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Physical behaviors and fundamental movement skills in British and Iranian children: An isotemporal substitution analysis

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Although the relationship between fundamental movement skills (FMS) and physical behaviors has been established, differences between countries are scarcely explored. The impact of the whole physical behavior composition, in relation to FMS, has yet to be investigated in 9-11 y children. The aims were to investigate the associations of substitution of physical behaviors with FMS score and to compare traditional linear regression and compositional data analysis and compare between England and Iran. Measures included accelerometer-derived activity (sleep (SL), sedentary behavior (SB), light physical activity (LPA), and moderate-to-vigorous physical activity (MVPA) and FMS, using the TGMD-2, in 119 children (64 boys) from Iran (mean (±SD) age: 9.8 ± 0.3 y; BMI of 18.2 ± 3.3 kg/m^2) and 139 (61 boys) children from England (mean (±SD) age: 9.5 ± 0.6 y; BMI of 17.7 ± 3.1 kg/m^2). Isometric log-ratio multiple linear regression models were used to discern the association between FMS and the mean activity composition, and for new compositions, where fixed durations of time were reallocated from one behavior to another, while the remaining behaviors were unchanged. In physical behaviors as a composition, FMS was significantly associated in both ethnicities. English children responded significantly positively to adding 5 or more minutes LPA at the expense of SB (FMS unit change from 0.05 [0.01, 0.09] at 5 minutes to 0.72 [0.01, 1.34] at 60 minutes). Adding 10 minutes or more of SL, at the expense of SB, was associated with a significant, positive change in FMS in all children. Investigation is needed to understand the composition of SB and its potential influence on FMS development.

KEYWORDS
children, composition, fundamental movement skills, isotemporal substitution, physical activity, sedentary behavior

1 | INTRODUCTION

The prevalence of global obesity epidemic has increased dramatically over the last 40 years. In 1975, 5% of children aged 5-19 years were classified as overweight or obese and this has risen to 25% worldwide.[1] It has been well documented that obesity is a multifactorial condition, with one of the main contributors being physical inactivity. Developed countries such as the UK have a much higher prevalence of obesity and physical inactivity compared to developing countries.[1]

Physical behaviors, including sleep (SL), sedentary behavior (SB), light physical activity (LPA), and moderate-to-vigorous physical activity (MVPA), are known to be interrelated, and health benefits may be optimized when all components of these behaviors are considered.[2] The link between MVPA and maintenance of a healthy body mass has been well established[3]; in addition, the relationship between fundamental movement skill (FMS) competency and childhood PA has been highlighted across the world, being identified in England,[4] Australia,[5] Finland,[6] Ireland,[7] Netherlands,[8] America,[9] and Indonesia,[10] to name a few.

However, despite positive associations being routinely reported between specific behaviors, most often MVPA, and FMS, considering physical behaviors in an isolated manner is a statistically flawed approach, given that such behaviors are necessarily bound to 1440 minutes per day and co-exist as a whole or composition, and thus, the time spent in one behavior effects, and is affected by, the other behaviors during the remaining time of the day.[11] Indeed, to combat this statistical incongruity, some studies have used a compositional data analysis approach in order to understand the relationship between physical behaviors and health outcomes,[12] and recently, compositional data analysis has been utilized to discern the relationship between physical behaviors and FMS in pre-school children.[13] However, an isotemporal substitution model has not been reported between PA intensities and FMS competency score in primary school children (9-11 years), so it remains unknown how time reallocated from SB, SL, or LPA to MVPA might affect FMS scores in this population. Additionally, due to developing and developed countries reporting differing PA and obesity rates,[1] it should not be assumed that results can be generalized across cultures.

Therefore, the aims of this research were threefold: firstly, to investigate the cross-sectional associations of substitution of PA behaviors with FMS score, secondly, to compare traditional linear regression and compositional data analysis of physical behavior data, and thirdly, to compare results between a developed (England) and developing country (Iran).

2 | MATERIALS AND METHODS

2.1 | Participants

Following institutional ethical approval from the LSI subcommittee at Middlesex University and signed informed parental consent, 119 children (64 boys) from Iran (mean (±SD) age of 9.8 ± 0.3 years and BMI of 18.2 ± 3.3 kg/m^2) and 139 (61 boys) children from England (mean (±SD) age of 9.5 ± 0.6 years and BMI of 17.7 ± 3.1 kg/m^2) were recruited. Children's date of birth and sex were provided, and pseudo anonymized by the schools. Participants were recruited from socially deprived areas, as defined by their respective National indices of deprivation (UK and Iran, respectively).

2.2 | Anthropometric measures

Children's height and mass were measured using a stadiometer (Seca, Germany model: SECA213) and electronic weighing scales (Seca, Germany model: SECA877). From this data, BMI was calculated (kg/m2).

2.3 | Fundamental movement skill competency

The test of Gross Motor Development 2nd edition (TGMD-2) was employed to assess FMS competency.[14] This test consists of six locomotor skills: run, leap, horizontal jump, slides, gallop, and hop and six object control skills: the throw, catch, kick, dribble, roll, and strike. Digital video cameras (Canon, Japan model: Legria HF R48-05) were set to record the children's performance. Before each test, assessors visually demonstrated the correct techniques for every skill, and however, children were not told which components were being assessed. Then, children performed every skill twice and their performance was recorded. Each skill consists of different specific movement criteria. Movement process characteristics were rated as "1" if a participant presents the behavior and "0" if the behavior is absent. Each skill was performed twice; therefore, each component had a score out of two. The sum of the component scores gave the raw scores for that skill. The raw scores of the six skills were then summed to provide scores for object control skill and locomotor skill (both subtest scores ranged from 0 to 48). Then, the total score of FMS was provided by adding the scores of the two subtests (ranged from 0 to 96). The higher the scores the better developed the child's locomotor, object control, and FMS, while low scores indicate weak developed skills.

2.4 | Physical activity assessment

Physical activity was measured objectively for seven days using The GENEActiv accelerometers which have demonstrated high criterion and concurrent validity.[15] The metabolic equivalent (MET) intensity levels to measure sedentary (<1.5 METs), light (1.5-<5 METs), moderate (3–5.99 METs), and vigorous (≥6 METs) intensity activities were used.[15] Children wore the accelerometers on their wrist for seven days during the waking hours including bathing and aquatic activities.

Participants with four or more valid days (including one weekend day) were included in the analysis,[15] while non-wear time was defined by at least 60 minutes of consecutive movement counts of 0, allowing for up to 2 minutes of movement counts between 0 and 100.[16] Since participants did not utilize sleep diaries, sleep onset, and offset were detected using an automatized algorithm, and sustained inactivity periods (based on low variability in the accelerometer z-angle) within these times were assigned to sleep, in accord with the work of Van Hees and colleagues.[17,18] Sixty-second epochs were used for analysis,[15] and the average minutes per day spent in SL, SB, LPA, and MVPA were calculated.

2.5 | Data analysis

Compositional data analyses were conducted in R (http://cran.r-project.org; R Core Team, version 3.6.1, 2019) using the compositions (version 1.40-1),[19] robCompositions (version 0.92-7),[20] and lmtest (version 0.9-35)[21] packages. Standard and compositional descriptive statistics were computed for comparison; where alternate to the standard arithmetic mean, the compositional mean is obtained by, firstly, computing the geometric mean for each individual behavior (time spent in SL, SB, LPA, and MVPA) and subsequently normalizing the data to the same constant as the raw data, that is, 1. This measure is coherent with the relative and symmetrical scale of the data,[22] while univariate statistical measures of dispersion, for instance standard deviation, are not coherent with the intrinsic inter-dependent multivariable nature of compositional data. Thus, multivariate dispersion of day composition was described using pairwise log-ratio variation.[23] The variability of the data was summarized in a variation matrix that contains all pairwise log-ratio variances, where a value close to zero indicates that time spent in two respective behaviors are highly proportional, while a value close to 1 indicates the opposite.

We adopted a compositional approach based on an isometric log-ratio (ilr) data transformation, adapted from Hron[24] (see 13 and 25) to adequately adjust the models for time spent in the other behaviors. Briefly, the ilr coordinates were created using a sequential binary partition (SBP) process,[26] which were obtained by partitioning the composition, where one set is designated to appear in the numerator of the first ilr coordinate, and the other in the denominator, next, one of the previously constructed sets is further partitioned into two sets, again coding the parts to be in the numerator (+1), the denominator (−1), and uninvolved parts (0). The final ilr's were constructed as normalized log-ratios of the geometric mean of parts.[11]

Covariates (age, BMI, and sex) were additionally included as explanatory variables. The ilr multiple linear regression models were further checked for linearity, normality, homoscedasticity, and outliers to ensure assumptions were not violated. The significance of the physical behavior composition (ie, 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. The ilr multiple linear regression models were used to identify differences in the outcome variables associated with the reallocation of a fixed duration of time between physical behaviors, while the third and fourth remained unchanged. This was done by methodically creating a range of new activity compositions to mimic the reallocation of 5 minutes between all physical behavior pairs, using the mean composition of the sample as the baseline, or starting composition. The new compositions were expressed as *ilr* coordinate sets, and each subtracted from the mean composition *ilr* coordinates, to generate *ilr* differences. These *ilr* differences (each representing a 5-minute reallocation between two behaviors) were then used in the linear models to determine estimated differences (95% CI) in all outcomes. This was repeated for pairwise reallocations, in 5-minute increments, from 5 to 60 minutes, respectively. The rationale for starting reallocation at 5 minutes is based on the fact that the revised 2019 PA guidelines for the UK[27] and US[28] have removed the 10-minute minimum bout duration for all age groups, and specifically for children, as there is not sufficient evidence for this. In addition, a descriptive comparison between UK and Iranian cohorts was reported.

TABLE 1 Descriptive statistics of time use, FMS, and participant characteristics

	All	UK	Iran
Sleep (min day^{-1})	680.8 (47%)	680.6 (48%)	674.9 (47%)
SB (min day^{-1})	341.7 (24%)	311.9 (21%)	366.2 (25%)
LPA (min day^{-1})	318.8 (22%)	370.1 (26%)	278.1 (19%)
MVPA (min day^{-1})	98.7 (7%)	77.4 (5%)	120.8 (9%)
FMS (SD)	66.4 (8.3)	66.8 (7.6)	66.1 (8.8)
Age (y)	9.7 (0.5)	9.5 (0.6)	9.8 (0.3)
BMI (kg m^2)	17.9 (3.1)	17.7 (3.1)	18.3 (3.3)
Sex (M/F)	125/133	64/55	61/78

Abbreviations: BMI, body mass index; FMS, fundamental movement skill score; SB, sedentary behavior; SL, sleep; LPA, light physical activity; MVPA, moderate-to-vigorous physical activity.

3 | RESULTS

Compositional means for SL, SB, LPA, and MVPA, and FMS scores are presented in Table 1. Children in Iran spent a significantly longer time engaged in MVPA (~57 mins/day^{-1}, 95% CI [38, 76], $d = 0.74$, $P < .001$) and SB (~60 mins/day^{-1}, 95% CI [32, 87], $d = 0.54$, $P < .001$) and significantly less time engaged in LPA (~83 mins/day^{-1}, 95% CI [58, 108], $d = 0.82$, $P < .001$), compared to UK children. There was no significant difference in FMS between UK and Iranian children ($P = .49$).

The variability of the overall data is summarized in the variation matrix (Table 2) containing all pairwise log-ratio variances. A value close to zero suggests that the time spent in the two respective behaviors is highly proportional. For instance, the variance of log(Sleep/Sedentary) is 0.136, which reflects the (proportional) relationship or co-dependence between the two behaviors. The highest log-ratio variance involves MVPA, suggesting that time spent in MVPA is the least co-dependent on any other behavior. No significant differences were evident between UK vs Iranian cohorts.

3.1 | Linear regression

Data were examined using linear regression, for each movement behavior independently. Results suggested that no single behavior was significantly associated with FMS score, besides MVPA in the Iranian children (Table 3).

3.2 | Compositional analysis and isotemporal substitution

When data were considered as a composition, adjusted for age, BMI, and sex, the 24-hour composition was significantly associated (95% CI) with FMS for the whole ($P = .001$; $r^2 = .08$), the UK only ($P = .01$; $r^2 = .12$), and Iran only samples ($P = .0001$; $r^2 = .14$), respectively. Following comprehensive isotemporal substitution (Appendix Table), English children responded in a significantly (95% CI) positive manner to adding LPA at the expense of SB, with a FMS unit change of 0.05 [0.01, 0.09] at 5 minutes, increasing to 0.72 [0.01, 1.34] at 60 minutes. Adding 10 minutes or more of SL, at the expense of SB, was associated with a significant, positive change in FMS in both Iranian and UK children (all: 0.3 [0.01,0.6]; English: 0.32 [0.01, 0.63]; Iran: 0.29 [0.01, 0.58].

TABLE 2 Pairwise log-ratio variation matrix

	Sleep	Sedentary	LPA	MVPA
Sleep		0.136	0.162	0.380
Sedentary	0.136		0.537	0.592
LPA	0.162	0.537		0.603
MVPA	0.380	0.592	0.603	

Note: A value approaching "0" indicates high proportionality between pairs of behaviors, while a value approaching "1" indicates the opposite.

Abbreviations: LPA, light physical activity; MVPA, moderate-to-vigorous physical activity.

4 | DISCUSSION

The aims of this research were threefold: firstly, to investigate the cross-sectional associations of substitution of PA behaviors with FMS score, secondly, to compare traditional linear regression and compositional data analysis of physical behavior data, and thirdly, to compare results between a developed (England) and developing country (Iran). Initially, the data were examined using traditional linear regression and the only variable that was associated with FMS was MVPA in Iranian children. This is inconsistent with previous research that has reported that PA may be a significant predictor of FMS in English children.[4] However, Bryant et al[4] used pedometers as a habitual PA measure and, thus, could not determine intensity, suggesting that perhaps intensities are more important for FMS in English children which requires further investigation as to why a difference could exist.

When the physical behaviors were considered as a composition in the present study, FMS was significantly associated in both ethnicities, highlighting that it is the composition of daily behavior that is more important than any singular component. Furthermore, when systematic isotemporal substitution was conducted, English children responded in a significantly positive manner to adding LPA at the expense of SB. Westerterp and Plasqui[29] also support the theory of the importance of LPA to English children's health. However, the same reallocation in Iranian children was equivocal. When MVPA was added at the expense of sleep, there were not any significant positive or negative results. However, adding 10 minutes or more of SL, at the expense of SB, was associated with a significant, positive change in FMS in both Iranian and UK children. The majority of PA guidelines, globally, encourage children to sit less and move more, with a focus on more MVPA.[30] It is clear from the key results described in this study, that it is as not as simple as removing sedentary time and replacing it with MVPA to elicit positive changes in children's FMS, particularly given that FMS are considered a prerequisite for PA.[4]

From the analysis presented in this study, it is apparent that the composition of SB in both English and Iranian children needs to be better understood to identify if certain types of SB are more or less beneficial to FMS competency and PA. Indeed, SB tends to have a negative connotation[31] as it has been associated with obesity/obesity-related diseases[32] and is often used interchangeably with screen time.[31] However, there are many types of SB, of which, some are very important to a child's development, such as reading, writing, fine motor tasks, and creativity (art and music).[33-36] Furthermore, it was reported by Stamatakis et al,[37] in children aged 2-12 years, that television viewing, but no other type of screen time, was associated with cardiovascular risk markers, independently of PA. Moreover, the authors posited

TABLE 3 Linear regression of movement variables

	Sleep B [95% CI]	*P* value (r^2)	Sedentary B [95% CI]	*P* value (r^2)	LPA B [95% CI]	P value (r^2)	MVPA B [95% CI]	*P* value (r^2)
FMS (all)	−4.85 [−18.68, 8.98]	.51 (.04)	−10.98 [−23.56, 1.59]	.08 (.11)	4.49 [−8.81, 17.85]	.51 (.001)	9.47 [−8.4, 27.33]	.29 (.004)
FMS (UK only)	−4.88 [−13.15, 2.7)	.43 (.07)	−10.44 [−28.07, 7.19]	.24 (.09)	5.05 [−16.97, 27.07]	.65 (.04)	6.74 [−15.06, 28.56]	.54 (.05)
FMS (Iran only)	−4.82 [−12.75, 3.1)	.55 (.01)	−10.75 [−30.57, 9.06]	.28 (.09)	1.36 [−17.48, 20.22]	.88 (.01)	61.05 [11.07, 111.03]	.01* (.22)

Note: All adjusted for age, BMI and sex.

Abbreviations: B, beta coefficient; CI, confidence interval; LPA: light physical activity; MVPA, moderate-to-vigorous physical activity.

*Significant at <.05.

that relying on a single indicator of screen time or SB is likely to conceal specific associations. Indeed, in the present study, theoretical changes in SB did not necessarily confer negative consequences to FMS, exemplifying the need to better discern types of SB.[37]

Obesity and obesity-related diseases are highly prevalent in both the UK[38] and Iran,[39] although culturally they are very different.[40] In Iran, children spend around 4.5 hours in school compared to English children who spend around 6 hours. This could explain some of the differences seen in the PA behaviors between the two countries. Time spent in school has been reported to be predominantly sedentary due to the more traditional academic pressures.[41] In Iran, there is a large emphasis on academic performance from schooling authorities and parents, which have been linked to declines in PA levels of Iranian children.[42-44] Thus, indicating that children in Iran will be more sedentary in school time may explain why they spend significantly more time in SB, per day, compared to English children. However, we concurrently highlighted that Iranian children spent significantly more time engaged in MVPA compared to English children. This demonstrates the need to understand if Iranian children are more active outside of school because there is more time for leisure activities due to the shorter school day. It has also been reported that in developing countries there is a lack of open spaces and playgrounds in schools and communities, which have been highlighted as barriers for children's physical activity suggesting the increased MVPA in Iranian children is not dependent on these.[45] In England, living in a low socioeconomic status (SES) has been linked to higher levels of obesity and lower levels of PA.[41] However, in Iran, living in a higher SES has been linked to higher rates of obesity and lower PA levels,[39] agreeing with other research and traditional cultural values in developing countries. The two samples in this study were from low SES status areas, as defined by national indices of deprivation, thus indicating some cultural differences within this status that could determine how SB is spent and where/how MVPA is achieved.

5 | CONCLUSION

This study is the first to highlight a cross-cultural comparison of a developed vs. developing country using isotemporal substitution and compositional analysis. From the analysis completed, and the discussion points raised, it is clear that future research must seek to discern the make-up, or type, of SB, and "*where*" children accrue their MVPA; this would yield a greater understanding on what is most influential for the development or improvement of FMS competency with regard to the daily physical behavior composition.

6 | PERSPECTIVE

This study provides novel insight into the cross-sectional associations of substitution of physical behaviors with FMS score and provides the first comparison between a developed (England) and developing country (Iran). When viewed compositionally, daily behaviors are significantly associated with FMS. However, when this composition is analyzed using isotemporal substitution, children from Iran and the UK appear to respond differently. Greater granularity in the characterization of PA and SB is required to better understand how the daily composition impacts on FMS. Furthermore, this study indicates that caution needs to be taken when interpreting results across cultures and demographics, alongside recommendations for children being feasible within the lifestyle norms for a population to maximize potential benefits. Finally, with regard to practical considerations, researchers and practitioners must consider the feasibility and practicality of advocating large increases in PA and the likely differences in children who already do vs. do not meet 24h movement guidelines.

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REFERENCES

1. World Health Organisation (WHO). Overweight and obesity. https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight. Accessed March 4, 2020.
2. Chaput JP, Carson V, Gray C, Tremblay M. Importance of all movement behaviors in a 24 hour period for overall health. *Int J Environ Res Public Health*. 2014;11(12):12575-12581.
3. Mitchell JA, Pate RR, España-Romero V, O'Neill JR, Dowd M, Nader PR. Moderate-to-vigorous physical activity is associated with decreases in body mass index from ages 9 to 15 years. *Obesity*. 2013;21:E280-E286. https://doi.org/10.1002/oby.20118
4. Bryant ES, Duncan MJ, Birch SL. Fundamental movement skills and weight status in British primary school children. *Eur J Sport Sci*. 2014;14(7):730-736.
5. Cohen KE, Morgan PJ, Plotnikoff RC, Callister R, Lubans DR. Fundamental movement skills and physical activity among children living in low-income communities: a cross-sectional study. *Int J Behav Nutri Phys Activity*. 2014;11(1):49–57.
6. Jaakkola T, Yli-Piipari S, Huotari P, Watt A, Liukkonen J. Fundamental movement skills and physical fitness as predictors of physical activity: a 6-year follow-up study. *Scand J Med Sci Sports*. 2016;26(1):74-81.
7. O'Brien W, Belton S, Issartel J. The relationship between adolescents' physical activity, fundamental movement skills and weight status. *J Sports Sci*. 2016;34(12):1159-1167.
8. van Aart I, Hartman E, Elferink-Gemser M, Mombarg R, Visscher C. Relations among basic psychological needs, PE-motivation and fundamental movement skills in 9–12-year-old boys and girls in physical education. *Phys Edu Sport Pedagogy*. 2017;22(1):15-34.
9. Zeng N, Johnson SL, Boles RE, Bellows LL. Social-ecological correlates of fundamental movement skills in young children. *J Sport Health Sci*. 2019;8(2):122-129.
10. Wibowo R, Nugraha E, Sultoni K. Fundamental movement skills and moods as predictors of games performance in primary school students. *ACTIVE: J Phys Edu Sport Health Recreation*. 2018;7(1):44-49.
11. Dumuid D, Pedišić Z, Stanford T, et al. The compositional isotemporal substitution model: a method for estimating changes in a health outcome for reallocation of time between sleep, physical activity and sedentary behaviour. *Stat Methods Med Res*. 2019;28(3):846-857.
12. Burns R, Kim Y, Byun W, Brusseau T. Associations of school day sedentary behavior and physical activity with gross motor skills: use of compositional data analysis. *J Phys Activity Health*. 2019;16(10):811-817.
13. Mota J, Clark CCT, Bezerra T, et al. Twenty-four-hour movement behaviours and fundamental movement skills in preschool children: a compositional and isotemporal substitution analysis. *J Sports Sci*. 2020;38,18:2071-2079, 2000. https://doi.org/10.1080/02640414.2020.1770415 14. Ulrich DA. Test of gross motor development. Austin, TX: PRO-ED.
14. Ulrich DA, Sanford CB. *Test of gross motor development*. Austin, TX: Pro-ED;1985.
15. Phillips LR, Parfitt G, Rowlands AV. Calibration of the GENEA accelerometer for assessment of physical activity intensity in children. *J Sci Med Sport*. 2013;16(2):124-128.
16. Colley RC, Garriguet D, Janssen I, et al. The association between accelerometer-measured patterns of sedentary time and health risk in children and youth: results from the Canadian Health Measures Survey. *BMC Public Health*. 2013;13(1):200. https://doi.org/10.1186/1471-2458-13-200
17. van Hees VT, Sabia S, Anderson KN, et al. A novel, open access method to assess sleep duration using a wrist-worn accelerometer. *PLoS ONE*. 2015;10(11):1–13. https://doi.org/10.1371/journal.pone.0142533
18. van Hees VT, Sabia S, Jones SE, et al. Estimating sleep parameters using an accelerometer without sleep diary. *Sci Rep*. 2018;8(1):12975. https://doi.org/10.1038/s41598-018-31266-z
19. Boogaart K, Tolosana-Delgado R. Compositions: a unified R package to analyze compositional data. *Comput Geosci*. 2008;34(4):320-338.
20. Templ M, Hron K, Filzmoser P. robCompositions: an R-package for robust statistical analysis of compositional data. In Pawlowsky-Glahn V, Buccianti A, eds. *Compositional Data Analysis*. 2011:341-354. https://doi.org/10.1002/9781119976462.ch25
21. Zeileis A. Lmtest: testing linear regression models. 2016. https://www.rdocumentation.org/packages/lmtest. Accessed February 01, 2020.
22. Aitchison J. The statistical analysis of compositional data. *J Roy Stat Soc: Ser B*. 1982;44(2):139-160.
23. Chastin S, Palarea-Albaladejo J, Dontje M, Skelton D. 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(10):e0139984.
24. HronK FP, Thompson K. Linear regression with compositional explanatory variables. *J Appl Stat*. 2012;39(5):1115-1128.
25. Bezerra TA, Clark CCT, Souza Filho AN, et al. 24-hour movement behaviour and executive function in preschoolers: a compositional and isotemporal reallocation analysis. *Eur J Sport Sci*. 2020;1-9. https://doi.org/10.1080/17461391.2020.1795274
26. Egozcue JJ, Pawlowsky-Glahn V. Groups of parts and their balances in compositional data analysis. *Math Geol*. 2005;37:795-828.
27. Department of Health and Social Care. Guidance from the Chief Medical Officers in the UK on the amount and type of physical activity people should be doing to improve their health. 2019. Accessed February 12, 2020.
28. Services, U. S. Department of Health and Human. *US Department of Health and Human Services 2008 Physical Activity Guidelines for Americans*. Hyattsville, MD: Department of Health and Human Services;2008.
29. Westerterp KR, Plasqui G. Physical activity and human energy expenditure. *Curr Opin Clin Nutr Metab Care*. 2004;7(6):607-613.
30. WHO. To grow up healthy, children need to sit less and play more. 2019. https://www.who.int/news-room/detail/24-04-2019-to-grow-up-healthy-children-need-to-sit-less-and-play-more. Accessed on February 2, 2020.
31. Carson V, Hunter S, Kuzik N, et al. Systematic review of sedentary behaviour and health indicators in school-aged children and youth: an update. *Appl Physiol Nutr Metab*. 2016;41(6):S240-S265.
32. Saunders TJ, Chaput JP, Tremblay MS. Sedentary behaviour as an emerging risk factor for cardiometabolic diseases in children and youth. *Can J Diabet*. 2014;38(1):53-61.
33. Bagley S, Salmon JO, Crawford D. Family structure and children's television viewing and physical activity. *Med Sci Sports Exerc*. 2006;38(5):910-918.

34. Barr-Anderson DJ, Robinson-O'Brien R, Haines J, Hannan P, Neumark-Sztainer D. Parental report versus child perception of familial support: which is more associated with child physical activity and television use? *J Phys Activity Health*. 2010;7(3):364-368.
35. Barr-Anderson DJ, Van Den Berg P, Neumark-Sztainer D, Story M. Characteristics associated with older adolescents who have a television in their bedrooms. *Pediatrics*. 2008;121(4):718-724.
36. Biddle SJ, Gorely T, Marshall SJ. Is television viewing a suitable marker of sedentary behavior in young people? *Ann Behav Med*. 2009;38(2):147-153.
37. Stamatakis E, Coombs N, Jago R, et al. Type-specific screen time associations with cardiovascular risk markers in children. *Am J Prev Med*. 2013;44(5):481-488.
38. NHS. Obesity. 2020. https://www.nhs.uk/conditions/obesity/. Accessed February 27, 2020.
39. Khashayar P, Kasaeian A, Heshmat R, et al. Childhood overweight and obesity and associated factors in iranian children and adolescents: a multilevel analysis; the CASPIAN-IV study. *Front Pediat*. 2018;21(6):393. https://doi.org/10.3389/fped.2018.00393
40. United Nations. Country classification. 2014. https://www.un.org/en/development/desa/policy/wesp/wesp_current/2014wesp_country_classification.pdf. Accessed March 2, 2020.
41. Taylor SL, Curry WB, Knowles ZR, Noonan RJ, McGrane B, Fairclough SJ. Predictors of segmented school day physical activity and sedentary time in children from a Northwest England low-income community. *Int J Environ Res Public Health*. 2017;14(5):534–549.
42. Mozaffari H, Nabaei B. Obesity and related risk factors. *Indian J Pediatrics*. 2007;74(3):265-267.
43. Kelishadi R, Ghatrehsamani S, Hosseini M, Mirmoghtadaee P, Mansouri S, Poursafa P. Barriers to physical activity in a population-based sample of children and adolescents in Isfahan, Iran. *Int J Preventive Med*. 2010;1(2):131–137.
44. Mohammadpour-Ahranjani B, Abdollahi M, Pallan MJ, Adab P. Perceptions of local parents and school staff on childhood obesity prevention interventions in Iran. *Nutr Food Sci Res*. 2014;1(1):33-40.
45. Gupta N, Goel K, Shah P, Misra A. Childhood obesity in developing countries: epidemiology, determinants, and prevention. *Endocr Rev*. 2012;33(1):48-70.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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