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A source of systematic bias in self-reported physical activity: The cutpoint bias hypothesis

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ABSTRACT

Objectives: Estimates of adults' moderate-to-vigorous physical activity (MVPA) based on self-report are generally higher than estimates derived from criterion measures. This study examines a possible explanation for part of this discrepancy: the cutpoint bias hypothesis. This hypothesis proposes that inter- and intra-individual variability in energy expenditure, combined with the fact that adults perform a high proportion of daily activities at or just above the traditional 3 MET cutpoint, result in systematic over-estimates of MVPA.

Design: Cross-sectional.

Methods: Time-use recalls (n = 6862) were collected using the Multimedia Activity Recall for Children and Adults from 2210 adults (1215 female, age 16–93 years) from 16 studies conducted in Australia and New Zealand between 2008-2017. Minutes spent in MVPA were estimated using models with varying levels of intra- and inter-individual (total variability) *Unadjusted* (0% total variability), *Low* (11.9%), *Best Guess* (20.7%), and *High* (30.0%).

Results: In the Unadjusted model, participants accumulated an average of 129 (standard deviation 127) min/day of MVPA. Estimated MVPA was 98 (110), 99 (107) and 108 (107) min/day in the Low, Best Guess and High variability models, respectively, with intra-class correlation coefficients with the Unadjusted model ranging from 0.78 to 0.83.

Conclusions: These findings support the hypothesis of a cutpoint bias, which probably contributes to the large disparities seen between self-reported and criterion measures of MVPA. Future studies are needed to confirm these findings using other self-report instruments and in other populations.

Practical implications

- Self-report measures often overestimate moderate to vigorous physical activity compared with criterion measures.
- The findings from this study support the notion of a cutpoint bias, related to the 3 MET threshold for MVPA.
- The cutpoint bias hypothesis suggests that self-report methods will systematically overestimate moderate to vigorous physical activity due to variation in energy expenditure within and between individuals and the large amount of time spent in activities that fall at or about the 3-MET threshold for moderate to vigorous intensity physical activity.

1. Introduction

Estimates of adults' moderate-to-vigorous physical activity (MVPA) based on self-report are generally higher than estimates derived from criterion and device-based measures.[1–3] Over the years, a number of possible explanations have been proposed for this discrepancy. Firstly, *social desirability bias* is the over-reporting of perceived "good" behavior when completing self-report instruments. Desire for social approval has been found to be modestly associated with differences between device-measured and self-reported MVPA in both adults[4] and children {Adams, #4107}.[5]

A second explanation is related to *device calibration and algorithms*. Estimates of MVPA derived from accelerometry are known to vary widely according to the choice of analytical protocols.[7,9] The third is based on *epoch length*, that is, the duration over which the intensity of an activity is averaged. In accelerometry, this refers to the epoch over which the accelerations will be averaged and

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an accelerometer cut-point applied (e.g. per minute), which can have a marked effect on estimates of physical activity. For example, Aibar and Chanal[6] found that varying epoch length from 1 s to 60 s changed the estimated percentage of MVPA from 25% to 31%. In self-report instruments, the epoch length refers to the the minimum increment of time the instrument requires participants to recall activities in (typically between 5–60 min[7]). Consider a game of tennis lasting 30 min. Much of that time, the player is standing still, for example waiting to receive a serve. When measured by criterion measures, these periods would likely not register as MVPA, but averaged out over the 30 min it is likely that the rate of energy expenditure would exceed the threshold for MVPA. Previous studies have reported that only 30–50% of an activity considered >3 METs was actually captured as MVPA using device-based measures.[6,8]

We outline here a fourth possible explanation, the *Cutpoint Bias Hypothesis,* related to the 3 MET threshold used to characterize activity of at least moderate intensity. Briefly, we will argue that because of inter- and intra-individual variability in the rate of energy expenditure while performing the same activity, much self-reported activity notionally requiring energy expenditures at or a little above the traditional cutpoint of 3 METs for MVPA will in fact fall below the threshold. Because in time-use surveys people report spending only a small amount of time performing activities putatively requiring rates of energy expenditure just *below* the MVPA threshold (3 METs), but a lot of time at or just *above* the threshold, there will be an asymmetrical compensation, and self-report will systematically over-estimate actual MVPA.

The aim of this study was to examine the extent to which the use of the 3-MET cutpoint for MVPA, without considering inter- and intra-individual variability, biases estimates of MVPA based on self-report data from a large adult sample.

2. Methods

Cutpoint bias arises from a failure to take into account intra- and inter-individual *variability* when actual *population values* are unevenly distributed about a given *threshold*. In the current analysis, *variability* is variation in actual energy expenditure when different individuals perform the same activity, or when the same individual performs an activity at different times. The *threshold* is the commonly accepted 3-MET cutpoint for MVPA, and *population values* are the minutes individuals actually report spending in activities at or around the threshold.

To estimate the duration of MVPA, self-report instruments often rely on compendia such as the Ainsworth compendium[10,11] or, for children, the Youth Compendium of Physical Activities,[12,13] which assign activities an expected rate of energy expenditure in METs, based either on empirical studies or educated guesses.[10,12] When using compendia to classify self-report data, any activity thought to require ≥3 METs has conventionally been taken to constitute MVPA. While the origin of the 3 MET cut-off is unclear,[14] it is used widely in the scientific literature and in physical activity guidelines, with “brisk walking” being the commonly used behavioural indicator.

There are very few free-living activities that are performed in the same way with the same EE across and within individuals due to difference in body size and kinetics. Therefore, for any given activity, there is both inter- and intra-individual variability in rates of energy expenditure. For example, Welk et al.[15] measured the energy cost of shoveling (in the garden) to be 4.7 ± 1.57 METs, with an inter-individual coefficient of variation (CV_{inter}) of 33%. Gomersall (unpublished data) collated data on 183 estimates of energy expenditure from 50 studies involving 4409 adults. The average CV_{inter} was 19.5 (7.5)%. The CV_{inter} for the 118 studies involving activities with an estimated MET value of ≥3 was a little smaller (18.8 ± 7.6%). This is broadly in agreement with Pfeiffer et al.,[16] who found CV_{inter} values in ranging from 3 to 28% for a wide range of activities in adolescent girls.

There are fewer data on intra-individual variability. Durnin and Namyslowski[17] found an intra-individual coefficient of variation (CV_{intra}) of 10.2 ± 4.9% for standardised tasks such as walking, sitting and climbing. Fares et al.[18] found a CV_{intra} of 5% for easy cycling. Some of both the inter- and intra-individual variability will be due to measurement error ($CV_{measurement}$), generally taken to be about 3% for indirect calorimetry.[19] Adjusting Gomersall's estimates of CV_{inter} (18.8%) and Durnin's estimate of CV_{intra} (10.2%) for a 3% measurement error, the estimates of biological variability would be 18.3% and 9.7%, respectively. Assuming these sources of variability are independent, then total biological variance will be $\sqrt{(CV_{inter}^2 + CV_{intra}^2)}$ = 20.7%. In other words, a randomly chosen individual on a randomly chosen day doing the same activity will have energy expenditures varying by ±20.7%.

Importantly, if we assume that compendia accurately capture the population average rate of energy expenditure for activities, then in 50% of cases a minute of self-reported MVPA at a putative energy cost of 3 METs would not actually be MVPA if it were accurately measured. If activities at 3 METs constituted the entirety of MVPA, then self-report would overestimate actual MVPA by a factor of 2. Even activities classified in compendia as requiring on average >3 METs would often in practice fall below the 3-MET threshold. Using the value of 20.7% for total biological variance, 44% of activities at a notional 3.1 METs, 38% at 3.2 METs, 25% at 3.5 METs, 11% at 4 METs and 3% at 5 METs would not register as MVPA if they were accurately measured.

This would obviously constitute a very large over-estimation at group level of actual MVPA by self-report if it were not compensated by variability in the actual energy cost of activities below the threshold. But 43% of activities classified as 2.9 METs would actually elicit ≥3 METs, and therefore count as MVPA, as would 37% of activities at 2.8 METs, 17% of activities at 2.5 METs and 1% of activities at a notional 2 METs. These percentages are a little lower than the corresponding figures above the 3 MET threshold because we are using coefficients of variation, so the estimated standard deviation is a little less for smaller MET values.

Critically, the extent of compensation will depend on the amount of time people spend on activities near and either side of 3 METs. If people spend a lot of time doing activities requiring a notional 3 METs or a little above, then self-report will substantially over-estimate their actual MVPA. If they spend a lot of time in activities notionally requiring a little less than the 3 MET threshold, then self-report will underestimate their actual MVPA.

Looking at the adult compendium,[10] a lot of common activities cluster close to and above 3 METs, particularly walking, for example walking at 4 km/h (3.0 METs) and walking the dog (3.0 METs). However, we need empirical data to quantify the actual distribution of time spent in activities around the 3-MET threshold. To quantify the effects of cutpoint bias, we examined time-use recalls from 2210 adults (1215 female, age range 16–93 years), collated from 16 studies conducted in Australia and New Zealand between 2008 and 2017 using a variety of populations and a variety of sampling frames. Participants recalled a total of 6864 individual days, an average of 3.1 recall days per person. Time-use data had been collected using the validated[20–22] Multimedia Activity Recall for Children and Adults (MARCA),[21,23] administered by computer-assisted telephone interview. Participants were asked to recall their previous day, or up to two previous days. The MARCA uses estimates of activity-specific rates of energy expenditure based on adult[11] and youth compendia.[13] All studies were approved by the relevant Human Research Ethics Committees.

Minutes of MVPA were first estimated assuming zero inter- or intra-individual variability in energy cost. This assumes the compendium MET values assigned were accurate for all individuals

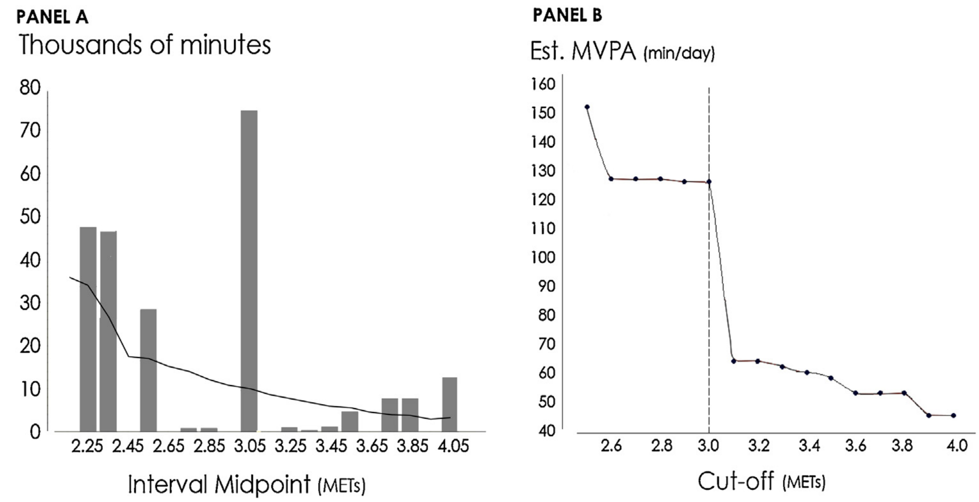

Fig. 1. Panel A: Distribution of minutes of activity across MET levels from 2.15 to 4.05 for the *Unadjusted* (zero variability, shaded bars) and *Best Guess* (added variability, dark line) analyses. Panel B: Estimated MVPA (min/d) as the threshold varies from 2.5 to 4.0 METs.

Table 1
Estimated mean MVPA (min/d) and SD under various simulation scenarios. Also shown are the estimated means as a percentage of Unadjusted (no variability), and the correlations between the simulated and the unadjusted values.

	CV_{inter}	CV_{intra}	CV_{tot}	MVPA (min/d)	SD (min/d)	% of Unadjusted	ICC
Unadjusted	0	0	0	129	127		
Low variability	10.7	5.3	11.9	98	110	76	0.83
Best guess	18.3	9.7	20.7	99	107	77	0.80
High variability	25.9	15.1	30.0	108	107	84	0.78

Notes: CV_{inter} = inter-individual coefficient of variation; CV_{intra} = intra-individual coefficient of variation; CV_{tot} = total coefficient of variation ($=\sqrt{(CV_{inter}{}^2 + CV_{intra}2)}$; MVPA = moderate-to-vigorous physical activity; ICC = intra-class correlation coefficient; SD = standard deviation.
The *Unadjusted* model has no added variability; the *Best Guess* model uses the default value for total variability (20.7%); the *Low* and *High Variability* models use upper and lower confidence estimates for variability (11.9% and 30% respectively).

and activities. We will call this the *Unadjusted* model. We then created a model where we took into account potential intra- and inter-individual variability within the compendium MET values. To do this, we added Gaussian noise to the compendium MET values, simulating our best estimate of variability [CV_{inter} = 18.3% and CV_{intra} = 9.7%,[17] total variability = 20.7%]. We will call this our *Best Guess* model. To simulate *High* and *Low* estimates of variability, we used values one standard deviation above and below the Best Guess estimates (High: CV_{inter} = 25.9% and CV_{intra} = 15.1%, total variability = 30.0%; Low: CV_{inter} = 10.7% and CV_{intra} = 5.3%, total variability = 11.9%). In all models, only activities with estimated rates of energy expenditure above 3 METs were counted as MVPA. This process was repeated 100 times for each simulation. Estimates varied by ≤2 min/day, so average values were retained.

Inter-individual variability may reflect structural or functional characteristics of the individual which are specific to particular activities, or which may operate across a wide range of activity types. For example, an individual may have a particularly inefficient running style but may in other activities be quite normal. Alternatively, they may have characteristics such as joint stiffness or lung inelasticity which increase the energy cost of all activities. In the former case, intra-individual variability should be simulated for each activity; in the latter for each individual. To simulate both of these possibilities, we applied Gaussian noise both to represent the variability associated with each individual, and the variability due to the interaction between the individual and the activity.

3. Results

Fig. 1 (Panel A) shows a histogram of the number of minutes spent at various MET values from 2.15 to 4.05 METs in the Unadjusted (zero variability) and Best Guess (added variability) analyses. In the Unadjusted analysis many minutes are accumulated at exactly 3 METs. In the Best Guess analysis, these minutes have been spread out on either side of the 3-MET mark.

In the Unadjusted model, participants accumulated an average of 129 (SD 127) min/day of MVPA. Of this, 62 (SD 91) min was accumulated at an intensity of exactly 3.0 METs, including 22 min of walking, 22 min of household chores, and 15 min of occupational activities. The effect of varying the MVPA cut-off from 2.5 to 4 METs is shown in Fig. 1 (Panel B). The precipitous drop at 3 METs reflects the amount of MVPA accumulated at just that intensity. Conversely, the estimated amount of MVPA is quite stable for thresholds under 3 METs. This is because the amount of time spent in activities notionally requiring 2.5 METs (24 min) and 2.6–2.9 METs (<2 min) was relatively small. Similarly, above the 3 METs threshold, the estimates are again stable, because little time is spent at 3.1–3.4 METs (<6 min/day).

When random noise was added to simulate variability, estimated MVPA was 21–31 min/day (16–24%) lower (Table 1). High variability was associated with a smaller difference from the Unadjusted model because under high variability conditions some of the activities notionally requiring <3 METs (particularly household activities clustering around 2.5 METs) were now captured as MVPA. There were wide limits of agreement. The bias (mean difference) between the Unadjusted model and the Best Guess model was 30 min/day (Unadjusted − Best Guess), and the limits of agreement were +163 to −103 min/day. Intraclass correlations were nonetheless strong (0.78–0.83). These results were almost identical (<1 min difference) whether inter-individual variability was simulated at the individual or the individual x activity level.

4. Discussion

Cutpoint bias, modeled using empirical estimates of variability and a large, diverse adult dataset, appears to result in an overestimation of "true" MVPA by 19–32% when using self-report and its associated energy expenditure compendium. If device-based methods such as accelerometry accurately measure energy expenditure, then this will account for a considerable part of the disparity between self-report and device-based measures. This effect is due to the choice of a threshold at an energy expenditure level near that at which people spend a lot of time. From the perspective of cutpoint bias, this is mathematically the worse possible choice for a threshold. Our analyses are probably a little conservative, because less standardised activities like household chores show somewhat larger inter-individual variability (22% vs 19.5% in the current dataset), and because the variability data we have were typically measured under standardised laboratory conditions. However, in spite of differences in mean values in estimates of MVPA, unadjusted and added-variability data were strongly correlated (ICC = 0.78–0.83).

Although we have focused on the effect of cutpoint bias on MVPA, it will also affect other energy expenditure bands. For example, if we define sedentary time as activities notionally eliciting $\leq$1.5 METs while awake, self-report in our dataset will underestimate actual sedentary time by 4% (High variability) to 22% (Low variability) due to cutpoint bias. Because both MVPA and sedentary time are overestimated, light physical activity will be underestimated.

This study is, as far as we are aware, the first to highlight the effects of cutpoint bias on self-report estimations of MVPA. We have used novel simulation techniques and a large and diverse dataset to quantify the effects of cutpoint bias across a range of assumed variabilities based on empirical data.

This analysis refers to a particular recall instrument, the MARCA, and a specific, albeit diverse, population of Australasian adults. It is possible that the effect may be specific to MET levels used in the MARCA. The MARCA is based on the Ainsworth compendium,[11] but as not all of the activities listed in the compendium are used in the MARCA; inclusion decisions were made which may influence these findings. Furthermore, the Ainsworth compendium itself is regularly updated, and MET values for some common activities close to the 3 MET threshold have been revised. In 1993, for example, cleaning the house, moderate effort (code 05030) was 3.5 METs.[24] In 2000 this was revised to 3.0 METs,[11] and 3.3 METs in 2011.[10] To model the effect of differences in MET values across different compendia, we calculated the effect of recoding all activities rated at 3 METs in the MARCA compendium to values between 2.8 and 3.4 METs. If all activities currently rated at 3 METs were re-rated to 2.8 METs, the baseline value (129 min/day) would overestimate estimated mean MVPA (using Best Guess variability settings) by 37 min/day. The corresponding figures for 2.9–3.4 METs are +16 to +34 min/day. So even with a relatively wide difference in compendium MET estimates, there would still be substantial overestimation.

The effect of cutpoint bias will vary according to how the population spends its time. It is likely that in populations which do less walking and less housework (young adults, for example), the bias will be attenuated. However, a recent comparison on adult time use in Australia, the US and Germany showed broadly similar patterns of energy expenditure across energy expenditure bands and activity domains.[7]

While other factors, such as social desirability bias and the epoch effect, doubtless impact on differences in estimated MVPA between self-report and device-based measures, cutpoint bias appears to also play an important role. Cutpoint bias may also explain why accelerometers can yield such disparate estimates of MVPA, even when using validated accelerometer cutpoints. If it is true that so much of human activity takes place at or about 3 METs, an accelerometer which is slightly miscalibrated so that it interprets an activity performed at 3 METs to be 2.9 METs will grossly underestimate actual MVPA. However, an accelerometer which is miscalibrated in the opposite direction so that it interprets an activity performed at 3 METs to be 3.1 METs will not grossly overestimate actual MVPA. Because cutpoints have largely been validated in laboratory conditions, using standardised continuous activities, such miscalibration is quite possible.[25] The effects of miscalibration are asymmetrical in this very sensitive zone, yet this phenomenon is yet to be tested empirically. The existence of cutpoint bias in self-report does not therefore necessarily mean that we should put more faith in accelerometry than in self-report.

Uncertainty around estimates of MVPA duration is troubling for assessing compliance to guidelines and making recommendations for population health, in terms of understanding the association between MVPA and health, especially since guidelines have largely been developed based on dose-response relationships between self-reported MVPA and health outcomes. However, differences in average values will be less important for correlational analyses when there are strong correlations between different methods of quantifying MVPA.

Minutes of human activity across a day are not evenly distributed across the intensity spectrum. Rather, physical activity tends to cluster around the intensities elicited when engaged in sitting activities and slow-to-brisk paced ambulatory tasks. Assigning MET levels to self-reported bouts of activity, coupled with variation in how physical activity is performed both across and within individuals, leads to the mathematical phenomenon of cutpoint bias. Cutpoint bias will likely contribute some part to the large disparities we see between self-reported and device-measured levels of MVPA, although the major contributors are likely to be social desirability bias, reporting by bouts,[26] the accelerometry epoch effect and the various calibration study designs and data processing decisions around accelerometry data.[25] Future research should determine if this bias exists using other self-report instruments and if it extends to data collected via accelerometry. These results may alter the way researchers use intensity thresholds to analyse and interpret their physical activity data.

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