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The associations between physical activity, screen time and weight from 6 to 14 yrs: The Raine Study

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Abstract

To examine the strength and direction of the relationship between physical activity level, screen use and BMI in a cohort at ages 6, 8, 10 and 14 yrs as part of a prospective longitudinal cohort study. The sample comprised 1403 males and females who participated in the follow-up survey at 14 yrs of age between 2003 and 2005. Exploratory structural equation modelling was used to examine the interrelationships between physical activity level, BMI and screen time at 6, 8, 10 and 14 yrs. Predictors of BMI at 6, 8, 10 and 14 yrs explained 1.3, 76.1, 80.1 and 73.1 percent of the variances, respectively, with previous BMI the largest predictor [$\chi^2 = 43.082$, df = 36, $p = 194$]. Increased screen time predicted higher BMI and lower physical activity at 8 and 10 yrs but not 14 yrs. At 14 yrs, physical activity predicted BMI. Sedentary patterns of behaviour in early childhood were predictive of later and concurrent obesity, whereas physical activity was predictive of obesity in adolescence. Different intervention targets are required for children and adolescents.

Keywords: Children; Adolescents; Television viewing; Body Mass Index; Longitudinal; Physical activity

1. Introduction

Numerous cross sectional studies have identified associations between lower levels of physical activity and greater time engaged in sedentary pursuits such as screen time and higher Body Mass Index (BMI) among children and adolescents.[1,2] The strength of the associations are inconsistent which may be due in part to the primary outcome of interest or the age of the cohort. Associations between physical activity, sedentary behaviours such as screen time and weight status differ if cohorts are grouped according to weight (overweight/obese vs acceptable),[1–4] screen use (high vs low),[4,5] and activity (high vs low).[5,6] For example, comparisons of overweight and acceptable weight cohorts found that overweight children and adolescents spent more time engaged in sedentary pastimes, including screen use, and less time involved in sports and other activities compared to their normal weight counterparts.[4,6–8] When grouped according to screen use, the high screen users were more likely to be overweight or obese,[4,5] but not necessarily less physically active.[5,9,10] Finally, when active and inactive cohorts were compared, no relationship was found with weight status[6,11] and mixed results were reported for screen time.[1,5,12]

In order to better understand these associations and the direction of the relationship, longitudinal studies are required. However, to date we have not identified any studies that used longitudinal data from childhood into adolescence to examine the directional relationships between physical activity level, screen time and BMI. Recently, Metcalf et al.[13] reported that obesity leads to physical inactivity using data from a short longitudinal study tracking a cohort of children from 7 to 10

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yrs of age. It is important to determine if this relationship holds true into adolescence. The purpose of this paper was to report on the application of exploratory structural equation modelling (SEM) to examine the interrelationships between BMI, physical activity and screen viewing behaviours in a cohort tracked from childhood (6 yrs) to adolescence (14 yrs) and to contribute to the directionality debate.

2. Methods

The Western Australian Pregnancy Cohort (Raine) Study recruited 2979 pregnant women reporting to antenatal clinics in Perth, Western Australia from 1989 to 1991, which resulted in 2868 live born children.[14] This cohort has since been followed in surveys at 1, 2, 3, 6, 8, 10, and 14 yrs of age and is broadly representative of the Western Australian population.[15]

We based our analyses on the anthropometric and physical activity data for 1403 adolescents who participated in the 14-yr survey. The group comprised 729 males ($M = 14.02$ yrs, $SD = 0.20$) and 674 females ($M = 14.02$ yrs, $SD = 0.19$). Numbers vary for some variables as parents and participants did not participate in all components at each of the earlier follow-ups. Age was calculated from the date of questionnaire completion. For each survey, some participants completed the questionnaires by mail and some attended the Telethon Institute for Child Health Research for physical examinations and to complete questionnaires. The study was approved by the Institutional Ethics Committee.

In order to run an exploratory structural equation model, data for each variable across time must be comparable. Consequently, the data for physical activity and screen time at each follow-up were converted to dichotomous variables using the procedures described below.

Parents reported by questionnaire on their child's physical activity during the 6, 8, and 10-yr follow ups. At 6 yrs, parents answered Yes/No to two questions asking if their child was involved in any organized sport at school or with a club or organized activity such as music, dancing, Kindygym or other clubs. No activity (No to each question) was scored as 0 and one or more activity was scored as 1. At the 8-yr follow-up, parents were asked to rate their child's level of activity as either sedentary or slightly active, which were both coded as 0, or active (involved in an organised activity 2–3 times per week) which was coded as 1. At the 10-yr follow up parents diarised the time in minutes for their child's daily physical activities over a typical week. A total score was derived and participants grouped into the lowest tertile categorized as low active (0) and the others classified as active (1). At the 14-yr follow-up, the participants responded to three questions about time spent exercising vigorously during physical education at school (none, about a quarter of the time, about half the time, more than half the time, to almost all the time), how often they got out of breath or sweated while exercising outside school hours (once a month, once a week, 2–3 times a week, 4–6 times a week, every day) and how many hours they got out of breath or sweated while exercising outside school hours (none, about 1/2 h/week, about 1 h/week, about 2–3 h/week, about 4–6 h/week, 7 or more hours/week). Responses were summed to create a composite variable with a maximum possible score of 13. Participants in the lowest tertile were categorized as low active (0) and the others were classified as active (1).

For the 6, 8 and 10-yr surveys, parents reported on their child's screen time. At 6 and 8 yrs, the six category question asked only about television viewing, and response options ranged from none to more than three hours per day. For the 10-yr questionnaire, a similarly coded question was used, which also asked about time spent watching TV and/or computer games. At 14 yrs, the adolescents responded to two five category questions about the number of hours per day watching TV or videos, and the number of hours per day playing video or computer games. The response options ranged from not at all to 4 h or more per day. These two questions were combined to create overall screen time categories. For each survey, it was possible to categorise the data for participants into those reporting greater than or less than 2 h of screen time. This cut off is based on the Australian recommendations for hours of screen time per day for adolescents.[16]

Extensively trained researchers completed all anthropometric measures. Weight was measured to the nearest 100 g using calibrated Wedderburn digital scales and height was measured to the nearest 0.1 cm with a calibrated Holtain stadiometer. Body Mass Index (BMI) (wt/ht^2) was derived from the height and weight measures taken at each survey.

Analyses were performed using SPSS version 17 (SPSS Inc., Chicago, IL). Gender and adolescent weight status group differences were investigated using *t*-tests and chi-square. Exploratory structural equation modelling (SEM) (AMOS v17) was used to test a longitudinal model of interrelationships between screen time, physical activity and BMI at each time point and across time from 6, 8, 10 to 14 yrs. We hypothesized that each variable would track across time and that the interrelationships between each variable would strengthen with time, with possible lag effects (e.g. screen time at 6 yrs would have a direct effect on physical activity at 6 yrs and lag effects on physical activity at 8, 10 and 14 yrs). Normality was within the recommended limits.[17] Due to the presence of missing data (0–11.2% missing at random), a series mean replacement of missing values was conducted in SPSS to create a complete dataset for single-step model building (adding pathways).[18] This permitted model building to be explored by the addition of theoretically sound pathways based on modification indices.[17] Model building was conducted one pathway at a time, by examining both directions between variables at each time point, and lag effects between variables over time. Directionality of pathways was determined by statistical strength of association based on modification indices. The original dataset (with missing values) was then used for single step model trimming (removing pathways one at a time),[18] with a maximum likelihood estimation procedure.[19] A test

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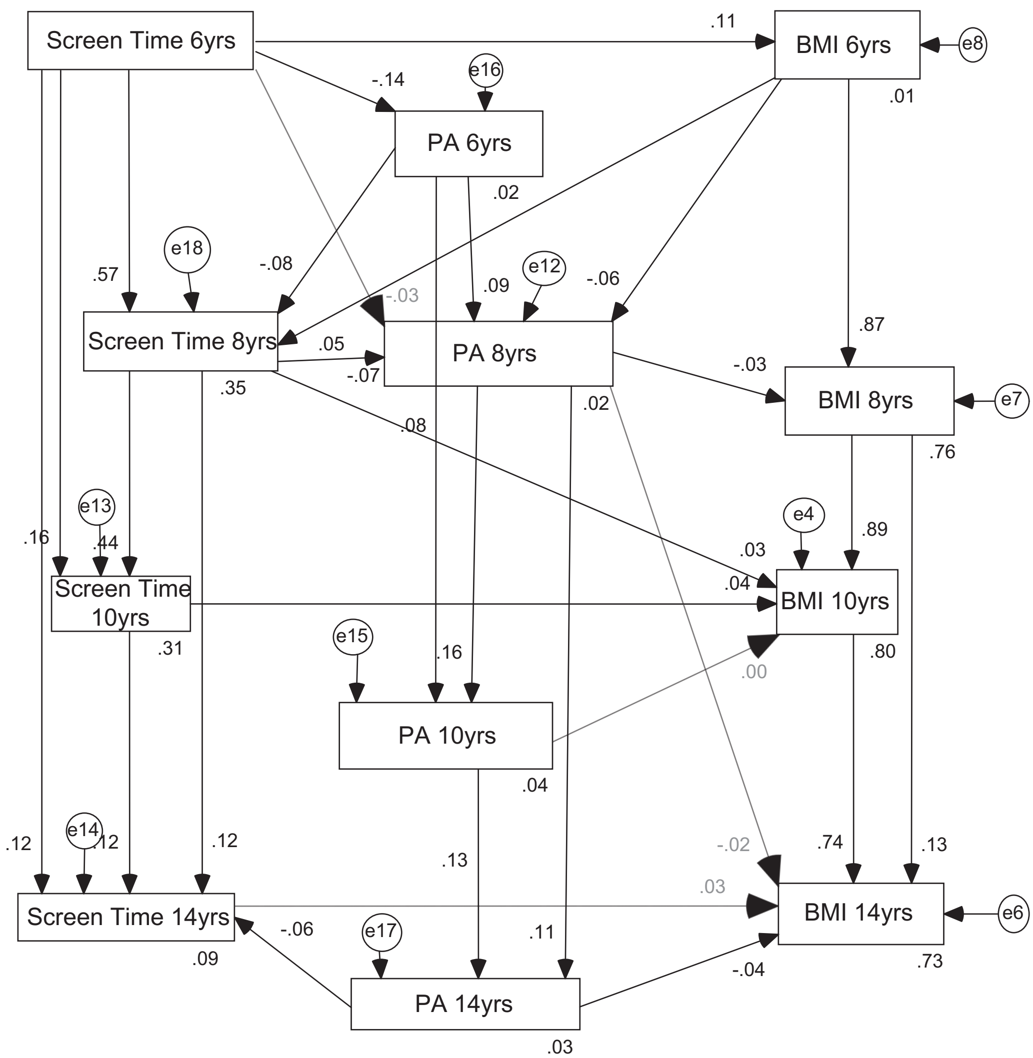

Fig. 1. Interrelationships of screen time, physical activity and Body Mass Index at 6, 8, 10 and 14 yrs. Standardized estimates shown with paths estimate near arrow head and estimate of squared multiple correlation shown at bottom right of variable. Individual variable error variances are depicted by an e. PA: physical activity, BMI: Body Mass Index. Paths with a dashed line are not significant in overall model. [Chi-square (df = 36) = 43.082, p = 0.194; RMSEA = 0.012 (0.0–0.023); CFI = 0.999; TLI = 0.998]. (Model Fit Indices: Chi-square (χ^2), Root Mean Square Error of Approximation (RMSEA) with upper and lower confidence interval (CI), Comparative Fit Index (CFI) and Tucker Lewis Index (TLI).)

of correlated residuals for repeated measures BMI was conducted to assess shared method variance. Results revealed non-significant covariances, with no significant difference between the non-correlated residuals model (reduced model) and the correlated residuals model,[20] therefore the reduced model was retained. This model was assessed separately for each sex using multi-group analysis[19] with additional significant pathways found. The final model (Fig. 1) included all significant pathways for both sexes.

3. Results

The characteristics of the cohort at 6, 8, 10 and 14 yrs of age are presented in Table 1, with gender differences noted. At 14 yrs only, the females had a higher BMI than the males (p = .012). From 6 yrs onwards, more females were categorised as low active than males, but there were no differences in screen time at any age. Table 2 reports the percentage of participants categorised as overweight, low active or a high screen user in the earlier surveys between those identified as overweight/obese or a healthy weight at 14 yrs. There were significant weight status group differences between the two groups for all variables except activity at 6 yrs and 10 yrs. A higher percentage of the overweight adolescents were already overweight and high screen users at 6 yrs, compared to the healthy weight group.

The exploratory SEM depicting the pathways between screen time, physical activity and BMI is shown in Fig. 1 and reported a good fit (χ^2 = 43.082, df = 36, p = .194; RMSEA = .012; CI .000–.023; CFI = .999; TLI = .998). Standardised estimates shown in Fig. 1 represent changes in

Table 1
Characteristics of the total cohort, males and females at 6, 8, 10 and 14 yrs.

Variable	Total		Male		Female		Gender difference	
	N	*M* (SD)	*N*	*M* (SD)	*N*	*M* (SD)	*t*	*p*
14 yrs								
Age (months)	1403	168.3(2.3)	729	168.2(2.4)	674	168.3(2.3)	−0.54	.59
BMI (kg/m^2)	1403	21.4(4.2)	729	21.1(4.2)	674	21.7(4.2)	**−2.51**	**.01**
10 yrs								
Age (months)	1315	126.4(2.4)	686	126.5(2.5)	629	126.3(2.3)	1.16	.25
BMI (kg/m^2)	1246	18.6(4.2)	650	18.6(3.4)	596	18.7(3.3)	−0.62	.53
8 yrs								
Age (months)	1309	96.6(4.2)	676	96.6(4.1)	633	96.5(4.3)	0.53	.60
BMI (kg/m^2)	1271	16.8(2.5)	652	16.8(2.5)	619	16.8(2.5)	−0.34	.74
6 yrs								
Age (months)	1307	70.3(2.3)	679	70.3(2.4)	628	70.3(2.3)	0.05	.96
BMI (kg/m^2)	1259	15.8(1.8)	656	15.9(1.8)	603	15.8(1.8)	1.02	.31
	N	%	*N*	%	*N*	%	χ^2	*p*
14 yrs								
Physical activity	1396		722		674		**33.5**	**<.001**
Low active	628	44.8	271	37.5	357	53.0		
Active	768	54.7	451	62.5	317	47.0		
Screen use min/day	1398		724		674		3.3	.07
<120 min	693	49.6	342	47.2	351	52.1		
>120 min	705	50.4	382	52.8	323	47.9		
Weight status	1403		676		623			
Healthy weight	1043	74.3	553	75.9	490	72.7	1.8	.10
Overweight/obese	360	25.7	176	24.1	184	27.3		
10 yrs								
Physical activity	1252		658		594		**16.4**	**<.001**
Low active	422	33.7	188	28.6	234	39.4		
Active	830	66.3	470	71.4	360	60.6		
Screen use min/day	1312		686		626		0.2	.64
<120 min	912	69.5	473	69.0	439	70.1		
>120 min	400	30.5	213	31.0	187	29.9		
Weight status	1330		693		637		.33	.31
Healthy weight	1026	77.1	539	77.8	487	76.5		
Overweight/obese	304	22.9	154	22.2	150	23.5		
8 yrs								
Physical activity	1308		676		632		**14.9**	**<.001**
Low active	803	61.4	381	56.4	422	66.8		
Active	505	38.6	295	43.6	210	33.2		
Screen use min/day	1309		676		633		0.0	.97
<120 min	1018	77.8	526	77.8	492	77.7		
>120 min	219	22.2	150	22.2	141	22.3		
Weight status	1271		652		619		1.3	.14
Healthy weight	1055	83.0	549	84.2	506	81.7		
Overweight/obese	216	17.0	103	15.8	113	18.3		
6 yrs								
Physical activity	1303		678		625		**28.1**	**<.001**
None	587	45.0	353	52.1	234	37.4		
1 or more activities	716	55.0	325	47.9	391	62.6		
Screen use min/day	1303		678		625		2.8	.09
<120 min	982	75.4	498	73.5	484	77.4		
>120 min	321	24.6	180	26.5	141	22.6		
Weight status	1259		656		603		.65	.23
Healthy weight	1059	84.1	557	84.9	502	83.3		
Overweight/obese	200	15.9	99	15.1	101	16.7		

Note: Significant differences are in bold.

standard deviations. For example, 1SD increase in 6 yrs screen time is associated with a 0.11 SD increase in 6 yrs BMI, and 1SD increase in BMI at 8 yrs is associated with 0.89 SD increase in BMI at 10 yrs. Predictors of BMI at 6, 8, 10 and 14 yrs explained 1.3, 76.1, 80.1 and 73.1% of the variances respectively, with previous BMI the largest predictor. BMI at 8 yrs was predicted by BMI at 6 yrs and PA at 8 yrs, and BMI at 10 yrs was predicted by screen time at 8 and 10

Table 2
Percentage (%) in unhealthy categories at 6, 8 and 10 yrs according to weight category at 14 yrs.

Unhealthy category	Weight category at 14 yrs			
	Total $N = 1403$	Overweight/obese $N = 360$	Healthy weight $N = 1043$	p
Overweight/obese				
6 yrs	15.9	45.9	5.6	.000
8 yrs	17.0	53.8	4.3	.000
10 yrs	22.9	67.8	7.6	.000
Low active				
6 yrs	45.0	48.6	43.9	.076
8 yrs	61.4	69.8	58.5	.000
10 yrs	33.7	37.1	32.6	.083
14 yrs	45.0	52.2	42.5	.001
High screen use				
6 yrs	24.6	33.3	21.7	.000
8 yrs	22.2	26.6	20.7	.016
10 yrs	30.5	37.2	28.2	.002
14 yrs	50.4	55.3	48.8	.019

yrs and BMI at 8 yrs. Finally BMI at 14 yrs was predicted by BMI at 8 and 10 yrs and PA at 14 yrs. Overall, screen time, physical activity and BMI each tracked over time, with evidence of lag effects. In early childhood (6 and 8 yrs) screen time influenced physical activity levels, but this influence was absent at 10 yrs and reversed by adolescence, with physical activity levels at 14 yrs now influencing the amount of screen time. Screen time had a direct influence on BMI at 6 yrs and 10 yrs, with an indirect influence through physical activity at 8 yrs. Screen time at 8 yrs also reported a lag effect on BMI at 10 yrs. Both BMI and Physical activity at 6 yrs influenced screen time at 8 yrs. There was a direct influence of physical activity on BMI at 8 and 14 yrs. Multi-group analysis for gender found no differences between males and females in the pathways reported for the final structural equation model.

4. Discussion

This study examined the interrelationships between BMI, physical activity and screen time cross sectionally and over time in a cohort of Australian children participating in a prospective longitudinal study. The prevalence of unhealthy behaviours in childhood were higher among obese adolescents (Table 2). Our data showed that 46% of the obese adolescents were already obese, inactive (49%) or high screen users (33%) at 6 yrs.

Further the SEM revealed that screen time, physical activity level and BMI each tracked from 6 to 14 yrs indicating that weight status and patterns of behaviour are established at an early age. The direction of prediction between BMI, physical activity and screen use changed over time, with associations during childhood (6, 8 and 10 yrs) different from those during adolescence. It is probable that factors leading to overweight and obesity in childhood are different to those leading to obesity during adolescence. Early obesity may arise from familial and genetic factors whereas later obesity may be due to more lifestyle and environmental factors.[21,22] In our sample, 15.9% of the sample were already overweight or obese at 6 yrs (Table 1). A longitudinal model of BMI using data from this cohort[23] found that children were already on the pathway to adolescent obesity by age 3 yrs. The time engaged in screen-based behaviours but not physical activity contributed to BMI at this early age. The weak association between weight status and physical activity is interesting as a strong causal relationship is often expected.[24] Some researchers have found overweight and obese children and adolescents to be less active[13,25,26] whereas many others have not.[26–28] In this cohort, we found a pathway from physical activity to BMI at 8 yrs and at 14 yrs, whereas BMI at 6 yrs was contributing to physical activity at 8 yrs. This latter direction is similar to the results reported by Metcalf et al.[13] in 7–10-yr-olds who also found fatness preceded inactivity.

Screen use was a predictor of physical activity at age 6 and 8 yrs, but by 14 yrs this reversed so that physical activity predicted screen use. In other words, screen time was displacing physical activity time among the younger children but not the adolescents. Evidence for this displacement hypothesis is mixed[5,29,30] however our finding is not surprising, given that younger children's involvement in organized activity is principally driven by their parents. They also have fewer waking hours than older children. Therefore, if young children are not being active during daylight hours, they are more likely to watch television, whereas older children may participate in organized activities after school and then watch television or other screen based activities in the evenings. Adolescents may be able to engage in at least 2 h of screen based activities as well as maintain an adequate level of physical activity. This is probably the case for many normal weight participants. As shown in Table 2, the percentage of both normal weight and overweight/obese participants who spent more than 2 h per day in screen use increased from early childhood to 48.8% and 55.3%, respectively at 14 yrs. This stronger relationship between time spent in physical activity rather than sedentary behaviour on overweight and obesity in adolescence concurs with another study involving 12-yr-old

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children. Mitchell et al.[30] found that the association between time spent in sedentary behaviour and overweight and obesity disappeared when adjusted for moderate and vigorous physical activity.

Cross sectional or longitudinal studies involving a limited age range are not able to identify the changing relationships observed in our model. We propose that the relationships between physical activity, weight status and screen-based sedentary behaviours change over time and that a critical window exists between 6 and 10 yrs. During this time, sedentary patterns of behaviours such as screen time are predicting BMI more than physical activity. Once adolescent, screen time is not predictive whereas physical activity becomes important. This suggests that those adolescents participating in physical activity during and after school hours are less likely to be obese regardless of screen time, however if they were high screen users in childhood they were likely to already be obese. This critical developmental window in late childhood was observed by Eaton et al.[31] who reported a peak in physical activity among children between 7 and 9 yrs of age. Physical activity levels notably decline around puberty[32] and may therefore become more critical during adolescence.

This study makes a unique contribution to the debate surrounding the directions of causality between physical activity, screen time, and obesity. Directionality discussions are extended by our exploratory SEM which has the advantage of being able to simultaneously model all regression equations and test a range of causal pathways,[33] providing a more powerful statistical process to that used by Metcalf et al.[13] Few studies have data spanning 8 yrs, and most involve adults rather than children and adolescents.[34] The interrelationships in the exploratory model highlight childhood as a critical time for the development of sedentary behaviours which track into adolescence and play a role in concurrent and future adiposity. The variation in the strength of association between these variables with age may be influenced by the growing independence of adolescent interests and behaviours, as well as physical changes associated with maturity.

Interpretation of findings must be considered in respect to study limitations. In our study, physical activity measures were a notable limitation with a variation between surveys. Measures were relatively crude and subjective and could not account for casual physical activity. Physical activity measures shifted from a proxy parent report at 6, 8 and 10 yrs to participant response at 14 yrs. Proxy reports are considered appropriate for young children given self-report questionnaires are not reliable,[35] and the challenge of measuring physical activity in young children is yet to be resolved. However little is known about the comparability of parent reports for children (at age 6, 8 and 10 yrs) to self-report data at 14 yrs. While data from longitudinal studies are valuable, one limitation is the potential for variation in measures used in consecutive survey waves. It should also be noted that the 6-yr follow up was conducted in 1995–1998 and so the questions relating to physical activity and screen use have changed with each survey to reflect the rapid advances in screen based technology since the study began in 1989.

The measure used to determine level of adiposity may also affect findings. For example, Kimm et al.[25] reported a difference between physical activity level and weight status determined by skin-fold, and Metcalf et al.[13] reported on directionality based on percent body fat and accelerometers. In this study, adiposity was based on BMI which was found to be the most appropriate measure with this cohort.[36]

In respect to the SEM depicted, it must be emphasized that this was derived by exploratory processes and ideally the validation of the model is required by external replication with another cohort sample.[20] However the purpose in this study was to use this model to diagrammatically articulate the interrelationships between the variables over time. In addition to the novel use of SEM, a strength of the study is the longitudinal nature of the data and the potential to track these constructs as the cohort matures into adulthood. This provides a starting point for further confirmatory approaches and testing of hypotheses.

5. Conclusion

This paper extends the directionality debate between screen time, physical activity and BMI. Results highlight the importance of establishing healthy behaviours in the early years in order to minimize poor health outcomes when older. Physical activity, screen time and obesity need to be considered as both independent and interactive entities. Consequently, preventive actions may need to target each separately, particularly in early childhood. The most important role of physical activity may be in counter-acting negative behaviours in adolescence, in particular screen time, which has been strongly associated with adiposity. Reducing screen time, increasing physical activity participation and preventing early adiposity before 6 yrs are all critical in developing positive behaviours for the maintenance of healthy weight and prevention of future obesity.

Practical implications

- Many potentially unhealthy characteristics are established in early childhood. Physical activity, screen time and weight status at 6 yrs are predictive of outcomes at 14 yrs.
- These results highlight the importance of early interventions as many children are already overweight, high screen users and low active at 6 yrs.
- Interventions should target screen time in early childhood and physical activity in adolescence. This difference needs to be considered in future research and interventions targeting specific age groups.

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