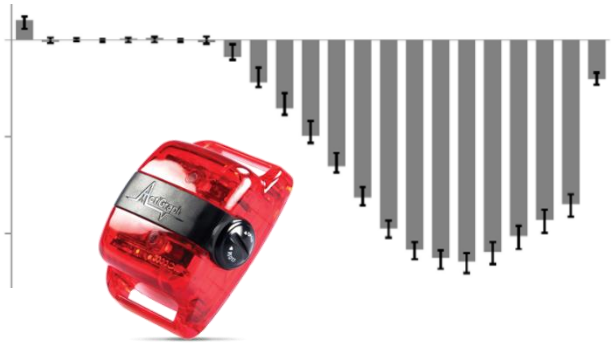
Multivariate pattern analysis of the physical activity intensity spectrum – what have we learned?

5th Nordic Seminar on Technical Measurement of Physical Activity and Sedentary behavior, Trondheim 2.-3. June 2022



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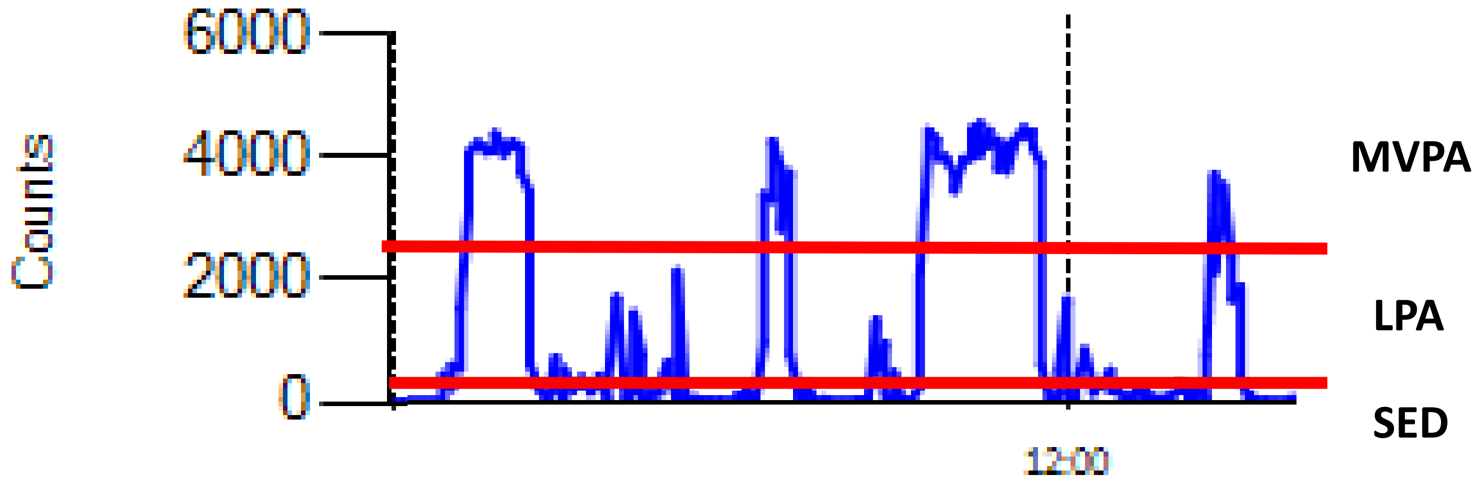
Outline

Multivariate pattern analysis

- What is it and why do we need it?
- How can it be applied to accelerometry intensity spectra?
- What have we learned?

Limitations of the traditional analytic approach to determine associations with accelerometry PA data

- Studies have primarily used **blunt descriptions of PA**, mainly total PA, MVPA, and/or SED - this practice may lead to loss of information and residual confounding
- Due to **multicollinearity of PA variables**, multiple variables should not be included in the same statistical model when applying ordinary least squares linear regression
- The **whole specter of PA intensities should be included**, possibly using a greater resolution than the commonly used gross intensity categories

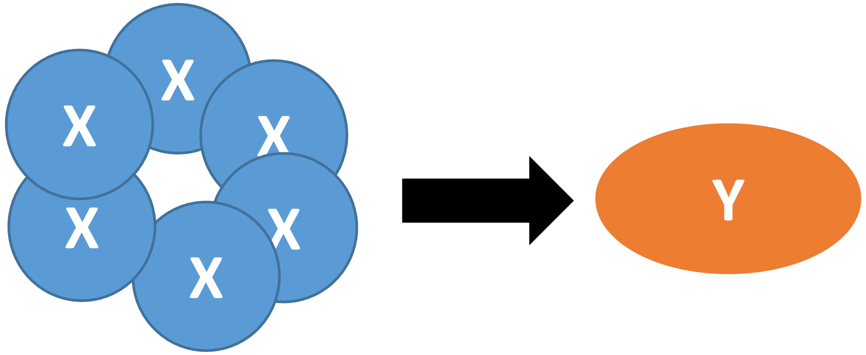


Poitras et al, Appl Physiol Nutr Metab 2016; van der Ploeg et al, Int J Behav Nutr Phys Act 2017; Pedisic, Kinesiology 2014

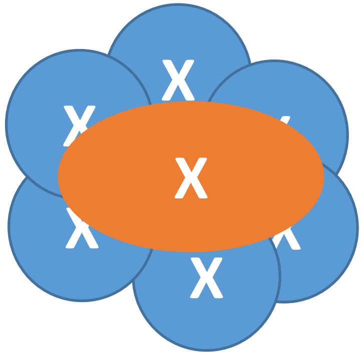
Multivariate pattern analysis

- Is a dimension reduction method
- Uses **latent variable modelling**, rather similar to Principal Component Analysis (PCA), but

- **Multivariate pattern analysis** **maximizes variance between many explanatory variables and an outcome**



- **PCA** **maximizes variance among the explanatory variables**



Rajalahti & Kvalheim, Int J Pharm 2011; Rajalahti et al, J Proteome Res 2010, Wold et al, SIAM J Sci Comput 1984

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RESEARCH Open Access

The multivariate physical activity signature associated with metabolic health in children

Eivind Aadland[1*], Olav Martin Kvalheim[2], Sigmund Alfred Anderssen[1,3], Geir Kåre Resaland[1,4] and Lars Bo Andersen[1]

Abstract

Background: Physical activity is a cornerstone for promoting good metabolic health in children, but it is heavily debated which intensities (including sedentary time) are most influential. A fundamental limitation to current evidence for this relationship is the reliance on analytic approaches that cannot handle collinear variables. The aim of the present study was to determine the physical activity signature related to metabolic health in children, by investigating the association pattern for the whole spectrum of physical activity intensities using multivariate pattern analysis.

Methods: We used a sample of 841 children (age 10.2 ± 0.3 years; BMI 18.0 ± 3.0; 50% boys) from the Active Smarter Kids study, who provided valid data on accelerometry (ActiGraph GT3X+) and several indices of metabolic health (aerobic fitness, abdominal fatness, insulin sensitivity, lipid metabolism, blood pressure) that were used to create a composite metabolic health score. We created 16 physical activity variables covering the whole intensity spectrum (from 0–100 to ≥ 8000 counts per minute) and used multivariate pattern analysis to analyze the data.

Results: Physical activity intensities in the vigorous range (5000–7000 counts per minute) were most strongly associated with metabolic health. Moderate intensity physical activity was weakly related to health, and sedentary time and light physical activity were not related to health.

Conclusions: This study is the first to determine the multivariate physical activity signature related to metabolic health in children across the whole intensity spectrum. This novel approach shows that vigorous physical activity is strongest related to metabolic health. We recommend future studies adapt a multivariate analytic approach to further develop the field of physical activity epidemiology.

Trial registration: The study was registered in Clinicaltrials.gov (www.clinicaltrials.gov) 7th of April 2014 with identification number NCT02132494.

Keywords: Multivariate pattern analysis, Metabolic risk factors, Pediatric, Childhood, Accelerometer, Intensity

Background

Physical activity (PA) is a cornerstone for promoting good metabolic health in children [1, 2]. Specifically, moderate-to-vigorous PA (MVPA) has consistently been associated with single risk factors as well as with composite measures of metabolic health in childhood [1–4]. Additionally, sedentary time (SED), defined as time spent sitting or reclined with an energy consumption minimally above resting values (< 1.5 metabolic equivalents) [5], has received great attention for possibly being detrimental to child health beyond overall PA or MVPA [6–8]. However, the evidence for an influence of SED beyond MVPA on metabolic health in children is weak [3, 9].

The majority of pediatric studies investigating relationships between PA and metabolic health have been limited to investigating associations for MVPA and

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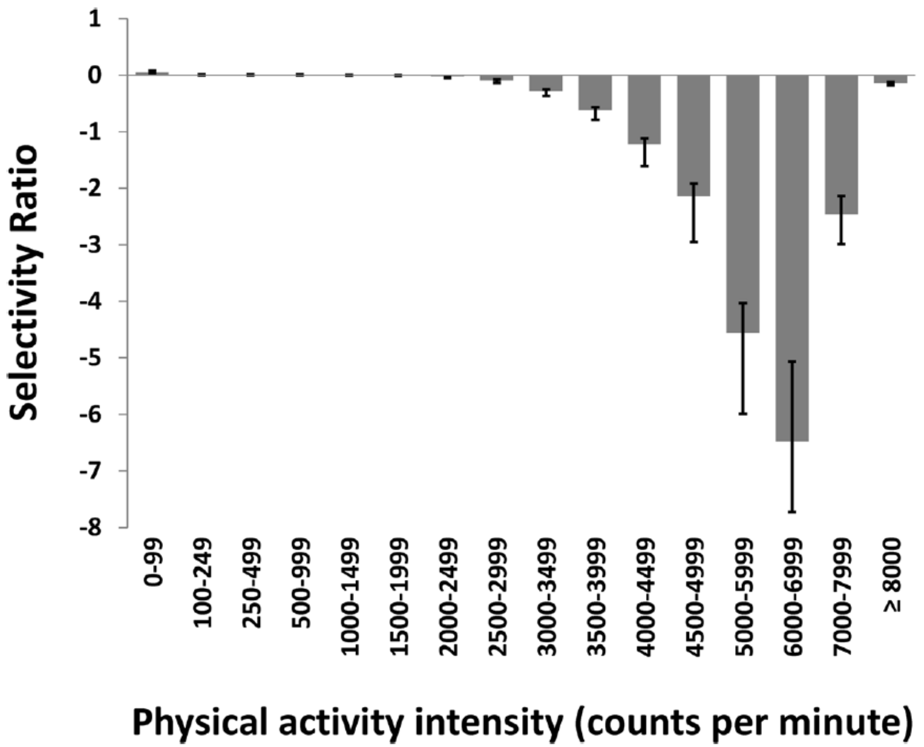
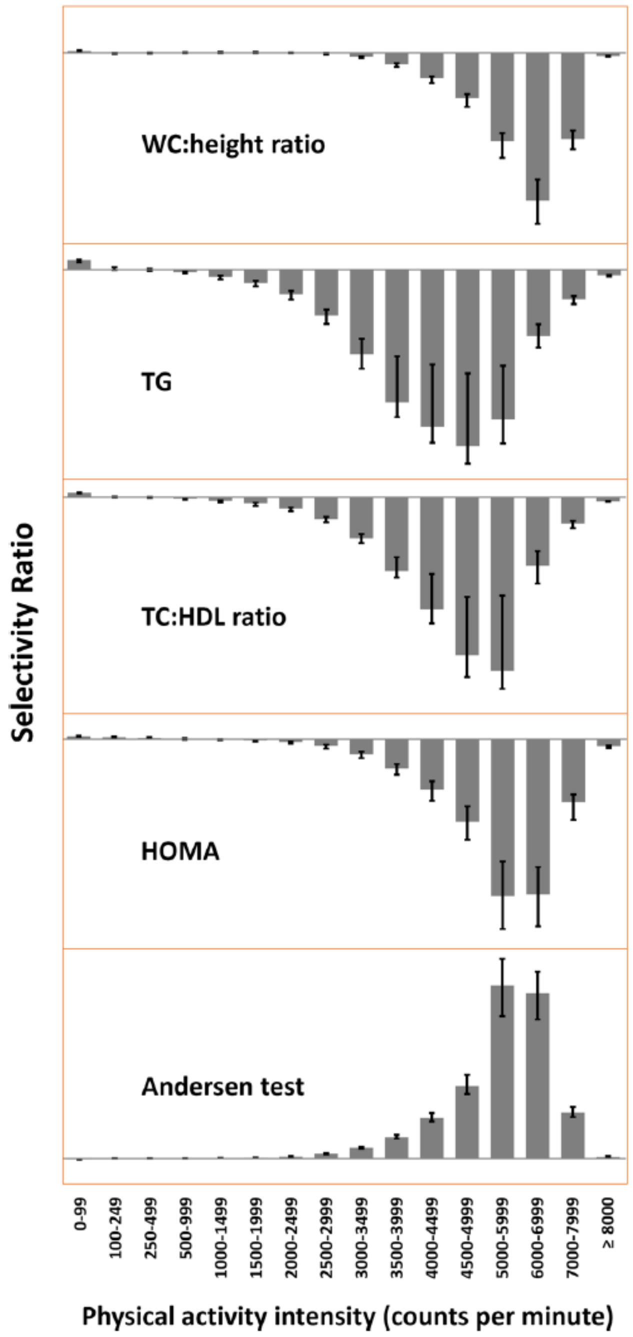


Fig. 1 The multivariate PA signature associated with a composite metabolic health score in children displayed as a selectivity ratio (SR) plot. The PLS regression model includes 3 components, $R^2 = 13.3\%$, and is adjusted for age and sex. The SR for each variable is calculated as the ratio of explained to residual variance on the predictive (target projected) component. A negative bar implies that increased PA are associated with better metabolic health



Association patterns were similar, but *strengths of associations* differed

Fig. 2 The multivariate PA signature associated different risk factors in children displayed as a selectivity ratio (SR) plot. The models (PLS regression) is adjusted for age and sex. WC:height ratio = waist circumference to height ratio (3 components, $R^2 = 13.6\%$); TG = triglyceride (1 component, $R^2 = 2.2\%$); TC:HDL ratio = total to high-density lipoprotein cholesterol ratio (1 component, $R^2 = 3.1\%$); HOMA = homeostasis model assessment (2 components, $R^2 = 6.6\%$); Andersen test (3 components, $R^2 = 21.0\%$). The SR for each variable is calculated as the ratio of explained to residual variance on the predictive (target projected) component. A negative bar implies that increased PA are associated with better metabolic health

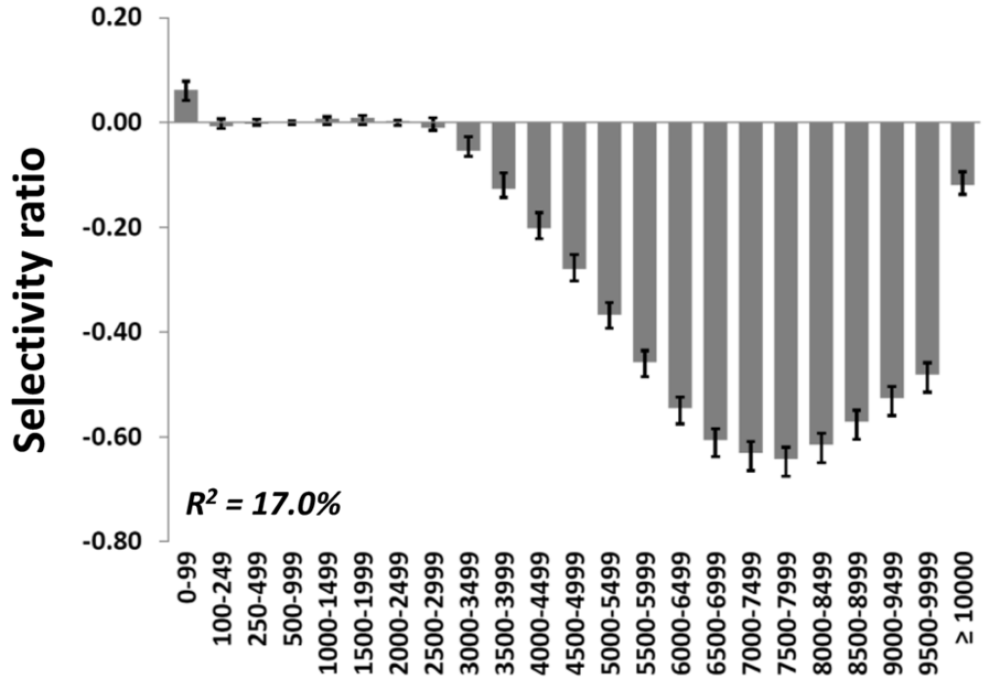
2 types of information are useful

The total explained variance of the model

- How much of the variation in the outcome is explained by <u>ALL</u> PA variables jointly?

The association signature/profile/pattern

- Which part of the intensity spectrum is strongest associated with the outcome?



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PHYSICAL ACTIVITY, HEALTH AND EXERCISE

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Accelerometer epoch setting is decisive for associations between physical activity and metabolic health in children

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ABSTRACT

When analysing physical activity (PA) levels using accelerometry, the epoch setting is critical to capture intensity-specific PA correctly. The aim of the present study was to investigate the PA intensity signatures related to metabolic health in children using different epoch settings. A sample of 841 Norwegian children (age 10.2 ± 0.3 years; BMI 18.0 ± 3.0; 50% boys) provided data on accelerometry (ActiGraph GT3X+) and several indices of metabolic health (aerobic fitness, abdominal fatness, insulin sensitivity, lipid metabolism, blood pressure) that were used to create a composite metabolic health score. We created intensity spectra from 0–99 to ≥ 10000 counts per minute (cpm) for files aggregated using 1, 10, and 60-second epoch periods and used multivariate pattern analysis to analyse the data. The association patterns with metabolic health differed substantially between epoch settings. The intensity intervals most strongly associated with metabolic health were 7000–8000 cpm for data analysed using 1-second epoch, 5500–6500 cpm for data analysed using 10-second epoch, and 4000–5000 cpm analysed using 60-second epoch. Aggregation of data over different epoch periods has a clear impact on how PA intensities in the moderate and vigorous range are associated with childhood metabolic health.

ARTICLE HISTORY
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KEYWORDS
Multivariate analysis; risk factors; child; accelerometry; intensity

Introduction

Moderate-to-vigorous physical activity (MVPA) has consistently been associated with metabolic health outcomes in childhood (Ekelund, Luan, & Sherar et al., 2012; Janssen & LeBlanc, 2010; Poitras et al., 2016). Because clustering of risk factors for cardiovascular disease is evident already in childhood (Andersen, Lauersen, & Brønd et al., 2015), and tracks into adulthood (Camhi & Katzmarzyk, 2010), knowledge of how physical activity (PA) and particularly how different intensities of PA relates to metabolic health in children is needed. However, the evidence for the association between intensity-specific PA and metabolic health is limited by several analytic challenges. First, restricting exposure variables to MVPA and sedentary time (SED) (Janssen & LeBlanc, 2010), probably to avoid collinearity, causes a loss of information, increases susceptibility to residual confounding, and ignores the possible influence of other PA intensities on health outcomes (i.e., light (LPA), moderate (MPA), vigorous (VPA), and very vigorous intensity PA) (Janssen & LeBlanc, 2010; Poitras et al., 2016; van der Ploeg & Hillsdon, 2017). Second, what kind of activities and which intensities are captured as MVPA by accelerometry depends on the data reduction algorithms and scoring protocols applied, which leads to confusion in interpreting results from studies using different methodology (Cain, Sallis, Conway, Van Dyck, & Calhoon, 2013; Migueles et al., 2017). Specifically, the choice of epoch durations used to aggregate data and the choice of cut points used to score data have a profound influence on the resulting levels of intensity-specific PA (Banda et al., 2016; Froberg, Berg, Larsson, Boldemann, & Raustorp, 2017).

Children's PA is characterised by sporadic and intermittent bursts of PA generally lasting less than 10 seconds (Aadland, Andersen, Anderssen, Resaland, & Kvalheim, 2018; Bailey et al., 1995; Rowlands, Pilgrim, & Eston, 2008; Sanders, Cliff, & Lonsdale, 2014). Because the vast majority of bouts in the light to vigorous intensity range has a duration of only some few seconds when analysed at 1-second epoch (Aadland, Andersen, Anderssen, Resaland, & Kvalheim, 2018; Sanders et al., 2014), summation of PA over longer epochs leads to loss of time spent in the lower and higher end of the intensity spectrum, as these intensities are averaged over a long period. Thus, SED, VPA, and MVPA are consistently underestimated and LPA overestimated, when epoch duration increases from 1 to 60 seconds (Aadland, Andersen, Anderssen, Resaland, & Kvalheim 2018; Banda et al., 2016; Froberg et al., 2017; Nettlefold et al., 2016; Nilsson, Ekelund, Yngve, & Söström, 2002; Sanders et al., 2014; Vale, Santos, Silva, Soares-Miranda, & Mota, 2009), suggesting that short epoch settings are recommended to capture PA correctly. Furthermore, MPA is less affected than VPA (Banda et al., 2016; Froberg et al., 2017; Nilsson et al., 2002; Vale et al., 2009) or show a pattern contrary to VPA (Froberg et al., 2017; Nettlefold et al., 2016; Sanders et al., 2014), when aggregating data over longer epochs. These effects mask the specific levels, and thus health influence of VPA, when summing these intensities into MVPA. The influence of epoch settings on PA levels also depends on the applied PA intensity cut points, because the specific effect

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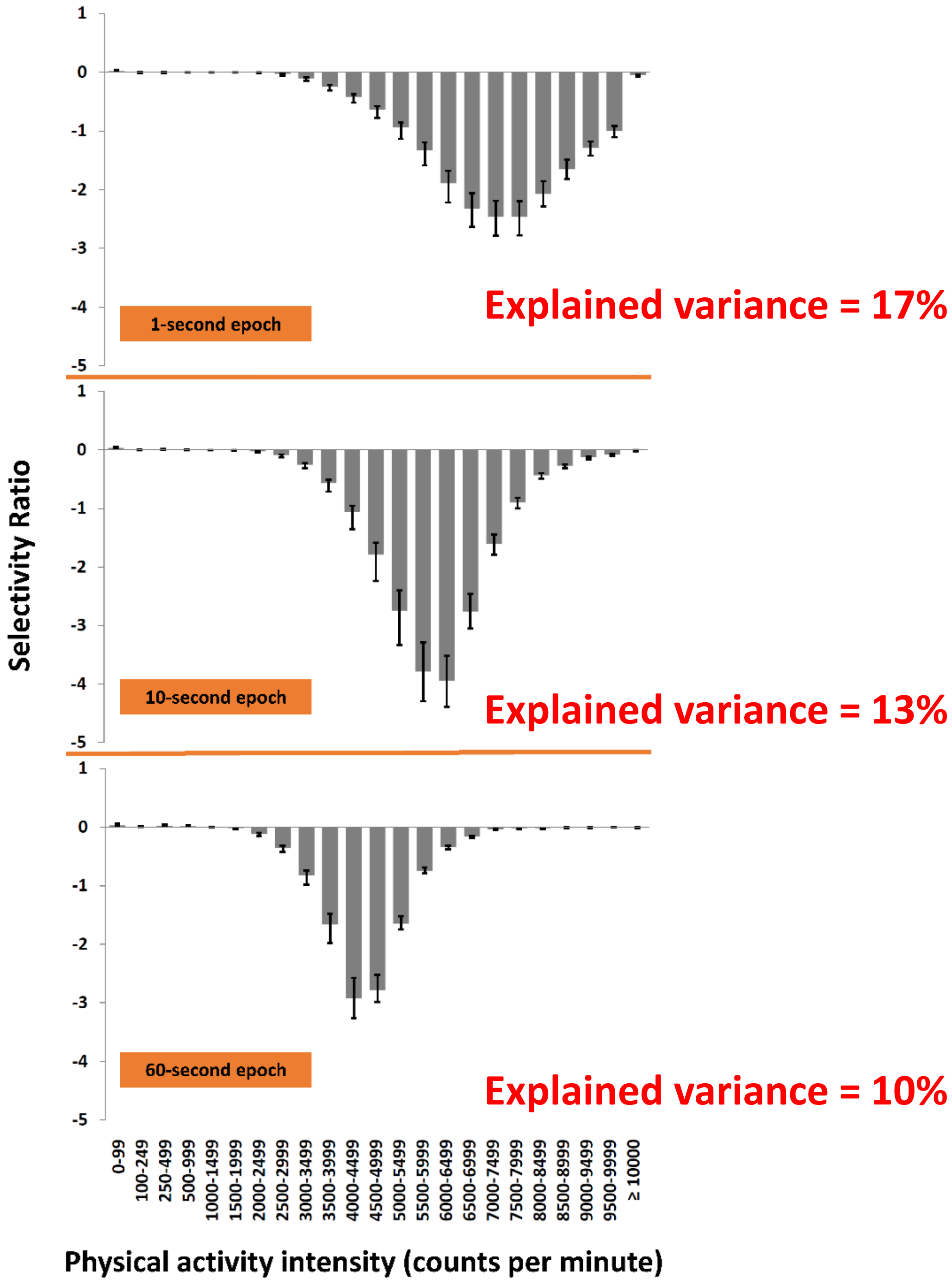

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International Journal of Behavioral Nutrition and Physical Activity

METHODOLOGY **Open Access**

Multicollinear physical activity accelerometry data and associations to cardiometabolic health: challenges, pitfalls, and potential solutions

Eivind Aadland[1*], Olav Martin Kvalheim[2], Sigmund Alfred Anderssen[1,3], Geir Kåre Resaland[4] and Lars Bo Andersen[1]

Abstract

Background: The analysis of associations between accelerometer-derived physical activity (PA) intensities and cardiometabolic health is a major challenge due to multicollinearity between the explanatory variables. This challenge has facilitated the application of different analytic approaches within the field. The aim of the present study was to compare association patterns of PA intensities with cardiometabolic health in children obtained from multiple linear regression, compositional data analysis, and multivariate pattern analysis.

Methods: A sample of 841 children (age 10.2 ± 0.3 years; BMI 18.0 ± 3.0; 50% boys) provided valid accelerometry and cardiometabolic health data. Accelerometry (ActiGraph GT3X+) data were characterized into traditional (four PA intensity variables) and more detailed categories (23 PA intensity variables covering the intensity spectrum; 0–99 to ≥10,000 counts per minute). Several indices of cardiometabolic health were used to create a composite cardiometabolic health score. Multiple linear regression and multivariate pattern analyses were used to analyze both raw and compositional data.

Results: Besides a consistent negative (favorable) association between vigorous PA and the cardiometabolic health measure using the traditional description of PA data, associations between PA intensities and cardiometabolic health differed substantially depending on the analytic approaches used. Multiple linear regression lead to instable and spurious associations, while compositional data analysis showed distorted association patterns. Multivariate pattern analysis appeared to handle the raw PA data correctly, leading to more plausible interpretations of the associations between PA intensities and cardiometabolic health.

Conclusions: Future studies should consider multivariate pattern analysis without any transformation of PA data when examining relationships between PA intensity patterns and health outcomes.

Trial registration: The study was registered in Clinicaltrials.gov 7th of April 2014 with identification number NCT02132494.

Keywords: Multivariate pattern analysis, Compositional data analysis, Multiple linear regression, Multicollinearity, Statistics, Children, Accelerometer, Intensity

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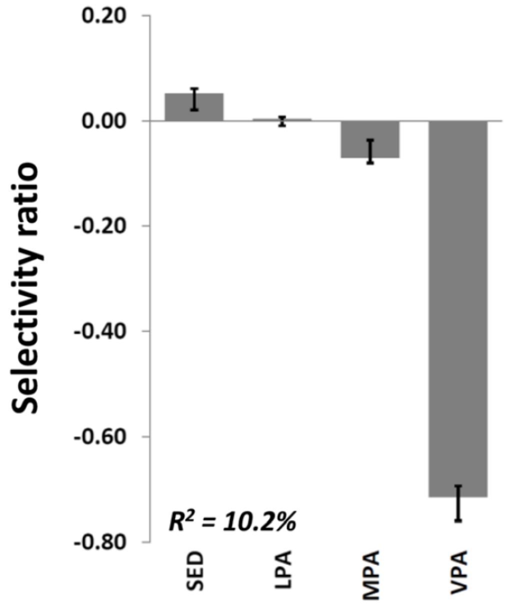

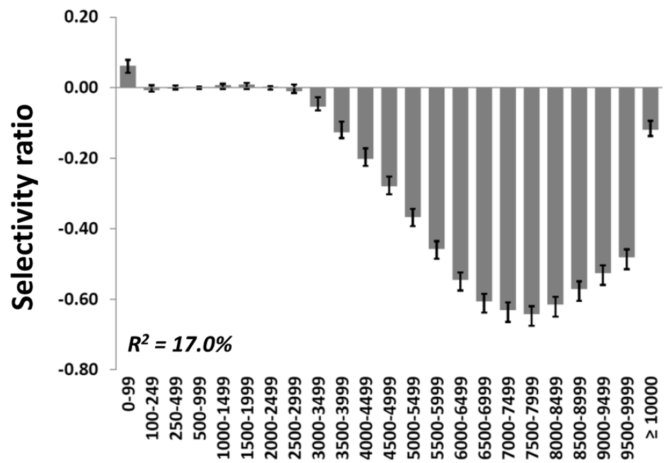

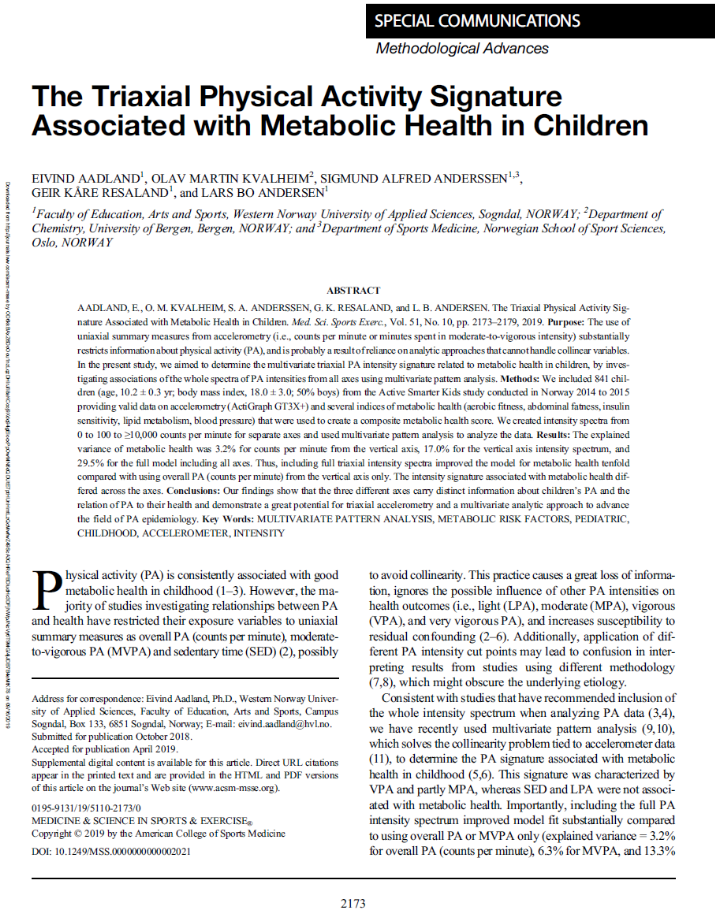

SPECIAL COMMUNICATIONS

Methodological Advances

The Triaxial Physical Activity Signature Associated with Metabolic Health in Children

EIVIND AADLAND[1], OLAV MARTIN KVALHEIM[2], SIGMUND ALFRED ANDERSSEN[1,3], GEIR KÅRE RESALAND[1], and LARS BO ANDERSEN[1]

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ABSTRACT

AADLAND, E., O. M. KVALHEIM, S. A. ANDERSSEN, G. K. RESALAND, and L. B. ANDERSEN. The Triaxial Physical Activity Signature Associated with Metabolic Health in Children. *Med. Sci. Sports Exerc.*, Vol. 51, No. 10, pp. 2173–2179, 2019. **Purpose:** The use of uniaxial summary measures from accelerometry (i.e., counts per minute or minutes spent in moderate-to-vigorous intensity) substantially restricts information about physical activity (PA), and is probably a result of reliance on analytic approaches that cannot handle collinear variables. In the present study, we aimed to determine the multivariate triaxial PA intensity signature related to metabolic health in children, by investigating associations of the whole spectra of PA intensities from all axes using multivariate pattern analysis. **Methods:** We included 841 children (age, 10.2 ± 0.3 yr; body mass index, 18.0 ± 3.0; 50% boys) from the Active Smarter Kids study conducted in Norway 2014 to 2015 providing valid data on accelerometry (ActiGraph GT3X+) and several indices of metabolic health (aerobic fitness, abdominal fatness, insulin sensitivity, lipid metabolism, blood pressure) that were used to create a composite metabolic health score. We created intensity spectra from 0 to 100 to ≥10,000 counts per minute for separate axes and used multivariate pattern analysis to analyze the data. **Results:** The explained variance of metabolic health was 3.2% for counts per minute from the vertical axis, 17.0% for the vertical axis intensity spectrum, and 29.5% for the full model including all axes. Thus, including full triaxial intensity spectra improved the model for metabolic health tenfold compared with using overall PA (counts per minute) from the vertical axis only. The intensity signature associated with metabolic health differed across the axes. **Conclusions:** Our findings show that the three different axes carry distinct information about children's PA and the relation of PA to their health and demonstrate a great potential for triaxial accelerometry and a multivariate analytic approach to advance the field of PA epidemiology. **Key Words:** MULTIVARIATE PATTERN ANALYSIS, METABOLIC RISK FACTORS, PEDIATRIC, CHILDHOOD, ACCELEROMETER, INTENSITY

Physical activity (PA) is consistently associated with good metabolic health in childhood (1–3). However, the majority of studies investigating relationships between PA and health have restricted their exposure variables to uniaxial summary measures as overall PA (counts per minute), moderate-to-vigorous PA (MVPA) and sedentary time (SED) (2), possibly to avoid collinearity. This practice causes a great loss of information, ignores the possible influence of other PA intensities on health outcomes (i.e., light (LPA), moderate (MPA), vigorous (VPA), and very vigorous PA), and increases susceptibility to residual confounding (2–6). Additionally, application of different PA intensity cut points may lead to confusion in interpreting results from studies using different methodology (7,8), which might obscure the underlying etiology.

Consistent with studies that have recommended inclusion of the whole intensity spectrum when analyzing PA data (3,4), we have recently used multivariate pattern analysis (9,10), which solves the collinearity problem tied to accelerometer data (11), to determine the PA signature associated with metabolic health in childhood (5,6). This signature was characterized by VPA and partly MPA, whereas SED and LPA were not associated with metabolic health. Importantly, including the full PA intensity spectrum improved model fit substantially compared to using overall PA or MVPA only (explained variance = 3.2% for overall PA (counts per minute), 6.3% for MVPA, and 13.3%

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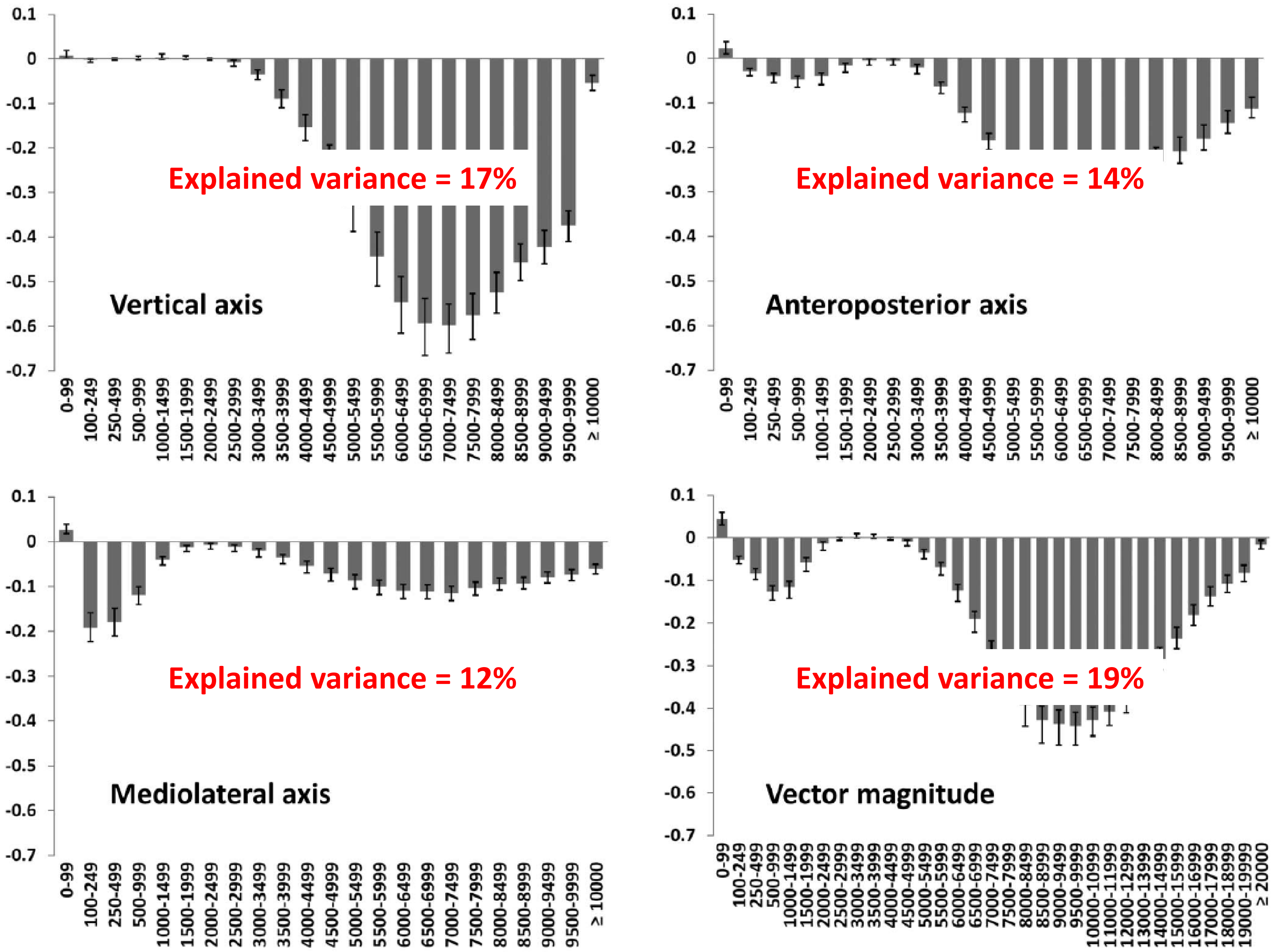

Joint model: 30% explained variance

More information from accelerometry

Sample

- 821 schoolchildren (10-year-olds)
- Composite metabolic health outcome
- *1 sec epoch*

Explained variance

- CPM: 3%
- MVPA: 7%
- SED, LPA, MPA, VPA: 10%
- Uniaxial intensity spectrum: 17%
- Triaxial intensity spectrum: 30%


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The multivariate physical activity signature associated with body mass index in young children

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ABSTRACT

The evidence regarding associations between intensity-specific physical activity and adiposity in young children is conflicting. Moreover, the evidence is limited by analytical approaches that cannot handle the multicollinearity among multiple variables across the entire intensity spectrum. We aimed to determine the multivariate physical activity intensity signature associated with body mass index in a large sample of preschool children aged 3–6 years. 1182 Norwegian preschool children (mean age 4.7 years, 51% boys) provided data on physical activity (ActiGraph GT3X+) and body mass index during 2015–2016. Multivariate pattern analysis was used to determine associations between the entire triaxial intensity spectra (time spent in intensities from 0-99 to ≥ 15000 counts per minute) and body mass index in the total sample and in subgroups split by sex and age (median split). The association patterns were comparable across the three axes. For the vertical axis, associations were negative for time spent sedentary (0–99 counts per minute), positive for time spent in lower intensities (100–2999 counts per minute), and negative for time spent in vigorous intensities (4000–12,999 counts per minute). Associations were stronger in older than in younger children and no associations were observed for vigorous intensities among younger children. Association patterns were comparable for boys and girls. In conclusion, we found clear associations with body mass index across the physical activity intensity spectrum in preschool children. However, the age-specific association patterns suggest negative (unfavorable) associations with vigorous physical activity intensities develop around 5–6 years of age.

1. Introduction

Overweight and obesity are major health concerns globally (The Global Burden of Disease 2015 Obesity Collaborators, 2017) and develop in many cases from an early age (Monteiro and Victora, 2005). While there is convincing evidence of a negative association for physical activity (PA) with adiposity and metabolic health in school-aged children and youth (Poitras et al., 2016; Ekelund et al., 2012; Aadland et al., 2018a; Jimenez-Pavon et al., 2010; Cooper et al., 2015), the evidence for such an association in younger children is weaker and mixed (Carson et al., 2017; Bingham et al., 2016; Wiersma et al., 2020). These findings suggest the association between PA and adiposity develops over time, but it is uncertain when this relationship starts to emerge.

The conflicting evidence regarding the association between PA and adiposity in preschool-aged children probably results from several limitations of the prevailing literature. First, sample sizes of existing studies are small to moderate ($n \leq 540$ among the 56 studies included in the most recent systematic review and meta-analysis by Wiersma et al (2020)). Given the weak associations sought uncovered, such sample sizes will inherently lead to instable association estimates and heterogeneity among study conclusions.

Second, while Wiersma et al. (Wiersma et al., 2020), in line with other systematic reviews (Carson et al., 2017; Bingham et al., 2016), generally found no association between PA and body mass index (BMI), significant associations were observed for percentage body fat and weight status (normal weight versus overweight or obese). The stronger association with weight status (a dichotomous variable) than with BMI (a continuous variable) is unexpected given the loss of information resulting from categorization, an approach which is generally not recommended (Altman and Royston, 2006; Dawson and Weiss, 2012). Similarly, many studies apply a dichotomized PA variable of whether children achieve the guideline amount of PA or not. Thus, application of

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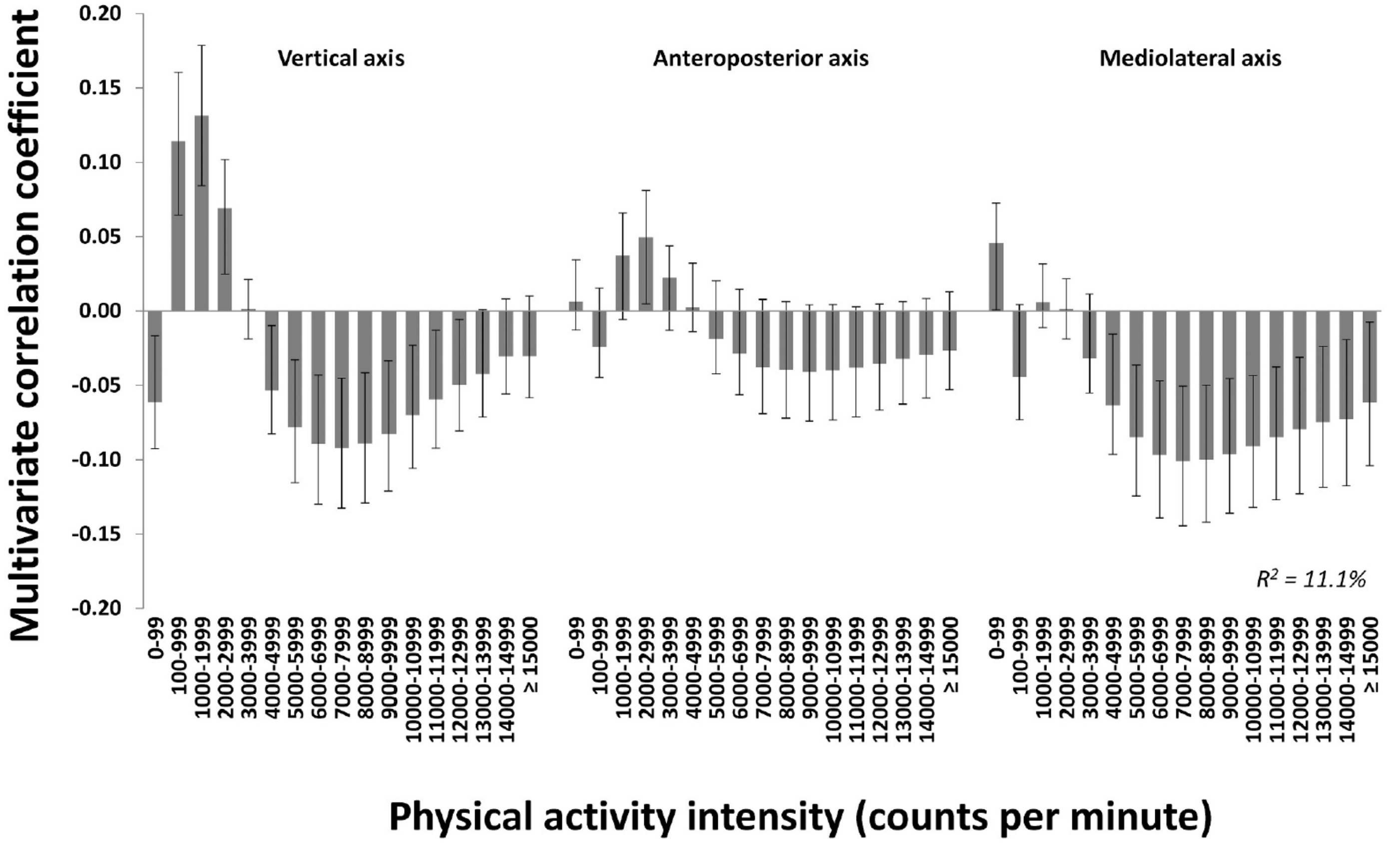

Fig. 1. The multivariate physical activity signature associated with body mass index in preschoolers. Results are reported as multivariate correlation coefficients from a joint model including all 51 physical activity intensities from the triaxial accelerometry (explained variance 11.1%, 6 PLS components). Correlations coefficients can be interpreted equivalent to bivariate correlations, though they are derived from the full multivariate model.

Explained variance

- Uniaxial intensity spectrum: 6.2%
- Triaxial intensity spectrum: 11.1%

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The multivariate physical activity signature associated with metabolic health in children and youth: An International Children's Accelerometry Database (ICAD) analysis

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ABSTRACT

There is solid evidence for an association between physical activity and metabolic health outcomes in children and youth, but for methodological reasons most studies describe the intensity spectrum using only a few summary measures. We aimed to determine the multivariate physical activity intensity signature associated with metabolic health in a large and diverse sample of children and youth, by investigating the association pattern for the entire physical intensity spectrum. We used pooled data from 11 studies and 11,853 participants aged 5.8–18.4 years included in the International Children's Accelerometry Database. We derived 14 accelerometry-derived (ActiGraph) physical activity variables covering the intensity spectrum (from 0–99 to ≥8000 counts per minute). To handle the multicollinearity among these variables, we used multivariate pattern analysis to establish the associations with indices of metabolic health (abdominal fatness, insulin sensitivity, lipid metabolism, blood pressure). A composite metabolic health score was used as the main outcome variable. Associations with the composite metabolic health score were weak for sedentary time and light physical activity, but gradually strengthened with increasing time spent in moderate and vigorous intensities (up to 4000–5000 counts per minute). Association patterns were fairly consistent across sex and age groups, but varied across different metabolic health outcomes. This novel analytic approach suggests that vigorous intensity, rather than less intense activities or sedentary behavior, are related to metabolic health in children and youth.

1. Introduction

There is clear evidence of favorable associations between physical activity (PA) and metabolic health outcomes in children. While associations are evident for moderate-to-vigorous PA (MVPA) and vigorous PA (VPA), associations appears to be weak for light PA (LPA) and

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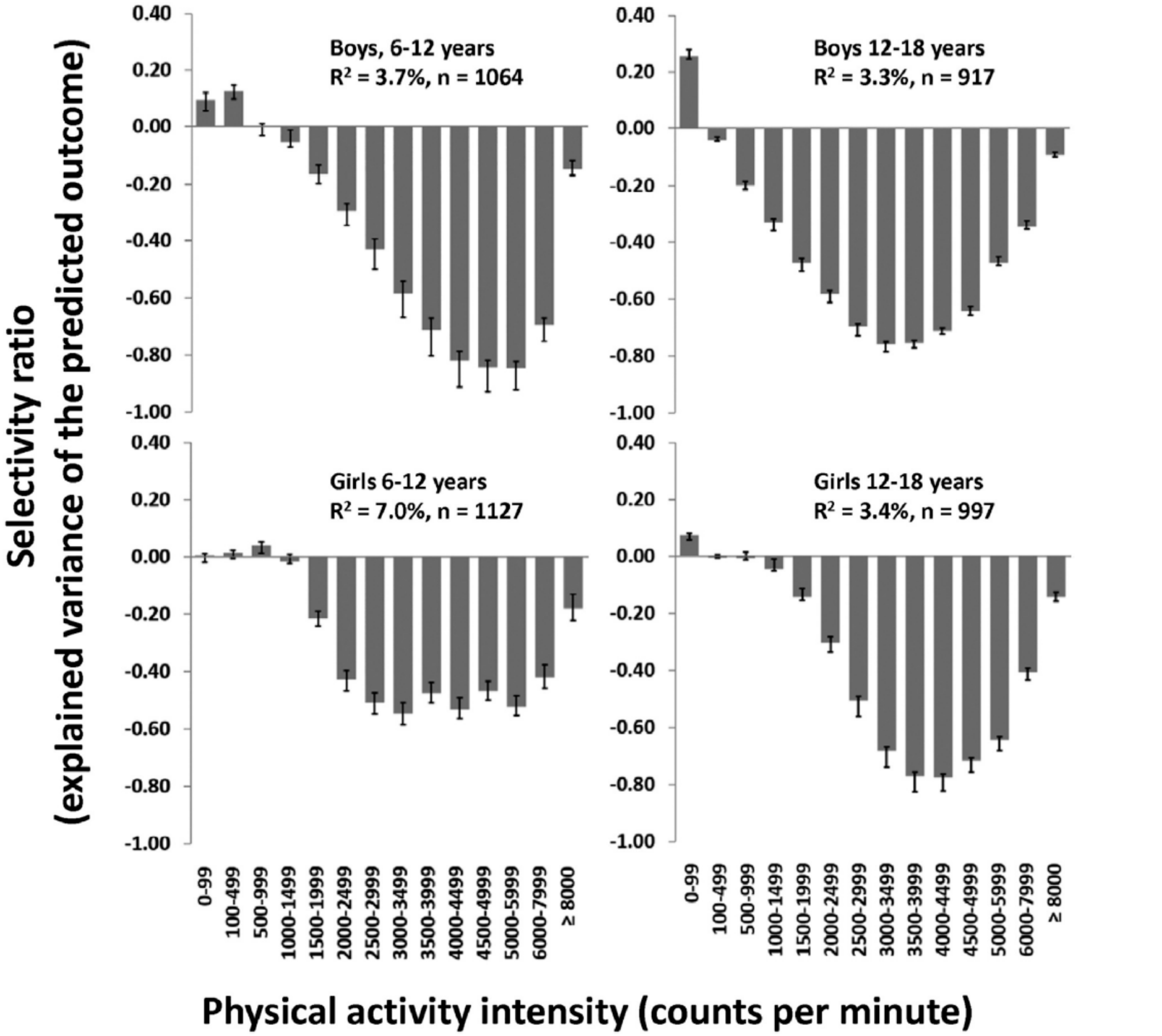

Fig. 2. The multivariate physical activity signatures associated with metabolic health by sex and age. The composite score includes waist circumference to height ratio, systolic blood pressure, homeostasis model assessment of insulin resistance, total to high-density lipoprotein cholesterol ratio, and triglyceride (a lower score is more favorable). The PLS regression models are adjusted for age and sex and include two, one, four, and one components, respectively, for 6–12-year-old boys, 12–18-year-old boys, 6–12-year-old girls, and 12–18-year-old girls. The selectivity ratio for each variable is the explained to total variance of the predictive (target projected) component. A negative bar implies that increased physical activity is associated with better metabolic health. R^2 = explained variance.

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The Multivariate Physical Activity Signatures Associated With Self-Regulation, Executive Function, and Early Academic Learning in 3–5-Year-Old Children

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The evidence regarding associations between intensity-specific physical activity and cognitive and learning outcomes in preschoolers is inconsistent and limited by low sample sizes and analytical approaches that cannot handle the multicollinearity among multiple physical activity intensity variables. We aimed to determine the multivariate physical activity intensity signatures associated with self-regulation, executive function, and early academic learning in preschool children aged 3–5 years. A 711 Norwegian preschool children (mean age 4.6 years, 52% boys) provided valid data on physical activity (ActiGraph GT3X+), self-regulation, executive function, and early academic learning during 2019–2020. Multivariate pattern analysis was used to determine associations between uniaxial and triaxial intensity spectra (time spent in intensities from 0–99 to ≥15,000 counts per minute) and the outcomes in the total sample and in subgroups split by sex and age (median split). Uniaxial data led to the highest explained variances (R^2) and were reported as the primary findings. We found significant association patterns between physical activity and numeracy (R^2 = 4.28%) and inhibition (R^2 = 1.48%) in the total sample. The associations with numeracy were negative for time spent sedentary (0–99 counts per minute) and positive for time spent in moderate to vigorous intensities (≥ 1,000 counts per minute). The associations with inhibition were positive for time spent sedentary (0–99 counts per minute) and in vigorous intensities (≥ 8,500 counts per minute) and negative for time spent in low to moderate intensities (100–3,499 counts per minute). Associations with numeracy were stronger in boys (R^2 = 5.58%) and older children (R^2 = 7.27%), and associations with inhibition were stronger in girls (R^2 = 3.12%) and older children (R^2 = 3.33%). In conclusion, we found weak associations with numeracy and inhibition across the physical activity intensity spectrum in preschool children.

Keywords: cognition, preschool (kindergarten), accelerometer, self-regulation, executive function, learning

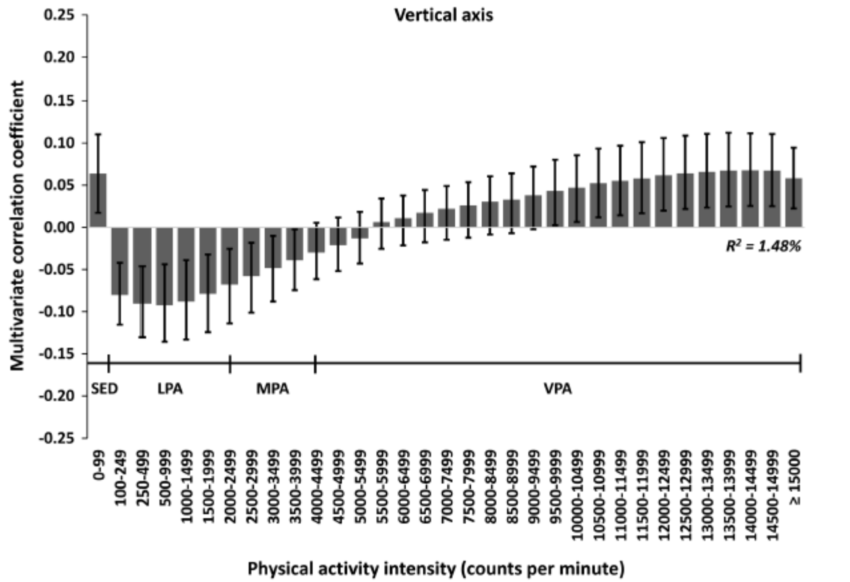

FIGURE 2 | The multivariate physical activity signature for the uniaxial spectrum associated with inhibition in preschoolers. Results are reported as multivariate correlation coefficients. The model (PLS regression) is adjusted for sex, age, wear time (only PA variables), BMI, parental education level, and sleep (model 2).

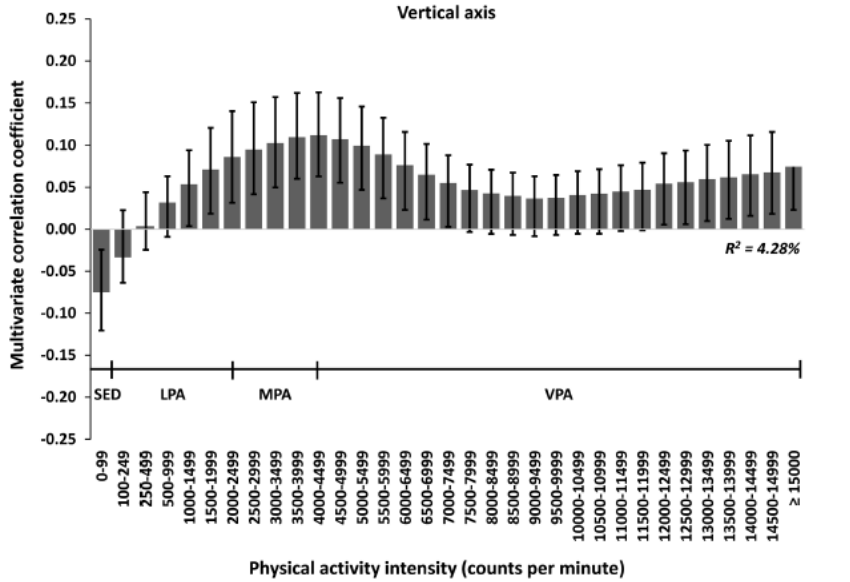

FIGURE 3 | The multivariate physical activity signature for the uniaxial spectrum associated with numeracy in preschoolers. Results are reported as multivariate correlation coefficients. The model (PLS regression) is adjusted for sex, age, wear time (only PA variables), BMI, parental education level, and sleep (model 2).

Middle-aged to older adults

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Physical activity intensity profiles associated with cardiometabolic risk in middle-aged to older men and women

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A R T I C L E I N F O

Keywords:
Physical activity
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Adiposity
Cardiometabolic
Multivariate pattern analysis
Collinearity

A B S T R A C T

Accelerometers provide detailed data about physical activity (PA) across the full intensity spectrum. However, when examining associations with health, results are often aggregated to only a few summary measures [e.g. time spent "sedentary" or "moderate-to-vigorous" intensity PA]. Using multivariate pattern analysis, which can handle collinear exposure variables, we examined associations between the full PA intensity spectrum and cardiometabolic risk (CMR) in a population-based sample of middle-aged to older adults. Participants ($n = 3660$; mean ± SD age = 69 ± 8y and BMI = 26.7 ± 4.2 kg/m^2; 55% female) from the EPIC-Norfolk study (UK) with valid accelerometry (ActiGraph-GT1M) data were included. We used multivariate pattern analysis with partial least squares regression to examine cross-sectional multivariate associations (r) across the full PA intensity spectrum [minutes/day at 0–5000 counts-per-minute (cpm); 5 s epoch] with a continuous CMR score (reflecting waist, blood pressure, lipid, and glucose metabolism). Models were sex-stratified and adjusted for potential confounders. There was a positive (detrimental) association between PA and CMR at 0-12 cpm (maximally-adjusted $r = 0.08$ (95%CI 0.06–0.10). PA was negatively (favourably) associated with CMR at all intensities above 13 cpm ranging between $r = -0.09$ (0.07–0.12) at 800-999 cpm and $r = -0.14$ (0.11–0.16) at 75–99 and 4000-4999 cpm. The strongest favourable associations were from 50 to 800 cpm ($r = 0.10$–0.12) in men, but from ≥2500 cpm ($r = 0.18$–0.20) in women; with higher proportions of model explained variance for women ($R^2 = 7.4\%$ vs. 2.3%). Most of the PA intensity spectrum was beneficially associated with CMR in middle-aged to older adults, even at intensities lower than what has traditionally been considered "sedentary" or "light-intensity" activity. This supports encouragement of PA at almost any intensity in this age-group.

1. Introduction

Recent research utilising wearable devices (accelerometers) has shown physical activity (PA) intensity may play a role in mortality risk over and above total PA volume (Strain et al., 2020). Accelerometers provide high resolution time-stamped data on both total PA volume and across the full spectrum of PA intensities (Doherty et al., 2017; Golubic et al., 2014; Berkemeyer et al., 2016; Lindsay et al., 2019). However, one barrier to investigating the full PA intensity spectrum in relation to health outcomes is that time spent at different intensities are highly correlated with each other (i.e. multicollinearity) and thus challenging to model together. Although compositional data analysis approaches can address co-dependency of PA intensities, it remains common to collapse detailed PA intensity information into broad summary variables (e.g. time spent in moderate-to-vigorous intensity activity, sedentary time) using pre-defined cutpoints to give behavioural and biological meaning (Whitaker et al., 2019; Swindell et al., 2018; Powell et al., 2018; LaMonte et al., 2017; Alessa et al., 2017; Brocklebank et al., 2015; Henson et al., 2013; Healy et al., 2008; Healy et al., 2007). While this approach can lead to more easily interpretable messages, it can lead to loss of information and, importantly, pre-supposes which intensities are most important to examine with respect to health, rather than letting

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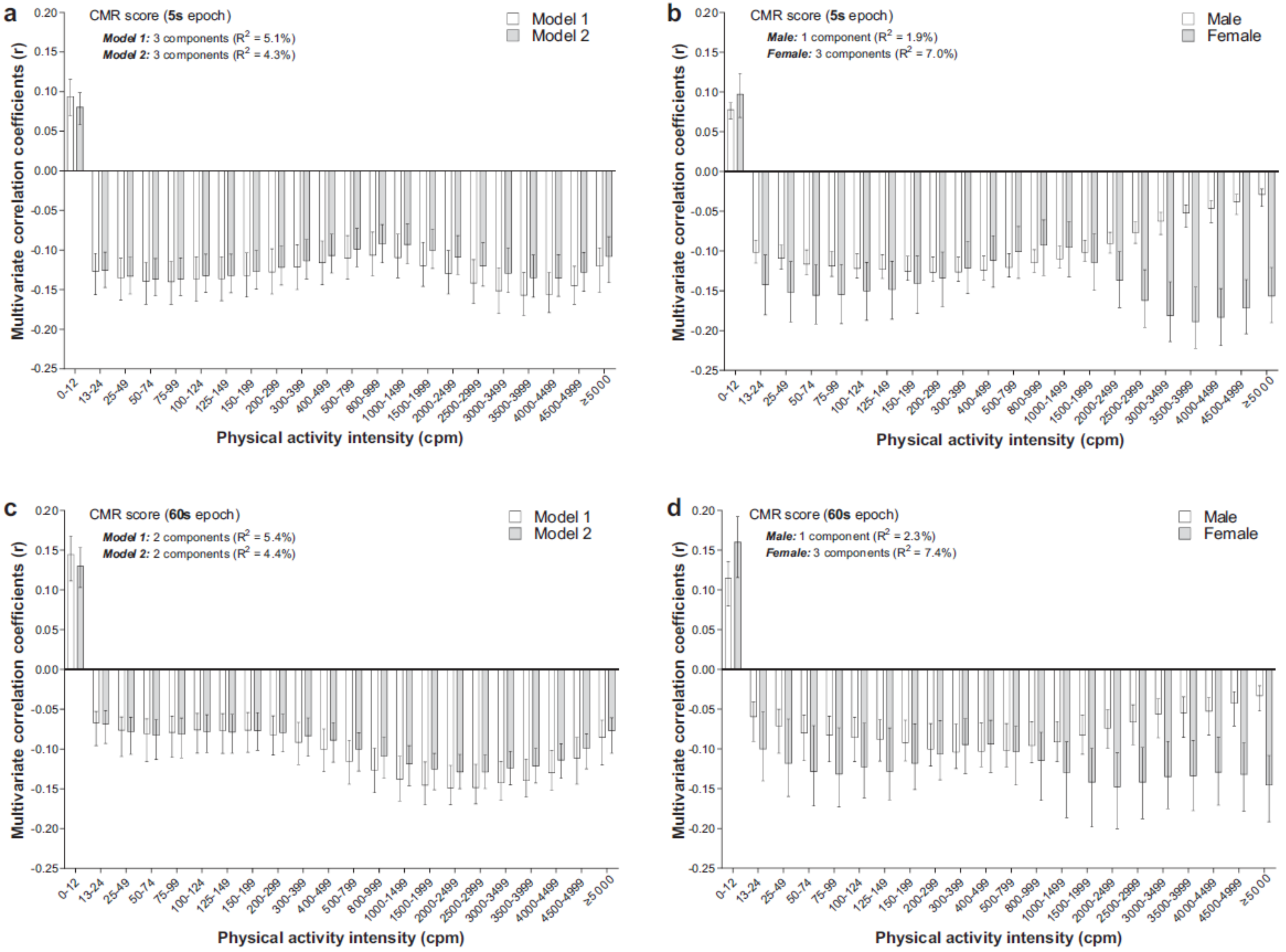

Fig. 2. Multivariate PA intensity profile associated with the CMR score. Multivariate correlation coefficients with 95% CIs from the multivariate model including m = 22 PA intensity variables are displayed for the whole sample (panels a and c) and by sex (panels b and d). Physical activity variables are shown for 5 s (panels a and b) and 60 s (panels c and d) epoch resolution. Model 1 adjusted for age and sex. Model 2 additionally adjusted for potential confounders (education level, smoking status, alcohol intake, baseline history of diabetes, anti-hypertensive and dyslipidaemia medications, and prevalent heart disease/stroke). Sex-specific models are based on model 2 (with no adjustment for sex). The number of PLS components and total explained variance (R^2) for each model are also displayed. A negative bar implies a more favourable association with the CMR score. *Note:* equivalent plots are displayed for higher intensity resolutions (m = 37 and 57 PA variables) in *Supplemental Fig. S3.1–2*, and for illustration only in m = 3 PA variables (*Supplementary Fig. S6*).

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METHODOLOGY **Open Access**

Multicollinear physical activity accelerometry data and associations to cardiometabolic health: challenges, pitfalls, and potential solutions

Eivind Aadland[1*], Olav Martin Kvalheim[2], Sigmund Alfred Anderssen[1,3], Geir Kåre Resaland[4] and Lars Bo Andersen[1]

Abstract

Background: The analysis of associations between accelerometer-derived physical activity (PA) intensities and cardiometabolic health is a major challenge due to multicollinearity between the explanatory variables. This challenge has facilitated the application of different analytic approaches within the field. The aim of the present study was to compare association patterns of PA intensities with cardiometabolic health in children obtained from multiple linear regression, compositional data analysis, and multivariate pattern analysis.

Methods: A sample of 841 children (age 10.2 ± 0.3 years; BMI 18.0 ± 3.0; 50% boys) provided valid accelerometry and cardiometabolic health data. Accelerometry (ActiGraph GT3X+) data were characterized into traditional (four PA intensity variables) and more detailed categories (23 PA intensity variables covering the intensity spectrum; 0–99 to ≥10,000 counts per minute). Several indices of cardiometabolic health were used to create a composite cardiometabolic health score. Multiple linear regression and multivariate pattern analyses were used to analyze both raw and compositional data.

Results: Besides a consistent negative (favorable) association between vigorous PA and the cardiometabolic health measure using the traditional description of PA data, associations between PA intensities and cardiometabolic health differed substantially depending on the analytic approaches used. Multiple linear regression lead to instable and spurious associations, while compositional data analysis showed distorted association patterns. Multivariate pattern analysis appeared to handle the raw PA data correctly, leading to more plausible interpretations of the associations between PA intensities and cardiometabolic health.

Conclusions: Future studies should consider multivariate pattern analysis without any transformation of PA data when examining relationships between PA intensity patterns and health outcomes.

Trial registration: The study was registered in Clinicaltrials.gov 7th of April 2014 with identification number NCT02132494.

Keywords: Multivariate pattern analysis, Compositional data analysis, Multiple linear regression, Multicollinearity, Statistics, Children, Accelerometer, Intensity

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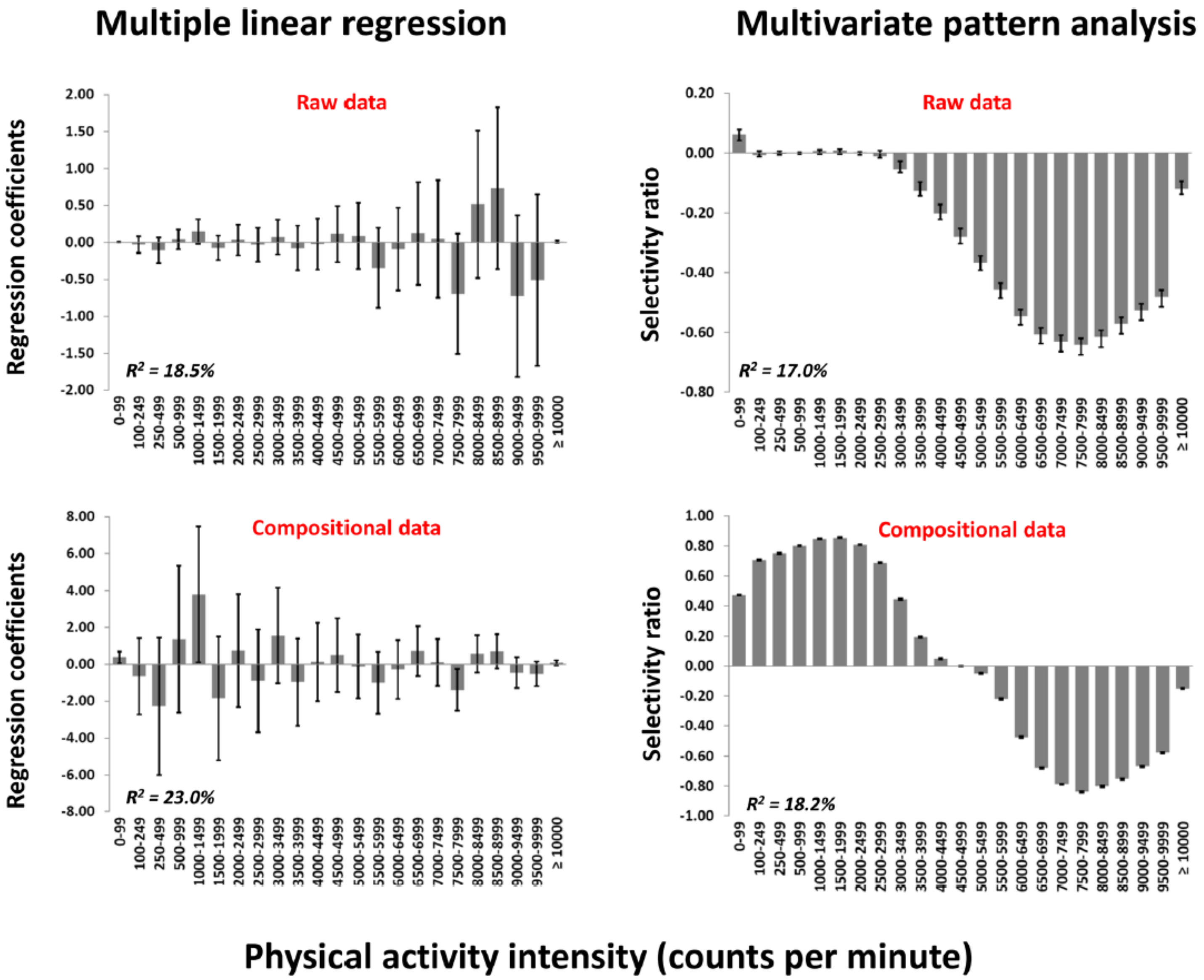
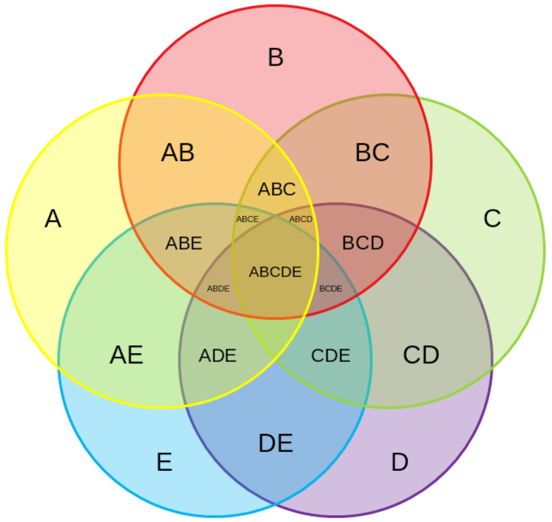


Fig. 4 Association patterns between physical activity intensities and a composite cardiometabolic health score using the spectrum description of 23 physical activity variables using different analytic approaches. Multiple linear regression with raw data (upper left panel), multiple linear regression with compositional data using the ilr-transformation (lower left panel), multivariate pattern analysis with raw data (upper right panel), and multivariate pattern analysis with compositional data using the clr-transformation (lower right panel). Selectivity ratio is calculated as the ratio of explained to total variance on the predictive (target projected) component. R^2 = explained variance of the model

2 challenges for interpretation

- Use of «**selectivity ratio**» as the statistic for reporting associations
  - Unknown for many researchers
  - Introduced «**multivariate correlation coefficients**»
    - Interpretation is equivalent to bivariate correlations

- Associations are **<u>not</u> independent**
  - Searching for independent associations make less sense when variables are highly correlated
  - PA variables from accelerometry profiles do not provide unique information – variables are not separable



How does interpretation of associations from multivariate pattern analysis models differ from linear regression models?

metabolites

MDPI

Article

Interpretation of Multivariate Association Patterns between Multicollinear Physical Activity Accelerometry Data and Cardiometabolic Health in Children—A Tutorial

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Abstract: Associations between multicollinear accelerometry-derived physical activity (PA) data and cardiometabolic health in children needs to be analyzed using an approach that can handle collinearity among the explanatory variables. The aim of this paper is to provide readers a tutorial overview of interpretation of multivariate pattern analysis models using PA accelerometry data that reveals the associations to cardiometabolic health. A total of 841 children (age 10.2 ± 0.3 years) provided valid data on accelerometry (ActiGraph GT3X+) and six indices of cardiometabolic health that were used to create a composite score. We used a high-resolution PA description including 23 intensity variables covering the intensity spectrum (from 0–99 to ≥10000 counts per minute), and multivariate pattern analysis to analyze data. We report different statistical measures of the multivariate associations between PA and cardiometabolic health and use decentile groups of PA as a basis for discussing the meaning and impact of multicollinearity. We show that for high-resolution accelerometry data; considering all explanatory variables is crucial to obtain a correct interpretation of associations to cardiometabolic health; which is otherwise strongly confounded by multicollinearity in the dataset. Thus; multivariate pattern analysis challenges the traditional interpretation of findings from linear regression models assuming independent explanatory variables

Keywords: multivariate pattern analysis; multiple linear regression; multicollinearity; statistics; cardiometabolic health; children; accelerometer; intensity

Table 4. Mean time (min/day) spent in PA intensities according to decentiles of time spent in 7000–7999 cpm.

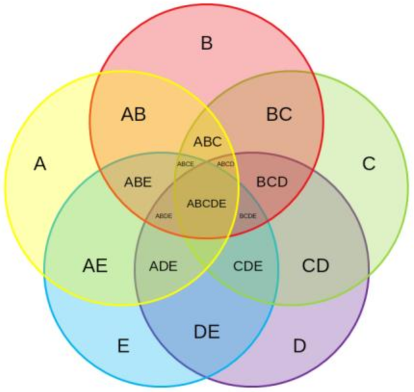
Physical Activity Intensity (cpm)	Decentiles of 7000–7999 cpm										
	1	2	3	4	5	6	7	8	9	10	Mean
Boys											
0–99	647	624	605	602	586	586	573	583	569	554	593
100–999	61.1	68.2	71.6	69.7	72.2	68.6	70.0	73.4	73.5	73.5	70.2
1000–1999	36.5	41.5	42.9	43.6	45.3	42.7	44.6	46.2	47.3	48.1	43.9
2000–2999	22.9	26.0	27.5	27.6	29.1	27.8	30.0	30.0	31.3	33.0	28.5
3000–3999	15.1	17.2	18.5	19.5	20.9	20.1	22.1	22.2	23.5	25.8	20.5
4000–4999	8.2	10.0	10.8	12.4	13.3	12.9	14.4	14.9	16.1	18.4	13.1
5000–5999	4.4	5.7	6.2	7.3	8.0	8.0	9.1	9.7	10.7	12.5	8.2
6000–6999	2.8	3.7	4.2	4.8	5.4	5.8	6.5	7.2	8.2	9.8	5.8
7000–7999	**1.55**	**2.23**	**2.59**	**3.02**	**3.41**	**3.77**	**4.20**	**4.72**	**5.45**	**6.81**	3.77
8000–8999	0.91	1.33	1.55	1.83	2.07	2.32	2.57	2.87	3.36	4.28	2.31
9000–9999	0.64	0.94	1.09	1.31	1.50	1.66	1.79	2.02	2.38	3.07	1.64
≥10000	2.83	4.21	5.80	6.57	8.33	8.59	8.29	9.72	12.16	14.97	8.14
2000–3999	38.0	43.2	46.0	47.1	50.0	47.9	52.1	52.2	54.8	58.8	49.0
≥4000	21.3	28.1	32.2	37.2	42.0	43.0	46.9	51.1	58.4	69.8	43.0
Girls											
0–99	646	624	620	607	597	587	604	590	567	567	601
100–999	61.6	66.7	69.8	66.3	71.0	66.4	71.4	72.2	72.1	76.1	69.4
1000–1999	34.9	38.9	40.4	38.6	42.6	40.8	42.2	43.8	48.2	20.7	41.5
2000–2999	20.7	23.2	24.4	23.7	26.6	26.4	27.0	28.7	27.4	31.8	26.0
3000–3999	13.2	15.2	16.4	16.5	18.0	18.2	19.2	19.9	19.5	23.1	17.9
4000–4999	7.2	8.7	9.6	10.0	10.7	11.1	11.8	12.3	12.6	15.1	10.9
5000–5999	3.8	4.9	5.6	5.8	6.5	6.8	7.1	7.6	7.8	9.7	6.5
6000–6999	2.4	3.2	3.7	3.9	4.5	4.7	5.1	5.5	5.8	7.2	4.6
7000–7999	**1.38**	**1.93**	**2.27**	**2.48**	**2.82**	**3.05**	**3.34**	**3.70**	**4.01**	**5.05**	3.00
8000–8999	0.82	1.20	1.33	1.50	1.72	1.89	2.05	2.32	2.58	3.24	1.86
9000–9999	0.58	0.87	0.96	1.07	1.22	1.36	1.45	1.71	1.87	2.30	1.34
≥10000	2.50	5.01	5.06	4.84	7.16	6.47	7.15	9.49	11.50	12.22	7.15
2000–3999	33.9	38.4	40.8	40.2	44.6	44.6	46.2	48.6	46.9	54.9	43.9
≥4000	16.2	20.8	23.5	24.8	27.5	28.9	30.8	33.1	34.7	42.6	28.2

The variable in bold indicates the basis for construction of decentiles.

What multicollinearity mean:

1 min

8 mins VPA in total

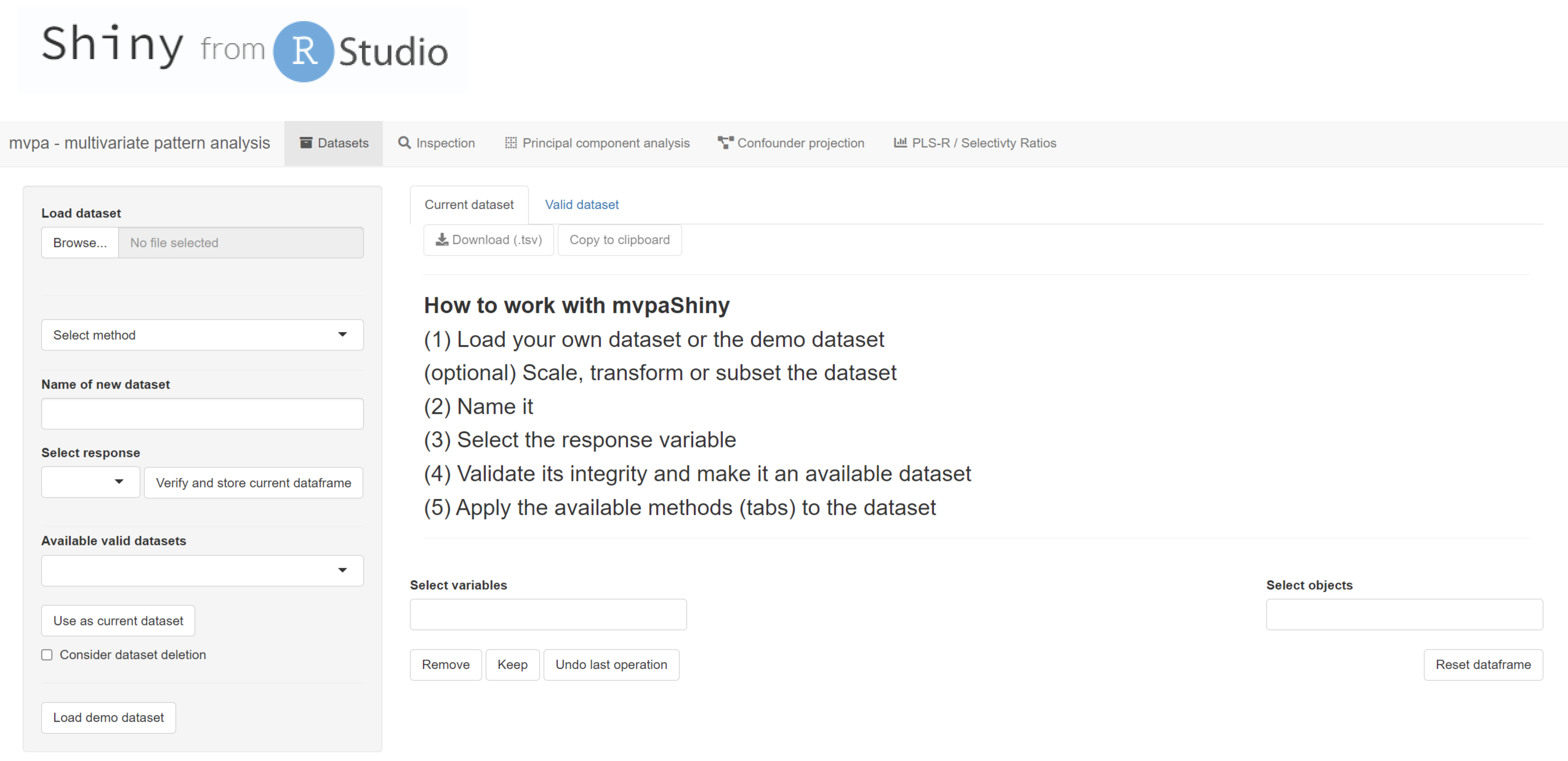


1 min

6 mins VPA in total

We have learned that multivariate pattern analysis …

- Is suitable to model multicollinear accelerometry datasets with any number of variables
- Provide 2 types of information that is useful – association pattern and total model fit
- Often lead to better association models (higher explained variance) for higher resolution (triaxial) intensity spectrum, but not always…
- May be a good tool to compare methods or groups, although testing of moderation (interactions) is difficult
- Can be applied to both cross-sectional and longitudinal data
- Can be applied to «raw» and compositional data
- May be difficult to interpret (is different from linear regression) – does NOT estimate independent associations
- Need a good method for covariate adjustment – have developed «confounder projection»


Shiny from R Studio
mvpa - multivariate pattern analysis
Datasets
Inspection
Principal component analysis
Confounder projection
PLS-R / Selectivty Ratios
Load dataset
Browse...
No file selected
Select method
Name of new dataset
Select response
Verify and store current dataframe
Available valid datasets
Use as current dataset
Consider dataset deletion
Load demo dataset
Current dataset
Valid dataset
Download (.tsv)
Copy to clipboard
How to work with mvpaShiny
(1) Load your own dataset or the demo dataset
(optional) Scale, transform or subset the dataset
(2) Name it
(3) Select the response variable
(4) Validate its integrity and make it an available dataset
(5) Apply the available methods (tabs) to the dataset
Select variables
Select objects
Remove
Keep
Undo last operation
Reset dataframe

The way forward

- Multivariate pattern analysis can provide a nuanced and complete picture of association patterns between accelerometry-derived PA data and diverse outcomes and contribute to advance our understanding of the importance of PA for health and development

- Future research should apply multivariate pattern analysis
  - In various populations
  - In various study designs
  - Using various outcomes
  - In direct comparisons with other approaches

Thank you for listening!

and thanks to participants, funding agencies and coauthors that made this research possible!

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