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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.

1. 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 (Beets et al., 2016). Children spend a significant proportion of waking hours in schools, which have the physical and curriculum infrastructures, and personnel to promote health and well-being. Further, schools can positively influence children's PA irrespective of socio-demographic characteristics, which drive health

Abbreviations: CRF, cardiorespiratory fitness; HRQL, health-related quality of life; IMD, indices of multiple deprivation; SRT, shuttle run test

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inequalities (Morton et al., 2016). However, while schools provide various opportunities for PA engagement, they are also environments where children are sedentary for long periods (Stralen et al., 2014).

The increased attention given to the role of PA in positively influencing children's academic performance (Santana et al., 2017; Martin and Murtagh, 2017; Marques et al., 2017) has led to PA beyond physical education classes being advocated as a regular element of the school day (Department of Health, 2016; Institute of Medicine, 2013). For example, in the US and UK it is recommended that children accrue at least 30 minute MVPA during the school day (Department of Health, 2016; Institute of Medicine, 2013). 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 (Owen et al., 2017; Hollis et al., 2017; Rafferty et al., 2016; Minatto et al., 2016; Mears and Jago, 2016). 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 (Pedisic et al., 2017). For example, the TAKE 10! Programme (Kibbe et al., 2011) involves swapping 10 min 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* (Dumuid et al., 2017a), made up of mutually exclusive parts of a whole (Aitchison, 1982). The sample space of compositional data differs from real space associated with unconstrained vectors (Aitchison, 1982), and therefore the mathematical properties of compositional vectors should be accounted for when analysing time-use data (Pedisic et al., 2017). Recently, studies have applied this *time-use epidemiology* concept (Pedisic et al., 2017) by treating activity behaviour data as compositional data (Carson et al., 2016; Chastin et al., 2015; Fairclough et al., 2017; Dumuid et al., 2017b,c, 2018a,b) to properly understand the relationships between health and activity (Pedisic et al., 2017). 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 (Tremblay et al., 2011), LPA (Carson et al., 2013), and MVPA (Janssen and Leblanc, 2010) 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 (Pedisic et al., 2017). 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 (Dumuid et al., 2018a), and (2) investigate predicted differences among these health indicators when a fixed duration of time was reallocated from one activity behaviour to another.

2. Methods

2.1. 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 (Fairclough et al., 2013), 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 (Public Health England, 2017). Ethical approval was obtained from the Liverpool John Moores University Research Ethics Committee (10/ECL/039). Data were collected between October and December 2010.

2.2. 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 (Lohman et al., 1991). BMI was calculated and BMI z-scores (zBMI) were assigned to each participant (Cole et al., 1995). Percentage waist-to-height ratio (%WHtR) was used as an indicator of central obesity (Mokha et al., 2010). Children completed the 20-m shuttle run test (20-m SRT) to provide an estimate of cardiorespiratory fitness (CRF) (Boddy et al., 2010; Tomkinson et al., 2016). The running speed at the last completed lap was used to estimate peak oxygen uptake (VO_2 peak; ml·kg·min^{-1}) (Tomkinson et al., 2016).

2.3. 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 (Department for Communities and Local Government, 2008).

2.4. Psychosocial and physical health-related quality of life (HRQL)

Each child completed the Pediatric Quality of Life Inventory (PedsQL™) generic core scales (Varni et al., 2006) 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.

2.5. 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 (Edwardson and Gorely, 2010) and consecutive 20 minute periods of zero counts were considered non-wear time (Catellier et al., 2005). 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 minute 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 (Saint-Maurice and Welk, 2015). The cutpoints of Evenson et al. (2008) 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 (Trost et al., 2011).

2.6. 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) (van den Boogaart and Tolosana-Delgado, 2008), robCompositions (version 0.92-7) (Templ et al., 2011), 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 (Aitchison, 1982; Chastin et al., 2015).

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 (Fox and Weisberg, 2011).

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 min) 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 min 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 min, 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) (Chastin et al., 2014) and the area between the predictions was interpolated using the MATLAB function alchemist/ternplot (Sandrock and Afshari, 2016) 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.

3. 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.

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.

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).

The predicted differences in the health indicators when 10 min 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 min 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 min 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 min 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 minute MVPA (−0.08 for ST; −0.32 for LPA) than the increase in zBMI predicted for

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	44,330	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	58,625	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	35,947	238		

10 min 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.

Fig. 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).

4. 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.

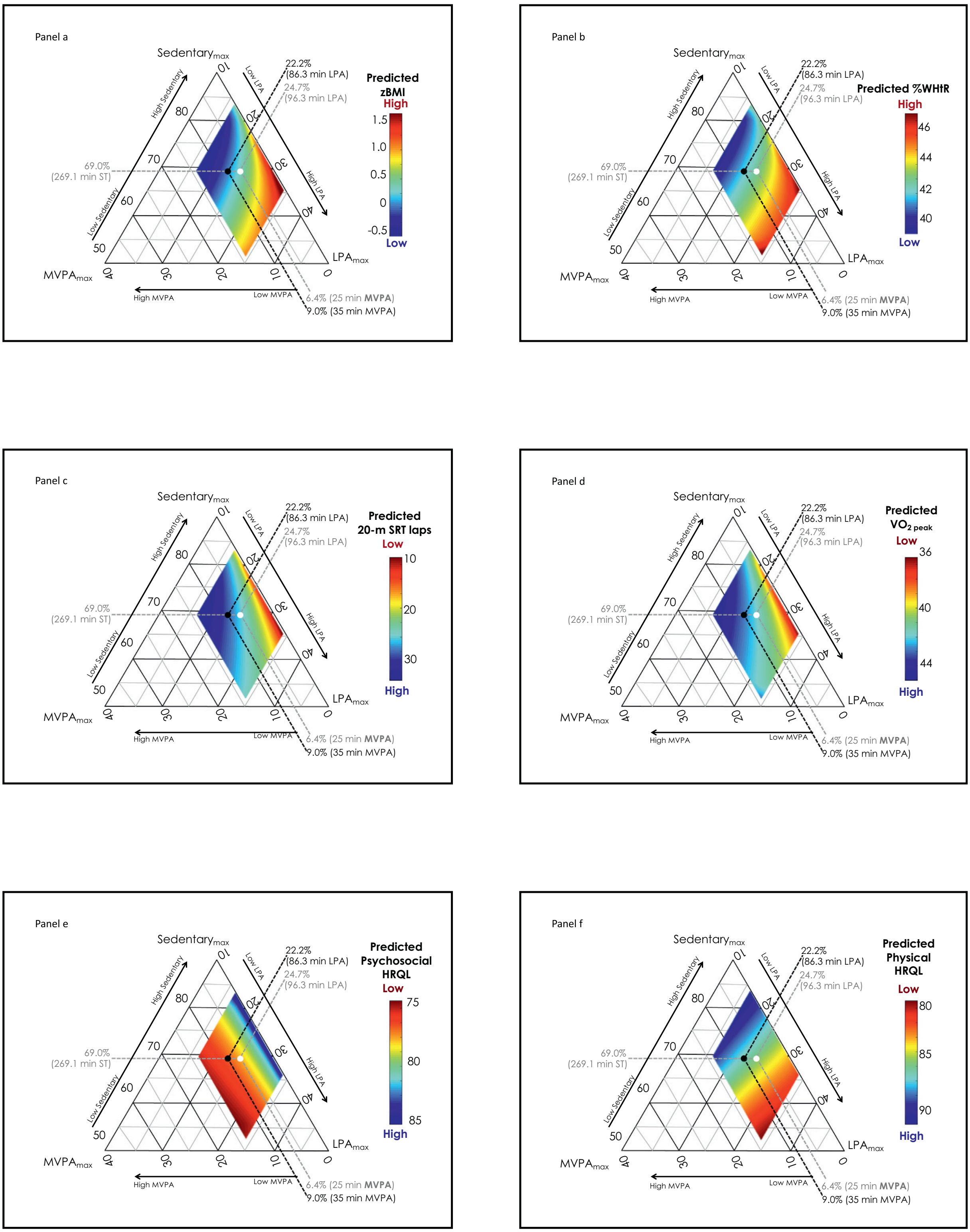
This is the first study to examine children's activity compositions constrained to the school day. The results concur with those reported from CoDA of children's free-living activity behaviours (Carson et al., 2016; Fairclough et al., 2017). A consistent finding was that when school time was reallocated 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 %

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

Add 10 min	Remove 10 min	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 min	**Remove 10 min**	**20-m SRT laps predicted change* (95% CI)**	**VO_2 peak predicted change (ml·kg·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 min	**Remove 10 min**	**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 *.

WHtR when time was reallocated from free-living MVPA to ST and LPA (Fairclough et al., 2017), while greater changes in zBMI were reported in a large sample of Canadian youth when MVPA was replaced by ST, than by LPA (Carson et al., 2016). 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 (Fairclough et al., 2017), whereby VO_2 peak was predicted to reduce by 2.4 ml·kg·min^{-1} when 15 min 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 (Carson et al., 2016). As expected, the predicted changes in adiposity and CRF were smaller than those reported in studies of free-living activity behaviours (Carson et al., 2016; Fairclough et al., 2017). Nonetheless, the predicted reductions in zBMI when MVPA replaced LPA were meaningful and



(caption on next page)

Fig. 1. a–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 min (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).

were greater than those reported in childhood obesity interventions (Fairclough et al., 2013; Ho et al., 2012; Kolsgaard et al., 2011; Larsen et al., 2015; Taylor et al., 2008; Watson et al., 2015). 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 (Tomkinson et al., 2016). 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 min school day MVPA (Department of Health, 2016; Institute of Medicine, 2013). Within the mean activity composition the children accumulated 23 min MVPA. When we reallocated 7 min to MVPA from ST and LPA to bring the MVPA element of the activity composition to 30 min, 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 min 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 (Atkin et al., 2012; Kang and Rowe, 2015), and that a higher threshold may be more appropriate (Kozey-Keadle et al., 2011). Moreover, 100 cpm is anchored to 1.5 METs (Tremblay et al., 2017), but it is recommended that children's sedentary behaviour be defined by 2 METs (Saint-Maurice et al., 2016). 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 (Fairclough et al., 2017). 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 (Carson et al., 2016) or negligible effects (Huang, 2016; Loprinzi et al., 2015; Aggio et al., 2015) 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 (Carson et al., 2016; Fairclough et al., 2017; Dumuid et al., 2018b) 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 (Chastin et al., 2014). ST accounted for 69% of the school day, compared to 24.7% and 6.4% for LPA, and MVPA, respectively. Taking 10 min from MVPA is a more significant relative change than taking 10 min from ST or LPA (Chastin et al., 2015). Moreover, the children in our study were relatively active, accumulating ~54 min MVPA across the full day (Fairclough et al., 2013) and were at low risk of overweight (Cole et al., 2000). 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 (LeBlanc and Janssen, 2010; Pahkala et al., 2012; Mark and Janssen, 2008). Irrespective of the potential mechanisms of predicted change, our findings support previous work (Department of Health, 2016; Institute of Medicine, 2013; Dumuid et al., 2018b; Burns et al., 2017; Brusseau et al., 2016; Chen et al., 2014) 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 (Wylie, 2016) and Marathon Kids (Kids Run Free, 2018) 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 (Chesham et al., 2018).

Associations between the school day activity composition and HRQL scores were not significant. These scores were comparable with previously reported PedsQL™ psychosocial and physical HRQL scores in UK children (Upton et al., 2005) and straddle the 'minor clinical risk/healthy' classification threshold (Huang et al., 2009). 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 (Wong et al., 2017) (Dumuid et al., 2018a). 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.

4.1. 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 (Burns et al., 2017). 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 (Evenson et al., 2008) that have demonstrated strong classification accuracy (Trost et al., 2011), 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 socio-demographic 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 (Chastin et al., 2015).

5. 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.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pmedr.2018.07.011.

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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.

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