) [22-24], Van Cauwenberghe et al. (VC) [25], and Evenson et al.

104　(EV) [26].

105　　　The development and validation of the prediction equations followed a similar procedure

106　previously used by Bornstein et al. (2011) [12]. Linear and non-linear regression models, accounting for

107　valid days and repeated measures on a single participant (i.e. longitudinal data) were used to develop the

108　conversion equations. Due to the nature of the dataset, access to raw accelerometer count data were not

109　available. However, an additional analysis was run to explore if any fixed effects existed between studies

110　that collected data using 60 second epochs (n=14), and studies employing shorter epochs (E.g. 5-30

111　second epochs, n=7). A 'leave one out' cross-validation procedure was employed to assess how well each

112　equation performed [27]. In this procedure, each study assumed the role of the validation sample and the

113　remaining 20 studies were used as the derivation sample. This procedure was repeated 21 times until each

114　study had served as the validation sample.

115　　　The development of the prediction equations included linear and non-linear terms where

116　appropriate. Furthermore, key covariates were incorporated into the equations where these added

117　significantly to the model including: age (years); gender; and wear time (average wear time per day in

118　minutes). Inclusion criteria for these variables were contingent upon a significant increase in the

119　proportion of variance explained (R^2), and a reduction in the average error and absolute percent error.

120　Average error (a) and absolute percent error (b) were calculated using the following formulae:

121　(a) $\sqrt{\left[\sum \frac{(Y - Yprime)^2}{(N-1)}\right]}$　　　　(b) $[(Y - Yprime)/Y] \times 100$

122　Above, "Y" is the actual MVPA value and "$Yprime$" is the predicted MVPA value from the generated

123　equation [12]. All equations containing significant demographic variables (e.g. age, gender, wear time) were

124　reported. Finally, Bland Altman plots [28] were used to illustrate the agreement between the actual MVPA

125　value and the predicted MVPA values. Limits of agreement were calculated as [$\dot{m} \pm (2 \times \dot{s})$] where "$\dot{m}$"

126 is the mean difference between the actual and predicted MVPA, and "$\hat{s}$" is the mean standard deviation [28].

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

128

129 **Results**

130 The final ICAD sample consisted of 43,112 files, representing 31,113 children (female 61.5%)

131 between the ages of 3-18 years. Table 1 displays the average MVPA in minutes per day (min.d^{-1}) for the

132 six sets of cutpoints for the entire sample. Across the six cutpoints, MVPA estimates were from PY 29.65

133 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),

134 PT 77.55 min.d^{-1} (± 38.49), and FR3 126.12 min.d^{-1} (± 75.82). Prediction models with the corresponding

135 proportion of variance explained, average error, and absolute percent error are displayed in Table 2. In

136 total, 61 prediction equations were generated. With the exception of two of these equations (VC from EV,

137 and EV from VC), age contributed significantly to the models, while gender was included in three models

138 (VC from FR3, EV from FR3, and PY from FR3). The third covariate under consideration, wear time,

139 did not contribute significantly to any of the models. Additionally, there were no fixed effects between

140 studies that originally used 60 second epochs, and those studies collecting data in shorter epochs,

141 therefore, this was not considered further in any of the models. Using the best model from each possible

142 conversion, the mean absolute percent error was 12.6%, with 1.3% and 30.1% representing the minimum

143 (VC from EV) and maximum (PY from FR3) percent error, respectively. The proportion of variance

144 explained ranged from 66.7% (FR3 from PY) to 99.8% (VC from EV). Figures 1 (a) and (b) illustrates the

145 best (VC from EV) and the worst (FR3 from PY) prediction equations in the form of Bland Altman plots.

146 The mean difference for VC from EV was -0.110 min.d^{-1}, with -2.623 to 2.402 representing the lower and

147 upper bounds of the limits of agreement (LOA), respectively. The mean difference for FR3 from PY was

148 34.76 min.d^{-1} (LOA -60.392 to 129.910).

149

150   **Discussion**

151   The use of accelerometers provides researchers with a practical, reliable, and valid tool to

152   objectively measure physical activity levels of children and adolescents. Despite these benefits, the

153   widespread use of accelerometers in the field of physical activity measurement has continued to be

154   burdened by CNE[4, 11, 29]. The use of different cutpoints has resulted in contrasting estimates of physical

155   activity for children and adolescents, thereby, significantly limiting comparisons of the estimates of

156   physical activity intensity and the prevalence of meeting physical activity guidelines[9, 15, 29].

157   This study has built on the concept of cutpoint conversion first demonstrated by Bornstein et al.

158   (2011) for preschool-aged children, and provides a solution to the problem of CNE for children and

159   adolescents aged 3-to-18 years. Table 3 (supplementary table) demonstrates the utility and accuracy of

160   this equating system by using previous research that has published MVPA estimates (min.d^{-1}) on two or

161   more cutpoints coinciding with the cutpoints used in this study [10, 25, 29]. Recognizing the problem of CNE,

162   Guinhouya et al. examined MVPA of children aged 9 years using FR3 and PY cutpoints [10]. Of concern,

163   was the difference in the estimate of MVPA between the two sets of cutpoints (113 MVPA min.d^{-1}) [10].

164   Using the specific conversion equation developed herein for these two cutpoints, the difference is reduced

165   to 7 MVPA min.d^{-1}. In comparison, converting FR3 MVPA in to PY MVPA has taken MVPA estimates

166   from uninformative (141 MVPA min.d^{-1} vs. 28 MVPA min.d^{-1}) [10], to coherence (21 MVPA min.d^{-1} vs. 28

167   MVPA min.d^{-1}). It must be noted that a degree of heteroscedasticity can be observed in Figure 1b, where

168   the proportion of variance explained was low (>33%). Rosetta Stone users must interpret their MVPA

169   predictions with caution when using some of the 'poorer performing' prediction equations (R^2 = <60%).

170   Ultimately, these conversion equations present a practical solution to synthesizing the growing body of

171   literature that reports estimates of youth MVPA using accelerometers to guide public health policy for

172   children and adolescent physical activity recommendations.

173   A major strength of this study is the diversity and sample size of the data used to derive the

174   conversion equations. The ICAD sample consisted of information on over 30,000 children and

175   adolescents, from 10 different countries, representing 21 studies using waist-mounted Actigraph

176   accelerometers [17]. Although the conversion equations are limited to the six cutpoints used for this study,

177   the cutpoints employed herein are commonly used within the physical activity literature [21], therefore

178   providing widespread utility of the prediction equations for future research to evaluate their findings.

179   Lastly, the equating system is relatively simple to use and requires commonly published and accessible

180   information (e.g. MVPA min.d$^{-1,}$ age, gender).

181   On the other hand, there are limitations to this study that need to be considered. As mentioned

182   previously, the original cutpoints provided by ICAD do not represent the entire range of cutpoints

183   available for use in the field (e.g. Treuth[30], Mattocks[22]), however, future iterations of the Rosetta Stone

184   should look to include new prediction equations developed on different cutpoints than those employed in

185   this study. It must be noted that the cutpoints employed in this analysis were developed with some

186   amount of error, and the prediction equations generated within this study bring an additional degree of

187   error. However, while this error exists, one must consider what is worse - comparing estimates of MVPA

188   that indicate a difference of over 100 min·d^{-1} between cut points or 7 min·d^{-1}? Also, the 21 studies

189   forming the ICAD database reported epochs ranging from 5 seconds to 60 seconds. The ICAD database

190   reintegrated seven of the 21 studies into 60 second epochs [17], and research has shown how MVPA data

191   collected in shorter epochs (e.g. 5 seconds) can result in higher estimates of MVPA compared to MVPA

192   data collected in longer epochs [18]. Although an additional analysis confirmed no fixed effects existed

193   between studies that collected data using 60 second epochs and studies employing shorter epochs, the

194   impact the reintegration procedure may hold over conversion equations is still unknown. Further

195   investigation is required into the degree of error surrounding the formation of prediction equations from

196   different epoch lengths, and how that may compromise the generalizability of the conversions.

197   **Conclusion**

198   In summary, this study proposes a solution to CNE by illustrating the use of an equating system

199   that demonstrates acceptable accuracy allowing for comparisons across six different sets of cutpoints used

200   for measuring MVPA in children and adolescents. Until a universally accepted cutpoint can be agreed,

201   researchers will continue to select different cutpoints, and disparities will continue among studies

202   evaluating physical activity levels of similar populations. This considerably impedes efforts to synthesize

203   the growing body of literature on children and adolescents physical activity behavior. Utilizing the

204   equating system gives researchers, practitioners and policymakers the capacity to "paint a better picture"

205   of physical activity levels through which relevant policies can be developed and evaluated.

206

Practical Implications

207

208   -   The prediction equations developed within this study allow practitioners to synthesize

209   accelerometer-derived MVPA estimates of children and adolescents between the ages of 3 and 18

210   years across six commonly used Actigraph cutpoints.

211   -   Converting accelerometer-derived MVPA estimates into the same set of cutpoints for evaluation

212   purposes allows practitioners, policy-makers, and researchers to interpret the abundance of

213   evidence on physical activity levels of populations (e.g. youth of different ages) from a common

214   standpoint.

215   -   With a coherent understanding of the population prevalence of physical activity, policy-makers

216   can evaluate, and potentially reconsider, the realism of policies and standards pertaining to

217   children and adolescents physical activity.

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Acknowledgements

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

MVPA Cutpoint	Symbol	Age (yrs.)																Mean[a]	SD
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18		
Pate et al.	PT	1680	1680	1680	1680	1680	1680	1680	1680	1680	1680	1680	1680	1680	1680	1680	1680	77.5	38.5
Puyau et al.	PY	3201	3201	3201	3201	3201	3201	3201	3201	3201	3201	3201	3201	3201	3201	3201	3201	29.7	21.4
Freedson et al. (3 METS)	FR3	369	446	527	614	706	803	906	1017	1136	1263	1400	1547	1706	1880	2068	2274	126.1	75.8
Freedson et al. (4 METS)	FR4	1090	1187	1290	1400	1515	1638	1770	1910	2059	2220	2392	2580	2781	3000	3239	3499	64.9	47
Van Cauwenberghe et al.	VC	2340	2340	2340	2340	2340	2340	2340	2340	2340	2340	2340	2340	2340	2340	2340	2340	47.8	28.5
Evenson et al.	EV	2296	2296	2296	2296	2296	2296	2296	2296	2296	2296	2296	2296	2296	2296	2296	2296	49.4	29.2

Note: All cut-points are presented as counts per minute (CPM).

[a] MVPA minutes per day (N = 43,112)

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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

Outcome Variable [a]	Predictor Variable	Prediction Equations [1]				Demographics		Adjusted R²	Leave One Out Cross Validation*	
		Intercept	MVPA (min.d⁻¹)	MVPA (min.d⁻¹) Squared	MVPA (min.d⁻¹) Square root	Age (years)	Gender [b]		Average Error [c] (min/day)	Absolute % Error [d]
Freedson (4 MET)	Van Cauwenberghe	-4.5855	1.7206	-0.0026				0.611	34.68	30.9
	Van Cauwenberghe	118.5514	1.0465	0.0004		-9.0859		0.931	15.18	13.0
	Evenson	-2.9598	1.4872	-0.0017				0.618	34.30	30.6
	Evenson	117.2174	1.0222	0.0004		-9.0203		0.933	14.97	12.8
	Pate	-15.8486	1.0409					0.726	29.15	25.5
	Pate	112.5384	1.0780	0.0003	-5.2759	-7.7031		0.945	13.43	12.3
	Freedson (3 MET)	-10.0605	0.4168	0.0002	1.4270			0.904	15.94	14.9
	Freedson (3 MET)	-57.4086	0.5821	0.0002	0.3919	3.3287		0.921	15.06	13.6
	Puyau	-6.5762	0.7572	-0.0009	9.8330			0.498	39.82	36.3
	Puyau	133.2262	1.3785	-0.0015	1.5535	-9.9722		0.894	18.81	16.3
Van Cauwenberghe	Freedson (4 MET)	-10.6973	0.0346	-0.0001	7.5217			0.640	20.88	24.7
	Freedson (4 MET)	-112.7420	0.6121	-0.0009	5.8395	7.1432		0.916	10.35	11.5
	Evenson	-0.4432	0.9772					0.998	1.28	1.3
	Pate	3.0936	0.8355	0.0001	-2.4403			0.937	8.07	11.1
	Pate	-11.4262	0.9492	-0.0002	-3.1015	1.1471		0.950	7.01	9.9
	Freedson (3 MET)	-17.4535	0.2050	-0.0005	4.7324			0.467	24.43	30.9
	Freedson (3 MET)	-148.3597	0.6616	-0.0007	1.8747	9.2024		0.778	15.73	20.3
	Freedson (3 MET)	-142.2791	0.5771	-0.0006	2.6592	8.9591	-5.2698	0.785	15.49	19.9
	Puyau	0.2787	1.1261	-0.0011	3.0543			0.946	7.31	10.0
	Puyau	11.4445	1.1768	-0.0011	2.3872	-0.7958		0.953	6.74	9.2

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Table 2. (Continued)

Accelerometer cutpoint MVPA min.d⁻¹   Prediction Equations [I]   Demographics   Leave One Out Cross Validation*

Outcome Variable [a]	Predictor Variable	Intercept	MVPA (min.d⁻¹)	MVPA (min.d⁻¹) Squared	MVPA (min.d⁻¹) Square root	Age (years)	Gender [b]	Adjusted R^2	Average Error [c] (min/day)	Absolute % Error [d]
Evenson	Pate	-7.6013	0.7347					0.941	8.05	10.6
	Pate	-22.9695	0.7633			1.1398		0.953	6.87	9.4
	Freedson (3 MET)	-17.7246	0.2088	-0.0005	4.8722			0.475	24.86	30.3
	Freedson (3 MET)	-151.3777	0.6753	-0.0007	1.9502	9.3962		0.785	15.89	19.7
	Freedson (3 MET)	-145.2212	0.5898	-0.0006	2.7444	9.1499	-5.3351	0.792	15.64	19.2
	Van Cauwenberghe	0.5413	1.0215					0.998	1.31	1.3
	Freedson (4 MET)	-10.6026	0.0329	0.0000	7.7146			0.647	21.18	24.1
	Freedson (4 MET)	-114.2384	0.6204	-0.0009	5.9992	7.2554		0.919	10.39	11.2
	Puyau	-0.0162	1.0679	-0.0007	3.6674			0.942	7.77	10.4
	Puyau	12.2396	1.1234	-0.0008	2.9359	-0.8736		0.950	7.13	9.1
Pate	Freedson (3 MET)	-19.5240	0.2505	-0.0006	7.2571			0.616	28.65	21.2
	Freedson (3 MET)	-181.2504	0.8145	-0.0008	3.7267	11.3690		0.880	16.40	11.3
	Van Cauwenberghe	15.1517	1.3052					0.935	11.27	9.6
	Van Cauwenberghe	36.4870	1.2695			-1.7003		0.952	9.41	8.2
	Freedson (4 MET)	-5.3433	0.0244	0.0002	10.6224			0.754	23.44	17.4
	Freedson (4 MET)	-116.4227	0.6531	-0.0007	8.7913	7.7757		0.934	11.67	9.2
	Evenson	14.3381	1.2802					0.941	10.80	9.2
	Evenson	34.7490	1.2459			-1.6215		0.956	9.02	7.7
	Puyau	3.7073	0.8087	-0.0007	9.9610			0.817	18.79	16.0
	Puyau	41.4428	0.9799	-0.0009	7.7065	-2.6895		0.860	16.05	13.9

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Table 2. (Continued)

Accelerometer cutpoint MVPA min.d⁻¹   Prediction Equations ᴴ

Outcome Variable [a]	Predictor Variable	Intercept	MVPA (min.d⁻¹)	MVPA (min.d⁻¹) Squared	MVPA (min.d⁻¹) Square root	Demographics Age (years)	Gender [b]	Adjusted R^2	Leave One Out Cross Validation* Average Error [c] (min/day)	Absolute % Error [d]
Freedson (3 MET)	Van Cauwenberghe	-8.7703	1.0464	-0.0025	14.1213			0.430	68.67	33.3
	Van Cauwenberghe	247.3136	0.6734	0.0005	8.9683	-18.3805		0.908	27.39	13.7
	Freedson (4 MET)	12.5470	2.0066	-0.0022				0.910	26.89	13.0
	Freedson (4 MET)	120.4882	1.5802	-0.0017		-7.2474		0.950	19.98	9.9
	Evenson	22.1710	2.5511	-0.0065				0.436	68.31	33.1
	Evenson	266.2679	1.6217	-0.0021		-18.3044		0.910	27.26	13.5
	Pate	10.3366	1.5058					0.566	59.91	28.0
	Pate	233.2335	1.1204			-16.6202		0.940	22.86	10.3
	Puyau	1.1251	-0.5376	0.0011	27.3953			0.3234	74.95	37.2
	Puyau	273.8841	0.6415	-0.0001	11.7666	-19.4780		0.8735	31.42	16.3
Puyau	Pate	-8.8032	0.4958					0.799	10.66	23.2
	Pate	-27.3259	0.5302			1.3738		0.833	9.50	21.2
	Freedson (3 MET)	-2.0648	0.3641	-0.0007				0.343	19.80	41.5
	Freedson (3 MET)	-109.0616	0.5579	-0.0006		6.9629		0.659	14.00	30.7
	Freedson (3 MET)	-101.9867	0.5345	-0.0006		6.7734	-4.1982	0.667	13.85	30.1
	Van Cauwenberghe	-2.4459	0.6144	0.0009				0.943	5.61	11.8
	Van Cauwenberghe	-9.8824	0.6432	0.0007		0.5610		0.949	5.25	11.1
	Freedson (4 MET)	3.2866	0.5067	-0.0010				0.510	17.86	34.7
	Freedson (4 MET)	-82.9904	0.8491	-0.0014		5.7854		0.832	10.55	20.4
	Evenson	-2.5646	0.5941	0.0009				0.939	5.80	12.4
	Evenson	-10.5480	0.6249	0.0007		0.5994		0.946	5.40	11.7

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Table 2. (Continued)

Key:

ᴵ Prediction equations developed using entire sample (n = 43112)

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

ᵇ 1 = males, 0 = Females

ᶜ Average Error calculated using formula: $\sqrt{[\Sigma(Y - Y')^2 / (N - 1)]}$ where Y is the actual value and Y' is the predicted value

ᵈ Absolute Percent Error calculated using formula: [(Y - Y')/Y] x 100

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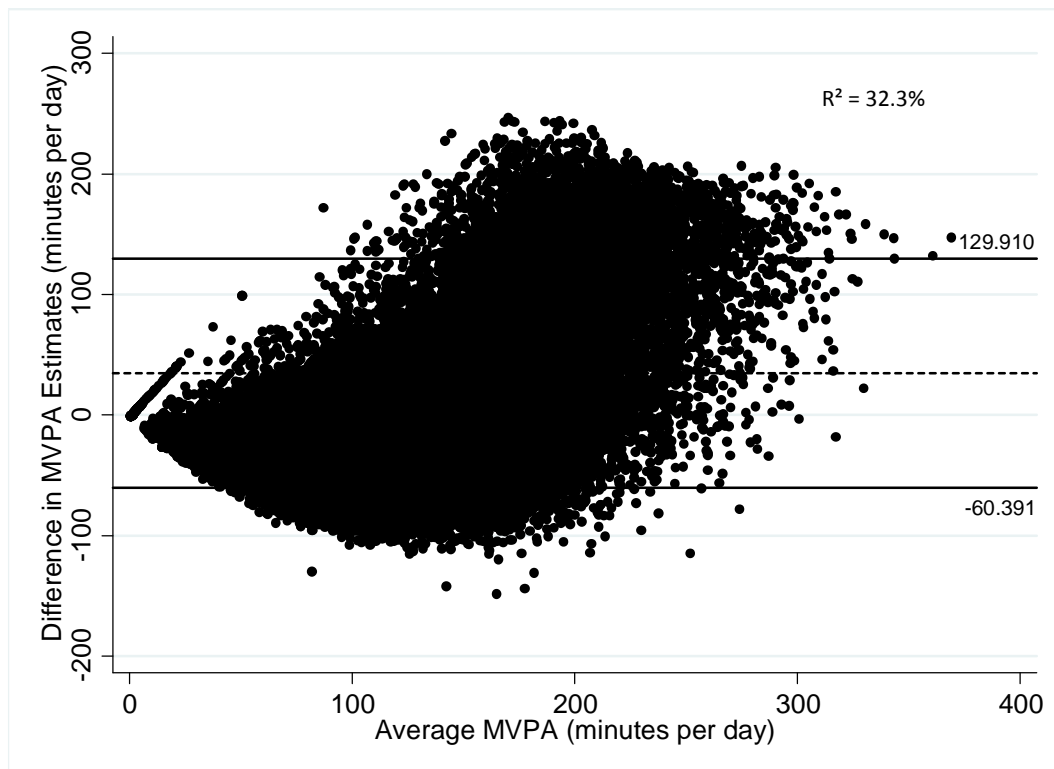
350   Figure 1. Bland Altman plots of best (a) and worst (b) agreement between actual MVPA and predicted
351   MVPA values.

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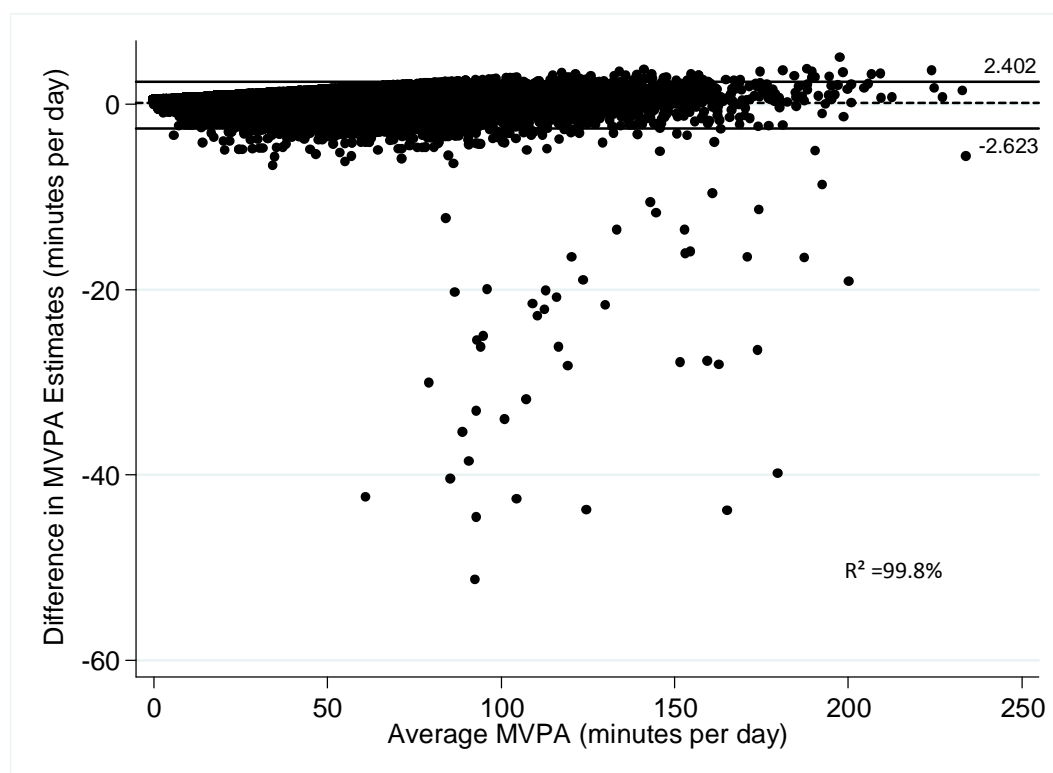
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354   (a) Van Cauwenberghe MVPA predicted from Evenson MVPA. Dashed line signifies mean
355   difference (-0.110 min.d^{-1}).
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358   (b) Freedson (3MET) MVPA predicted from Puyau MVPA (Age not in model). Dashed line signifies
359   mean difference (34.76 min.d^{-1})
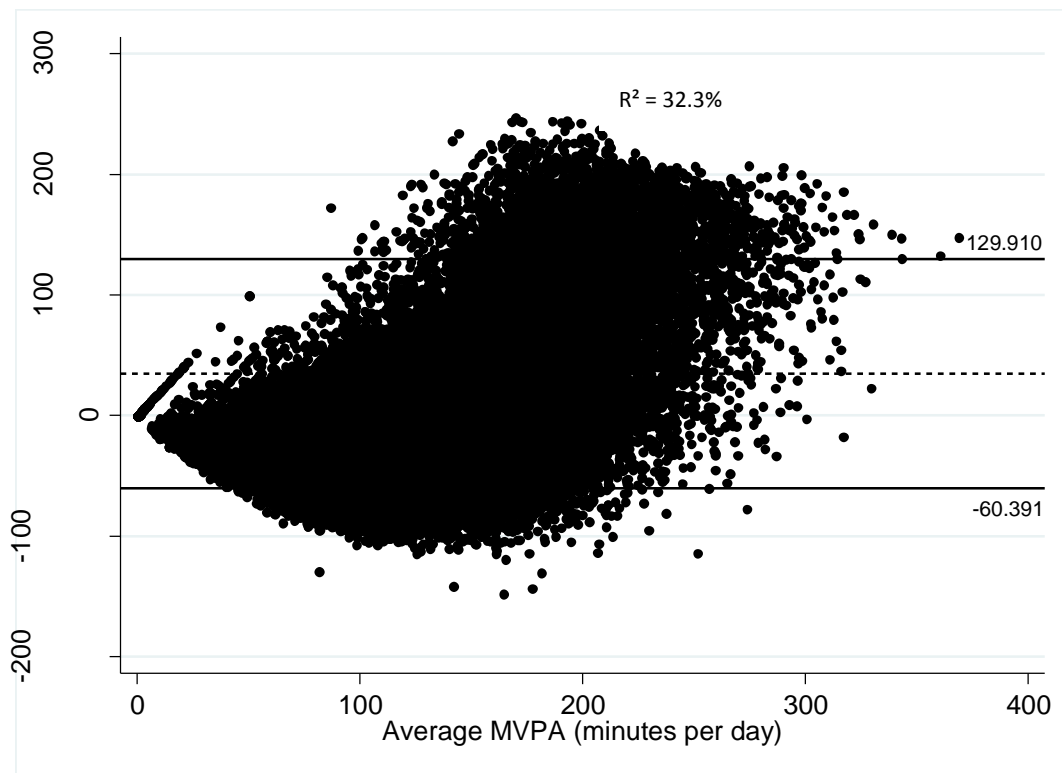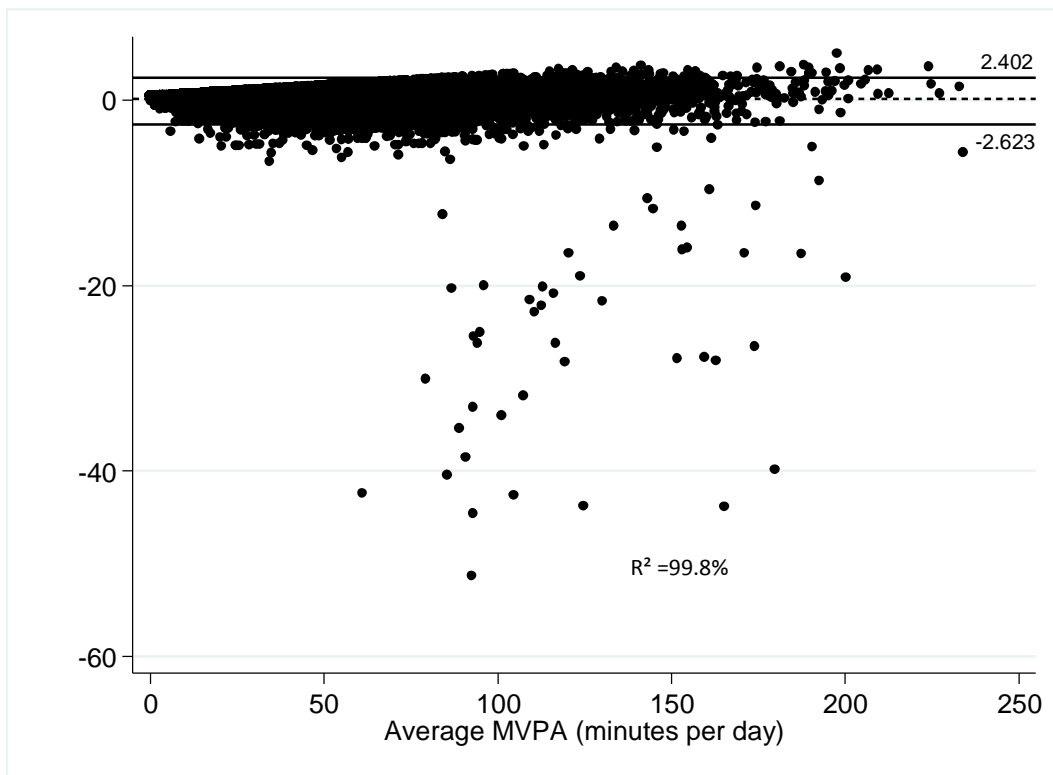
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Figure(s)

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

	Pre-Conversion Comparison of MVPA (min.d^{-1})				Post-Conversion Comparison of MVPA (min.d^{-1})		
Study [a]	Cutpoint 1	Cutpoint 2	Abs. Difference	MVPA Conversion [b]	Cutpoint 1	Cutpoint 2	Abs. Difference
Guinhouya et al. (2006)	FR3: 141	PY: 28	113	FR3 predicted from PY	21	28	7
				PY predicted from FR3	141	183	42
Loprinzi et al. (2012)	FR4: 59	PY: 23	36	FR4 predicted from PY	59	61	2
				PY predicted from FR4	26	23	3
Van Cauwenberghe et al. (2011)	VC: 55	EV: 58	3	VC predicted from EV	55	56	1
				EV predicted from VC	57	58	1
	VC: 55	PT: 91	36	VC predicted from PT	97	91	6
				PT predicted from VC	55	50	5

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