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ARTICLE

Pediatrics

Weight status and health-related quality of life during childhood and adolescence: effects of age and socioeconomic position

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Abstract

Background Overweight and obesity in children is associated with poor health-related quality of life (HRQoL), but the nuances of this relationship across different age and socio-demographic groups are not well-established. The aim of this study is to examine how the association between weight status and HRQoL changes with age and socioeconomic position (SEP) throughout childhood and adolescence.

Methods We used data from the Longitudinal Study of Australian Children (LSAC), a cohort study in which children were interviewed biennially from ages 4 to 17 years over seven waves of data. Measurements of HRQoL (using PedsQL^{TM}), body mass index (BMI), and socio-demographic characteristics were collected at each interview. Of the 4983 children recruited into the study, we included data from 4083 children (a total of 24,446 observations). We used generalised estimating equations to assess whether age and SEP modified the association between weight status and HRQoL, after controlling for sex, long-term medical condition, language spoken to child and maternal smoking status.

Results Age was a significant modifier of the association between weight status and HRQoL, with adjustment for known predictors of HRQoL ($P < 0.001$). At age 4, children with obesity had, on average, a 0.99 (95% CI 0.02–1.96) point lower PedsQL total score than children at healthy weight. This difference became clinically important by age 9 at 4.50 (95% CI 3.86–5.13) points and increased to 6.69 (95% CI 5.74–7.64) points by age 17. There was no evidence that SEP modified the relationship between weight status and HRQoL ($P > 0.05$).

Conclusions Our results demonstrate that the relationship between overweight and obesity status and poor HRQoL is strengthened with increasing age through childhood and adolescence, but is not affected by SEP. Paediatricians, researchers and carers of children with obesity should acknowledge HRQoL outcomes, particularly for older children and adolescents.

Introduction

Despite countless calls to action, commissions and government initiatives, tackling childhood obesity remains one of the most daunting public health challenges of our time. One likely reason for the limited success of existing approaches is an inadequate grasp of the complex drivers and consequences of childhood obesity. For example, there is a growing body of evidence showing that the consequences extend beyond physical health and that children and adolescents with overweight or obesity have poorer quality of life than those at healthy weight [1–6]. Adding to this complexity are indications that this relationship is sensitive to demographic factors. In two Australian studies, for instance, the relationship between higher weight status and poorer health-related quality of life (HRQoL), as measured by the Paediatric Quality of Life Inventory^{TM}

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(PedsQL) tool, only became apparent from age 8 in one study [3] and age 6 in the other [6]. However, in a German study of children aged 8–16 years, the opposite effect was observed where the HRQoL impairment, as measured by KIDSCREEN-27, in adolescents with obesity compared with those at healthy weight was not as severe as the impairment in pre-adolescents [7].

In addition to the effects of age, there are indications that socioeconomic position (SEP), including individual, parental, household and area-level dimensions, also impacts the weight status-HRQoL relationship. In descriptive analyses of 9–12-year-old children from Victoria, Australia, children of mothers with low education status had larger decrements in PedsQL scores associated with higher weight categories than children of mothers with high education [2]. Furthermore, a cross-sectional study in English adults found a significant interaction between weight status and SEP when assessing their impact on HRQoL, measured by the EQ-5D [8].

However, no study, to our knowledge, has used longitudinal analysis to examine the contributing effects of age and SEP to the relationship between weight status and HRQoL throughout childhood and adolescence. With the published cross-sectional analyses, the direction of the age effects, and whether they are driven by changes to sample characteristics over time, rather than age itself, is unclear. Furthermore, the impact of SEP on the relationship has only been examined descriptively in childhood or adolescent populations and has not been assessed with inferential statistics.

In this study, we use longitudinal analysis to investigate the relationship between weight status and HRQoL in a nationally representative community sample of children with twelve years of follow-up through the childhood and adolescent periods. Specifically, we formally investigated: first, how the association between weight status and HRQoL, including its physical and psychosocial components, changes through childhood and adolescence; and, second, if the association between weight status and HRQoL changes with SEP. This analysis will bring some clarity to the complex outcomes of children and adolescents with overweight or obesity.

Subjects and methods

Study data

Data from the Longitudinal Study of Australian Children (LSAC) were used in this analysis with approval from the University of Sydney Human Research Ethics Committee (Project Number 2018/726). LSAC is an ongoing nationwide cohort study that has followed two cohorts of children since 2004. Here, data collected from the Kindergarten cohort were used to follow the transition from childhood to adolescence. These children and their families were interviewed biennially resulting in seven waves of data; the children were aged 4–5 years at wave 1, 6–7 years at wave 2, 8–9 years at wave 3, 10–11 years at wave 4, 12–13 years at wave 5, 14–15 years at wave 6 and 16–17 years at wave 7. Participants were selected using a two-stage clustered design to obtain a sample representative of all Australian children born between March 1999 and February 2000, except for those residing in remote areas. The sampling design is described in detail elsewhere [9].

Measures

Health-related quality of life

The primary outcome analysed was HRQoL measured using the PedsQL Version 4.0 Generic Core Scales (GCS) (hereafter PedsQL for brevity), a validated multidimensional scale that measures HRQoL in populations aged 2–18 years. PedsQL is a 23-item scale with four subscales: Physical Functioning (8 items), Social Functioning (5 items), Emotional Functioning (5 items) and School/Day care Functioning (5 items) [10]. A five-point Likert scale is utilised for each item and the response is then reverse transformed to a number between 0 to 100 where a higher number corresponds to better HRQoL. The PedsQL demonstrates high reliability and validity, and the parent-proxy version exhibits strong concordance with the self-report version [10]. In LSAC, the parent-proxy version was used and answered by the parent who knew the study child best, which was usually the child's biological mother [11]. The total PedsQL score was calculated as the mean of all answered questions, with no total score calculated if more than 50% of items were missing, although missing item responses were minimal: of the interviews where any PedsQL questions were answered, 93% had all questions answered and only 0.03% had no total score calculated. In addition to total PedsQL score, we conducted secondary analyses on the physical health summary score (mean of Physical Functioning items) and the psychosocial health summary score (mean of Social, Emotional and School/Day care functioning items).

Weight status

The primary exposure was the child's weight status at each wave as a categorical variable with three groups: healthy and underweight, overweight and obese. In LSAC, anthropometric measurements of the child's height and weight were taken at every wave [12]. Height was measured using an Invicta stadiometer in waves 1–3 and a laser stadiometer in waves 4–7. Two measurements were taken at each wave

and if they differed by 0.5 cm or more, a third was taken. The mean of the two closest measurements was recorded. Weight was measured using Salter Australia glass bathroom scales in wave 1, HoMedics digital BMI bathroom scales in waves 2 and 3 and Tanita body fat scales in waves 4–7. Height and weight were converted to Body Mass Index (BMI) and top-coded to allow data to remain confidential. We categorised BMI into three groups using World Health Organisation cut-offs for each age and sex [13, 14].

Demographic factors

The study child's age was calculated as the time between their date of birth and the date of their interview at each wave and was included as a continuous variable precise to the day. A composite measure of SEP, provided by the LSAC, was used which combined parents' education, parents' occupation and family income into a single variable, converted to a z-score [15]. We categorised this variable into high and low SEP corresponding to a z-score of above or equal to 0, and a z-score below 0, respectively. For the primary analysis, SEP from the first wave was included as a permanent characteristic for each participant.

Predictors of HRQoL

The following known predictors of child HRQoL were included as controlling covariates: indigenous status [3], language other than English (LOTE) spoken to child [3, 16], mother's current smoking status [16], and child's long-term medical condition or disability (present, not present) [17]. Indigenous status and LOTE spoken to child were included as permanent characteristics using baseline values. Information on mother's current smoking status was collected at every wave except the final wave and was included as a time-varying variable. A last observation carried forward approach was used to impute the mother's smoking status in the final wave as previous smoking status was likely the strongest predictor of current smoking status. Information on whether the study child had a long-term medical condition or disability (defined as lasting six months or longer) was collected at every wave and was also included as a time-varying variable.

Statistical analysis

We fitted linear models with generalised estimating equations (GEE), with a compound-symmetry working correlation matrix, to determine the association between weight status and each HRQoL outcome (total PedsQL score, physical health summary score and psychosocial health summary score), and if this association was modified by age or SEP. Fitting the models with GEE accounts for intra-individual correlation caused by the repeated measurement of each variable, collected for each child over the seven waves of the study. Other benefits of this approach are that it can incorporate time-varying covariates and use partial information from participants who have missed some waves of data collection [18, 19]. We fitted a linear model for weight status and each outcome; first, unadjusted for covariates; second, adjusted for age, SEP, indigenous status, LOTE spoken to child, mother's current smoking status and child's long-term medical condition or disability; and third, adjusted for the same covariates with added interaction terms between weight status and SEP, and weight status and age. The assumption of linearity was met between age, the only continuous variable in these models, and each HRQoL outcome.

Finally, we predicted the mean total PedsQL scores, physical health summary scores and psychosocial health summary scores from the third model with interactions by integer age (in years) and weight status using the *margins* command in STATA with mean values specified for all covariates. We also predicted mean total PedsQL scores by integer age, weight status and SEP. Except for mother's smoking status at Wave 7, imputation was not conducted as the missingness of covariates among observations complete for weight status and PedsQL was less than 3%. All analyses were conducted in STATA version 15.0.

Sensitivity analysis

We conducted sensitivity analyses to test whether certain analytical decisions and assumptions affected the results. Firstly, we reanalysed the data using CDC growth standards [20] rather than WHO growth standards for categorisation of BMI. We also reanalysed the data with underweight status, based on WHO growth standards, included as a separate category. We further reanalysed the data using population longitudinal weights provided in the LSAC dataset [21] to assess whether loss of participants over the seven waves of data collection was likely to have influenced the results. Finally, we reanalysed the data using a time-varying measure of SEP (high/low) at each wave, rather than using baseline SEP.

Results

General characteristics of the study population at baseline

At baseline (wave 1), the study sample comprised of 4983 children born between March 1999 and February 2000 and aged between 4 and 5 years [12] of whom 4171 (84%) had BMI and total PedsQL scores recorded (Tables 1 and 2).

Table 1 General characteristics by weight status at baseline (age 4–5)[a].

	Healthy and underweight[b] ($n = 2804$)	Overweight ($n = 999$)	Obese ($n = 368$)
	n (%)		
Socioeconomic position			
Low SEP	1425 (50.8)	549 (55.0)	226 (61.4)
High SEP	1374 (49.0)	449 (44.9)	140 (38.0)
Missing	5 (0.2)	1 (0.1)	2 (0.5)
Sex			
Male	1375 (49.0)	549 (55.0)	204 (55.4)
Female	1429 (51.0)	450 (45.1)	164 (44.6)
LOTE spoken to child			
Yes	504 (18.0)	184 (18.4)	93 (25.3)
No	2300 (82.0)	815 (81.6)	275 (74.7)
Indigenous status			
Indigenous	76 (2.7)	32 (3.2)	24 (6.5)
Not indigenous	2728 (97.3)	967 (96.8)	344 (93.5)
Mother's smoking status			
Current smoker	606 (21.6)	216 (21.6)	117 (31.8)
Not current smoker	2139 (76.3)	767 (76.8)	246 (66.9)
Missing	59 (2.1)	16 (1.6)	5 (1.4)
Long-term medical condition			
Yes	539 (19.2)	202 (20.2)	97 (26.4)
No	2265 (80.8)	797 (79.8)	271 (73.6)
	mean (SD)		
PedsQL scores			
Total PedsQL score	81.0 (0.2)	81.5 (0.3)	79.1 (0.7)
Physical health summary score	82.8 (0.2)	83.3 (0.4)	81.1 (0.8)
Psychosocial health summary score	79.9 (0.2)	80.3 (0.4)	77.8 (0.7)

[a]Counts, proportions and means are within those with complete information on BMI and PedsQL

[b]23 children were underweight at baseline

Three hundred and sixty-eight (9%) of these children had obesity, 999 (24%) were overweight but did not have obesity, and the remaining 2804 (67%) were of healthy weight or underweight. As there were only 23 children who were underweight at baseline, underweight and healthy weight categories were combined (hereafter healthy weight for brevity). Among children with obesity, there was a higher representation of those in low SEP, with a LOTE spoken to the child, with indigenous status, with mothers who were current smokers and with a long-term medical condition compared with those of lower weight status (Table 1). At baseline, unadjusted mean total PedsQL scores and the summary scores were slightly lower in children with obesity than the other weight status categories (Table 1).

Attrition and missingness

With 4983 children recruited into the LSAC Kindergarten cohort, and seven waves of interviews, there were a possible 34,881 observations that could be entered into this analysis. Throughout the study, there has been a steady attrition of participants, but by Wave 7, 3089 of the original 4983 children were still participating (Table 2) and this corresponded to 28,529 administered interviews (82%). Of the participants that were interviewed in each wave, those with complete information on BMI and total PedsQL ranged between 77 and 96% (Table 2) corresponding to 25,103 observations (88% of interviews). Within observations that had complete data on BMI and total PedsQL, less than 3% had missing data for the baseline SEP, sex, LOTE spoken to child, indigenous status, mother's smoking status, and long-term medical condition covariates, leaving 24,446 observations included in each multivariate analysis.

Statistical analysis

In the models unadjusted (Supplementary Table 1) and adjusted for all covariates without interaction terms (Table 3), HRQoL measured by the total PedsQL score was significantly associated with overweight and obese status ($P < 0.001$). As shown by the model with interaction terms included (Table 4), age affected the association between weight status and total PedsQL score ($P < 0.001$ for both age by overweight and age by obese interaction terms). As age increased, the relationship between higher weight status and lower total PedsQL score strengthened. Sex was not significantly associated with total PedsQL score ($P = 0.50$), but was strongly associated with both the physical health summary score ($P = 0.001$) and psychosocial health summary score ($P = 0.005$) in opposite directions. On average, girls had lower physical health and higher psychosocial health scores than boys. Children of lower SEP had a slightly lower total PedsQL score (~2 points) across all ages and weight classes, but SEP did not affect the association between weight status and total PedsQL score ($P = 0.79$ for low SEP by overweight interaction and $P = 0.62$ for low SEP by obese interaction). We found similar results when conducting analyses using physical and psychosocial health summary scores (Table 4). Overall, these results indicate that age, but not SEP, modifies the relationship between weight status and HRQoL.

The adjusted mean total PedsQL scores and summary scores by integer age and weight status, as predicted by the multivariate models with interactions, are presented in Fig. 1. Children with healthy weight had total PedsQL

Table 2 Attrition and missingness over seven waves of data collection in the Longitudinal Study of Australian Children.

Wave	Age of children (years)	Children interviewed (n)	Children with complete information on BMI and PedsQL *n* (%)[a]	Children with complete information on all covariates (final analysis population) *n* (%)[b]
1	4–5	4983	4171 (83.7)	4083 (97.9)
2	6–7	4464	3455 (77.4)	3410 (98.7)
3	8–9	4331	3775 (87.2)	3715 (98.4)
4	10–11	4169	3982 (95.5)	3880 (97.4)
5	12–13	3956	3740 (94.5)	3616 (96.7)
6	14–15	3537	3197 (90.4)	3101 (97.0)
7	16–17	3089	2783 (90.1)	2641 (94.9)
Total observations		28529	25103 (88.0)	24446 (97.4)

[a]Proportions are within the number of children interviewed

[b]Proportions are within the number of children with complete information on BMI and PedsQL

Table 3 GEE adjusted analyses without interactions for total PedsQL score, physical health summary score and psychosocial health summary score.

	Total PedsQL score		Physical health summary score		Psychosocial health summary score	
	Coefficient (95% CI)	*P* value	Coefficient (95% CI)	*P* value	Coefficient (95% CI)	*P* value
Overweight	−0.97 (−1.36 to −0.58)	<0.001	−1.55 (−2.06 to −1.04)	<0.001	−0.64 (−1.05 to − 0.23)	0.002
Obese	−3.93 (−4.54 to −3.33)	<0.001	−5.92 (−6.67 to −5.16)	<0.001	−2.92 (−3.55 to −2.28)	<0.001
Age	−0.20 (−0.23 to −0.17)	<0.001	−0.11 (−0.16 to −0.07)	<0.001	−0.24 (−0.28 to −0.21)	<0.001
Female	0.15 (−0.41 to 0.72)	0.593	−1.11 (−1.72 to −0.50)	<0.001	0.82 (0.21 to 1.43)	0.006
Low SEP	−2.00 (−2.57 to −1.42)	<0.001	−1.57 (−2.19 to −0.94)	<0.001	−2.22 (−2.84 to −1.59)	<0.001
Indigenous	−2.94 (−4.60 to −1.27)	0.001	−2.46 (−4.31 to −0.62)	0.009	−3.21 (−5.00 to −1.41)	<0.001
LOTE spoken to child	−2.65 (−3.37 to −1.93)	<0.001	−3.53 (−4.31 to −2.75)	<0.001	−2.26 (−3.03 to −1.48)	<0.001
Mother is a current smoker	−1.42 (−1.96 to −0.89)	<0.001	−1.74 (−2.40 to −1.09)	<0.001	−1.34 (−1.91 to −0.78)	<0.001
Has long-term medical condition	−3.19 (−3.67 to −2.71)	<0.001	−3.16 (−3.79 to −2.52)	<0.001	−3.44 (−3.94 to −2.94)	<0.001
Constant	83.75 (83.12 to 84.38)	<0.001	86.88 (86.13 to 87.62)	<0.001	82.04 (81.37 to 82.72)	<0.001

scores that decreased slightly from age 4 to age 17 years (Fig. 1a). The decrease in total PedsQL scores was steeper in children who were overweight and even steeper in those with obesity. At age 4 years, the difference in the predicted mean total PedsQL scores between those with healthy weight and those with obesity was 1.0 point (95% CI 0.0–2.0), by age 9 it was 4.5 points (95% CI 3.9–5.1) and by age 17 it was 6.7 points (95% CI 5.7–7.6). Similar trends were observed for children with overweight and obesity with regards to the summary scores (Fig. 1b, c), whereas children at healthy weight had slightly increasing physical health summary scores from age 4 to age 17 years. By age 17 years, the difference in physical health summary scores between those at healthy weight and those with obesity increased from 1.2 points (95% CI 0.1–2.5) to 10.4 points (95% CI 9.1–11.6). As shown in Fig. 2, for children at all three weight statuses, those of low SEP had consistently lower total PedsQL scores than those of high SEP.

Sensitivity analyses

Separate analyses of the data using CDC growth standards (Supplementary Table 2), LSAC longitudinal weights (Supplementary Table 3), a time-varying measure of SEP (Supplementary Table 4), and underweight as a separate category (Supplementary Table 5) did not alter the main results from this study. While the coefficients changed slightly, the relationship between higher weight status and lower total PedsQL score was shown to strengthen with age in every analysis ($P < 0.02$ for each interaction with age in each analysis), whilst there was no evidence that SEP modified this relationship ($P > 0.1$ for each interaction with SEP).

Discussion

In this study, we used a large dataset from a national longitudinal study to investigate how demographic factors

Table 4 GEE adjusted analyses with interactions for total PedsQL score, physical health summary score and psychosocial health summary score.

	Total PedsQL score		Physical health summary score		Psychosocial health summary score	
	Coefficient (95% CI)	*P* value	Coefficient (95% CI)	*P* value	Coefficient (95% CI)	*P* value
Overweight	1.13 (0.12 to 2.14)	0.029	1.11 (−0.25 to 2.47)	0.109	1.13 (0.07 to 2.19)	0.037
Obese	0.92 (−0.61 to 2.44)	0.238	1.88 (−0.12 to 3.89)	0.066	0.29 (−1.30 to 1.89)	0.720
Age	−0.12 (−0.15 to −0.08)	<0.001	0.01 (−0.05 to 0.06)	0.799	−0.18 (−0.22 to −0.13)	<0.001
Female	0.17 (−0.40 to 0.73)	0.562	−1.10 (−1.71 to −0.48)	0.001	0.83 (0.22 to 1.44)	0.007
Low SEP	−1.97 (−2.60 to −1.34)	<0.001	−1.41 (−2.11 to −0.70)	<0.001	−2.26 (−2.93 to −1.58)	<0.001
Indigenous	−2.96 (−4.62 to −1.29)	<0.001	−2.48 (−4.33 to −0.64)	0.008	−3.22 (−5.02 to −1.43)	<0.001
LOTE spoken to child	−2.68 (−3.39 to −1.96)	<0.001	−3.56 (−4.34 to −2.78)	<0.001	−2.28 (−3.05 to −1.50)	<0.001
Mother is a current smoker	−1.43 (−1.96 to −0.90)	<0.001	−1.75 (−2.41 to −1.10)	<0.001	−1.35 (−1.91 to −0.79)	<0.001
Has long-term medical condition	−3.22 (−3.69 to −2.74)	<0.001	−3.19 (−3.83 to −2.56)	<0.001	−3.46 (−3.95 to −2.96)	<0.001
Age*Overweight	−0.21 (−0.29 to −0.13)	<0.001	−0.24 (−0.35 to −0.13)	<0.001	−0.19 (−0.28 to −0.11)	<0.001
Age*Obese	−0.44 (−0.55 to −0.33)	<0.001	−0.71 (−0.86 to −0.55)	<0.001	−0.28 (−0.40 to −0.17)	<0.001
Low SEP*Overweight	0.10 (−0.68 to 0.88)	0.794	−0.35 (−1.36 to 0.67)	0.500	0.35 (−0.46 to 1.17)	0.395
Low SEP*Obese	−0.31(−1.53 to 0.92)	0.622	−0.50 (−2.05 to 1.05)	0.526	−0.29 (−1.58 to 1.00)	0.661
Constant	82.84 (82.16 to 83.52)	<0.001	85.57 (84.75 to 86.39)	<0.001	81.36 (80.63 to 82.09)	<0.001

affect the relationship between weight status and HRQoL through childhood and adolescence. Our results show that children with overweight and obesity have poorer HRQoL than those at healthy weight and demonstrate that age modifies this relationship (Table 3). Specifically, as children move into adolescence, the inverse relationship between weight status and HRQoL strengthens. At age four, only minor decrements in HRQoL in children with obesity compared with children at healthy weight are observed, but by age nine, this decrement grows to a clinically meaningful magnitude of 4.5 points [10], following adjustment for known predictors of poor HRQoL.

Our results support those of a study using the first four waves of LSAC data, when the participants were aged between 4 and 11 years, which showed that the coefficients for BMI z-scores on PedsQL scores increased, and their corresponding *P* values decreased, with each progressive wave [3]. Our study included six additional years of follow up and demonstrated that this trend continues into adolescence. However, our results contrast with those from a study of German children in which adolescent children with obesity had smaller impairments in HRQoL than pre-adolescent children [7]. The authors of that study attribute the smaller relative effect in the older age group to the overall substantial decrease in HRQoL observed over the childhood to adolescent transition period; a trend that was barely detectible in children at healthy weight in our study (Fig. 1).

Another main finding of our study is that, while SEP has an independent impact on HRQoL, there is no evidence of an interaction between SEP and weight status. Although socioeconomic inequalities exist in both obesity prevalence [22] and HRQoL (measured by KIDSCREEN) [23] in childhood, our results show that the *association* between weight status and HRQoL in 4–17-year-old children is not affected by SEP. This differs from previous descriptive analyses of 9–12-year-old children [2] and regression analyses in adults [8]. This may be because the observed effects in children in the study by Williams et al. were driven by predictors of HRQoL that were not controlled for [2] or that the interaction only exists in adults and not children.

The significant age-weight status interaction found in our study may explain why studies in younger children often do not detect an association between weight status and HRQoL. For example, a recent study in the United Kingdom did not find any evidence of an association between weight status and a preference-based measure of HRQoL (CHU-9D) in a sample of over 1000 children between 5 and 10 years of age [24]. Similarly, no evidence of an association was found in a recent Australian study of five-year-old children that also used a preference-based measure of HRQoL (HUI3) [25]. However, it should be noted that this may be because preference-based measures may not be sufficiently sensitive to detect small HRQoL changes. Our secondary outcome analyses revealed that the age-weight status interaction is also present for the physical health and psychosocial health summary scores of the PedsQL, suggesting that the primary outcome effect is the result of the net effect of different aspects of HRQoL. Interestingly, the adjusted mean physical health scores for children at healthy weight gradually increased from 4 to 17 years of age, while those with overweight status or obesity had decreasing scores and this decrease was particularly dramatic in those classified as obese (Fig. 1). One possible explanation for

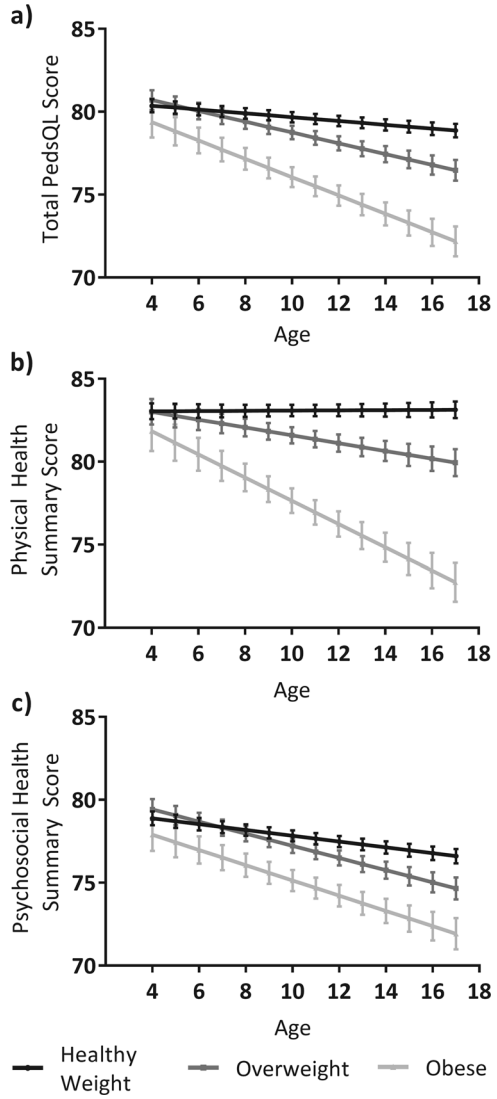

Fig. 1 Association between weight status and HRQoL score. Plotted values are the predicted adjusted mean and 95% confidence intervals for: **a** total PedsQL scores, **b** physical health summary scores and **c** psychosocial health summary scores by weight status and age.

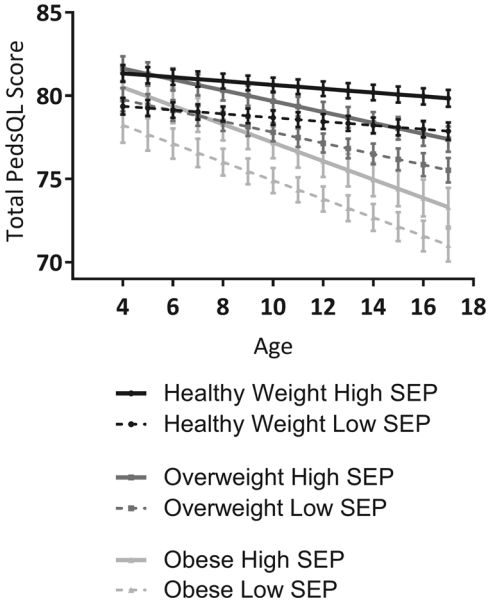

Fig. 2 HRQoL by socioeconomic position, weight status and age. Plotted values are the predicted adjusted mean total PedsQL scores and 95% confidence intervals.

this is that children with overweight status or obesity have slower development of general motor skills or physical fitness than those at healthy weight, which is consistent with findings from recent cohort studies investigating physical development in children and adolescents [26, 27].

Considering that the transition from childhood to adolescence coincides with major biological and social changes, it is not surprising that an overall decrease in psychosocial health was observed during this period. Adolescents are particularly susceptible to weight stigma and discrimination, which can lead to emotional distress and problematic social relationships [28, 29]. In contrast to our results, a recent study found that psychosocial outcomes were stable, but still poor, in children with overweight status or obesity aged 8–13 years at baseline [30]. However, the follow-up period was only 2 years in that study, so it's possible that the period of follow-up was not sufficient to observe an age-dependent relationship.

To our knowledge, ours is the first study to utilise longitudinal data following the same children over a decade into late adolescence to examine how age and SEP affects the weight status-HRQoL relationship. The study by Jansen et al. [3], for example, only captured the primary-school years. Furthermore, the study by Wake et al. [6] extracted data for three different cohorts of participants, covering different age groups, and did not combine physical and psychosocial scores to examine overall HRQoL. Therefore, the study was not able to disentangle age effects on the weight status-HRQoL association across the spectrum of childhood and adolescent years. A strength of our study is that, in contrast to both these studies where separate cross-sectional analyses were conducted in different age groups, we used GEE, which allowed us to collate over 24,000 observations from seven waves of interviews and provide conservative estimates for our research questions. The use of this technique facilitated the statistical assessment of the potential modifying effects of age and SEP through interaction analyses, which would not have been possible by conducting multiple cross-sectional regression analyses. A further strength is that sensitivity analyses of four key analytical decisions made demonstrated that our results and conclusions were robust (Supplementary Tables 2–5).

The main limitation of our analysis is the loss of participants over the seven waves of data collection, which could potentially introduce bias. However, when using the

population longitudinal weights, which are calculated to increase the weighting of participants with similar characteristics to those who are lost, the coefficients only changed slightly and the overall conclusion remained unaffected (Supplementary Table 3); namely, there was strong evidence that age modified the relationship between weight status and HRQoL ($P = 0.017$ for age by overweight and $P < 0.001$ for age by obese interaction terms). Furthermore, while it is possible that the participants that were lost by the final wave had different outcomes at later waves than at baseline (and different to those that continued to be followed up), it is unlikely that the losses were biased towards children with better health outcomes (i.e. low BMI and high PedsQL scores). Another limitation is that, by using GEE, we were unable to simultaneously account for the complex sampling strategy used in the selection process of the LSAC study. While the study sample may not be considered representative of the whole Australian childhood population, the results still holds true for the almost 5000 children who participated. Finally, we have interpreted our results as evidence that current weight status is the main contributor to HRQoL, after controlling for other known predictors. However, it's possible that *change* in weight status, such as movement from obesity to overweight, or from healthy weight to overweight could also be influencing current HRQoL. Our analysis is unable to isolate this effect from that of current weight status. Despite this, only 14% of observations used in the primary analysis involved a change in weight status in consecutive waves (data not shown), so it's unlikely to have had a major impact on our overall results.

In conclusion, our study reveals a worsening relationship between higher weight and lower HRQoL through childhood and adolescence. An average 17-year-old with obesity has a PedsQL score of 72.2, which is similar to the score of a child with chronic health conditions such as asthma, diabetes, ADHD, and juvenile rheumatoid arthritis [10]. In light of these results, clinicians treating paediatric patients with obesity and researchers trialling obesity treatment or prevention strategies should consider the age of their target group when implementing their interventions. Interventions targeted at children under 9 years may not have an immediate impact on HRQoL but may prevent severe impairments in HRQoL at later ages. If interventions are targeted at adolescents, weight loss may result in a direct improvement in their HRQoL. Considering that the age-dependent nature of the weight-HRQoL association appears to be related to both biological and social impacts of obesity, we would expect that the results would also be generalisable to other high-income countries in which societal expectations in relation to weight are comparable to Australia's. However, further research is needed to confirm this. Future work should also investigate if the modifying effect of age continues into early adulthood.

Code availability

The data from LSAC used in this study is available by application to the data custodians: Department of Social Services, Australian Government. The code to analyse these data, based in STATA version 15.0, are available by request to the corresponding author.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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