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Multidimensional physical activity: An opportunity not a problem

Dylan Thompson, Oliver Peacock, Max Western, Alan M. Batterham¹

Department for Health
University of Bath
Bath, BA2 7AY
UK

¹ Health and Social Care Institute
Teesside University
Middlesbrough, TS1 3BA
UK

Address for correspondence:

Professor Dylan Thompson
Department for Health
University of Bath
Bath, BA2 7AY, UK
Tel: 0044(0)1225 383177; FAX: 0044(0)1225 383275
Email: d.thompson@bath.ac.uk

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32 **ABSTRACT**

33

34 Our research shows that no single metric will adequately reflect an individual's physical
35 activity because multiple biologically-important dimensions are independent and unrelated.
36 We propose that there is an opportunity to exploit this multidimensional characteristic of
37 physical activity in order to improve personalised feedback and offer physical activity options
38 and choices that are tailored to an individual's needs and preferences.

39

40 **SUMMARY**

41

42 We demonstrate how it will be possible to exploit emerging technology to improve the quality
43 of informational physical activity feedback.

44

45 **KEY WORDS**

46

47 Physical activity status, physical activity recommendations, physical activity monitoring,
48 physical activity energy expenditure, physical activity patterns

49

50

51

52 **INTRODUCTION**

53

54 In the past 5-10 years, there has been an explosion in the availability of technologies for the
55 general public to monitor and receive feedback on their physical activity. Many major
56 international companies have entered this market and self-monitoring of physical activity is
57 available to millions of people around the world – including patients who are being
58 counselled about the need to increase their physical activity. It is inevitable that technological
59 advances in the next generation of widely available physical activity monitors will be
60 extremely rapid. Commercial devices from major international companies such as Apple,
61 Garmin, Microsoft, Nike, Philips, Samsung, Fitbit, and Jawbone are all currently available.
62 Thus, we are entering an era where the capture of free-living physical activity energy
63 expenditure will become more-and-more accessible and commonplace. In this new era, we
64 hypothesise that it will be important to improve the way in which these data are used and
65 portrayed in order to provide a more accurate and integrated picture of an individual’s
66 physical activity that cuts across the biologically important dimensions – as well as using this
67 information to offer people a smörgåsbord of physical activity options and choices.

68

69 **SAME RAW ENERGY EXPENDITURE DATA, DIFFERENT PHYSICAL ACTIVITY STATUS**

70

71 In principle, it should be straightforward for individuals to use technology to self-monitor and
72 answer what appears a simple question “*Am I doing enough of the right kind of physical*
73 *activity for health?*”. However, our research using sophisticated measurement instruments
74 shows that providing an unambiguous answer to this question is far from straightforward
75 (27). In this study, we set out to perform what we thought would be a simple task – to take
76 data using a device which has been shown to accurate and precise and determine whether
77 an individual met recommended levels of physical activity (27). Part of our initial motivation
78 was to be able to give people who took part in our research studies a clear message about
79 whether they were doing an adequate amount of physical activity for health. We examined a
80 number of recommendations from various agencies and organizations to examine the extent
81 of variability in physical activity status according to recommendation. We were very surprised
82 to find that up to 90% of men could be described as either active or insufficiently active

83 based on the same physical activity energy expenditure data (Figure 1). This means that, in
84 response to our simple question, nine out of every ten people would get an answer that was
85 something like ‘yes’, ‘no’, or ‘it depends’.

86

87 *** Figure 1 about here ***

88

89 The discrepancy highlighted in Figure 1 is based on a *post hoc* analysis of the same raw
90 data and thus this disagreement and inconsistency is unrelated to errors at the data capture
91 stage (27). It is also not due to an unrepresentative study sample – this group of middle-aged
92 men had an energy expenditure from physical activity which was similar to the median
93 reported in the UK (23). Instead, it appears that the required dose of physical activity and/or
94 the way in which it is expressed has a powerful effect on apparent physical activity status.

95 One example from this study is illustrated in Figure 2 which shows normalised physical
96 activity energy expenditure (Physical Activity Level or PAL) and a recommendation that uses
97 time engaged in moderate to vigorous intensity physical activity. As demonstrated in the
98 example in this figure, some people can accumulate considerable energy expenditure
99 through physical activity without also meeting the time/intensity based recommendation (and
100 *vice versa*).

101

102 *** Figure 2 about here ***

103

104 Therefore, it is possible to take the same raw data for physical activity energy expenditure
105 and form very contrasting views about whether a given individual is active or insufficiently
106 active if we base our interpretation on one recommendation instead of another. This has
107 clear implications for the public and practitioners – especially over the next decade as
108 commercially-available monitoring technologies move towards an accuracy and precision
109 similar to the research instruments that we used. Although some of the discrepancies were
110 associated with imprecision in the construction or communication of a given physical activity
111 recommendation, the biggest differences were due to the fact that different recommendations
112 draw on different physical activity characteristics. Figure 3 demonstrates how the way in
113 which these key characteristics are extracted from daily energy expenditure data will

114 influence the picture that emerges. These kinds of characteristics often form the basis for
115 specific physical activity recommendations – for example, the Institute of Medicine focuses
116 primarily on normalised physical activity energy expenditure (PAL) whereas other
117 recommendations use time engaged in activity of a specific intensity (1). Thus, a major cause
118 of the discrepancy depicted in Figures 1 and 2 appears to come down to philosophical
119 differences in terms of the type of physical activity that ‘counts’.

120

121 *** Figure 3 about here ***

122

123 **PHYSICAL ACTIVITY IS MULTIDIMENSIONAL**

124

125 It is quite reasonable to carve up physical activity energy expenditure in different ways
126 depending on a given perspective or paradigm. However, it is also reasonable to anticipate
127 that this could impact upon the message that an individual receives. In a recent paper, we
128 set out to explore the extent of any heterogeneity in terms of some of the physiologically-
129 important physical activity dimensions which ‘count’ towards health (26). Our aim was quite
130 simple – we wanted to determine the extent to which people score consistently or variably in
131 terms of different potentially-important physical activity dimensions/characteristics. There is
132 ongoing uncertainty about the various dimensions which are biologically relevant and
133 important for health but one key dimension is overall physical activity energy expenditure
134 which is naturally the most important consideration for weight loss or maintenance (16).
135 However, other specific forms of physical activity generate profound health-related benefits
136 that are unrelated to overall energy expenditure and energy balance – and these should also
137 be considered (3, 11-13, 18, 32). As a further example of the exclusive nature of the different
138 physical activity dimensions, a recent meta-analysis shows how sedentary time impacts upon
139 risk of cancer even after adjustment for physical activity (22). Importantly, our analysis
140 demonstrates that there is considerable heterogeneity across physical activity dimensions
141 that have been shown to be physiologically important (26). Indeed, individuals who ostensibly
142 appear similar for one physical activity measure (e.g., time engaged in moderate intensity
143 physical activity) can score very differently for other metrics (e.g., overall physical activity
144 energy expenditure). Only a very few people score consistently across all physical activity

145 dimensions (26). Several authors had previously proposed that there are conceptual
146 differences in selected physical activity dimensions (10, 20, 29), but this had not been tested
147 empirically and across some of the key (multiple) dimensions known to exert potentially
148 powerful effects on health.

149
150 Some of the results from this analysis are shown in Figure 4 (26). In spite of a very large
151 correlation between normalised physical activity energy expenditure (PAL) and time engaged
152 in moderate intensity physical activity, the coloured quadrants illustrate and highlight the
153 message a given group of individuals would receive if they were to be provided with one
154 physical activity descriptor alone (Figure 4, D). In this case, there is a group of men in
155 quadrant B3 who score highly for time engaged in moderate intensity physical activity but
156 relatively poorly for physical activity energy expenditure (i.e., lower scores for PAL) than the
157 group in quadrant C4 who have higher scores for PAL but without as much moderate
158 intensity physical activity. The same thing applies for vigorous intensity physical activity
159 where there is a clear difference in scores for time engaged in vigorous intensity physical
160 activity between groups that have a similar PAL (Figure 4, E). In Figure 4 (F), we illustrate
161 how two groups of people look similar for sedentary time but different for overall physical
162 activity energy expenditure (PAL). Clearly, if we provided these individuals with only one
163 physical activity score then they would form an incomplete or inaccurate picture of their
164 overall physical activity. The solution to such potential misclassification is to avoid the
165 reliance on just one physical activity outcome or descriptor.

166
167 *** Figure 4 about here ***

168
169 Thus, with the expansion of technology-enabled feedback aimed at individuals and
170 consumers, there is the danger that many people will form an erroneous opinion about their
171 physical activity if they are guided to focus on one physical activity dimension alone. We
172 propose that it is unlikely that there is a single outcome or descriptor which reflects all the
173 relevant information about physical activity – and that, instead, we need to capture physical
174 activity ‘profiles’ across the physiologically-important dimensions.

175

176

177

178 **MULTIDIMENSIONAL PHYSICAL ACTIVITY: IMPLICATIONS FOR RESEARCHERS**

179

180 Based on the above discussion, physical activity is much more interesting than simply ‘high’
181 versus ‘low’ – a situation not dissimilar to the multiple aspects of diet that are known to be
182 important. We propose that we should avoid collapsing the thousands of data points
183 generated by physical activity measurement technologies into a single outcome measure that
184 we call ‘physical activity’. This might initially seem like a headache for epidemiologists in that
185 it is more convenient to treat physical activity as a single exposure or outcome. However, this
186 is familiar territory and there will be innovative solutions. For example, we previously
187 proposed that it may be possible to learn from parallel situations such as the metabolic
188 syndrome where multiple inputs are used to generate a criterion-based score for physical
189 activity (26). It may even be possible to determine the absence of any healthful physical
190 activity across the key dimensions and we might call this something like the ‘Physical
191 Inactivity Syndrome’ (26). Alternatively, we might develop an iterative classification system
192 based on scores in each dimension in order to build an integrated profile. Clearly, such a
193 system is untested and there are important questions to be tackled. For example, are all
194 dimensions equally important and/or are there other physical activity dimensions that have
195 not been identified? Two particularly good examples of emerging dimensions which might
196 need to be considered in the future comes from studies showing the powerful effect of very
197 brief periods of high intensity physical activity (18) and the impact of relatively small amounts
198 of light-to-moderate intensity activities distributed throughout the day (2, 4, 5).

199

200 Taking a multidimensional approach to physical activity also has implications for researchers
201 conducting trials of physical activity or exercise training interventions. For example, if
202 participants are recruited based on the absence or presence of a specific score in a
203 particular pre-defined physical activity dimension (e.g., high sedentary time), this could
204 ignore other differences in physical activity phenotype which could influence the response to
205 a given intervention. We have previously proposed that this may explain at least some of the
206 heterogeneity in response to classical exercise training studies such as HERITAGE (25, 26).

207 To illustrate this point, if two recruited participants score similarly and poorly for one
208 (measured) physical activity dimension or parameter that is used as the basis for recruitment
209 but they also score differently for another (unmeasured) parameter then we cannot conclude
210 that any divergent response between individuals to a standardised exercise stimulus reflects
211 genotypic differences. The divergent response could be partly due to differences in pre-
212 intervention physical activity phenotype – which were not measured or used as a basis for
213 inclusion.

214

215 **MULTIDIMENSIONAL PHYSICAL ACTIVITY IS AN OPPORTUNITY NOT A PROBLEM**

216

217 A multidimensional approach to physical activity creates future opportunities for researchers
218 but we feel that the most immediate benefit will be for the public and technology companies.
219 In addition to offering a more integrated and complete view of physical activity, a key
220 opportunity which arises from the provision of a multidimensional picture is that it offers a
221 smörgåsbord of physical activity options and choices that can be tailored to an individual's
222 needs and preferences. A multidimensional physical activity profile helps to focus feedback
223 on the individual's perspective and takes a more holistic view. Even the simplest version has
224 advantages over a more unidimensional approach (Figure 5).

225

226 *** Figure 5 about here ***

227

228 ***Multidimensional Physical activity profiles: a powerful stimulus for sustained change?***

229

230 A multidimensional representation of physical activity will provide a more accurate depiction
231 of physical activity that reduces the chance of misclassification and/or misinformation. It is
232 more educational and provides a better and more holistic representation of physical activity.
233 For example, many people overestimate their own physical activity and are thus less likely to
234 intend to change, or even have an awareness of the need to change, their behaviour (31).
235 Part of the problem is that people sometimes focus on just certain physical activity
236 behaviours without taking into account other dimensions. For example, many forms of
237 structured physical activity have only a small thermogenic effect so that total energy

238 expenditure is minimally affected by participation (30). This might not be so important for
239 some specific metabolic and health benefits – but it is important for the individual to know
240 why they are not losing (or possibly even gaining) weight; and weight loss will be critically
241 important for some health outcomes and personal goals. The deeper understanding provided
242 by a multidimensional physical activity profile will be more revealing and potentially more
243 persuasive. For example, rather than receiving a single physical activity score, the provision
244 of a multidimensional profile will demonstrate how some people are failing to make use of
245 any of multiple ways in which physical activity can impact upon health (e.g., participant 2 in
246 Figure 5). If an individual in this situation chooses to undertake moderate to vigorous
247 intensity physical activity then this should be applauded – but it might have only a modest
248 impact on sedentary time or overall energy expenditure. Similarly, if they choose to reduce
249 their sedentary time then this is unlikely to impact upon some of the other dimensions.
250 Clearly, the capture and provision of feedback across these physical activity dimensions will
251 be more useful and revealing than the reliance on a single outcome or continuum.

252
253 An understanding of personalised physical activity is integral to various models of behaviour
254 change and regulation (15, 33). Moreover, the diverse physical activity options and choices
255 associated with multidimensional physical activity profiling creates an exploitable social
256 marketing opportunity. The marketing of personalised physical activity profiling is potentially
257 a key step towards greater empowerment (or self-determined engagement) via the support of
258 autonomy and competence. When patients experience autonomy and competence in their
259 treatment they experience greater volitional engagement and demonstrate greater
260 maintenance of desirable health behaviours (21). With a multidimensional profile, the options
261 for physical activity can be flexible and dynamic – with the opportunity to target different
262 dimensions at different times.

263
264 For the healthcare practitioner, advice can be tailored to the individual (i.e., context-specific
265 guidance such as physical activity for weight loss) and this advice is more likely to be
266 perceived as being personally relevant and meaningful. In the future, it is possible that
267 different people might be encouraged to do different things depending on
268 genotype/phenotype. For example, targeting glucose control in people with type 2 diabetes

269 might benefit more from focussing on certain physical activity dimensions rather than on
270 others. It is clearly too early to say at present, but there are already signs that this might be
271 the case (8).

272

273 ***Multidimensional Physical activity profiles: a helpful prop during transition?***

274

275 The effectiveness of physical activity interventions ultimately relies on the net change in a
276 given physical activity dimension(s). In the case of energy expenditure, the introduction of
277 'new' physical activity will (inevitably) substitute for some other activity (probably of a lower
278 intensity) so that the net effect is smaller than the effect predicted from the novel activity
279 alone (28, 30). There is also the possibility that some people compensate for an increase in
280 one type of physical activity behaviour by decreasing another (9). These factors can mean
281 that in spite of the introduction of a novel behaviour there is no net effect on total energy
282 expenditure (30). Of course, providing a clear multidimensional picture will help people to
283 understand how even a substantial change in one physical activity dimension might not have
284 much of an effect on other dimensions. This improved awareness will allow people to take
285 greater responsibility for managing their physical activity – which will contribute to greater
286 self-determination via support for an individual's sense of autonomy and competence (21,
287 24). Feedback and support in the form of a multidimensional physical activity profile allows
288 an understanding of what has been realised, what is achievable and in what timescale.

289

290 As summarised and illustrated in Figure 6, a multidimensional approach to physical activity
291 provides a more integrated picture and creates many inter-related opportunities. We have
292 recently begun a trial which draws on technology-enabled self-monitoring using
293 multidimensional physical activity feedback in at-risk men and women as part of the Mi-PACT
294 project (19).

295

296 ***Figure 6 about here ***

297

298 At present, many commercially-available devices might not capture information with sufficient
299 resolution to reflect the different physical activity dimensions. However, the accuracy and

300 precision of these technologies will improve and there are already some commercially-
301 available instruments with excellent reported validity (14, 34). The future will bring
302 tremendous opportunities to use the information from these emerging technologies to help
303 people engage and sustain appropriate physical activity.

304

305 ***Data visualisation and design of web-based applications***

306

307 An exciting challenge will be the communication of multidimensional physical activity data in
308 a way that is readily understandable as well as informative and motivating. One risk is that
309 people could find multidimensional physical activity to be complicated and difficult to
310 comprehend. In this context, when data is potentially complex or intangible, visualisations
311 have a fundamental role in helping to foster understanding (6, 17). Approaches to
312 communicating multidimensional physical activity information could use graphics and
313 exploratory web-based applications linking data and visualisations with an interactive
314 platform (7). It is unlikely that there will be a definitive design solution to meet the needs of
315 everyone and, given the diversity of the potential audience, user-centred and participatory
316 approaches that involve stakeholders in the design process will be required to ensure that
317 the diversity of user needs are met.

318

319 **CONCLUSION**

320

321 We now have the necessary tools and techniques to capture and generate an integrated and
322 well-rounded picture for an individual's physical activity. This approach reduces the risk of
323 people forming an erroneous conclusion about their physical activity status because it
324 recognises that there are multiple ways in which to benefit from physical activity.

325 Furthermore, in addition to being more educational and informative, a multidimensional
326 physical activity profile can be used to produce a smörgåsbord of physical activity options
327 and choices rather than a single one-size-fits-all recommendation. This approach firmly
328 focuses on the individual at the centre as a user of information in control of their personal
329 physical activity and, as technology becomes more accessible and affordable, there are
330 exciting opportunities to be exploited.

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332

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341

342

343 **Figure legends**

344

345 Figure 1: The proportion of middle-aged men in this sample who either met or failed to
346 meet each of the 12 recommendations included in this analysis. A full
347 description of these recommendations has been provided previously (27).
348 Briefly, we included recommendations and various versions of
349 recommendations from the American College of Sports Medicine (ACSM),
350 Center for Disease Control (CDC), American Heart Association (AHA), UK
351 Department of Health (DoH), Institute of Medicine (IOM) and US Department
352 of Health and Human Services (USDHHS).

353

354 Figure 2: One example of the discrepancy at the individual level between different
355 physical activity recommendations based upon different physical activity
356 characteristics (27). Ranked individual data for physical activity energy
357 expenditure is expressed as Physical Activity Level or PAL (Total Energy
358 expenditure/Basal Metabolic Rate). The horizontal dashed line indicates a
359 PAL-specific threshold of 1.6 (i.e., from the Institute of Medicine) whereas the
360 shaded columns indicate where this specific participant also met the
361 time/intensity recommendation from ACSM/AHA (i.e., either 5 days of
362 moderate intensity activity or 3 days of vigorous activity per week).

363

364 Figure 3: Physical activity energy expenditure analysed and dissected according to a
365 few selected potentially important physical activity characteristics and
366 dimensions. In this example, two individuals have similar scores for overall
367 physical activity energy expenditure but they have accumulated physical
368 activity in very different ways. **A**, Physical Activity Level (PAL); **B**, time
369 engaged in physical activity > 3 metabolic equivalents (METs) accumulated in
370 bouts of at least 10 min; **C**, time engaged in physical activity > 6 METs; **D**,
371 time spent below 1.5 METs (sedentary time). As demonstrated in the
372 summary, using one descriptor alone and in isolation will lead to a very
373 different picture regarding physical activity status.

374

375 Figure 4: Heterogeneity in physical activity across various physical activity dimensions
376 (26). **A**, PAL *versus* daily time engaged in physical activity > 3 METs
377 accumulated in bouts of at least 10 min; **B**, PAL *versus* daily time engaged in
378 physical activity > 7.2 METs accumulated in bouts of at least 10 min; **C**, PAL
379 *versus* daily time engaged in sedentary activities as a proportion of the waking
380 day (i.e., below 1.5 METs accumulated on a minute-to-minute basis). Pearson
381 correlations with 95% confidence intervals are reported. **D-E** shows the same
382 relationships but with quadrants superimposed and highlighted (see text for
383 details).

384

385 Figure 5: A simple representation for physical activity profiles across selected
386 physiologically-important dimensions. As described previously (26), each
387 profile captures five different physical activity dimensions for five participants
388 and demonstrates how a multidimensional profile is more revealing than a
389 unidimensional score. For example, participants 2 and 8 have similar physical
390 activity energy expenditure (PAL) but differ for other dimensions which could
391 be important for health. Participants 28 and 75 are similar for sedentary time
392 but differ for many of the other dimensions (including PAL). In this simple
393 iteration, we have used green/red to indicate the clear achievement/failure to
394 achieve each threshold; with amber indicating that values were within 20% of
395 the target value.

396

397 Figure 6: A schematic illustrating some of the advantages and opportunities from
398 multidimensional physical activity profiling. This theoretical depiction includes
399 three individuals with distinct physical activity patterns coupled to a simple
400 iterative process to build a basic profile across four physical activity
401 dimensions. Even this simple approach produces opportunities – and more
402 sophisticated profiles will be able to include other considerations such as
403 magnitude based scores and/or performance in other physical activity
404 dimensions.

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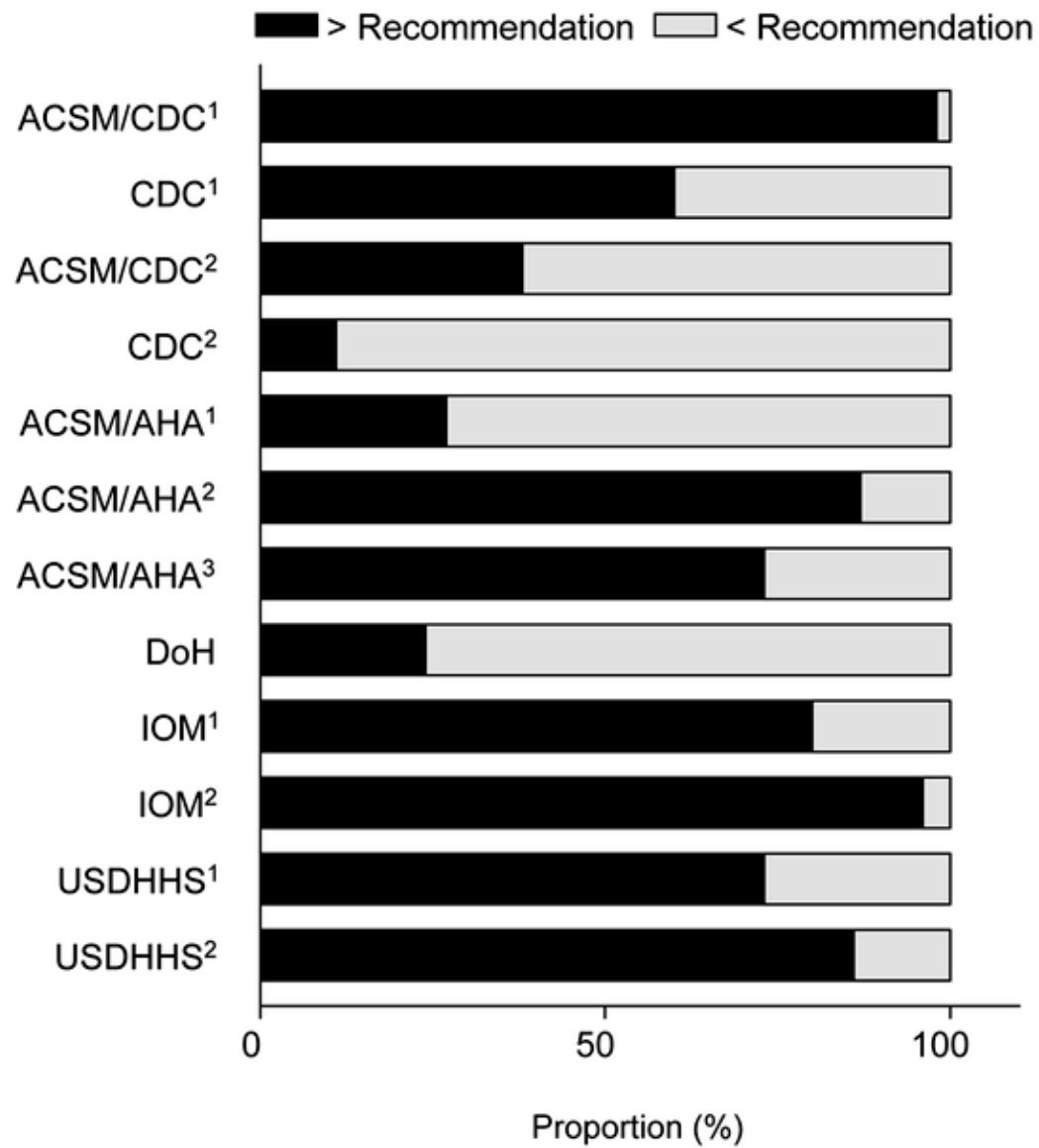


Figure 1

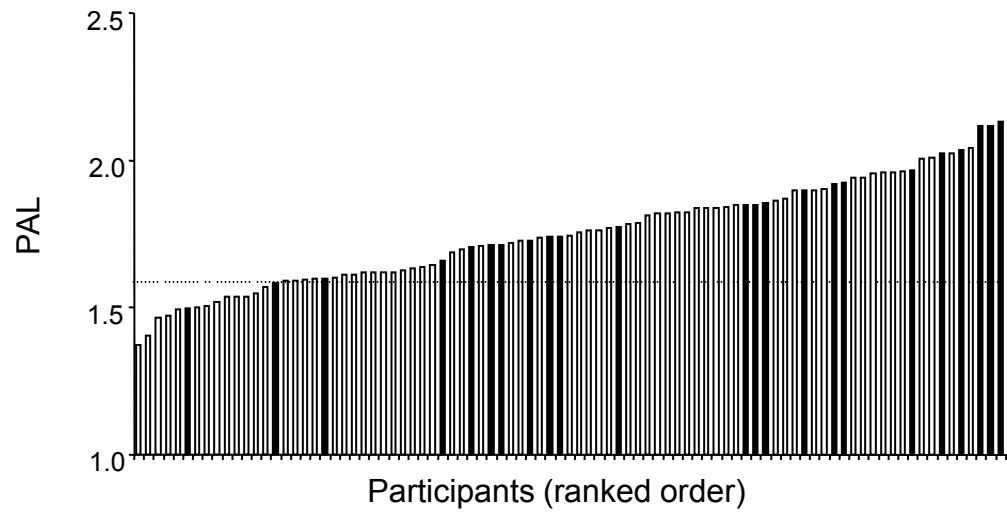
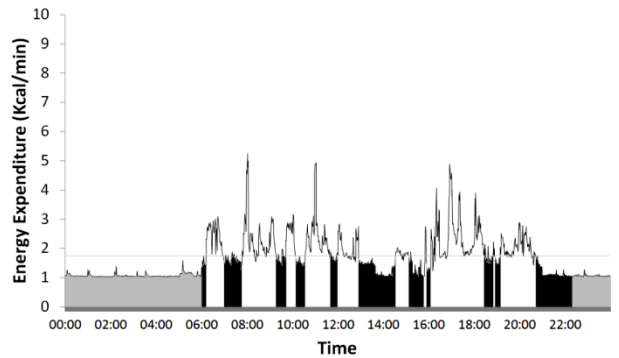
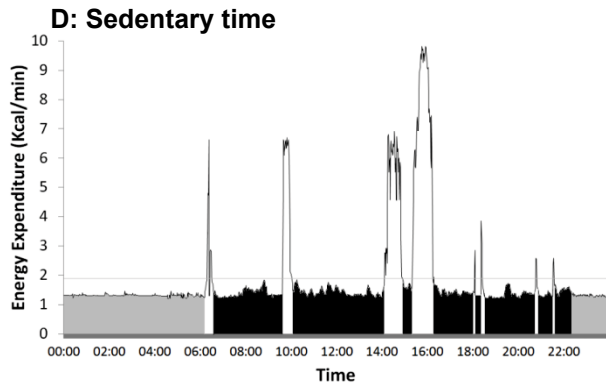
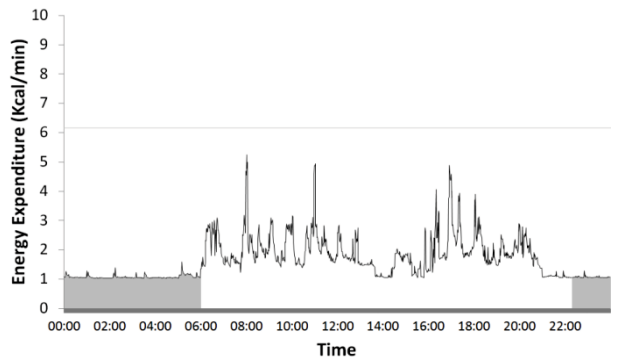
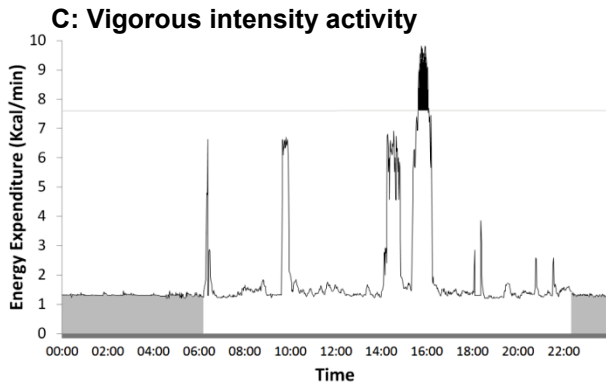
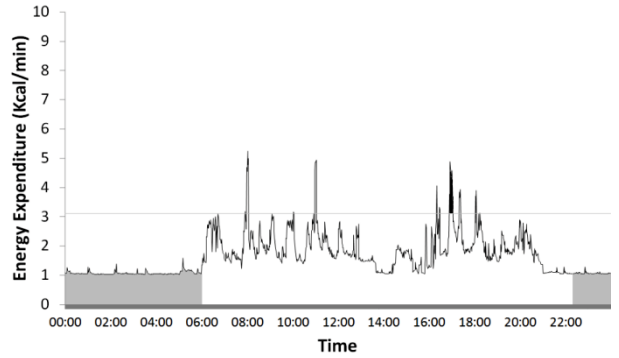
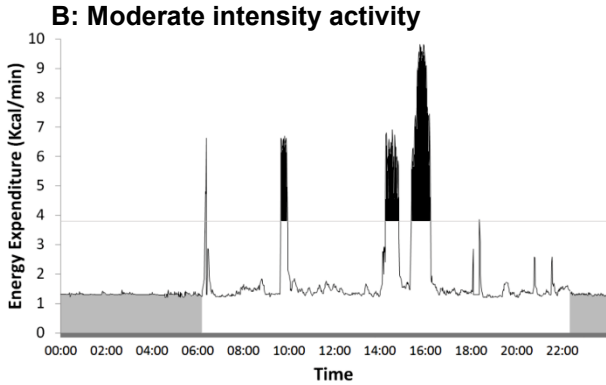
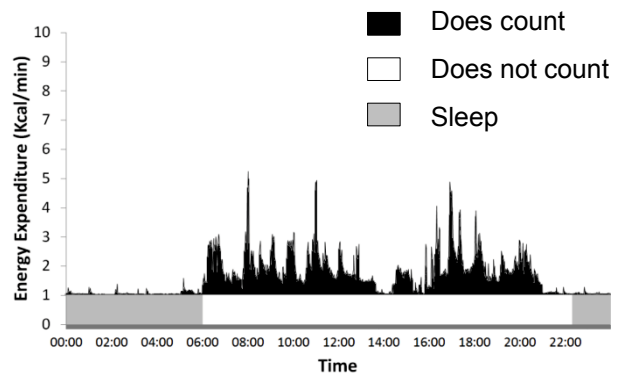
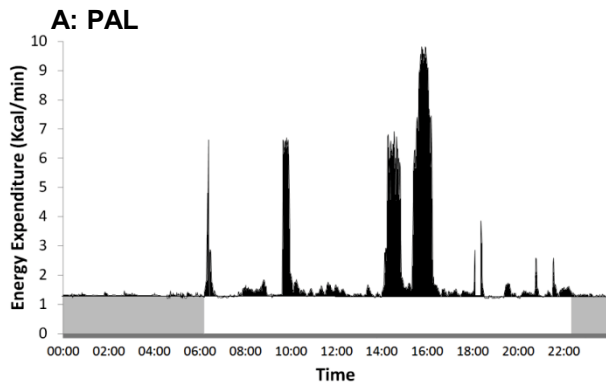


Figure 2



BILL

BEN

	PAL	Moderate	Vigorous	Sedentary time
Bill	1.68	80 minutes	20 minutes	12 hours
Ben	1.69	10 minutes	0 minutes	5 hours
Notes	<i>Similar</i>	<i>Bill better than Ben</i>	<i>Bill better than Ben</i>	<i>Ben better than Bill</i>

Figure 3

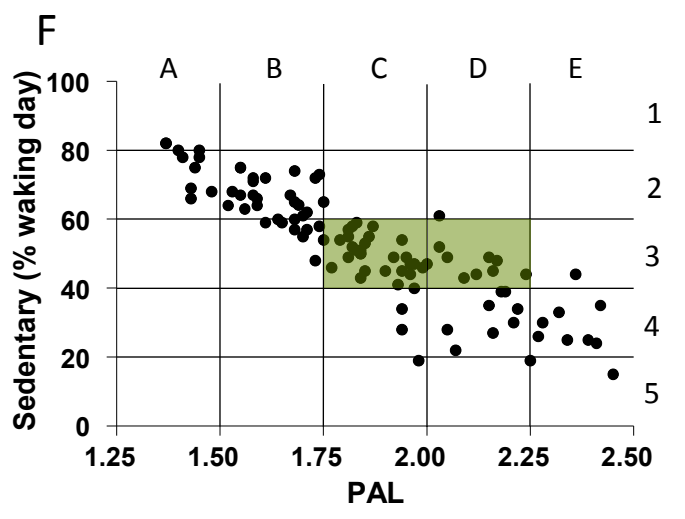
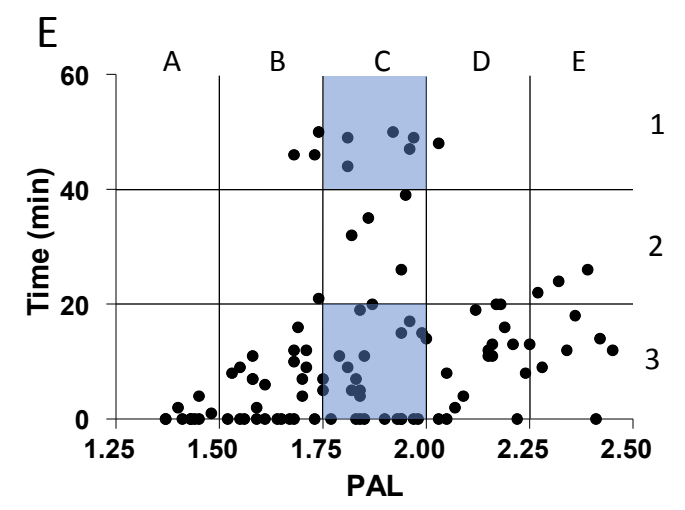
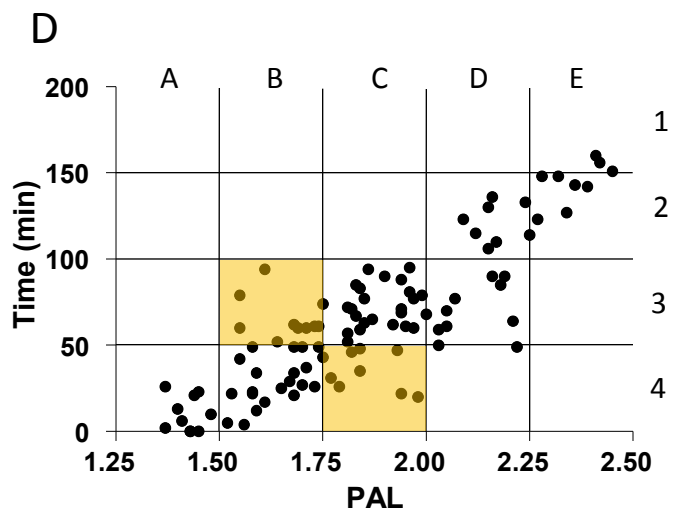
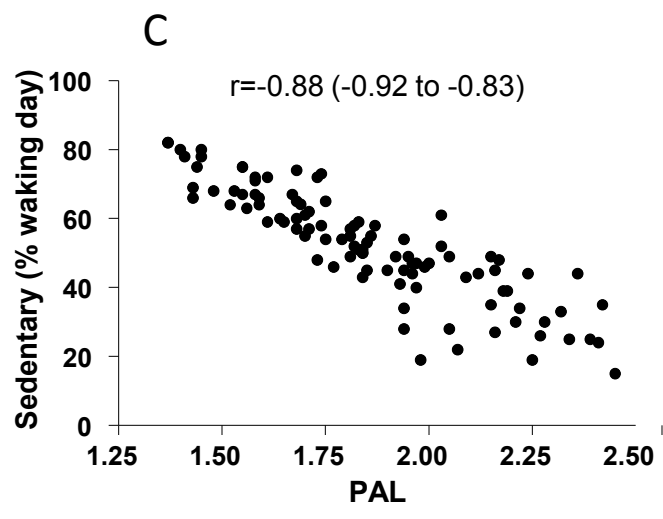
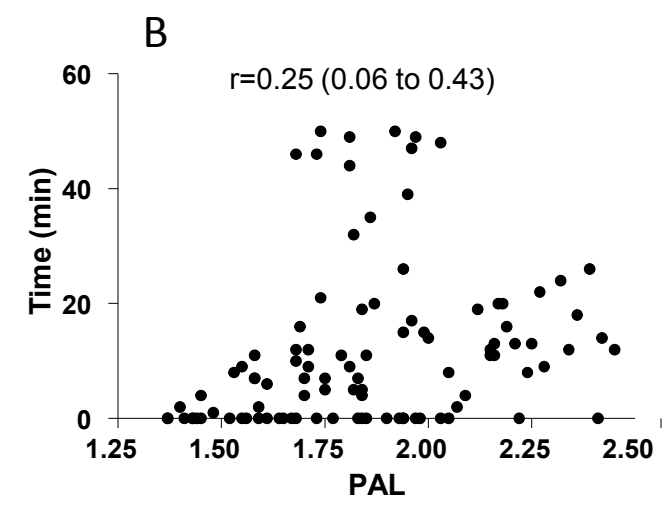
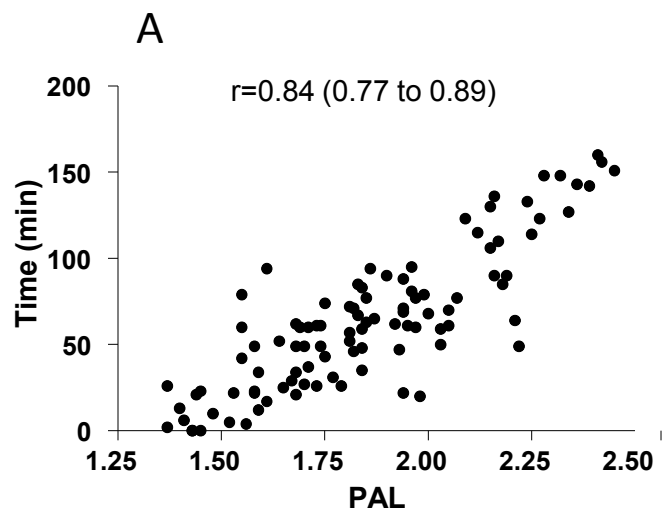


Figure 4

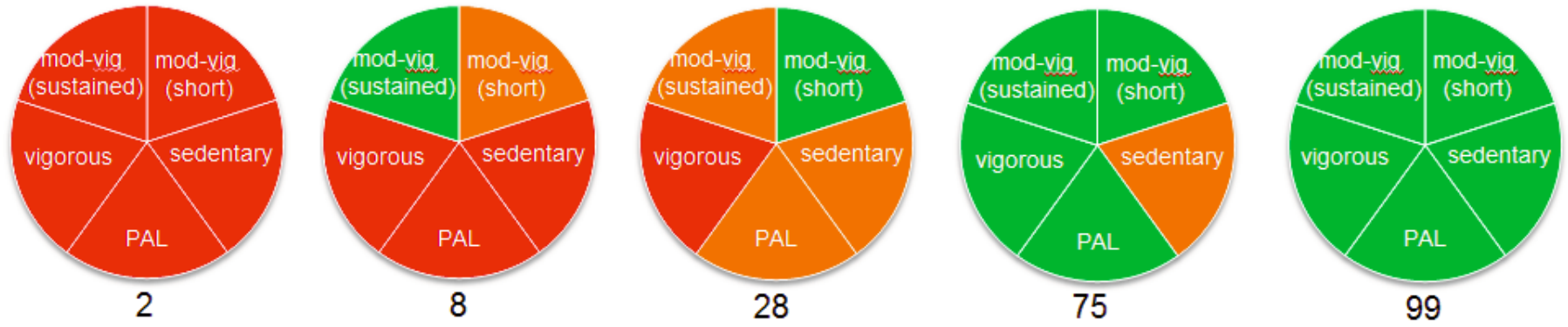
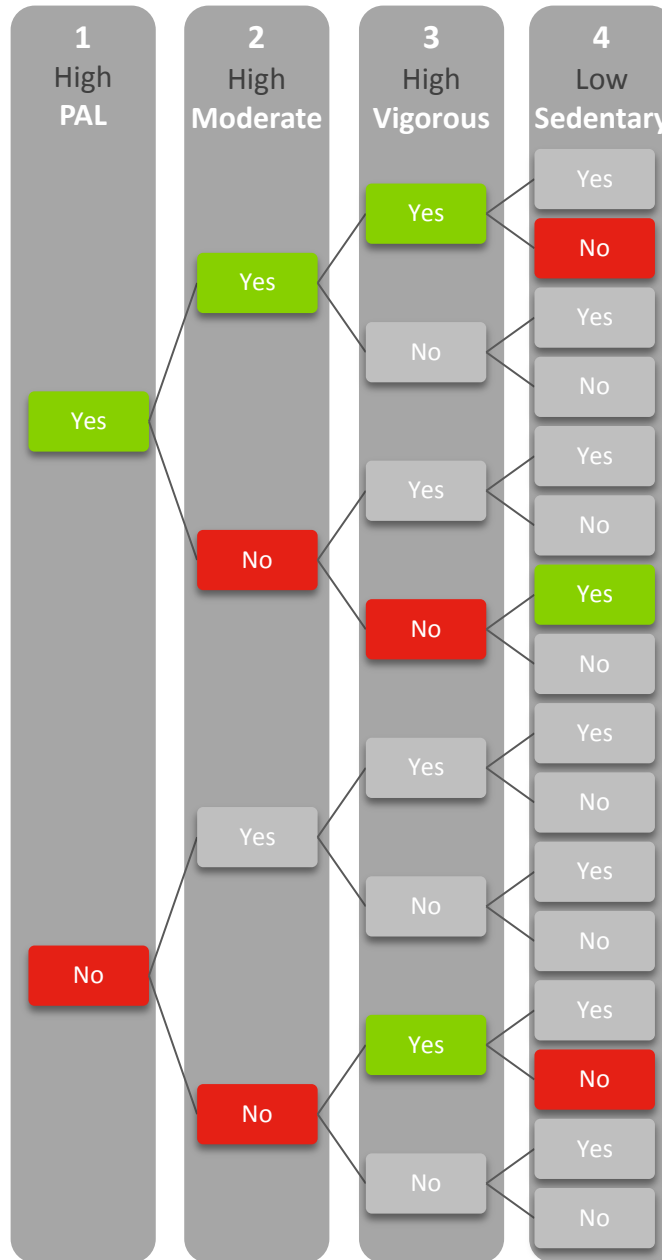


Figure 5

Activity Assessment



Personalised Integrated Multidimensional Profiling



Opportunities

Bespoke

Integrated

Holistic

Revealing

Accurate

Educational

Meaningful

Relevant

Choice

Options

Dynamic

Flexible

Motivating