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TITLE: Adiposity, fitness, health-related quality of life and the reallocation of time between children's school day activity behaviours: a compositional data analysis

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Abstract

Sedentary time (ST), light (LPA), and moderate-to-vigorous physical activity (MVPA) constitute the range of school day activity behaviours. This study investigated whether the composition of school activity behaviours was associated with health indicators, and the predicted changes in health when time was reallocated between activity behaviours. Accelerometers were worn for 7-days between October and December 2010 by 318 UK children aged 10-11, to provide estimates of school day ST, LPA, and MVPA. BMI z-scores and percent waist-to-height ratio were calculated as indicators of adiposity. Cardiorespiratory fitness (CRF) was assessed using the 20-m Shuttle Run Test. The PedsQL™ questionnaire was completed to assess psychosocial and physical health-related quality of life (HRQL). Log-ratio multiple linear regression models predicted health indicators for the mean school day activity composition, and for new compositions where fixed durations of time were reallocated from one activity behaviour to another, while the remaining behaviours were unchanged. The school day activity composition significantly predicted adiposity and CRF (*p*=0.04-0.002), but not HRQL. Replacing MVPA with ST or LPA around the mean activity composition predicted higher adiposity and lower CRF. When ST or LPA were substituted with MVPA, the relationships with adiposity and CRF were asymmetrical with favourable, but smaller predicted changes in adiposity and CRF than when MVPA was replaced. Predicted changes in HRQL were negligible. The school day activity composition significantly predicted adiposity and CRF but not HRQL. Reallocating time from ST and LPA to MVPA is advocated through comprehensive school physical activity promotion approaches.

Trial registration: ISRCTN03863885

Key words: time-use epidemiology, physical activity, sedentary behaviour, accelerometer, schools, children, health, CoDA

[1]

[1] Non-standard abbreviations. CRF: cardiorespiratory fitness, HRQL: health-related quality of life, IMD: indices of multiple deprivation, SRT: shuttle run test

Introduction

Schools are key settings for initiatives to engineer moderate-to-vigorous physical activity (PA) (MVPA) into children's daily routines, through expansion, extension, and enhancement of existing school day activity opportunities [1]. Children spend a significant proportion of waking hours in schools, which have the physical and curriculum infrastructures, and personnel to promote health and wellbeing. Further, schools can positively influence children's PA irrespective of socio-demographic characteristics, which drive health inequalities [2]. However, while schools provide various opportunities for PA engagement, they are also environments where children are sedentary for long periods [3].

The increased attention given to the role of PA in positively influencing children's academic performance [4-6] has led to PA beyond physical education classes being advocated as a regular element of the school day [7, 8]. For example, in the US and UK it is recommended that children accrue at least 30 minutes MVPA during the school day [7, 8]. Such advocacy reflects the increased awareness of the influence of PA on child health and wellbeing, which is demonstrated by the volume and range of school-based PA initiatives and interventions reported over the last decade [9-13]. Such interventions require using a finite amount of time in the school day for one activity behaviour at the expense of another, which makes the proportions of time spent in these activity behaviours perfectly collinear [14]. For example, the TAKE 10! Programme [15] involves swapping 10 minutes of classroom sedentary activity with MVPA. This means that every change in time spent sitting is intended to result in a corresponding opposite change in time spent in MVPA. Data on children's activity behaviours at school are therefore constrained, or *compositional data* [16], made up of mutually exclusive parts of a whole [17]. The sample space of compositional data differs from real space associated with unconstrained vectors [17], and therefore the mathematical properties of compositional vectors should be accounted for when analysing time-use data [14]. Recently, studies have applied this *time-use epidemiology* concept [14] by treating activity behaviour data as compositional data [18-24] to properly understand the relationships between health and activity [14]. School day activity behaviours (i.e., sedentary time (ST), light PA (LPA), and MVPA) collectively constitute the range of activity behaviours that children engage in during this period. Associations between children's ST [25], LPA [26], and MVPA [27] and various health outcomes have been reported, but rarely have these individual exposure variables been analysed relative to the other activity behaviours which help compose the full period of time under examination [14]. Furthermore, it is unclear what the potential health effects are of substituting one school day behaviour, such as ST, for another, such as MVPA. Considering the importance placed on schools promoting child health and wellbeing and the range of school-based interventions that are advocated, the aims of this study were to (1) examine whether the school day activity composition was associated with indicators of physical health and health-related quality of life, which is increasingly used as an indicator of general health and wellbeing in epidemiological studies [23], and (2) investigate predicted differences among these health indicators when a fixed duration of time was reallocated from one activity behaviour to another.

Methods

Participants

This cross-sectional study was a secondary analysis of baseline data from the Children's Health, Activity, Nutrition: Get Educated! (CHANGE!) intervention (ISRCTN03863885). The methods have previously been reported [28], but are described briefly here. Four-hundred and twenty children aged 10-11 years from 12 UK primary schools were invited to participate. Schools were located in Wigan, northwest England, which is an area of high deprivation and health inequalities. Parental consent and child assent were obtained for 318 children (75.7% participation rate), approximately 95% of whom were of white British ethnicity which was representative of the local school age population [29]. Ethical approval was obtained from the Liverpool John Moores University Research Ethics Committee (10/ECL/039). Data were collected between October and December 2010.

Anthropometric and fitness measures

Stature to the nearest 0.1 cm (Seca Ltd. Birmingham, UK), body mass to the nearest 0.1 kg (Seca Ltd. Birmingham, UK), and waist circumference to the nearest 0.1 cm were measured using standard techniques [30]. BMI was calculated and BMI z-scores (zBMI) were assigned to each participant [31]. Percentage waist-to-height ratio (%WHtR) was used as an indicator of central obesity [32]. Children completed the 20-m shuttle run test (20-m SRT) to provide an estimate of cardiorespiratory fitness (CRF) [33, 34]. The running speed at the last completed lap was used to estimate peak oxygen uptake (VO_2 peak; $ml \cdot kg \cdot min^{-1}$) [34].

Demographic measures

Decimal age was calculated from dates of birth and dates of data collection. Neighbourhood-level socio-economic status (SES) was calculated from home postcodes to generate indices of multiple deprivation (IMD) scores, with higher scores representing higher degrees of deprivation [35].

Psychosocial and physical health-related quality of life (HRQL). Each child completed the Pediatric Quality of Life Inventory (PedsQL™) generic core scales [36] supervised by the research team. The PedsQL™ consists of four scales measuring physical functioning (8 items), emotional functioning (5 items), social functioning (5 items), and school functioning (5 items) on 5-point likert scales. Item scores are reversed and transformed to a 0-100 scale, with higher scores representing better wellbeing. The psychosocial HRQL score was computed as the mean of the scores in the emotional, social, and school functioning scales. The physical HRQL score was represented by the physical functioning score.

Activity behaviours: Physical activity and sedentary time. Each child wore a waist-mounted ActiGraph GT1M accelerometer for 7 consecutive days. Children were asked to wear the monitor during waking hours only and to only remove it during water-based activities or contact sports where it might cause injury or get damaged. Monitors were set to record using 5 second epochs [37] and consecutive 20 minute periods of zero counts were considered non-wear time [38]. Data were analysed in agd format using ActiLife v.6.11.5 (ActiGraph, Pensacola, FL). Each school day commenced at 09:00 and ended at 15:30 (i.e., 390 minutes school day duration). Children were included in the data analysis if they wore the monitor for at least 70% of the school day on at least 3 days [39]. The cutpoints of Evenson et al. [40] were used to define ST, LPA, and MVPA, which were the exposure variables used to form the school day activity composition. These cutpoints have previously been shown to demonstrate strong classification accuracy across a range of intensities [41].

Statistical analyses

Exploratory and descriptive analyses were undertaken using IBM SPSS Statistics Version 24 (IBM Corp., Armonk, NY). To account for nested data (i.e., children within schools), intra-class correlations were calculated to determine the dependency of the child data on schools. A negligible school-level effect was observed (ICC = 0.02 to 0.04) and so subsequent analyses were not adjusted for clustering of children within schools. Compositional data analyses (CoDA) were performed in R (http://cran.r-project.org) using the compositions (version 1.40-1) [42], robCompositions (version 0.92-7) [43], and lmtest (version 0.9-35) packages. The school day composition (daily school time spent in ST, LPA, and MVPA) was described in terms of central tendency (the geometric mean of time spent in each part, linearly adjusted so that together all parts summed to the total school day for interpretation in min·day^{-1}, or 100%, for interpretation in percentages of the school day). Multivariate dispersion of the school day composition was described by pairwise log-ratio variation [17, 19].

Multiple linear regression models were used to investigate the relationship between school day activity behaviour composition (explanatory variable) and each health indicator (dependent variable). Prior to inclusion in the regression model, the composition was expressed as a set of two isometric log ratios (*ilr*) co-ordinates. Sociodemographic covariates (sex, age, and IMD score) were also included as explanatory variables. The outcome variables were zBMI, %WHtR, VO_2 peak, number of completed 20-m SRT laps, psychosocial HRQL, and physical HRQL. The *ilr* multiple linear regression models were checked for linearity, normality, homoscedasticity and outlying observations to ensure assumptions were not violated. The significance of the school day activity behaviour composition (i.e., the set of *ilr* coordinates) was examined with the car::Anova() function, which uses Wald Chi squared to calculate Type II tests according to the principle of marginality, testing each covariate after all others [44].

The above *ilr* multiple linear regression models were used to predict differences in the outcome variables associated with the reallocation of a fixed duration of time (10 minutes) between two activity behaviours, keeping the third unchanged. This was done by systematically creating a range of new activity compositions to mimic the reallocation of 10 minutes between all activity behaviour pairs, using the mean composition of the sample as the baseline, or starting composition. The new compositions were all expressed as *ilr* coordinate sets, and each subtracted from the mean composition *ilr* coordinates, to generate *ilr* differences. These *ilr* differences (each representing a 10-minute reallocation between two behaviours) were used in the linear models to determine estimated differences (95% CI) in outcomes. Predictions were repeated for pairwise reallocations of up to 60 minutes, and corresponding estimates were plotted to aid interpretation (Supplementary Files 1-3).

The associations between the school day activity behaviour composition and health outcomes were further explored by using the same *ilr* linear multiple regression models to predict health outcomes for a large number (2000) of randomly generated school day compositions (expressed as *ilr* coordinates). The predictions were plotted in colour on a ternary diagram (with axes for ST, LPA, and MVPA) [45] and the area between the predictions was interpolated using the MATLAB function alchemist/ternplot [46] to produce a continuous response surface where increasing blue saturation represented a more favourable health outcome, and increasing red saturation less favourable association with the health outcome.

Results

The mean age of the children was 10.6 years and 54% were girls (Table 1). Mean IMD scores reflected that most children lived in areas of high relative deprivation (IMD quintile 4). On average the children achieved the accelerometer wear time criterion on 4.4 days from 5, and the mean accelerometer wear time was 359 min·school day^{-1}, which represents 92% of the school day. Application of the wear time inclusion criteria resulted in an analytical sample of 243 children (76.7% of consenting children) whose descriptive characteristics did not differ from those of the excluded children (p = 0.24 – 0.95).

Table 1. Participant characteristics. Study took place in the UK in 2010.

	All (n = 243)
Age (years)	10.6 (0.3)
Sex (%)	
Boys	46.1
Girls	53.9
Stature (cm)	144.2 (7.4)
Mass (kg)	37.6 (9.1)
BMI ($kg·m^2$)	18.0 (3.3)
zBMI	0.14 (1.28)
Waist circumference (cm)	61.8 (7.7)
%WHtR	42.9 (4.8)
20-m SRT laps	29.3 (15.7)
VO_2 peak ($ml·kg·min^{-1}$)	43.4 (4.3)
IMD score	24.4 (15.0)
Accelerometer wear time ($min·day^{-1}$)	359.1 (22.9)
Psychosocial HRQL	78.2 (16.0)
Physical HRQL	85.4 (12.7)

Data are presented as mean ± SD for continuous variables and as percentage for sex. *BMI* body mass index; *zBMI* body mass index z-score; *%WHtR* percentage waist circumference-to-height ratio; *20-m SRT* 20-metre shuttle run test; *VO_2 peak* peak oxygen uptake; *IMD* indices of multiple deprivation

Compositional means for ST, LPA, and MVPA are presented in Table 2. Children spent 69% of the school day in ST, and approximately 25% of the day engaged in LPA. Analysis of variance of multiple linear regression model parameters indicated that the school day activity composition (expressed as *ilr* coordinates) was a statistically significant predictor of zBMI, %WHtR, VO_2 peak, 20-m SRT laps, but not of psychosocial HRQL and physical HRQL (Table 3).

Table 2. Geometric means of school day activity behaviours. Study took place in the UK in 2010.

	n = 243
ST (min·day^{-1})	247.8 (69.0%)
LPA (min·day^{-1})	88.7 (24.7%)
MVPA (min·day^{-1})	23.0 (6.4%)

Data are presented as geometric means (adjusted to sum the total school day (390 min)) and percentages of the school day. The spread of the compositions is described by variation matrices in Supplementary file 4.

Table 3. Multiple linear regression models for each health indicator: Analysis of Variance. Study took place in the UK in 2010.

	Sum Sq	df	F value	p
zBMI				
Isometric log-ratio co-ordinates	19.97	2	6.56	0.002
IMD score	6.90	1	4.54	0.03
Sex	2.68	1	1.77	0.19
Residuals	363.77	239		
%WHtR				
Isometric log-ratio co-ordinates	277.8	2	6.59	0.002
IMD score	218.4	1	10.36	0.001
Sex	52.3	1	2.48	0.12
Residuals	5039.3	239	1.2	
VO_2 peak				
Isometric log-ratio co-ordinates	166.8	2	5.28	0.006
IMD score	87.2	1	5.52	0.02
Sex	295.1	1	18.69	<0.001
Residuals	3772.9	239		
20-m SRT laps				
Isometric log-ratio co-ordinates	1230	2	3.30	0.04
IMD score	544	1	2.92	0.09
Sex	3222	1	17.30	<0.001
zBMI	5109	1	27.43	<0.001
Residuals	44330	238	0.0	0.99
Psychosocial HRQL				
Isometric log-ratio co-ordinates	305	2	0.62	0.54
IMD score	2101	1	8.53	0.004
Sex	76	1	0.31	0.58
zBMI	818	1	3.32	0.07
Residuals	58625	238		
Physical HRQL				
Isometric log-ratio co-ordinates	469	2	1.55	0.21
IMD score	656	1	4.34	0.04
Sex	1	1	0.005	0.95
zBMI	992	1	6.57	0.01
Residuals	35947	238		

The predicted differences in the health indicators when 10 minutes of the school day were reallocated between pairs of activity behaviours with the other activity behaviour remaining constant, are presented in Table 4. When 10 minutes were reallocated from MVPA to LPA, zBMI was predicted to be 0.37 units higher than the predicted mean zBMI (See Supplementary file 5 for predicted mean health indicator values at the mean activity composition). %WHtR was predicted to be 1.13 percentage units higher than the predicted mean when 10 minutes were reallocated from MVPA to LPA. Similar trends in %WHtR were observed when ST replaced MVPA, but these changes were not significant based on the 95% CIs. The predicted changes in 20-m SRT laps and VO_2 peak were significantly lower than the predicted mean values when 10 minutes of MVPA were reallocated to ST or LPA. The opposite 10-minute reallocations (i.e., adding time to MVPA at the expense of ST or LPA) predicted lower zBMI, lower %WHtR, higher 20-m SRT laps, and higher VO_2 peak values. However, these relationships were asymmetrical, as the greatest predicted changes in each outcome were observed when MVPA was replaced with ST or LPA. For example, predicted zBMI was reduced by a smaller amount with the addition of 10 minutes MVPA (−0.08 for ST; −0.32 for LPA) than the increase in zBMI predicted for 10 minutes less MVPA (+0.22 for ST; +0.37 for LPA). The predicted changes in psychosocial and physical HRQL as a result of time reallocation between activity behaviours were negligible.

Table 4. Predicted changes in health indicators following reallocation of 10 minutes between school day activity behaviours. Study took place in the UK in 2010.

Add 10 minutes	Remove 10 minutes	zBMI predicted change (95% CI)	%WHtR predicted change (95% CI)
ST	LPA	**-0.24 (-0.37, -0.10)**	**-0.92 (-142, -0.42)**
ST	MVPA	0.16 (-0.08, 0.39)	0.28 (-0.58, 1.15)
LPA	ST	**0.22 (0.10, 0.35)**	**0.86 (0.39, 1.32)**
LPA	MVPA	**0.37 (0.10, 0.65)**	**1.13 (0.12, 2.14)**
MVPA	ST	-0.08 (-0.24, 0.07)	-0.11 (-0.69, 0.47)
MVPA	LPA	**-0.32 (-0.53, -0.12)**	**-1.03 (-1.81, -0.26)**
Add 10 minutes	Remove 10 minutes	20-m SRT laps predicted change* (95% CI)	VO_2 peak predicted change ($ml \cdot kg \cdot min^{-1}$) (95% CI)
ST	LPA	1.06 (-0.47, 2.58)	**0.53 (0.10, 0.96)**
ST	MVPA	**-3.02 (-5.6, -0.45)**	**-0.91 (-166, -0.16)**
LPA	ST	**-0.97 (-2.39, 0.45)**	**-0.49 (-0.89, -0.08)**
LPA	MVPA	**-3.98 (-7.04, -0.93)**	**-1.40 (-2.27, -0.52)**
MVPA	ST	**1.95 (0.22, 3.68)**	**0.57 (0.07, 1.07)**
MVPA	LPA	**3.01 (0.66, 5.35)**	**1.10 (0.43, 1.77)**
Add 10 minutes	Remove 10 minutes	Psychosocial HRQL* (95% CI)	Physical HRQL* (95% CI)
ST	LPA	0.11 (-1.65, 1.86)	1.19 (-0.18, 2.56)
ST	MVPA	1.63 (-1.33, 4.60)	0.27 (-2.05, 2.59)
LPA	ST	-0.11 (-1.74, 1.52)	-1.11 (-2.39, 0.16)
LPA	MVPA	1.53 (-1.99, 5.04)	-0.83 (-3.58, 1.92)
MVPA	ST	-1.11 (-3.10, 0.88)	-0.29 (-1.85, 1.27)
MVPA	LPA	-1.00 (-3.7, 1.69)	0.91 (-1.20, 3.02)

Bold type indicates statistical significant change in health indicator. All analyses adjusted for sex and SES. Analyses additionally adjusted for zBMI indicated with*

Figure 1a-f presents ternary response surface plots describing predicted changes in each health outcome for variations in the movement behaviour compositions. Panels a and b demonstrate that a gradient towards higher predicted zBMI and %WHtR respectively (red areas) were observed in the direction of higher relative LPA, and lower MVPA. The ternary response surface plots representing the time reallocations for the CRF outcomes (Panels c and d) show that higher relative MVPA and lower relative LPA predicted higher 20-m SRT laps and VO_2 peak values, respectively (blue areas). Panel e describes the gradient towards lower perceived psychosocial HRQL (red area), which was observed in the direction of higher relative MVPA and lower relative ST. A gradient towards higher perceived physical HRQL (blue area) was observed in the direction of higher relative MVPA and lower relative LPA (Panel f).

FIGURE 1a-f HERE (THIS FIGURE SHOULD BE IN COLOUR)

Discussion

We examined whether the school day activity composition was associated with indicators of physical health and HRQL, and investigated the predicted differences among these indicators when time was reallocated between activity behaviours. The results demonstrate that the school day activity composition was significantly associated with adiposity and CRF, but not HRQL HRQL.

This is the first study to examine children's activity compositions constrained to the school day. The results concur with those reported from CoDA of children's free-living activity behaviours [18, 20]. A consistent finding was that when school time was reallocated from MVPA to LPA with ST held constant, significant positive changes in zBMI and %WHtR were predicted. Both adiposity indicators were predicted to increase when MVPA was swapped with ST, but these changes were not significant. Our previous work demonstrated meaningful predicted increases in zBMI and %WHtR when time was reallocated from free-living MVPA to ST and LPA [20], while greater changes in zBMI were reported in a large sample of Canadian youth when MVPA was replaced by ST, than by LPA [18]. Time reallocations from school day MVPA to LPA and ST were reflected by significant predicted decreases in CRF. This finding also mirrors free-living data from similarly aged children [20], whereby VO_2 peak was predicted to reduce by 2.4 $ml{\cdot}kg{\cdot}min^{-1}$ when 15 minutes were reallocated from MVPA to ST and LPA. More modest decreases in CRF were reported in Canadian youth who undertook a sub-maximal step test [18]. As expected, the predicted changes in adiposity and CRF were smaller than those reported in studies of free-living activity behaviours [18, 20]. Nonetheless, the predicted reductions in zBMI when MVPA replaced LPA were meaningful and were greater than those reported in childhood obesity interventions [28, 47-51]. Moreover, the predicted increases in VO_2 peak would substantially contribute to shifting a child up into the next centile of international normative VO_2 peak values [34]. Combined, these findings reinforce the importance of making regular school day MVPA opportunities available to all children, and support recommendations for daily engagement in 30 minutes school day MVPA [7, 8]. Within the mean activity composition the children accumulated 23 minutes MVPA. When we reallocated 7 minutes to MVPA from ST and LPA to bring the MVPA element of the activity composition to 30 minutes, the significant predicted differences in adiposity and CRF were still apparent, although as expected they were smaller (Supplementary File 6). Our data suggest that regularly achieving the school day 30 minute MVPA recommendation by reallocating time from ST or LPA is favourable for promoting healthy weight and CRF.

Reallocating LPA for MVPA resulted in more unfavourable differences in adiposity and CRF than when ST replaced MVPA. This may have been partially due to accelerometer cutpoint intensity misclassification, whereby some ST was misclassified as LPA. Although we used the widely adopted 100 cpm as the ST cutpoint, it has been suggested that the validity evidence for this threshold is quite limited [52, 53], and that a higher threshold may be more appropriate [54]. Moreover, 100 cpm is anchored to 1.5 METs [55], but it is recommended that children's sedentary behaviour be defined by 2 METs [56]. Therefore, it is possible that the 100 cpm threshold underestimated ST and overestimated LPA. Misclassification may also explain the observed influence on adiposity and CRF when ST and LPA were reallocated, which reflects similar analysis of free-living activity compositions [20]. We observed favourable differences in adiposity and CRF when ST replaced LPA, and unfavourable differences when the reallocation was reversed. These findings are equivocal when compared with previous CoDA and isotemporal substitution studies that have reported unfavourable [18] or negligible effects [57-59] on adiposity and CRF when ST was replaced by LPA.

The relationships between reallocated school day ST, LPA, and MVPA around the average compositions for adiposity and CRF indicators were asymmetrical. As has previously been observed [18, 20, 24] the magnitudes of change in predicted zBMI, %WHtR, 20-m SRT laps, and VO_2 peak were smaller when MVPA replaced ST or LPA. This has been attributed to the relative contributions of the different activity behaviours to the period of constrained time under consideration [45]. ST accounted for 69% of the school day, compared to 24.7% and 6.4% for LPA, and MVPA, respectively. Taking 10 minutes from MVPA is a more significant relative change than taking 10 minutes from ST or LPA[19]. Moreover, the children in our study were relatively active, accumulating ~54 minutes MVPA across the full day [28] and were at low risk of overweight [60]. Thus, it is possible that additional MVPA for these relatively active children would predict somewhat smaller improvements in adiposity and CRF, which is consistent with the dose-response relationship observed between youth PA and cardiometabolic risk [61-63]. Irrespective of the potential mechanisms of predicted change, our findings support previous work [7, 8, 24, 64-66] advocating that during school, optimal opportunities for MVPA are provided to avoid unfavourable effects on adiposity and CRF. Initiatives that target MVPA and that are becoming more embedded as part of the regular school day, such as The Daily Mile [67] and Marathon Kids [68] have potential to meaningfully influence children's health if implemented at scale, although currently there is limited formal evidence of the effectiveness of these programmes [69].

Associations between the school day activity composition and HRQL scores were not significant. These scores were comparable with previously reported PedsQL^{TM} psychosocial and physical HRQL scores in UK children [70] and straddle the 'minor clinical risk/healthy' classification threshold [71]. Thus, the children's HRQL was perceived as being high and so the ceiling effect of these scores may have diminished the potential associations with the activity composition. Recent CoDA of HRQL and activity behaviours has highlighted equivocal associations between these exposure and outcome variables [72] [23]. Use of different HRQL methods, combined with the limited number of activity behaviour studies employing CoDA to investigate associations with HRQL, makes it challenging to generalise further about direction and strength of associations relative to our findings.

Study strengths and limitations

Study strengths include the objective measurement of activity behaviours, and the range of health and wellbeing indicators reported. Accelerometer wear compliance was very high, and the CoDA adjusted for all collinear and co-dependent activity behaviours occurring over the school day. Using CoDA with longitudinal data and appropriately presented visualisations of CoDA results could help shape health-promoting policies and targeted interventions, as part of a wider push towards implementing comprehensive school PA programmes [64]. The study also had a number of limitations. The data were collected in 2010 therefore may not reflect current movement behaviour compositions. Accelerometers would have been removed for swimming and possibly some physical education activities, which would have led to underestimations of movement behaviours. Though we used ActiGraph thresholds [40] that have demonstrated strong classification accuracy [41], activity estimates may have been subject to some intensity misclassification, and reintegration into 5-second epochs may have resulted in some overestimations of MVPA. Analyses were adjusted for sociodemographic variables, but there may have been some residual confounding from unmeasured factors. Children were sampled from an area of relatively high deprivation of northwest England, which limits generalisability. The data were cross-sectional and focused only on the school day, which precludes inferences being made about cause and effect, and the influence of out-of-school activity behaviours [19].

Conclusions

The school day activity composition significantly predicted zBMI, %WHtR, 20-m SRT laps, and VO_2 peak but did not predict psychosocial or physical HRQL. Replacing MVPA with ST or LPA around the mean activity composition predicted higher adiposity and lower CRF. The reverse was true when ST or LPA were reallocated for MVPA but the magnitude of the predicted differences was smaller. These findings amplify the benefits of MVPA and provide further evidence for the regular integration of MVPA into the school day. Creating opportunities for reallocating school time from ST and LPA to MVPA is advocated through whole-school comprehensive PA promotion approaches.

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Availability of data and material

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Conflicts of interest

The authors declare no conflicts of interest.

Figure caption

Figure 1a-f. Predicted health outcome response surfaces for school day activity compositions. Study took place in the UK in 2010.

a. Predicted zBMI (adjusted for SES and sex)
b. Predicted %WHtR (adjusted for SES and sex)
c. Predicted 20-m SRT laps (adjusted for SES, sex, and zBMI)
d. Predicted $VO_{2\ peak}$ (adjusted for SES and sex)
e. Predicted Psychosocial HRQL (adjusted for SES, sex, and zBMI)
f. Predicted Physical HRQL (adjusted for SES, sex, and zBMI)

Legend. The edges of the triangles are the "time" axes, each grid line represents 10% of the school day (390 min), i.e., 10 = 10% of 390 min, = 39 min. The white point represents the mean school-day composition (24.7% LPA; 69% SED, 6.4 % MVPA). The black point represents the composition where 10 minutes (i.e., 2.6% of the school day) have been reallocated from LPA to MVPA, and SED is unchanged. For zBMI the response surface under the white point is green, whereas under the black point it is blue, indicating that zBMI is predicted to decrease with this time reallocation. The colour legend accompanying each ternary surface plot enables interpretation of the white and black points for the other health indicators. Table 4 in the main text includes predicted differences for all 10-minute reallocations around the mean composition (i.e., the white point).

Supplementary files

Supplementary file 1. Adiposity line graphs (pdf)

Supplementary file 2. CRF line graphs (pdf)

Supplementary file 3. HRQL line graphs (pdf)

Supplementary file 4. Variation matrices (docx)

Supplementary file 5. Predicted health indicators at the mean activity composition (docx)

Supplementary file 6. Predicted changes in health indicators when 7 minutes reallocated to MVPA (docx)

References

1. Beets MW, Okely A, Weaver RG, Webster C, Lubans D, Brusseau T, et al. The theory of expanded, extended, and enhanced opportunities for youth physical activity promotion. Int J Behav Nutr Phys Act. 2016; 13:120.
2. Morton KL, Atkin AJ, Corder K, Suhrcke M, van Sluijs EMF. The school environment and adolescent physical activity and sedentary behaviour: a mixed-studies systematic review. Obes Rev. 2015:n/a-n/a.
3. Stralen MM, Yıldırım M, Wulp A, Velde SJ, Verloigne M, Doessegger A. Measured sedentary time and physical activity during the school day of European 10- to 12-year-old children: the ENERGY project. J Sci Med Sport. 2014; 17.
4. Santana CCA, Azevedo LB, Cattuzzo MT, Hill JO, Andrade LP, Prado WL. Physical fitness and academic performance in youth: A systematic review. Scand J Med Sci Sports. 2017; 27:579-603.
5. Martin R, Murtagh EM. Effect of active lessons on physical activity, academic, and health outcomes: A systematic review. Res Q Exerc Sport. 2017:1-20.
6. Marques A, Santos DA, Hillman CH, Sardinha LB. How does academic achievement relate to cardiorespiratory fitness, self-reported physical activity and objectively reported physical activity: a systematic review in children and adolescents aged 6–18 years. Br J Sports Med. 2017; doi: 10.1136/bjsports-2016-097361

7. Department of Health. Childhood obesity. A plan for action. London: DH; 2016.
8. Institute of Medicine. Educating the student body. Taking physical activity and physical education to school. Washington DC: Institute of Medicine; 2013.
9. Owen MB, Curry WB, Kerner C, Newson L, Fairclough SJ. The effectiveness of school-based physical activity interventions for adolescent girls: A systematic review and meta-analysis. Prev Med. 2017; 105:237-249.
10. Hollis JL, Sutherland R, Williams AJ, Campbell E, Nathan N, Wolfenden L, et al. A systematic review and meta-analysis of moderate-to-vigorous physical activity levels in secondary school physical education lessons. Int J Behav Nutr Phys Act. 2017; 14:52.
11. Rafferty R, Breslin G, Brennan D, Hassan D. A systematic review of school-based physical activity interventions on children's wellbeing. Int Rev Sport Exerc Psychol. 2016:1-16.
12. Minatto G, Barbosa Filho VC, Berria J, Petroski EL. School-based interventions to improve cardiorespiratory fitness in adolescents: systematic review with meta-analysis. Sports Med. 2016; 46:1273-1292.
13. Mears R, Jago R. Effectiveness of after-school interventions at increasing moderate-to-vigorous physical activity levels in 5- to 18-year olds: a systematic review and meta-analysis. Br J Sports Med. 2016. doi: 10.1136/bjsports-2015-094976.
14. Pedisic Z, Dumuid D, Olds T. Integrating sleep, sedentary behaviour, and physical activity research in the emerging field of time-use epidemiology: definitions, concepts, statistical methods, theoretical framework, and future directions. Kinesiol. 2017; 49.
15. Kibbe DL, Hackett J, Hurley M, McFarland A, Schubert KG, Schultz A, et al. Ten Years of TAKE 10!®: Integrating physical activity with academic concepts in elementary school classrooms. Prev Med. 2011; 52:S43-S50.
16. Dumuid D, Stanford TE, Martin-Fernandez JA, Pedisic Z, Maher CA, Lewis LK, et al. Compositional data analysis for physical activity, sedentary time and sleep research. Stat Methods Med Res. 2017. doi: 10.1177/962280217710835.
17. Aitchison J. The statistical analysis of compositional data. J Roy Statistical Soc. 1982; 44:139-177.
18. Carson V, Tremblay MS, Chaput J-P, Chastin SFM. Associations between sleep duration, sedentary time, physical activity, and health indicators among Canadian children and youth using compositional analyses. Appl Physiol Nutr Metab. 2016; 41:S294-S302.

19. Chastin SFM, Palarea-Albaladejo J, Dontje ML, Skelton DA. Combined effects of time spent in physical activity, sedentary behaviors and sleep on obesity and cardio-metabolic health markers: A novel compositional data analysis approach. PLoS ONE. 2015; 10:e0139984.
20. Fairclough SJ, Dumuid D, Taylor S, Curry W, McGrane B, Stratton G, et al. Fitness, fatness and the reallocation of time between children's daily movement behaviours: an analysis of compositional data. Int J Behav Nutr Phys Act. 2017; 14:64.
21. Dumuid D, Olds T, Lewis LK, Martin-Fernandez JA, Katzmarzyk PT, Barreira T, et al. Health-related quality of life and lifestyle behavior clusters in school-aged children from 12 countries. J Pediatr. 2017; 183:178-183 e172.
22. Dumuid D, Olds T, Martin-Fernandez JA, Lewis LK, Cassidy L, Maher C. Academic performance and lifestyle behaviors in australian school children: a cluster analysis. Health Educ Behav. 2017; 44:918-927.
23. Dumuid D, Maher C, Lewis LK, Stanford TE, Martin Fernandez JA, Ratcliffe J, et al. Human development index, children's health-related quality of life and movement behaviors: a compositional data analysis. Qual Life Res. 2018. doi: 10.1007/s11136-018-1791-x.
24. Dumuid D, Stanford TE, Pedišić Ž, Maher C, Lewis LK, Martín-Fernández J-A, et al. Adiposity and the isotemporal substitution of physical activity, sedentary time and sleep among school-aged children: a compositional data analysis approach. BMC Public Health. 2018; 18:311.
25. Tremblay M, LeBlanc A, Kho M, Saunders T, Larouche R, Colley R, et al. Systematic review of sedentary behaviour and health indicators in school-aged children and youth. Int J Behav Nutr Phys Act. 2011; 8:98.
26. Carson V, Ridgers ND, Howard BJ, Winkler EAH, Healy GN, Owen N, et al. Light-intensity physical activity and cardiometabolic biomarkers in us adolescents. PLoS ONE. 2013; 8:1-7.
27. Janssen I, Leblanc AG. Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. Int J Behav Nutr Phys Act. 2010; 7:40.
28. Fairclough S, Hackett A, Davies I, Gobbi R, Mackintosh K, Warburton G, et al. Promoting healthy weight in primary school children through physical activity and nutrition education: a pragmatic evaluation of the CHANGE! randomised intervention study. BMC Public Health. 2013; 13:626.

29. Public Health England. Overview of child health. 2017 https://fingertips.phe.org.uk/profile/child-health-overview/data -page/9/gid/1938132992/pat/6/par/E12000002/ati/102/are/E08000010/iid/92196/age/2/sex/4. Accessed 12 Dec 2017.
30. Lohman TG, Roche AFM, Martorell R. Anthropometric standardization reference manual. Illinois: Champaign, IL: Human Kinetics Books; 1991.
31. Cole T, Freeman J, Preece M. Body mass index reference curves for the UK, 1990. Arch Dis Child. 1995; 73:25 - 29.
32. Mokha JS, Srinivasan SR, DasMahapatra P, Fernandez C, Chen W, Xu J, et al. Utility of waist-to-height ratio in assessing the status of central obesity and related cardiometabolic risk profile among normal weight and overweight/obese children: The Bogalusa Heart Study. BMC Pediatr. 2010; 10:73.
33. Boddy LM, Hackett AF, Stratton G. Changes in fitness, body mass index and obesity in 9-10 year olds. J Hum Nutr Diet. 2010; 23:254-259.
34. Tomkinson GR, Lang JJ, Tremblay MS, Dale M, LeBlanc AG, Belanger K, et al. International normative 20 m shuttle run values from 1 142 026 children and youth representing 50 countries. Br J Sports Med. 2016. doi:10.1136/bjsports-2016-095987.
35. Department for Communities and Local Government. The English Indices of Deprivation 2007. Wetherby: Communities and Local Government Publications; 2008.
36. Varni JW, Burwinkle TM, Seid M. The PedsQL 4.0 as a school population health measure: feasibility, reliability, and validity. Qual Life Res. 2006; 15:203-215.
37. Edwardson CL, Gorely T. Epoch length and its effect on physical activity intensity. Med Sci Sports Exerc. 2010; 42:928-934.
38. Catellier DJ, Hannan PJ, Murray DM, Addy CL, Conway TL, Yang S, et al. Imputation of missing data when measuring physical activity by accelerometry. Med Sci Sports Exerc. 2005; 37:S555-S562.
39. Saint-Maurice PF, Welk GJ. Validity and Calibration of the Youth Activity Profile. PLoS ONE. 2015; 10:e0143949.
40. Evenson KR, Catellier DJ, Gill K, Ondrak KS, McMurray RG. Calibration of two objective measures of physical activity for children. J Sports Sci. 2008; 26:1557-1565.
41. Trost SG, Loprinzi PD, Moore R, Pfeiffer KA. Comparison of accelerometer cut-points for predicting activity intensity in youth. Med Sci Sports Exerc. 2011; 43:1360-1368.

42. van den Boogaart KG, Tolosana-Delgado R. 'Compositions': a unified R package to analyze compositional data. Computers and Geosciences. 2008; 34:320-338.
43. Templ M, Hron K, Filzmoser P. robCompositions: An R-package for robust statistical analysis of compositional data. In: Pawlowsky-Glahn V, Buccianti A, editors. Compositional data analysis: theory and applications. Chichester, UK: John Wiley & Sons, Ltd; 2011. p. 341-355.
44. Fox J, Weisberg S. An R companion to applied regression. London: Sage Publications; 2011.
45. Chastin SFM, Mandrichenko O, Helbostadt JL, Skelton DA. Associations between objectively-measured sedentary behaviour and physical activity with bone mineral density in adults and older adults, the NHANES study. Bone. 2014; doi: 10.1016/j.bone.2014.04.009.
46. Sandrock C, Afshari S: alchemyst/ternplot: DOI version. 2016; Zenodo.http://dx.doi.org/10.5281/zenodo.166760.
47. Ho M, Garnett SP, Baur L, Burrows T, Stewart L, Neve M, et al. Effectiveness of lifestyle interventions in child obesity: systematic review with meta-analysis. Pediatr. 2012; 130:e1647-1671.
48. Kolsgaard MLP, Joner G, Brunborg C, Anderssen SA, Tonstad S, Andersen LF. Reduction in BMI z-score and improvement in cardiometabolic risk factors in obese children and adolescents. The Oslo Adiposity Intervention Study - a hospital/public health nurse combined treatment. BMC Pediatr. 2011; 11:47.
49. Larsen LM, Hertel NT, Mølgaard C, Christensen RD, Husby S, Jarbøl DE. Early intervention for childhood overweight: A randomized trial in general practice. Scand J Prim Health Care. 2015; 33:184-190.
50. Taylor RW, McAuley KA, Barbezat W, Farmer VL, Williams SM, Mann JI. Two-year follow-up of an obesity prevention initiative in children: the APPLE project. Am J Clin Nutr. 2008; 88:1371-1377.
51. Watson PM, Dugdill L, Pickering K, Owen S, Hargreaves J, Staniford LJ, et al. Service evaluation of the GOALS family-based childhood obesity treatment intervention during the first 3 years of implementation. BMJ Open. 2015; http://dx.doi.org/10.1136/bmjopen-2014-006519.
52. Atkin AJ, Gorely T, Clemes SA, Yates T, Edwardson C, Brage S, et al. Methods of Measurement in epidemiology: Sedentary Behaviour. Int J Epidemiol. 2012; 41:1460-1471.

53. Kang M, Rowe DA. Issues and challenges in sedentary behavior measurement. Measure Phys Educ Exerc Sci. 2015; 19:105-115.
54. Kozey-Keadle S, Libertine A, Lyden K, Staudenmayer J, Freedson PS. Validation of wearable monitors for assessing sedentary behavior. Med Sci Sports Exerc. 2011; 43:1561-1567.
55. Tremblay MS, Aubert S, Barnes JD, Saunders TJ, Carson V, Latimer-Cheung AE, et al. Sedentary Behavior Research Network (SBRN) – Terminology Consensus Project process and outcome. Int J Behav Nutr Phys Act. 2017; 14:75.
56. Saint-Maurice PF, Kim Y, Welk GJ, Gaesser GA. Kids are not little adults: what MET threshold captures sedentary behavior in children? Eur J Appl Physiol. 2016; 116:29-38.
57. Huang. Isotemporal substitution analysis for sedentary behavior and body mass index. Med Sci Sports Exerc. 2016; 48:2135-2141.
58. Loprinzi PD, Cardinal BJ, Lee H, Tudor-Locke C. Markers of adiposity among children and adolescents: implications of the isotemporal substitution paradigm with sedentary behavior and physical activity patterns. J Diabetes Metab Disord. 2015; doi: 10.1186/s40200-015-0175-9.
59. Aggio D, Smith L, Hamer M. Effects of reallocating time in different activity intensities on health and fitness: a cross sectional study. Int J Behav Nutr Phys Act. 2015; 12:83.
60. Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. Br Med J. 2000; 320:1240-1244.
61. LeBlanc AG, Janssen I. Dose-response relationship between physical activity and dyslipidemia in youth. Can J Cardiol. 2010; 26:e201-e205.
62. Pahkala K, Heinonen OJ, Lagstrom H, Hakala P, Hakanen M, Hernelahti M, et al. Clustered metabolic risk and leisure-time physical activity in adolescents: effect of dose? Br J Sports Med. 2012; 46:131-137.
63. Mark AE, Janssen I. Dose–response relation between physical activity and blood pressure in youth. Med Sci Sports Exerc. 2008; 40:1007-1012.
64. Burns RD, Brusseau TA, Hannon JC. Effect of comprehensive school physical activity programming on cardiometabolic health markers in children from low-income schools. J Phys Act Health. 2017; 14:671-676.

65. Brusseau TA, Hannon J, Burns R. The Effect of a Comprehensive School Physical Activity Program on Physical Activity and Health-Related Fitness in Children From Low-Income Families. J Phys Act Health. 2016; 13:888-894.
66. Chen W, Mason SA, Hypnar AJ, Zalmout S, Hammond-Benett A. Students' daily physical activity behaviors: the role of quality physical education in a comprehensive school physical activity program. J Teaching Phys Educ. 2014; 33:592-610.
67. Wylie E. The Daily Mile! Combating childhood obesity one step at a time. In: BJSM blog, vol. 2017: Br J Sports Med; 2016. http://blogs.bmj.com/bjsm/2016/03/10/the-daily-mile-combating-childhood-obesity-one-step-at-a-time/. Accessed 12 Dec 2017.
68. Kids Run Free. Marathon Kids. 2018. https://www.kidsrunfree.co.uk/mk/. Accessed 12 Dec 2017.
69. Chesham RA, Booth JN, Sweeney EL, Ryde GC, Gorely T, Brooks NE, et al. The Daily Mile makes primary school children more active, less sedentary and improves their fitness and body composition: a quasi-experimental pilot study. BMC Med. 2018; 16:64.
70. Upton P, Eiser C, Cheung I, Hutchings H, Jenney M, Maddocks A, et al. Measurement properties of the UK-English version of the Pediatric Quality of Life InventoryTM 4.0 (PedsQL™) generic core scales. Health Quality of Life Outcomes. 2005; 3:22. doi: 10.1186/1477-7525-3-22
71. Huang IC, Thompson LA, Chi YY, Knapp CA, Revicki DA, Seid M, et al. The linkage between pediatric quality of life and health conditions: establishing clinically meaningful cutoff scores for the PedsQL™. Value Health. 2009; 12:773-781.
72. Wong M, Olds T, Gold L, Lycett K, Dumuid D, Muller J, et al. Time-use patterns and health-related quality of life in adolescents. Pediatr. 2017; doi: 10.1542/peds.2016-3656.