



## LJMU Research Online

**Brazendale, K, Beets, MW, Rowlands, AV, Chandler, JL, Fairclough, SJ, Boddy, LM, Olds, TS, Parfitt, G, Noonan, RJ, Downs, SJ and Cliff, DP**

**Converting between estimates of moderate-to-vigorous physical activity derived from raw accelerations measured at the wrist and from ActiGraph counts measured at the hip: The Rosetta Stone**

<http://researchonline.ljmu.ac.uk/id/eprint/7776/>

### Article

**Citation** (please note it is advisable to refer to the publisher's version if you intend to cite from this work)

**Brazendale, K, Beets, MW, Rowlands, AV, Chandler, JL, Fairclough, SJ, Boddy, LM, Olds, TS, Parfitt, G, Noonan, RJ, Downs, SJ and Cliff, DP (2018) Converting between estimates of moderate-to-vigorous physical activity derived from raw accelerations measured at the wrist and from ActiGraph**

LJMU has developed **LJMU Research Online** for users to access the research output of the University more effectively. Copyright © and Moral Rights for the papers on this site are retained by the individual authors and/or other copyright owners. Users may download and/or print one copy of any article(s) in LJMU Research Online to facilitate their private study or for non-commercial research. You may not engage in further distribution of the material or use it for any profit-making activities or any commercial gain.

The version presented here may differ from the published version or from the version of the record. Please see the repository URL above for details on accessing the published version and note that access may require a subscription.

For more information please contact [researchonline@ljmu.ac.uk](mailto:researchonline@ljmu.ac.uk)

<http://researchonline.ljmu.ac.uk/>



1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55

**Running Title:**

MVPA estimates from wrist and hip accelerometry

**Title:**

Converting between estimates of moderate-to-vigorous physical activity derived from raw accelerations measured at the wrist and from ActiGraph counts measured at the hip: The Rosetta Stone

**Keywords:**

Physical Activity, Conversion, Youth, Children, Obesity

**Authors:**

Keith Brazendale (1)  
Michael W. Beets (1)  
Alex V. Rowlands (2-4)  
Jessica L. Chandler (1)  
Stuart J. Fairclough (6, 7)  
Lynne M. Boddy (8)  
Tim S. Olds (4)  
Gaynor Parfitt (4)  
Robert J. Noonan (8)  
Samantha J. Downs (6)  
Dylan P. Cliff (5)

**Affiliations:**

1. Arnold School of Public Health, University of South Carolina, Columbia, SC USA
2. Diabetes Research Centre, University of Leicester, Leicester General Hospital, Leicester, UK
3. NIHR Leicester-Loughborough Diet, Lifestyle and Physical Activity Biomedical Research Unit, UK
4. Alliance for Research in Exercise, Nutrition and Activity (ARENA), Sansom Institute for Health Research, Division of Health Sciences, University of South Australia, Adelaide, Australia
5. Early Start Research Institute, School of Education, Faculty of Social Sciences, University of Wollongong, Wollongong, NSW, Australia

61  
62  
63  
64  
65

56  
57  
58  
59  
60

6. Department of Sport and Physical Activity, Edge Hill University, Ormskirk, UK
7. Department of Physical Education and Sport Sciences, University of Limerick, Limerick, Ireland

55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

8. Physical Activity Exchange, Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, Liverpool, UK

**Corresponding Author:**

Keith Brazendale

Arnold School of Public Health

Department of Exercise Science, University of South Carolina

921 Assembly Street

1<sup>st</sup> Floor Suite, Room 131

Columbia SC, 29208

PH: 803-777-3003

[brazendk@email.sc.edu](mailto:brazendk@email.sc.edu)

**Potential conflicts of interest:**

The authors declare no conflicts of interest

**Clinical Trials.gov**

Not Applicable

**Journal:**

Journal of Sport Sciences

## Acknowledgements

Study 1 was funded by the University of South Australia and Studies 2 and 3 were funded by Liverpool John Moores University. AR is with the National Institute for Health Research (NIHR) Diet, Lifestyle & Physical Activity Biomedical Research Unit based at University Hospitals of Leicester and Loughborough University, the National Institute for Health Research Collaboration for Leadership in Applied Health Research and Care – East Midlands (NIHR CLAHRC – EM) and the Leicester Clinical Trials Unit. The views expressed are those of the authors and not necessarily those of the NHS, the NIHR or the Department of Health. DPC is funded by an Australian Research Council (ARC) Discovery Early Career Researcher Award (DE140101588). The results of the present study do not constitute endorsement by the authors of the products described in this article. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. There are no conflicts of interest or financial interests with the products.

## Abstract

The ability to compare published group-level estimates of objectively measured moderate-to-vigorous physical activity (MVPA) across studies continues to increase in difficulty. The objective of this study was to develop conversion equations and demonstrate their utility to compare estimates of MVPA derived from the wrist and hip. Data from three studies of youth (N = 232, 9-12yrs, 50% boys) who concurrently wore a hip-worn ActiGraph and a wrist-worn GENEActiv for 7-days. ActiGraph hip count data were reduced using four established cutpoints: Evenson, Pate, Puyau, and Freedson 3MET. Wrist accelerations were reduced using the Hildebrand MVPA 200 mg threshold. Conversion equations were developed on a randomly selected subsample of 132 youth. Equations were cross-validated and absolute error, absolute percent error, and modified Bland-Altman plots were evaluated for conversion accuracy. Across equations  $R^2_{adj}$  was 0.51-0.56 with individual-level absolute error in minutes ranging from 7 (wrist-to-hip Puyau) to 14.5 minutes (wrist-to-hip Freedson 3MET) and absolute percent differences ranging from 13.9%-24.5%. Group-level cross-validation to convert hip-to-wrist MVPA resulted in average absolute percent errors ranging from 3.1%-4.9%. Conversion of wrist-to-hip MVPA resulted in average absolute percent errors ranging from 3.0%-10.0%. We recommend the use of these equations to compare published estimates of MVPA between the wear-site cut-point combinations presented.

## Introduction

As the body of scientific studies that describe or intervene on youth physical activity continues to expand, there is a growing need to be able to make comparisons across published studies, as well as synthesize the findings to inform policy-level decisions. One of the major limitations to synthesizing the youth physical activity literature is the numerous ways physical activity is measured. Objective measures of physical activity have largely been obtained using uniaxial accelerometers worn at the hip,(Stone, Faulkner, & Buliung, 2013; Troiano et al., 2008) but comparability between studies has been limited due to the large range of MVPA cut-points available for use with accelerometer data.(Bornstein et al., 2011; Brazendale et al., 2015) The advent of new technology and the growing popularity of the wrist wear-site only exacerbates the difficulties of comparing estimates of physical activity across studies.

The GENEActiv, ActiGraph GT3X+ and ActiGraph GT9X Link sample and store raw accelerations, rather than proprietary counts, and are designed for wrist-wear. The GENEActiv has grown in popularity as an objective measure of youth moderate-to-vigorous physical activity (MVPA) since it was first introduced in 2008 and is most commonly used on the wrist. (Esliger et al., 2011) The ActiGraph GT3X+, worn on the wrist, has been used in NHANES since 2011, and while estimates of physical activity intensity from these wrist-worn accelerometers have demonstrated strong reliability and validity, (Esliger et al., 2011; Phillips, Parfitt, & Rowlands, 2013) the estimates of



1  
2  
3  
4 physical activity from wrist-worn devices cannot be directly compared to estimates of  
5  
6  
7 physical activity from hip-worn devices.  
8  
9

10  
11  
12 Two previous studies have addressed the issue of non-comparable estimates of physical  
13  
14 activity across published studies through the development of conversion equations,  
15  
16 referred to as the Rosetta Stone (Bornstein, et al., 2011; Brazendale, et al., 2015). The  
17  
18 equations convert estimates of MVPA from widely used cutpoints from a single hip-worn  
19  
20 physical activity monitoring device (i.e., ActiGraph accelerometers). The application of  
21  
22 these equations was illustrated in a subsequent study (Coelho et al. 2017) where  
23  
24 published ActiGraph-derived estimates of MVPA for preschool-age children were  
25  
26  
27 “standardized” into a common cutpoint estimate of MVPA. This study illustrated that  
28  
29 when applying the Rosetta Stone equations, differences in the estimates of MVPA across  
30  
31  
32 studies could be improved from ~80 minutes/day (range 11.6 to 219) to ~14 minutes/day  
33  
34 (range 0.6 to 38.7). This reduced the differences in MVPA across studies due to the  
35  
36 application of the varying cutpoints to distill ActiGraph data into minutes of MVPA.  
37  
38  
39  
40  
41  
42  
43

44 In the absence of a comprehensive database containing all accelerometer-derived raw  
45  
46 data files that could be standardized using a single data reduction procedure, the  
47  
48 development of equating systems is necessary and should widely appeal to those seeking  
49  
50 to synthesize the growing body of literature on youth physical activity. While progress  
51  
52 has been made towards this effort, existing equating systems are limited to only a single  
53  
54 hip-worn device – ActiGraph accelerometer. We are unaware of any equating systems  
55  
56 that have been developed to compare estimates of MVPA across different wear-sites. A  
57  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4 previous study (Rowlands et al., 2016) made comparisons among wrist- and hip-worn  
5  
6  
7 accelerometer-derived MVPA and found that, depending on the data reduction procedure,  
8  
9 comparable estimates of minutes spent in MVPA could be obtained between the two  
10  
11 placements. However, this study did not provide a way to standardize previously  
12  
13 published group-level estimates of MVPA so numbers could be compared across  
14  
15 different cut-points or placements. Therefore, the purpose of this study was to develop a  
16  
17 series of Rosetta Stone conversion equations to compare estimates of MVPA derived  
18  
19 from accelerations measured at the wrist and from ActiGraph counts measured at the hip  
20  
21  
22 in elementary school-aged children.  
23  
24  
25  
26  
27  
28

## 29 **Methods**

30  
31  
32  
33  
34 This is a secondary data analysis using data from three studies: 1) 58 children, aged 10-12  
35  
36 years, recruited from primary schools in South Australia (Rowlands et al., 2014); 2) 129  
37  
38 children, aged 9-10 years, recruited from primary schools in Liverpool, UK (Fairclough  
39  
40 et al., 2016); 3) 81 children, aged 9-11 years, recruited from two primary schools in  
41  
42  
43 Liverpool, UK. The appropriate university research ethics committee approved each  
44  
45 study. Written informed consent and assent were obtained from the parents/guardians and  
46  
47 children, respectively. Height was measured to the nearest 0.1 cm and body mass to the  
48  
49 nearest 0.1 kg.  
50  
51  
52  
53  
54  
55

56 Free-living physical activity was measured by concurrent wear of the GENEActiv on the  
57  
58 non-dominant wrist and the ActiGraph GT3X+ positioned above the right hip, on a belt  
59  
60  
61  
62  
63  
64  
65

worn around the waist, for seven consecutive days. In study 1, children were requested to wear both monitors day and night, removing the hip-worn ActiGraph for water-based activities only. In studies 2 and 3, children were requested to wear both monitors at all times except when sleeping or during water-based activities.

The GENEActiv is a triaxial accelerometry-based activity monitor with a dynamic range of +/- 8g (Gravity Estimator of Normal Everyday Activity, ActivInsights Ltd, Cambridgeshire, UK). The ActiGraph GT3X+ is a triaxial accelerometry-based activity monitor with a dynamic range of +/- 6 g (ActiGraph LLC, Pensacola, FL, USA). Study 1: The GENEActivs were initialized to collect data at 87.5 Hz and data uploaded using GENEActiv PC software version 2.2. The ActiGraphs were initialized to collect data at 80 Hz and data uploaded using Actilife version 6.5.3. Data were collected between April and December 2012. Studies 2 and 3: The GENEActivs and ActiGraphs were both initialized to collect data at 100 Hz and data uploaded using GENEActiv PC software version 2.2 and Actilife version 6.11.4, respectively. Study 2 data were collected between January and May 2014 and study 3 data were collected in January and February 2015.

GENEActiv .bin files were analyzed with R-package GGIR version 1.2-0 (<http://cran.r-project.org>).(van Hees et al., 2014; van Hees et al., 2013) Signal processing in GGIR includes the following steps: 1. Autocalibration using local gravity as a reference;(van Hees, et al., 2014) 2. Detection of sustained abnormally high values; 3. Detection of non-wear; 4. Calculation of the average magnitude of dynamic acceleration, i.e. the vector magnitude of acceleration corrected for gravity (Euclidean Norm

$$\sum \sqrt{x^2 + y^2 + z^2} - g$$

1  
2  
3  
4 minus 1 g, ENMO) over user-defined s epochs:  
5  
6  
7

8  
9 ENMO = with negative values set to zero.  
10  
11  
12

13  
14 Study 1 captured data in 5 s epochs with studies 2 and 3 capturing data in 1 s epochs,  
15  
16 thus, for study 1, ENMO was averaged over 5 s epochs; and for studies 2 and 3, ENMO  
17  
18 was averaged over 1 s epochs.  
19  
20  
21  
22

23  
24 Files were excluded from all analyses if post-calibration error was greater than 0.02 g and  
25  
26 individual days were classified as invalid and excluded if wear-time was insufficient (16  
27  
28 h for the 24 h protocol in study 1, 10 h for the waking wear protocol in studies 2 and 3).  
29  
30  
31

32  
33 Detection of non-wear has been described in detail previously (See ‘Procedure for non-  
34  
35 wear detection’ in supplementary document to van Hees et al., 2013(van Hees, et al.,  
36  
37 2013)). In brief, non-wear is estimated based on the standard deviation and value range of  
38  
39 each axis, calculated for 60 min windows with 15-min moving increments. If for at least  
40  
41 2 out of the 3 axes the SD is less than 13 mg or the value range is less than 50 mg the  
42  
43 time window is classified as non-wear. The default non-wear setting was used, i.e. invalid  
44  
45 data were imputed by the average at similar timepoints on different days of the week. The  
46  
47 time spent above the children’s wrist acceleration MVPA threshold of 200 mg published  
48  
49 by Hildebrand et al. (2014)(Hildebrand, VT, Hansen, & Ekelund, 2014) was calculated  
50  
51 using the argument ‘ilevels’ from the GGIR package for comparison to widely used hip-  
52  
53 worn ActiGraph MVPA cut-points.  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

ActiGraph data were analyzed using Actilife version 6.13.0. The raw.gt3x files were summarized into uniaxial (vertical) proprietary counts in 5 s epochs, resulting in four ActiGraph files for analysis per participant. Non-wear was defined as 60 min of consecutive zero counts, with an allowance for 1-2 min of counts between 0 and 100 (Troiano et al., 2008). Individual days were classed as invalid and excluded if wear-time was insufficient (16 h for the 24 h protocol in study 1, 10 h for the waking wear protocol in studies 2 and 3). Each file was analyzed with four widely-used MVPA cut-points: very low (1100 CPM (counts per minute), approximately equivalent to the cut-point for an 11 y old (3 METs) using the age-specific criteria of the Freedson group, published by Trost et al. (2002);(S. G. Trost et al., 2002) low (1680 CPM, Pate et al., 2006);(Pate, Almeida, McIver, Pfeiffer, & Dowda, 2006) medium (2296 CPM, Evenson et al., 2008);(Evenson, Catellier, Gill, Ondrak, & McMurray, 2008) high (3200 CPM, Puyau et al., 2002).(Puyau, Adolph, Vohra, & Butte, 2002)

Consistent with established protocols, (Bornstein, et al., 2011; Brazendale, et al., 2015) linear and non-linear regression models were used to develop conversion equations in a development group of 132 participants, approximately half of the sample size. (Snee, RD, 1977) Age, gender, height, and weight were introduced as predictors and incorporated in the final model if the proportion of variance ( $R^2$ ) increased by  $\geq 1\%$  and/or the absolute error in minutes and percent decreased by  $\geq 1$  minute or 1%, respectively. For the equation cross-validation, the following procedures were used. First, the 100 participants were randomly selected, without replacement (i.e., a participant could not appear twice within the same group), into 20 groups of 25 participants to conduct the group-level 20-

1  
2  
3  
4 fold cross-validation. Average estimates of group-level MVPA were calculated for each  
5  
6  
7 of the 20 groups. The equations converting GENEActiv wrist to ActiGraph hip and  
8  
9 ActiGraph hip to GENEActiv wrist were applied to the group-level means. Actual  
10  
11 device-derived MVPA estimates were compared to the Rosetta Stone equation-estimated  
12  
13 MVPA. Differences, at the group-level, were calculated as the actual (i.e., device-derived  
14  
15 estimates) minus the Rosetta Stone converted estimates of MVPA. Since the equations  
16  
17 are designed to convert published group-level estimates rather than converting individual-  
18  
19 level data points, group-level validations were incorporated instead of individual-level  
20  
21 validations. Bland Altman plots were created to illustrate the agreement between actual  
22  
23 and predicted MVPA estimates.(Bland & Altman, 1986) In the absence of an empirically  
24  
25 derived range of acceptable error,  $\pm 10\%$  was chosen and plotted to depict reasonable  
26  
27 differences between actual and predicted MVPA values.  
28

## 32 33 34 35 36 **Results**

37  
38  
39  
40  
41 A summary of the sample characteristics and estimates of MVPA across devices and  
42  
43 cutpoints is presented in **Table 1**. Scatter plots illustrating the relationship among wrist  
44  
45 GENEActiv and hip ActiGraph estimates of MVPA in the derivation sample are  
46  
47 presented in **Supplemental Figure 1**. The Rosetta Stone equations converting  
48  
49 GENEActiv to ActiGraph and ActiGraph to GENEActiv are presented in **Table 2**.  
50  
51 Overall, the proportion of variation explained ranged from  $R^2_{adj}$  0.52 to 0.56. This  
52  
53 represented an absolute error in minutes ranging from 7.0 minutes/day up to 14.5  
54  
55 minutes/day or an absolute percent error ranging from 13.9% to 24.5%. The only models  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4 that included an additional independent explanatory variable were those converting  
5  
6  
7 GENEActiv with Pate ActiGraph cutpoints where age was included in the final models.  
8  
9

10  
11 --- Insert **Table 1** and **2**, and **Supplemental Figure 1** here ---  
12  
13

14  
15  
16  
17 The results from the 20-fold cross-validation are presented in **Table 3** and **Supplemental**  
18  
19 **Figure 2**. The average absolute minute difference and absolute percent difference of the  
20  
21 conversions for ActiGraph converted into GENEActiv estimates of MVPA demonstrated  
22  
23 a high degree of comparability. Specifically, the average absolute differences in minutes  
24  
25 ranged from 2.0 to 3.3 minutes/day, representing an average absolute percent error of  
26  
27 3.1% to 4.9%. Similar findings were observed when converting GENEActiv from  
28  
29 ActiGraph, with the average absolute difference in minutes ranging from 1.1 to 9.0  
30  
31 minutes/day, representing an average absolute percent error ranging from 3.0% to 10.0%.  
32  
33  
34  
35  
36  
37  
38

39 --- Insert **Table 3** and **Supplemental Figure 2** here ---  
40  
41  
42

## 43 **Discussion**

44

45  
46  
47  
48 The purpose of this study was to develop conversion equations for comparing raw  
49  
50 accelerations from wrist-worn GENEActiv and hip-worn ActiGraph derived estimates of  
51  
52 MVPA across published studies. Overall, the equations developed demonstrated a high  
53  
54 degree of accuracy when applied to the group-level means of the derivation sample. This  
55  
56 suggests that those who wish to compare estimates of MVPA across published studies or  
57  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4 wish to combine estimates of MVPA analytically across studies using different devices,  
5  
6  
7 for instance within a quantitative meta-analysis, can utilize the developed Rosetta Stone  
8  
9 equations to standardize the estimates into a common metric of choice.

10  
11  
12  
13  
14 As the options for objective monitoring devices continue to diversify, this renders direct  
15  
16  
17 comparisons of the estimates of physical activity across studies as problematic. This  
18  
19 problem has a long history in the field of physical activity, yet there are few  
20  
21 solutions.(Kim, Beets, & Welk, 2012; S. Trost, 2007; Welk, McClain, & Ainsworth,  
22  
23 2012) Without a unifying consensus on the device and protocols for reducing activity  
24  
25 intensity data, the field will continuously require some form of conversion procedures to  
26  
27  
28 facilitate direct comparisons across studies. The findings in this study provide evidence  
29  
30 that, with a moderately high degree of accuracy, comparisons can be made across studies  
31  
32  
33 reporting group-level estimates of either the GENEActiv or ActiGraph accelerometer  
34  
35 MVPA. This is important, especially as the use of the GENEActiv continues to increase,  
36  
37 as well as, the expansion of the body of literature that has used or is currently using  
38  
39 ActiGraph accelerometers.  
40  
41  
42  
43  
44

45  
46 There are several limitations that need attention. First, the sample for the development of  
47  
48 equations while statistically appropriate in terms of size, may not be entirely  
49  
50 representative of the estimates of GENEActiv and ActiGraph physical activity for youth  
51  
52 aged 9 to 12 years. Also, the equations are only applicable to ActiGraph hip studies that  
53  
54  
55 have used 5 second epochs – the epochs used to generate the hip worn ActiGraph  
56  
57 estimates of MVPA in this study. Thus, while the equations demonstrated a high degree  
58  
59  
60  
61  
62  
63  
64  
65



1  
2  
3  
4 of accuracy, additional equations may need to be developed to more accurately represent  
5  
6  
7 the “typical” activity levels of youth utilizing accelerations measured at the wrist and  
8  
9 ActiGraph counts measured at the hip. Ideally, a larger and international dataset, like the  
10  
11 International Children Accelerometry Database (ICAD) used in the past to develop  
12  
13 Rosetta Stone equations,(Brazendale, et al., 2015) would be created that includes youth  
14  
15 ( $\leq 18$  years) simultaneously wearing two or more commonly used objective motion  
16  
17 sensors. Further, the number of cutpoints evaluated herein does not represent the entirety  
18  
19 of the cutpoints that exist and are used in the published literature.(Kim, et al., 2012) Thus,  
20  
21 additional Rosetta Stone conversion equations are needed to convert all possible  
22  
23 reduction methods. Lastly, similar to the cutpoints employed to develop past Rosetta  
24  
25 Stone equations,(Bornstein, et al., 2011; Brazendale, et al., 2015) it must be noted that the  
26  
27 cutpoints included in the present analysis were developed with some amount of error, and  
28  
29 the prediction equations generated within this study bring an additional degree of error.  
30  
31  
32  
33  
34  
35  
36 Despite this, the equations can be used to make comparisons more “similar” by  
37  
38 standardizing them to a common metric, either MVPA derived from accelerations  
39  
40 measured at the wrist or ActiGraph counts measured at the hip. This alone, should hold  
41  
42 value to those seeking to compare activity levels from studies utilizing these two devices.  
43  
44  
45  
46

## 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65

In conclusion, the developed equations demonstrate a high level of consistency among device-derived MVPA and the group-level converted estimates of MVPA. The authors recommend the use of these equations when comparing published estimates of MVPA

1  
2  
3  
4 using either device. Further, using the Rosetta Stone equations provides researchers and  
5  
6  
7 public-health professionals with a practical solution to synthesize findings that can aid  
8  
9 with policy-level decisions regarding MVP  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

## References

- Bland, J. M., & Altman, D. G. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*, *1*(8476), 307-310.
- Bornstein, D. B., Beets, M. W., Byun, W., Welk, G., Bottai, M., Dowda, M., & Pate, R. (2011). Equating accelerometer estimates of moderate-to-vigorous physical activity: in search of the Rosetta Stone. *J Sci Med Sport*, *14*(5), 404-410. doi: S1440-2440(11)00075-2 [pii]10.1016/j.jsams.2011.03.013
- Brazendale, K., Beets, M., Bornstein, D., Moore, J., Pate, R., Weaver, R., . . . van Sluijs, E. (2015). Equating accelerometer estimates among youth: the Rosetta Stone 2. *Journal of Science and Medicine in Sport*.
- Coelho, C. D., Ravagnani, F., Brazendale, K., R.G., W., & Beets, M. W. (2017). Moderate-to-Vigorous physical activity in preschool children: Applying the Rosetta Stone. *Journal of Science and Medicine in Sports*.
- Esliger, D. W., Rowlands, A. V., Hurst, T. L., Catt, M., Murray, P., & Eston, R.G. (2011). Validation of the GENEA Accelerometer. *Med Sci Sports Exerc*, *43*(6), 1085-1093. doi: 10.1249/MSS.0b013e31820513be
- Evenson, K. R., Catellier, D. J., Gill, K., Ondrak, K. S., & McMurray, R. G. (2008). Calibration of two objective measures of physical activity for children. *J Sports Sci*, *26*(14), 1557-1565. doi: 904797576 [pii]10.1080/02640410802334196
- Fairclough, S. J., Noonan, R., Rowlands, A. V., Van Hees, V., Knowles, Z., & Boddy, L. M. (2016). Wear Compliance and Activity in Children Wearing Wrist- and Hip-Mounted Accelerometers. *Med Sci Sports Exerc*, *48*(2), 245-253. doi: 10.1249/MSS.0000000000000771
- Hildebrand, M., VT, V. A. N. H., Hansen, B. H., & Ekelund, U. (2014). Age group comparability of raw accelerometer output from wrist- and hip-worn monitors. *Med Sci Sports Exerc*, *46*(9), 1816-1824. doi: 10.1249/MSS.0000000000000289
- Kim, Y., Beets, M. W., & Welk, G. J. (2012). Everything you wanted to know about selecting the "right" Actigraph accelerometer cut-points for youth, but ... : A systematic review. *Journal of Science and Medicine in Sport*, *15*(4), 311-321. doi: 10.1016/j.jsams.2011.12.001
- Pate, R. R., Almeida, M. J., McIver, K. L., Pfeiffer, K. A., & Dowda, M. (2006). Validation and calibration of an accelerometer in preschool children. *Obesity (Silver Spring)*, *14*(11), 2000-2006.

- 1  
2  
3  
4 Phillips, L. R., Parfitt, G., & Rowlands, A. V. (2013). Calibration of the GENE A  
5 accelerometer for assessment of physical activity intensity in children. *J Sci Med*  
6 *Sport, 16*(2), 124-128. doi: 10.1016/j.jsams.2012.05.013  
7  
8  
9 Puyau, M. R., Adolph, A. L., Vohra, F. A., & Butte, N. F. (2002). Validation and  
10 calibration of physical activity monitors in children. *Obesity Research, 10*(3),  
11 150-157.  
12  
13  
14 Rowlands, A. V., Cliff, D. P., Fairclough, S. J., Boddy, L. M., Olds, T. S., Parfitt, G., . . .  
15 Beets, M. W. (2016). Moving Forward with Backward Compatibility: Translating  
16 Wrist Accelerometer Data. *Med Sci Sports Exerc.* doi:  
17 10.1249/MSS.0000000000001015  
18  
19  
20 Rowlands, A. V., Rennie, K., Kozarski, R., Stanley, R. M., Eston, R. G., Parfitt, G. C., &  
21 Olds, T. S. (2014). Children's physical activity assessed with wrist- and hip-worn  
22 accelerometers. *Med Sci Sports Exerc, 46*(12), 2308-2316. doi:  
23 10.1249/MSS.0000000000000365  
24  
25  
26 Snee, R. D. (1977). Validation of regression models: methods and  
27 examples. *Technometrics, 19*(4), 415-428.  
28  
29  
30 Stone, M. R., Faulkner, G. E., & Buliung, R. N. (2013). How active are children in  
31 Toronto? A comparison with accelerometry data from the Canadian Health  
32 Measures Survey. *Chronic Dis Inj Can, 33*(2), 61-68.  
33  
34  
35 Troiano, R. P., Berrigan, D., Dodd, K. W., Masse, L. C., Tilert, T., & McDowell, M.  
36 (2008). Physical activity in the United States measured by accelerometer. *Med Sci*  
37 *Sports Exerc, 40*(1), 181-188. doi: 10.1249/mss.0b013e31815a51b3  
38  
39  
40 Trost, S. (2007). Measurement of physical activity in children and adolescents. *American*  
41 *Journal of Lifestyle Medicine, 1*, 299-314.  
42  
43  
44 Trost, S. G., Pate, R. R., Sallis, J. F., Freedson, P. S., Taylor, W. C., Dowda, M., &  
45 Sirard, J. (2002). Age and gender differences in objectively measured physical  
46 activity in youth. *Medicine and Science in Sports and Exercise, 34*(2), 350-355.  
47 doi: Doi 10.1097/00005768-200202000-00025  
48  
49  
50 van Hees, V. T., Fang, Z., Langford, J., Assah, F., Mohammad, A., da Silva, I. C., . . .  
51 Brage, S. (2014). Autocalibration of accelerometer data for free-living physical  
52 activity assessment using local gravity and temperature: an evaluation on four  
53 continents. *J Appl Physiol (1985), 117*(7), 738-744. doi:  
54 10.1152/jappphysiol.00421.2014  
55  
56  
57 van Hees, V. T., Gorzelniak, L., Dean Leon, E. C., Eder, M., Pias, M., Taherian, S., . . .  
58 Brage, S. (2013). Separating movement and gravity components in an  
59 acceleration signal and implications for the assessment of human daily physical  
60 activity. *PLoS One, 8*(4), e61691. doi: 10.1371/journal.pone.0061691  
61  
62  
63  
64  
65

Welk, G. J., McClain, J., & Ainsworth, B. E. (2012). Protocols for Evaluating  
Equivalency of Accelerometry-Based Activity Monitors. *Medicine and Science in  
Sports and Exercise*, 44, S39-S49. doi: 10.1249/MSS.0b013e3182399d8f

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

**Table 1.** Total sample\* moderate-to-vigorous physical activity and demographics

	Total Sample (N = 232)			Derivation Sample (n = 132)			Validation Sample (n = 100)		
Sex (% boys)	50%			50%			48%		
Age (years)	10.4	±0.7		10.5	±0.7		10.3	±0.5	
Moderate-to-Vigorous Physical Activity (min d <sup>-1</sup> )	M	SD	Range	M	SD	Range	M	SD	Range
ActiGraph (hip-placed)									
Evenson	57.5	±16.5	(23.0, 129.4)	60.4	±17.5	(28.2, 129.4)	53.6	±14.6	(23.0, 108.8)
Pate	77.3	±20.4	(33.1, 179.4)	81.9	±21.6	(46.4, 179.4)	71.4	±17.3	(33.1, 139.4)
Puyau	38.3	±12.7	(13.1, 86.6)	39.8	±13.5	(13.1, 86.6)	36.3	±11.4	(13.6, 78.8)
Freedson 3MET	100.0	±25.7	(44.5, 243.8)	107.0	±27.2	(61.4, 243.8)	90.8	±20.2	(44.5, 170.7)
GENEActiv (wrist-placed)									
Hildebrand	69.3	±24.1	(14.7, 140.8)	71.8	±25.5	(14.7, 140.8)	66.3	±22.1	(25.6, 127.0)

\*6 children removed due to missing data (e.g., age, sex); M= Mean, SD = Standard Deviation

**Table 2.** Prediction equations to transform MVPA estimates from wrist GENEActiv cutpoint (200 mg) into MVPA estimates from ActiGraph hip-based cutpoints

Conversion	Regression Equations*				Absolute Error (minutes)		Absolute Percent Error (%)		
	Intercept	MVPA (min d <sup>-1</sup> )	Age	Adj. R <sup>2</sup>	Avg.	Range	Avg.	Range	
GENEActiv to Evenson	23.73773	0.5110695		0.5589	9.0	(0.0, 45.7)	15.8	(0.0, 64.6)	
Evenson to GENEActiv	6.015253	1.088575			13.2	(0.0, 51.9)	23.9	(0.0, 147.6)	
GENEActiv to Pate	61.16497	0.8653035	-5.734111	0.5553	10.9	(0.1, 69.3)	13.9	(0.1, 50.0)	
Pate to GENEActiv	-7.719662	0.6335803	4.199442		10.5	(0.0, 49.7)	24.5	(0.0, 166.2)	
GENEActiv to Puyau	15.40396	1.418296		0.5604	7.0	(0.0, 32.1)	19.6	(0.0, 101.7)	
Puyau to GENEActiv	11.31649	0.3961999			10.1	(0.0, 51.9)	21.6	(0.0, 129.6)	
GENEActiv to Freedson 3MET	-53.98608	0.753542	10.17694	0.5154	14.5	(0.4, 83.7)	15.4	(0.4, 57.7)	
Freedson 3MET to GENEActiv	95.82304	0.671705	-9.13186		13.1	(0.1, 51.8)	21.6	(0.1, 226.7)	

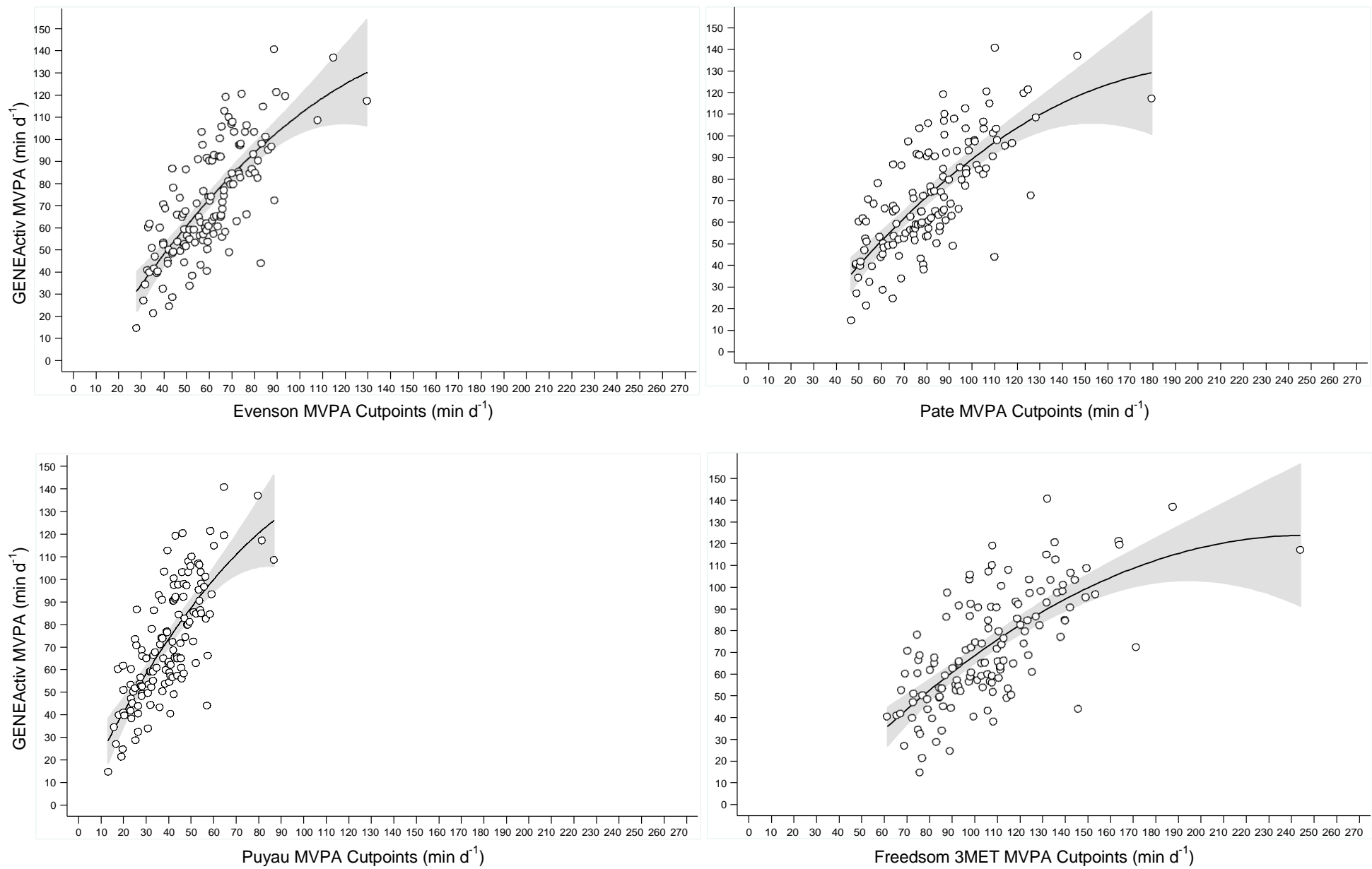
\*Covariates (e.g., age, sex) and non-linear terms (e.g., MVPA squared, square root of MVPA) were included in the model if statistically significant ( $p < 0.05$ )

**Table 3.** Group level estimate ( $n = 25$  per group) of GENEActiv minutes of MVPA compared to ActiGraph minutes of MVPA reduced using four cutpoints versus predicted minutes of MVPA using Rosetta Stone Equations

Conversion	GENEActiv from ActiGraph				ActiGraph from GENEActiv			
	Device Specific MVPA <sub>1</sub> (min·d <sup>-1</sup> ) Estimate	Rosetta Stone Predicted MVPA <sub>1</sub> (min·d <sup>-1</sup> ) Estimate	GENEActiv vs. Predicted from ActiGraph		Device Specific MVPA <sub>1</sub> (min·d <sup>-1</sup> ) Estimate	Rosetta Stone Predicted MVPA <sub>1</sub> (min·d <sup>-1</sup> ) Estimate	ActiGraph vs. Predicted from GENEActiv	
	GENEActiv	ActiGraph to GENEActiv	Difference (min·d <sup>-1</sup> )	Percent Difference	ActiGraph	GENEActiv to ActiGraph	Difference (min·d <sup>-1</sup> )	Percent Difference
Evenson and GENEActiv	66.1	64.7	2.3	3.4%	54.0	57.5	3.6	6.7%
Pate and GENEActiv	66.1	64.5	2.5	3.8%	71.8	77.2	5.4	7.6%
Puyau and GENEActiv	66.1	67.1	2.0	3.1%	36.5	37.5	1.1	3.0%
Freedson 3MET and GENEActiv	66.1	63.4	3.3	4.9%	91.2	100.2	9.0	10.0%

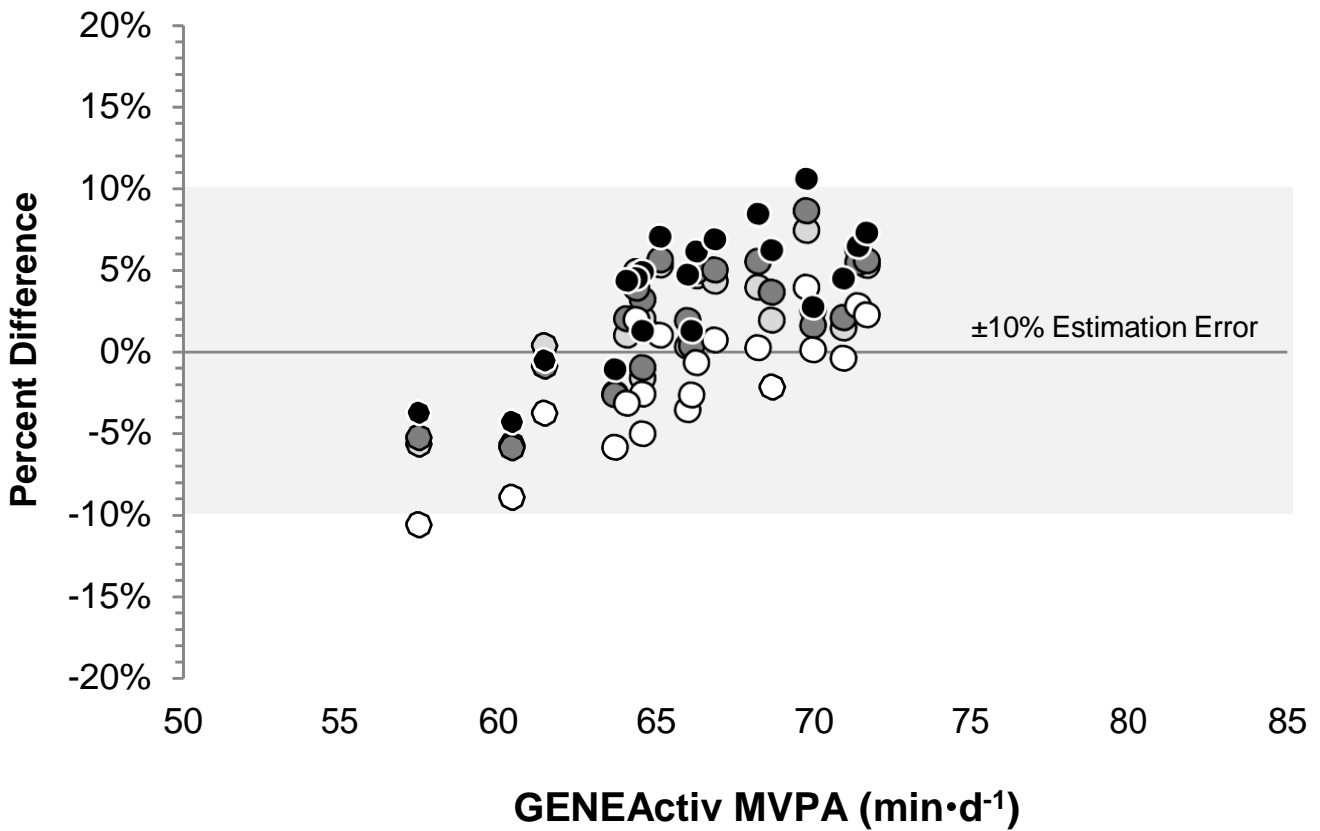
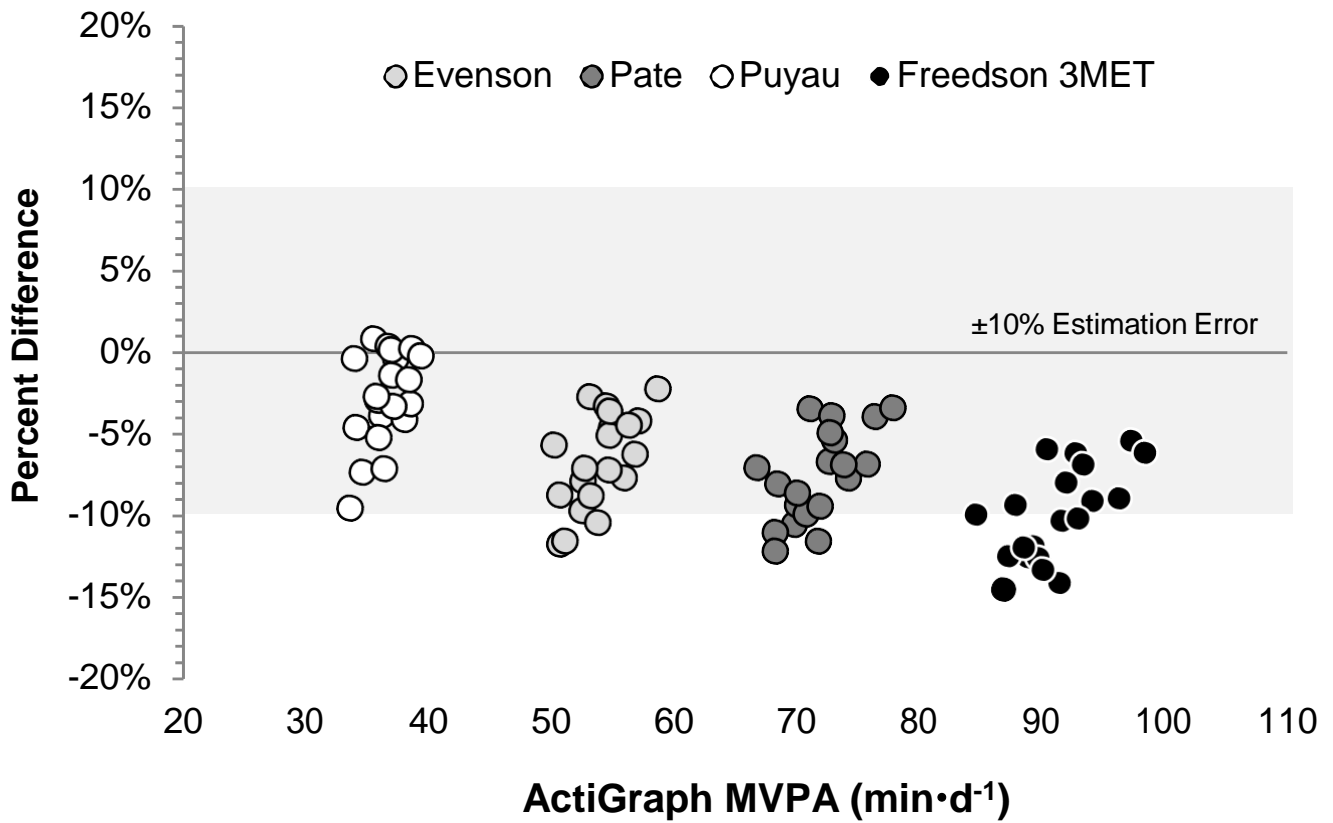
<sup>a</sup> Average error in minutes and percent error represent the absolute errors.





**Supplemental Figure 1.** Scatter plot of GENEActiv and four ActiGraph estimates of MVPA in the derivation sample ( $n = 132$ )

Note: Shaded area represents 95% confidence interval across line of best fit



**Supplemental Figure 2.** Bland Altman Plot comparing Rosetta Stone Converted and Unconverted GENEActiv estimates of MVPA to one of four ActiGraph MVPA cutpoints