Goldilocks Days: optimising children's time use for health and well-being

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ABSTRACT

Background One size rarely fits all in population health. Differing outcomes may compete for best allocations of time. Among children aged 11–12 years, we aimed to (1) describe optimal 24-hour time use for diverse physical, cognitive/academic and well-being outcomes, (2) pinpoint the 'Goldilocks Day' that optimises all outcomes and (3) develop a tool to customise time-use recommendations.

Methods In 2004, the Longitudinal Study of Australian Children recruited a nationally-representative cohort of 5107 infants with biennial follow-up waves. We used data from the cross-sectional Child Health CheckPoint module (2015–2016, n=1874, 11–12 years, 51% males). Time use was from 7-day 24-hour accelerometry. Outcomes included life satisfaction, psychosocial health, depressive symptoms, emotional problems, non-verbal IQ; vocabulary, academic performance, adiposity, fitness, blood pressure, inflammatory biomarkers, bone strength. Relationships between time use and outcomes were modelled using compositional regression.

Results Optimal daily durations varied widely for different health outcomes (sleep: 8.3–11.4 hours; sedentary: 7.3–12.2 hours; light physical activity: 1.7–5.1 hours; moderate-to-vigorous physical activity (MVPA): 0.3–2.7 hours, all models $p \leq 0.04$). In general, days with highest physical activity (predominantly MVPA) and low sedentary time were optimal for physical health, while days with highest sleep and lowest sedentary time were optimal for mental health. Days with highest sedentary time and lowest physical activity were optimal for cognitive health. The overall Goldilocks Day had 10 hours 21 min sleep, 9 hours 44 min sedentary time, 2 hours 26 min light physical activity and 1 hour 29 min MVPA. Our interactive interface allows personalisation of Goldilocks Days to an individual's outcome priorities.

Conclusion 'Goldilocks Days' necessitate compromises based on hierarchies of priorities for health, social and economic outcomes.

INTRODUCTION

It is a truth universally acknowledged, that a health system in possession of population data, must be in want of a single solution. This is rarely possible. The sun exposure that is best for skin health may be worst for bone health. An antibiotic that helps someone with an infection may harm others via antibiotic resistance. Children's optimal time use may differ vastly for academic success vs physical health. The first two scenarios have been extensively studied. The third—what is the time-use 'Goldilocks Day' that best optimises competing outcomes?—has not. Here, we bring novel computational and visual approaches to address this question and to enable children, parents and clinicians to apply their own values.

Governing bodies and health authorities such as the WHO have defined optimal time use for children in published guidelines for daily durations of sleep, physical activity and sedentary behaviour.[1–3] Current guidelines recommend school-aged children (between 5 and 12 years) sleep for 9–11 hours each night, accumulate an average of 1 hour each day of moderate-to-vigorous physical activity (MVPA) and limit recreational screen time to no more than 2 hours a day.[1]

Clinicians may advise children and parents to follow such guidelines without realising that they preference specific physical health outcomes. The corpus of underpinning evidence is dominated by adiposity over other outcomes contributing substantial burden of disease, such as mental health. For example, the physical activity review conducted to inform Australian guidelines for school-aged children[3] (itself built on a prior Canadian review[4]) included almost 90 studies with adiposity outcomes, but far fewer with well-being (n=5), cognitive (n=24) or skeletal (n=22) outcomes. Similarly, most studies in the Australian sedentary behaviour review[3] explored adiposity outcomes (>160 studies), with fewer than 40 having cardiometabolic outcomes (blood pressure, metabolites) and only six with distress outcomes. In the sleep review,[3] more than 80 studies had adiposity outcomes, only 29 had cardiometabolic outcomes and fewer than ten had outcomes related to well-being. Thus, although current guidelines do consider a range of health outcomes, the most research and thence strongest underpinning evidence is for adiposity. Optimal time use could differ for other valued aspects of health, raising competing demands. One-size-fits-all recommendations implicitly privilege certain outcomes above others, reflecting contemporary cultural, economic, educational and political priorities.

A second problem is that most reviews are based on studies that do not reflect real world experience. The included studies investigated each activity exposure as if it were independent of the other activities. This is not logical, given that sleep, physical activity and sedentary behaviour all compete for time shares in a 24-hour window. Increasing one behaviour must be at the expense of the other behaviour(s), meaning they are not independent but codependent. Research, and its interpretation and public health messages, should incorporate the codependency of time-use behaviours.[5] A new approach to the analysis of time-use data—compositional data analysis—now allows the interplay between daily activities to be modelled through a log-ratio transformation of the codependent data.[6 7] Although some studies using compostional data analysis were considered for the Canadian[8] and Australian 24-hour guidelines for children and young people, the lack of 24-hour studies was cited as the number one research gap.[3] None of the included studies identified optimal durations of daily activities, or 'Goldilocks Days', where these durations are 'just right', that is, not too long and not too short, for best health outcomes.[9]

In a national cohort of Australian children we aimed to (1) describe optimal 24-hour time-use compositions for each of the cohort's diverse physical, cognitive/academic and well-being domain outcomes, (2) pinpoint the 'Goldilocks' time-use composition that optimises all three domain outcomes and (3) develop a prototype interactive tool to customise time-use recommendations according to an individual's health priorities.

METHODS

Study design and participants

Participants were from the cross-sectional Child Health CheckPoint study,[10] nested between waves 6 and 7 of the Longitudinal Study of Australian Children (LSAC).[11] Briefly, in 2004, LSAC recruited a nationally-representative B (birth) cohort of 5107 infants through a two-stage random sampling design. Of these, n=3764 (74%) were retained to wave 6 (10–11 years). The Child Health CheckPoint comprised a physical health module of 1874 (50%) families from LSAC wave 6 (see online supplemental file 1 for participant flow). Written informed consent to participate in CheckPoint and for data linkage with LSAC and nationally administered academic outcome scores was provided by a parent/guardian. There were no exclusion criteria. Child participants (11–12 years) were assessed face to face between February 2015 and March 2016.

Procedure

CheckPoint measurements were taken at either a 3.5-hour visit to the Assessment Centre in one of Australia's seven major cities, a 2.5-hour Mini Centre visit in one of eight smaller regional cities, or a 1.5-hour home visit for those unable to attend a centre. LSAC measures were collected via home visits.

Measures

Exposure and outcome variables

Table 1 briefly describes the variables, with more details provided in online supplemental file 2. Time-use exposure variables were all derived from 7-day 24-hour wrist accelerometry collected for the CheckPoint assessment. CheckPoint outcome measures were used where available. Some measures were only collected during the LSAC waves. If variables were available at both LSAC waves 6 and 7 (depression and emotional problems), the wave 7 variable was used to limit potential reverse-causality. Similarly, the closest subsequent academic performance test was used (grade 7). Non-verbal IQ was drawn from wave 6 data; LSAC did not re-only collect this in wave 7 because IQ is very stable.

Covariates

All analyses were adjusted for a priori potential confounders of sex, age, pubertal status and household socioeconomic position (SEP).[12 13] Sex and date of birth were obtained from Medicare (Australia's healthcare system). Participants self-reported pubertal signs using an iPad version of the Pubertal Development Scale during the CheckPoint assessment.[14] From this, they were categorised as either pre-pubertal, early pubertal, mid-pubertal, late pubertal or postpubertal. A previously constructed composite *z*-score for LSAC (wave 6 scores), derived from parental occupation and education and household income, was used to indicate family-level SEP.[15] Body mass (for the bone strength model) was measured once (to the nearest 0.1 kg, without shoes and in light clothing) during the body composition assessment, using the bioimpedance analysis scales. Standing height was measured without shoes or socks, using a portable rigid stadiometer (Invicta IP0955, Leicester, UK). The average of two measurements (to nearest 0.1 cm) was used, with a third if the first two measures differed by ≥0.5 cm. Body mass index (for the fitness model) was calculated from mass and height and expressed as z-scores using international norms.[16]

Data treatment and statistical analysis

For each participant, accelerometry data from valid weekdays were averaged, and data from valid weekend day(s) were averaged. The weekday and weekend day averages were then weighted at 5:2 to represent the relative contribution of weekday and weekend days to a full week. Mean daily measured time use was 1432 min (SD=30). Using the R[17] Compositions package,[18] time-use compositions were described in terms of their compositional centre (the geometric means of each component, adjusted to sum to 24 hours or 1440 min). There were no zeros recorded in any activity variables.

Relationship between time use composition and outcomes

Time-use compositions (sleep, sedentary time, light physical activity and MVPA) were expressed as a set of isometric log-ratio (ilr) coordinates. Relationships between ilrs and individual health outcomes were explored using multiple linear regression models with robust standard errors. All models were adjusted for sex, age, pubertal status and SEP. The cardiovascular fitness model was additionally adjusted for body mass index z-score, and the bone strength model for total body mass. Where indicated, outcomes were transformed using Box-Cox, log or square-root transformations to normalise residual distributions. If model diagnostic plots indicated a non-linear relationship, quadratic terms for the composition (set of ilrs) were tested and retained if the quadratic term improved the model fit (partial F test $p<0.1$). Multiple regression parameters from the model type III analysis of variance indicated whether the overall time-use composition (set of ilrs) was associated with the outcome.

The optimal time-use composition for individual outcomes

The models were used to predict outcomes for a set of predictive time-use compositions that represented every possible 10 min combination of activities within the empirical activity footprint of the study population. The limits of the set of predictive compositions were truncated at ±3 SD. The ranges (in min/day) used for the predictive grid were: sleep=430–700; sedentary=360–790; light physical activity=90–420; MVPA=10–160.

The predictive compositions were expressed as ilrs. Next, the linear regression models described above were used to estimate the outcome for each predictive composition. The compositions associated at or above the 95th percentile (best 5%) of the outcome were considered to constitute the 'optimal' time-use zone. The optimal time-use composition for each individual outcome was described as the centre (compositional mean) of the optimal time-use zone.

Table 1 Exposure and outcome measures used in the study

Measurement	Equipment/tool	Brief protocol
Exposure: Time use		
Accelerometry* (sleep, sedentary, LPA, MVPA)	GENEActiv accelerometer (Activinsights, UK), paper log for bed/wake times and reason for removal.	24-hour protocol, over 7 days.[27] Data converted to 60 s epoch files. Sport non-wear imputed with 50% MVPA, 30% LPA and 20% sedentary time, based on Ridley *et al*.[28] Classified into energy expenditure bands using Phillips cutpoints.[29] Validity criteria: waking wear >10 hours, sleep >200 min or sedentary time <1000 min. At least four valid days.
Outcome: Mental health		
Life satisfaction*	Brief Multi-Dimensional Students' Life Satisfaction Scale[30]	Child completed five items via an iPad interface. Responses were averaged and linearly transformed to a 0–100 scale, higher scores indicating higher life satisfaction.
Psychosocial*	PedsQL 4.0[31]: Psychosocial	Average of emotional, social and school domains, linearly transformed to a 0–100 scale.
Depression†	SMFQ[32]	Responses to 13 items were reversed and summed (0–26 scale), higher scores indicating higher depressive feelings.
Emotional†	SDQ[33]	Scale of 5 items with three responses. Scored from 0 to 10, higher values indicating more problems.
Outcome: Cognition and academic performance		
Non-verbal IQ‡	Matrix Reasoning: Wechsler Intelligence Scale for Children, 4thEd[34]	The instrument comprises 35 items of increasing complexity. Children started on Item 4, as it was appropriate to their age. Reverse scoring was not implemented. Scores range from 0 to 20, with higher scores indicating higher non-verbal IQ.
Receptive vocabulary*	NIH Picture Vocab test[35]: NIH Toolbox software with Cognition package)	Child listened for word and then selected the picture that best represented the word's meaning. The adaptive test used computer-based algorithms to quickly approximate and then precisely pinpoint ability. Scaled scores are derived using population norms, higher values indicating better receptive vocabulary.
Academic Performance	Grade 7 tests National Assessment Programme-Literacy and Numeracy[36]	A nationally administered, standardised test for grade 7 assessed across five domains. Converted to a scale score (0–1000). Academic domains were collapsed into two: literacy (arithmetic mean of language, reading, writing and spelling scores) and numeracy, which were averaged to represent average academic performance.
Outcome: Physical measurements		
Adiposity: %Body fat*	Bioimpedance Analysis: 2-limb Tanita BC-351, (Kewdale, Australia) at home visits; 4-limb InBody230 (Biospace, Seoul, South Korea) at centre visits	Measured once to the nearest 0.1% in bare feet and light clothing.[37] Participant stood on the scale footplates and with the 4-limb scales also held onto the horizontal handles.
Cardiorespiratory fitness: VO_{2max}*	PWC170 test.[38] Cycle ergometer (Monark 928G3, Sweden). Heart rate monitor (Polar FT4, Finland).	60 RPM for three 2-min bouts, each bout at a higher work rate than the last. Estimated maximal work rate was calculated from a regression of work rate on heart rate for each stage, extrapolated to an estimated maximal heart.[39] VO_{2max} was estimated from maximal work rate (WR_{max}): VO_2max (mL/kg/min)=(0.012 WRmax (W)+0.36)/body mass (kg).[38]
Mean arterial blood pressure*	SphygmoCor XCEL (AtCor Medical, West Ryde, AUS)	Systolic (SBP) and diastolic blood pressure (DBP) was measured three times, 1 min apart.[40] Mean arterial pressures was calculated as $\frac{SBP-DBP}{3}+DBP$
Inflammation: Glyc A*	Nuclear MR (NMR)	Semi-fasted. The Nightingale NMR metabolomics platform (Helsinki, Finland) was used for metabolomic lipid profiling.[41]
Bone: Polar Stress-Strain Index (SSI) resistance*	Single Stratec XCT 2000L pQCT scanner (Medizintechnik, Germany).	Tibial 66% site (shin), scan speed of 200 mm/s, slice thickness of 2.4 mm and voxel side of 0.4 mm. Bone geometry and density measures derived with the MACRO analysis function,[42] polar SSI (bone strength) calculated using a threshold of 480 (mg/cm^3).[43]

*CheckPoint
†LSAC wave 7.
‡LSAC wave 6.
Glyc A, Glycoprotein acetylation; LPA, light physical activity; MVPA, moderate-to-vigorous physical activity; NIH, National Institutes of Health; PedsQL, Paediatric Quality of Life Inventory; pQCT, peripheral quantitative CT; SDQ, Strengths and Difficulties Questionnaire; SMFQ, Short Mood and Feelings Questionnaire; VO_{2max}, predicted maximal aerobic power.

The optimal time-use composition for overall health and well-being composite domains

The outcomes were classified into three domains, which were operationalised as composite sample-specific z-scores: mental health (life satisfaction, psychosocial, depression, emotional problems), cognition and academic performance (non-verbal IQ, vocabulary, academic performance) and physical measures (adiposity, fitness, blood pressure, inflammation, bone health). These domains were chosen as the outcome variables span public health, perceived physical and psychosocial health and education outcomes that are important to children, families and clinicians. The optimal time-use composition for each domain was described by finding the centre of the optimal compositions (best 5%) in that domain. To find the optimal time-use composition for overall health and well-being (Goldilocks Day), we found the compositional centre of the three optimal compositions for mental health, cognition and academic performance and physical measures.

Customisable weighting of health and well-being outcomes

Alternate Goldilocks solutions were determined by applying different weightings to the domains when calculating the overall compositional centre. We created an R Shiny app[19] (code provided in online supplemental file 3), images in the Supplemental File are author's own) to enable easy customisation of the weighting to be applied to each of the domains, providing a tailored Goldilocks solution.

RESULTS

Sample characteristics

Table 2 describes the largest analytical sample. Compared with non-retained individuals (LSAC wave 6 cohort without valid CheckPoint accelerometry and complete covariate data), they did not differ by age or sex, but showed higher household-level SEP (SEP z-score mean 0.24, SD 0.99 vs mean −0.11, SD 0.98).

Table 2 Participant characteristics

Characteristic	Largest analytical sample (n=1182)	
Sociodemographics		
Sex, n (%)	Male	603 (51)
	Female	579 (49)
Age (year), mean (SD)		12.0 (0.4)
Pubertal status, n (%)	Prepubertal	120 (10)
	Early pubertal	297 (25)
	Mid-pubertal	604 (51)
	Late pubertal	155 (13)
	Post-pubertal	6 (<1)
Socioeconomic z-score, mean (SD)		0.24 (0.99)
Time use		
24-hour activity (min/day), mean (SD)	Sleep	566 (47)
	Sedentary time	554 (81)
	LPA	251 (57)
	MVPA	62 (34)
24-hour activity (min/day), compositional centre*	Sleep; sedentary; LPA; MVPA	577; 560; 250; 53
Outcomes		
Life satisfaction, median (IQR)	Brief Multi-Dimensional Students' Life Satisfaction Scale	86 (76–94)$^{n=1180}$
Psychosocial, median (IQR)	PedsQL 4.0: Psychosocial Health domain	80 (68–88)$^{n=1182}$
Depression, median (IQR)	Short Mood and Feelings total score	2 (0–5)$^{n=1113}$
Emotional problems, median (IQR)	SDQ Emotional problems score	2 (1–4)$^{n=1113}$
Non-verbal IQ, median (IQR)	WISC-IV Matrix Reasoning scale score	11(9–13)$^{n=1163}$
Receptive vocabulary, mean (SD)	NIH picture vocabulary test scale score	11.3 (1.6) $_{n=936}$
Academic performance, mean (SD)	NAPLAN Grade 7 average	569 (61) $^{n=945}$
Adiposity, median (IQR)	Body fat% (all)	19.8 (15.4–26.4)$^{n=1175}$
	Body fat% (males)	17.9 (14.0–24.4)$^{n=598}$
	Body fat% (females)	21.5 (17.0–27.8)$^{n=577}$
Cardiorespiratory fitness (mL/kg/min), mean (SD)	VO_{2max}	48.0 (9.8)$^{n=811}$
Blood pressure (mm Hg), mean (SD)	Mean arterial pressure	77.6 (5.8)$^{n=1121}$
Inflammation (mmol/L), median (IQR)	GlycA	0.96 (0.90–1.0)$^{n=792}$
Bone strength (mm^3), mean (SD)	Polar SSI resistance	1704 (394)$^{n=806}$

*Compositional centre is calculated as the geometric means of each activity, linearly adjusted so that together all means sum to 1440 min/day. The compositional centre is not accompanied by univariate SD because it is a multivariate measure.
GlycA, Glycoprotein acetylation; LPA, light physical activity; MVPA, moderate-to-vigorous physical activity; NAPLAN, National Assessment Programme-Literacy and Numeracy; NIH, National Institutes of Health; PedsQL, Paediatric Quality of Life Inventory; SDQ, Strengths and Difficulties Questionnaire; SSI, Stress-Strain Index; VO_{2max}, predicted maximal aerobic power; WISC-IV, Wechsler Intelligence Scale for Children, 4th Ed.

Their area-level socioeconomic advantage and homogeneity (mean 1028, SD 60) was also slightly higher than Australians in general (national mean 1000, SD 100) on a census-derived composite index of relative socio-economic disadvantage at postcode level.[20]

Optimal time-use composition for individual outcomes

All health and well-being measures were associated with the time-use composition ilrs (*p* values for all models ≤0.04) (online supplemental file 4). Figure 1 shows estimated optimal compositions for all 12 outcomes. Generally, best mental health was associated with relatively long durations of sleep, together with shorter sedentary time and light physical activity (typically ≤3.0 hours) and about 2 hours of MVPA. Best cognitive and academic performance were associated with more sedentary time (≥10.5 hours) and less physical activity (light and MVPA). For physical measures, shorter sedentary time (≤9.3 hours) and longer MVPA (≥2.1 hours) were associated with best outcomes.

Overall optimal time-use composition for the three composite domains

The compositions with highest physical activity (predominantly MVPA) and low sedentary time were optimal for physical health, while compositions with highest sleep and lowest sedentary time were optimal for mental health (table 3, upper section). Compositions with highest sedentary time and lowest physical activity were most optimal for cognitive health (table 3, upper section). This is reflected in the Goldilocks Day solutions that prioritise one aspect of health and well-being over the others (table 3, lower section). If the three health domains were given equal importance, the best overall Goldilocks Day solution had 10.4 hours sleep, 9.7 hours sedentary time, 2.4 hours light physical activity and 1.5 hours MVPA.

Changing the relative importance of health and well-being outcomes caused the Goldilocks Day solution to change. Clinicians, families and children can play with our online prototype interactive interface at https://dotdumuid.shinyapps.io/Weighting_of_outcomes_for_optimal_time_use/ to personalise the Goldilocks Day according to their own weighted mix of outcome priorities (figure 2, illustration created by author).

DISCUSSION

Principal findings

Time in sleep, sedentary time, light physical activity and MVPA had important—but different—associations with the 12 markers of children's mental, cognitive/academic and physical health. Days with more sleep were associated with better mental health, leanness and lower blood pressure. Days with more sedentary time were associated with better cognitive and academic outcomes. Days with more light physical activity were associated with better cardiorespiratory fitness, while days with more MVPA were beneficially associated with all physical and mental health markers. The Goldilocks Day solution that optimised all domains equally had 10.4 hours sleep, 9.7 hours sedentary time, 2.4 hours light physical activity and 1.5 hours MVPA.

Strengths and weaknesses of the study

Strengths of this study include a large, population-based sample with objective 24-hour device-based measurements of children's time use and extensive standardised outcomes across multiple domains. These included objectively measured physical health outcomes, validated subjective measures of mental health and well-being, and standardised national academic performance testing. The analytical methods enabled all daily time-use activities to be considered in the same statistical model; non-linear terms were used as indicated and robust estimators reduced the

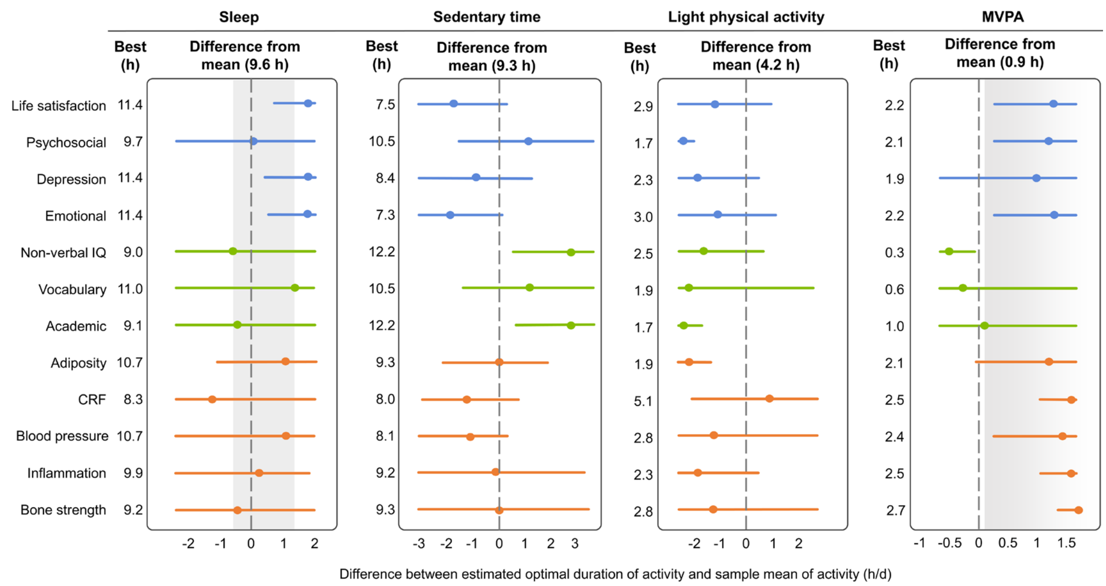

Figure 1 Optimal daily durations of activity behaviours relative to the compositional means of the sample. Optimal durations (shown as dots) are calculated as the compositional mean of the best 5% of time-use compositions for each of the outcomes. Daily durations do not always sum exactly to 24 hours due to rounding. The range associated with the best 5% is shown by the horizontal lines. Broken grey line represents the compositional mean of the sample. Grey shading indicates durations of sleep and MVPA recommended by current Australian 24-hour guidelines. All models adjusted for age, sex, puberty and household socioeconomic position. Bone model additionally adjusted for body mass, cardiorespiratory fitness model additionally adjusted for body mass index standardised to international norms. CRF, cardiorespiratory fitness; MVPA, moderate-to-vigorous physical activity.

potential influence of outlying observations. Limitations include the narrow age band (10.7–13.0 years) and the slight socioeconomic advantage of participating children, requiring caution in extrapolating findings. The cross-sectional nature of the CheckPoint study precludes inferences of causality, with reverse causality (eg, adiposity limiting MVPA, or high academic potential stimulating more study) and residual confounding (eg, by diet or parenting style) both possible. Two types of bioimpedance scales were used for %body fat measurement (Tanita BC-351 and InBody 230). While both devices are validated for %body fat, agreement between devices is not known. Our estimated optimal durations are directly dependent on the daily activity durations estimated by this accelerometry, and may not be generalisable for different devices, wear locations or data processing protocols.[21] Although accelerometry is 'objective' and considered gold standard for measuring time use, differences in the device used, wear site, wear-time protocol and data treatment can substantially influence estimated durations of activities.[21] Accelerometer counts in the CheckPoint study were collapsed into 60 s epochs, which is long in comparison to some child studies. Because children tend to accumulate MVPA sporadically, the long epoch length may have somewhat reduced the estimates for MVPA in this study. However, while the exact Goldilocks Day estimates might change if different devices/epochs/cutpoints were chosen, the key messages are unlikely to change. We imputed non-wear time if the paper-based activity logs indicated the accelerometer was removed for 'sport'. Although this helps to prevent systematic underestimation of MVPA, reasons for device removal were not always provided and the procedure has not been validated. Accelerometry is unable to differentiate between activity types and contexts that may have diverging effects on health, for example screen time and reading. This means that our findings about sedentary time apply to all forms of sedentary time (eg, including reading), rather than screen time alone; therefore, they are not directly applicable to the current 24-hour guidelines for children's screen time.

Table 3 Goldilocks Day solutions for individual health domains and overall health and well-being

	Sleep	Sedentary	LPA	MVPA
Health domain	(hour/day)*			
Mental	11.0	8.4	2.4	2.1
Cognitive/academic	9.7	11.7	2.0	0.6
Physical	9.8	8.9	2.8	2.5
Overall health and well-being				
Equal priorities across domains	10.4	9.7	2.4	1.5
Prioritise mental health†	10.5	9.4	2.4	1.6
Prioritise cognitive/academic health†	10.3	10.2	2.3	1.2
Prioritise physical health†	10.3	9.5	2.5	1.7

*Daily compositions do not all sum exactly to 24 hours due to rounding.
†Prioritised health domains are double weighted.
LPA, light physical activity; MVPA, moderate-to-vigorous physical activity

Comparison with previous literature

Our findings confirm previous time-use research showing that more MVPA, longer sleep and less sedentary time are associated with better physical health (predominantly adiposity).[8] They also confirm reports that more light physical activity is associated with higher adiposity and worse behavioural and cognitive outcomes.[22–25] Our findings associating longer light physical activity with better cardiorespiratory fitness appear to contradict one previous study, although of preschool children.[25] Comparable 24-hour time-use studies of other physical measurements, psychological and mental health outcomes and cognitive outcomes are lacking.

No previous study has attempted to describe durations of activities for best overall health and well-being across a 24-hour day. Yet, some qualitative research suggests that parents,

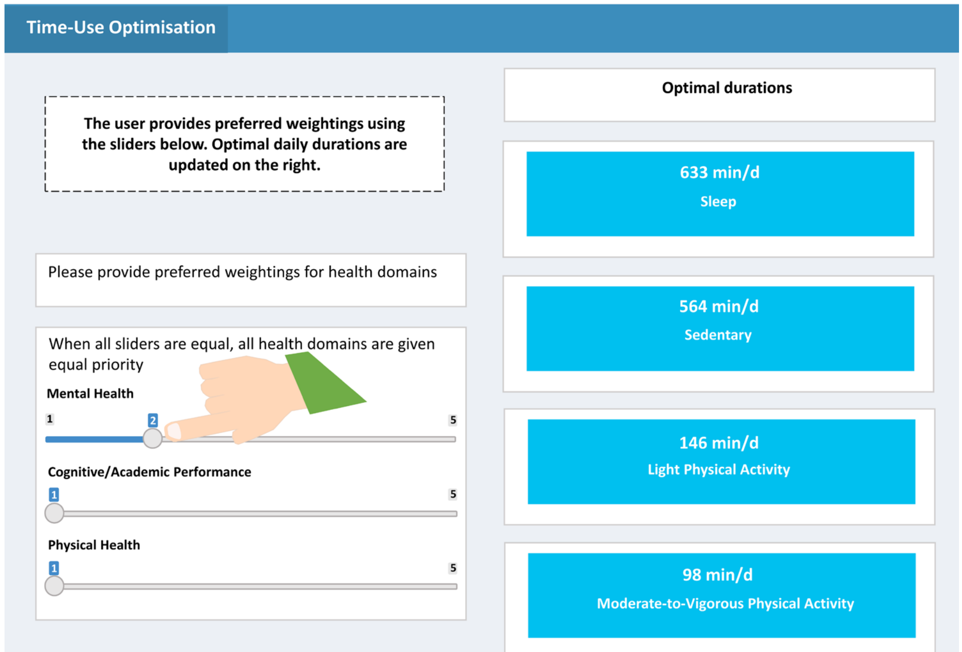

Figure 2 Prototype of online interactive interface to personalise the Goldilocks Day according to own health priorities. The online interface found at https://dotdumuid.shinyapps.io/Weighting_of_outcomes_for_optimal_time_use/ allows the user to define their own health priorities by adjusting sliders. Activity duration recommendations for the personalised Goldilocks Day are updated on the right. Illustration: author's own.

caregivers, clinicians and educators want definitive guidelines recommending time durations.[26] In lieu of supporting evidence for optimal durations across multiple domains, studies examining whether participants meeting one, two or more of the activity guidelines have better health compared with those who do not meet the guidelines are cited as evidence for the recommended durations.[2 3] Our estimated Goldilocks solution which gives equal weight to mental, cognitive and physical domains is consistent with the current 9–11 hours/day recommendation for sleep (10.4 hours/day). Our estimate for optimal MVPA is higher than the minimum threshold provided in the current recommendation (1.5 hours/day vs at least 1 hour/day), and provides support for its open-ended nature, that is, that more MVPA is better. We found large variability in the best estimated durations of light physical activity and sedentary time, possibly because the contexts and types of these behaviours are important to outcomes (eg, sedentary study vs sedentary recreational screen time). This may provide support to current 24-hour guidelines which do not provide specific time recommendations for light physical activity and total sedentary time. Nonetheless, it does seem important to consider the impacts of overall time spent being sedentary on health.

Interpretation and implications for clinicians and policy-makers

The important conclusion for health practitioners and policy-makers is that no one-size-fits-all prescription for time use is likely to optimise all outcomes simultaneously for all children. When providing lifestyle advice about time use, clinicians may consider tailoring these to parents' and children's health priorities. Were such an approach to be formalised into guidelines (beyond the scope of this paper), then evidence-based consideration would be required as to the relative weightings within each domain.

Policy-makers should consider how to develop flexible time-use guidelines that can readily be communicated, translated and varied according to what outcomes are felt to be most important for individuals or age groups. Such a hierarchy of health priorities is likely to differ by sociodemographic factors such as pre-existing health conditions, sex, age and culture. We presented one decision-making tool, but other methods might be used to determine population-level subjective weightings. Discrete choice experiments which ask participants to choose between a series of finite options in order to ascertain their priorities could be an option (eg, 'Which would you prefer: a 30% chance of depression and a 50% chance of academic success, or a 10% chance of depression and a 25% chance of academic success?'). Citizen's juries or questionnaires asking participants to rank health outcomes in order of importance to them or their children may be an alternative.

Future directions

Advanced optimisation methods are popular in fields of computer science and artificial intelligence, usually with commercial incentives. To our knowledge, such methods have not yet been integrated in time-use epidemiology—even though how children spend their day is one of the most fundamental decisions parents, schools and societies must make. Optimal daily durations estimated by this study should be confirmed by further studies among participants of different ages and of different countries and cultural backgrounds. Similar studies should be conducted among clinical populations. Future studies may apply more sophisticated methods to optimise time use. Machine learning could be used to find the objective functions best suited to the data and to identify multidimensional peaks or optima.

Future work may incorporate constraints to the optimisation procedure. For example, it is not helpful if the optimal durations are not possible or feasible for the average child to achieve. In this study we limited any optima to be within the ranges observed in the sample, the 'empirical time-use footprint'. Non-negotiable constraints such as passive travel commutes or school hours could be included in the optimisation procedure.

Other ways of classifying time use may lead to different recommendations. Separating MVPA into moderate and vigorous intensities was not feasible in this study, given the very small amounts of time children spent in the latter (mean (SD)=6 (7) min/day) with 50 children (4%) recording none at all. Posture-based classifications (sitting, standing, stepping) and classifications from time-use diaries or recalls that provide activity types (eg, screen time, chores, studying, socialising) are alternatives that may have different effects on the variety of outcomes reported here.

Instead of describing best days, future studies and public health strategies and guidelines may describe best weeks. This approach would allow greater flexibility in how activities are accumulated and may be more achievable for families. It may be difficult to modify behaviour during weekdays due to restrictions of school hours and parental work commitments. Weekends may be used to compensate for reduced sleep and physical activity during weekdays. For example, the best weekly balance of behaviours may favour some types of sedentary behaviour on weekdays (to optimise cognition and academic performance) but physical activity and sleep on the weekends (to optimise mental and physical health).

CONCLUSION

The best way children should spend their time across sleep, sedentary time and physical activity (light physical activity and MVPA) depends on the health outcomes of interest. For all outcomes (except cardiorespiratory fitness) estimated optimal sleep duration was ≥9 hours, and for all outcomes (except non-verbal IQ and vocabulary) optimal MVPA was >1 hour, as recommended by most guidelines. For three-quarters of outcomes, optimal MVPA duration was more than double the lower 1 hour/day threshold of current MVPA recommendations. Optimal durations for sedentary time and light physical activity varied widely. These findings challenge a one-size-fits-all approach to activity guidelines.

What is already known on this subject

- ► Time spent sleeping, sedentary and in physical activity impacts all areas of children's health and well-being.
- ► Parents, caregivers, clinicians and educators want activity guidelines that recommend durations of sleep, sedentary behaviour and physical activity.

What this study adds

- ► No one-size-fits-all 'Goldilocks Day' simultaneously optimised all outcomes—best durations of activities varied depending on health and well-being priorities.
- ► When providing lifestyle advice about time use, clinicians and policy-makers may consider tailoring these to parents' and children's health priorities.
- ► Our decision-making tool facilitates customisation of time-use recommendations.

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