Children's body mass index

Cohort, age and socio-economic influences

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Australian and international policy-makers recognise the childhood obesity epidemic (Wang & Lobstein, 2006) to be one of the most serious threats to the future health of the population and the viability of the health care system (Ludwig, 2007). Among its many adverse associations, having a high childhood body mass index (BMI) increases both cardiovascular risk in children (Andersen et al., 2008) and cardiovascular events in these children when they reach adulthood (Baker, Olsen, & Sorensen, 2007).

After a precipitous 20-year rise in childhood obesity since about 1985 (Norton, Dollman, Martin, & Harten, 2006), there is some evidence that its prevalence may now be stabilising (Ogden, Carroll, Curtin, Lamb, & Flegal, 2010; Ogden, Carroll, & Flegal, 2008), though there are as yet few reports that the prevalence has actually begun to fall (Nichols et al., 2011). Thus, around 6%, or a quarter of a million, 2–16 year old Australians are currently estimated to be obese (Australian Bureau of Statistics [ABS], 2010), with many more overweight (CSIRO Preventative Health National Research Flagship & University of South Australia, 2008). However, most Australian information about trends in childhood obesity comes from cross-sectional rather than longitudinal studies, precluding a life-course viewpoint of when and how obesity develops.

Australian governments have responded with initiatives aiming to increase physical activity and improve nutrition in preschool and school-aged children (e.g., Walking School Buses, Active After School, Kids Go for Your Life) and the development of clinical guidelines for primary care surveillance and lifestyle counselling of children and adolescents (e.g., National Health and Medical Research Council [NHMRC], 2003). Central to the efforts of the new Australian National Preventive Health Agency (ANPHA, 2011) is the promotion of a healthy lifestyle and good nutrition, and the reduction of the incidence of obesity among Australians.

It has long been recognised that there is an inverse relationship between socio-economic status and overweight/obesity in adult women (Sobal & Stunkard, 1989), and lower ranked occupations and lower education are linked to greater weight gain in both men and women (Ball & Crawford, 2004). However, most studies have been cross-sectional, with prospective studies of children being particularly limited. Thus, as late as the turn of this millennium, the relationship between socio-economic status and weight was not consistently demonstrated for children in Australia (Booth et al., 2001) or other countries (NHMRC, 2003). Socio-economic gradients have emerged more recently—for example, in 5–10 year old English children between 1974 and 2003 (Reilly et al., 2005)—with overweight/obesity in children from low-income families being responsible for much of the continuing acceleration of prevalence between 1997 and 2003. Cross-sectional associations have now been reported for the 4–5 year olds in the first wave of *Growing Up in Australia*: The Longitudinal Study of Australian Children (LSAC) (Wake, Hardy, Canterford, Sawyer, & Carlin, 2007), but longitudinal associations have yet to be examined.

Release of the third wave of LSAC makes available repeated measures of height and weight for two large, nationally representative cohorts of children born four years apart and aged between 2 and 9 years. This provides a unique opportunity to investigate, at a national level, how body mass index tracks across the preschool and early school years, and how these temporal patterns may vary according to socio-economic characteristics.

Thus, this chapter uses data from the B cohort at Waves 2 and 3, and the K cohort at all three waves. Weighted data are used throughout the chapter, unless otherwise specified. The following questions are addressed:

- What is the prevalence of underweight, normal weight, overweight and obesity in children at each of the three waves?
- How strongly does BMI correlate between time points (waves) in each cohort?
- What proportions of children remain in the same BMI category, or move up or down BMI categories, between waves?
- How many children are consistently overweight/obese or obese across all waves?
- How do family socio-economic position and neighbourhood disadvantage influence the persistence of overweight and obesity?

9.1 Definitions and methods

Height and weight measurements

At each wave, trained interviewers measured the children's weight in light clothing to the nearest 50 g using glass bathroom scales. Height was measured twice, without shoes, to the nearest 0.1 cm using a portable rigid stadiometer. The average of the two height measurements was used in the analyses; where the two differed by more than 0.5 cm, a third measurement was taken and the average of the two closest was used.

Body mass index

BMI is calculated as weight/height squared and expressed as kg/m^2. Child population surveys typically use BMI as an indicator of adiposity[1] because these measurements are feasible for large-scale, community-based studies. BMI could not be calculated for the B cohort at Wave 1, because measuring the length of infants poses technical challenges.

BMI status

The children were classified as being overweight or obese according to the International Obesity Taskforce (IOTF) age- and sex-specific BMI cutpoints (Cole, Bellizzi, Flegal, & Dietz, 2000), and as underweight using the Cole cutpoints derived using comparable methods (Cole, Flegal, Nicholls, & Jackson, 2007). All other children were classified as being of normal weight.

BMI *z*-score

To facilitate analysis, the children's raw BMI were transformed using the 2000 US Centers for Disease Control (CDC) growth reference data (Kuczmarksi et al., 2002) so that they had a mean of zero and a standard deviation of 1 in the populations from which they were derived (not strictly speaking *z*-scores, but usually referred to as such). A *z*-score below 0 implies the child is below the average for the reference population, and a *z*-score above 0 implies they are above the average.

Socio-economic position

Socio-economic position (SEP), as introduced in Chapter 1, was categorised into quartiles and grouped into the 25% most disadvantaged, the middle 50%, and the 25% most advantaged.

Neighbourhood disadvantage

Socio-Economic Indexes for Areas (SEIFA) values are standardised scores by geographic area compiled from Census data to numerically summarise the social and economic conditions of Australia (national mean 1,000, standard deviation (SD) 100; higher values represent greater advantage). At each wave, the family's SEIFA Disadvantage Index was recorded for the most recent

1 "Adiposity" refers to the proportion of a person's body that is made up of fat.

postcode of residence (ABS, 2008). SEIFA scores were categorised by quartile into the 25% most disadvantaged, the middle 50%, and the 25% most advantaged, using cutpoints from the distribution of national SEIFA scores.

9.2 Prevalence of underweight, overweight and obesity in Waves 1–3

As can be seen from Table 9.1, LSAC is a rich source of BMI data, with measurements available for virtually every child at every wave. The large sample size and high retention lends confidence to the interpretation of longitudinal and secular trends.

Table 9.1 BMI categories and mean BMI *z*-scores, B cohort Waves 2–3 and K cohort Waves 1–3

Age	Year	No. of observations	Underweight	Normal weight	Overweight	Obese	BMI *z*-score	
			%				Mean	Standard error
2–3 years	2006	4,522	5.3	71.3	18.6	4.8	0.53	0.02
4–5 years (B cohort)	2008	4,196	6.6	69.8	17.6	6.0	0.54	0.02
4–5 years (K cohort)	2004	4,934	5.2	74.2	15.1	5.5	0.55	0.02
6–7 years	2006	4,423	5.1	75.2	13.8	5.9	0.39	0.02
8–9 years	2008	4,289	5.5	69.5	17.9	7.1	0.40	0.02

On examining the continuous BMI *z*-score values, it is immediately obvious that the mean *z*-score range of 0.39 to 0.55 is well above the mean of 0.0 that, by definition, characterised the original normative population. For the CDC reference BMI data, this comprised children in the US Midwest in the 1960s to 1970s before the onset of the obesity epidemic (Kuczmarksi et al., 2002). These relatively high mean BMI *z*-score values have been a feature of modern populations since at least the mid-1990s (Lazarus, Wake, Hesketh, & Waters, 2000), indicating that not only has the prevalence of overweight and obesity increased, but that the BMI of the "average" child is now about half a standard deviation higher than 40 years ago.

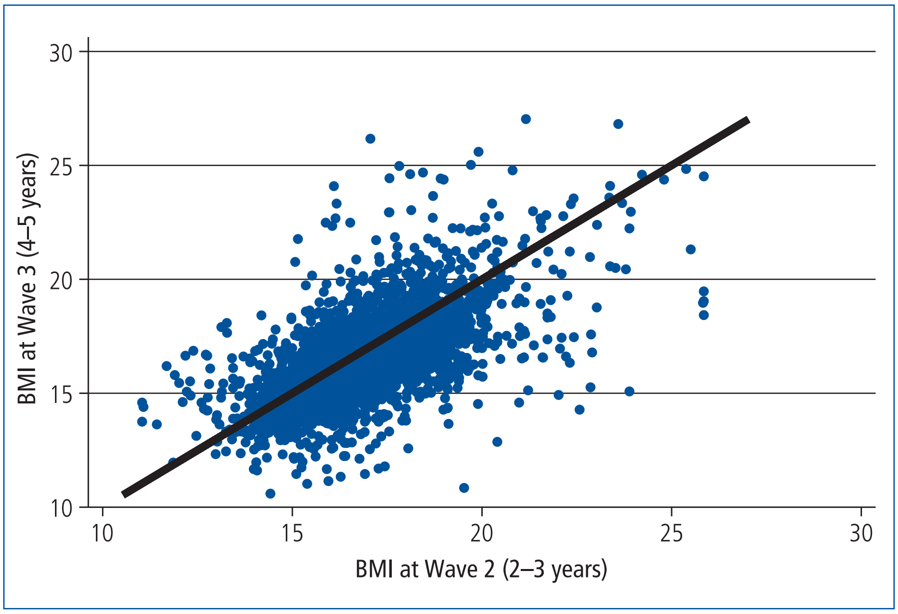
Table 9.1 also shows that, in both cohorts, the percentage of children in the "normal" BMI category fell to below 70% by Wave 3. In the K cohort, this was due almost solely to a rising prevalence of overweight/obese children (a 21% increase, from 21% at age 4–5 years to 25% at 8–9 years), while the prevalence of underweight remained relatively constant between 5% and 6%. Of particular concern was the sharp longitudinal rise in overweight/obesity in middle childhood for the K cohort from 20% at Wave 2 to 25% at Wave 3—a 27% increase in just two years.

Notwithstanding the socio-demographic differences between the two cohorts (see *LSAC Data User Guide* [AIFS, 2011]), also concerning is that the prevalence of overweight/obesity at age 4–5 years was 15% more for the B cohort at Wave 3 (24%) than the K cohort at Wave 1 (21%). This contrasts with recent Victorian data suggesting a fall in overweight/obesity between 1999 and 2007 for Victorian 3.5-year-olds (Nichols et al., 2011).

More surprisingly, changes in the B cohort were more prominent at the *opposite* end of the spectrum. While overweight/obesity rose within the cohort by less than one percentage point between Waves 2 and 3, underweight increased by 24% (from 5% at age 2–3 years to 7% at age 4–5 years). Similarly, comparing the two cohorts at age 4–5 years, the prevalence of underweight was 27% higher in the B cohort (7%) than the K cohort (5%) at the same age. Given the small absolute numbers, the short period of follow-up (since BMI was not available at Wave 1) and lack of adjustment for potential confounders, these figures must be interpreted with caution. Nonetheless, this apparent rise in underweight is supported by recent cross-sectional surveys internationally. For example, studies from Spain (Martinez-Vizcaino et al., 2009), Norway (Bjornelv, Lydersen, Mykletun, & Holmen, 2007) and Western Australia (Martin et al., 2008) have all identified trends over time to more underweight in 9–17 year olds, in parallel with rising or stable overweight/obesity, resulting in a net reduction of children and adolescents in the normal weight category.

9.3 Correlations of BMI between time points (waves)

Figure 9.1 shows a scatterplot of BMI in the B cohort at age 2–3 years (Wave 2) plotted against their BMI at age 4–5 years (Wave 3). Each dot in the scatterplot represents a single child. Dots along the diagonal represent children with BMI that were similar in both waves. Dots that are further above the diagonal represent children whose BMI increased from Wave 2 to Wave 3, while dots that are further below the diagonal represent children whose BMI decreased from Wave 2 to Wave 3. There is a strong positive linear relationship between children's BMI at Wave 2 and Wave 3 (rho = 0.63, $p < .001$), with 40% of variance between BMI in common.



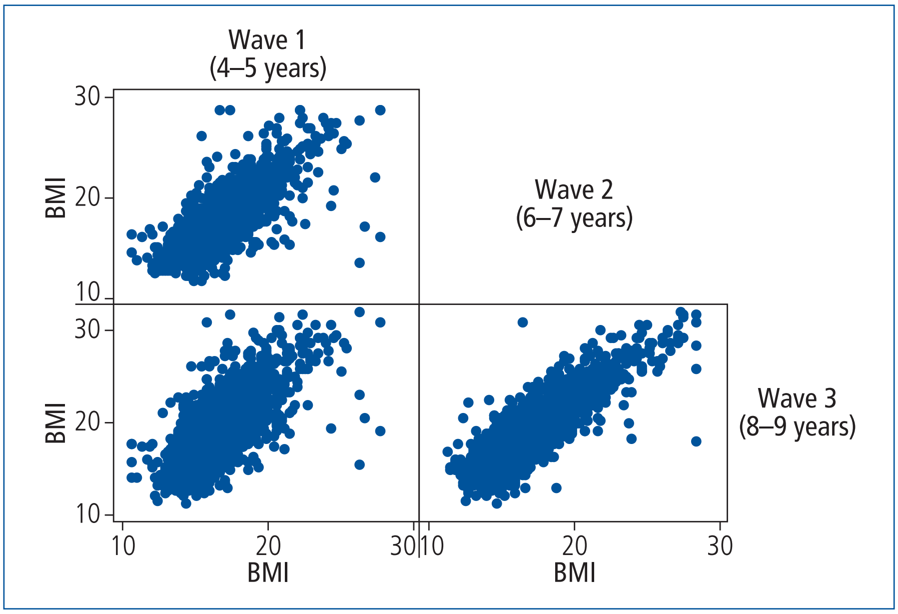
Note: Scatterplot shows unweighted data.

Figure 9.1 Correlation between BMI, B cohort Wave 2 vs Wave 3

Figure 9.2 (on page 95) similarly shows three BMI scatterplots that summarise the relationships between BMI for the K cohort at ages 4–5, 6–7 and 8–9 years. Compared to the modest tracking[2] displayed by the younger age group, K cohort BMI track increasingly strongly as the children progress through the primary school years (80% correlation from Wave 1 to Wave 2, 87% from Wave 2 to Wave 3, and 73% from Wave 1 to Wave 3). Nonetheless, a substantial minority still shows evidence of divergent trajectories over this time.

Taken together, it can be seen that BMI track ever more strongly from the ages of 2 to 9 years in these two large, population-based cohorts. The immediate policy implication is that, with obesity becoming more entrenched and therefore possibly less reversible by the middle school years, early and effective prevention and intervention is essential throughout the preschool and school transition years.

2 "Tracking" refers to the stability of children's BMI across waves. Figures 9.1 and 9.2 show that as children get older, the scatterplots of their BMI between waves becomes increasingly clustered and linear across the diagonal of the graph. This means that as they get older, their BMI is less likely to change between waves; that is, it tracks more strongly.



Note: Scatterplots show unweighted data.

Figure 9.2 Correlation between BMI, K cohort Waves 1 vs 2, Waves 2 vs 3 and Waves 1 vs 3

9.4 Stability and change in BMI categories between time points (waves)

Table 9.2 summarises movement between BMI categories for the B cohort between Waves 2 and 3. The shaded cells on the diagonal of the table indicate those children who remained in the same category between waves. Overall, nearly three-quarters (74%) of children remained in the same underweight, normal weight, or overweight/obese category, while 26% moved either up (13%) or down (13%) in category. Only 0.2% of children moved up or down by two categories, that is, from underweight to overweight/obese or vice versa.

Table 9.2 Movement between BMI categories, B cohort Waves 2–3

Wave 2 (2–3 years) \ Wave 3 (4–5 years)	Underweight	Normal weight	Overweight/ obese	Totals
		%		%
Underweight	2.2 [a]	3.0	0.1	5.4
Normal weight	4.3	58.0 [a]	9.4	71.6
Overweight/obese	0.1	8.7	14.2 [a]	23.0
Totals (*n* = 4,126)	6.6	69.7	23.7	100.0

Note: [a] The percentages in these cells indicate those children who remained in the same BMI category from Waves 2 to 3. Percentages may not total exactly 100.0% due to rounding.

Similarly, Table 9.3 (on page 96) summarises movement between BMI categories for the K cohort between Waves 1 and 2. The shaded cells on the diagonal of the table indicate those children who remained in the same category between waves. As would be expected from the stronger BMI correlations reported in section 9.3 (on page 94), the great majority (83%) of children remained in the same BMI category, with only 17% moving either up (8%) or down (9%) in category. Unlike the toddler age group, marked changes in BMI category did not occur in this age group; no child moved two categories; that is, from underweight to overweight/obese or vice versa.

Table 9.3	Movement between BMI categories, K cohort Waves 1–2			
Wave 1 (4–5 years) \ Wave 2 (6–7 years)	Underweight	Normal weight	Overweight/ obese	Totals
		%		%
Underweight	2.5 [a]	2.4	0.0	4.9
Normal weight	2.6	66.4 [a]	5.3	74.3
Overweight/obese	0.0	6.3	14.4 [a]	20.7
Totals (*n* = 4,394)	5.1	75.1	19.8	100.0

Note: [a] The percentages in these cells indicate children who remained in the same BMI category from Waves 1 to 2. Percentages may not total exactly 100.0% due to rounding.

Table 9.4 shows changes in BMI category for the K cohort between Waves 2 and 3, stratified by initial underweight, normal weight, and overweight/obese BMI status at Wave 1. Moving two categories remained extremely uncommon across this four-year span but, when it did occur, was mainly in the direction of weight gain. Thus, while 1% of initially underweight children became overweight/obese by Wave 3, only 0.1% of the initially overweight/obese children became underweight by Wave 3.

Table 9.4	Movement between BMI categories, K cohort Waves 1, 2 and 3				
Wave 1 (4–5 years) \ Wave 3 (8–9 years)		Underweight	Normal weight	Overweight/ obese	Totals
			%		%
Wave 1: Underweight					
Wave 2 (6–7 years)	Underweight	39.7	11.2	0.0	50.9
	Normal weight	6.2	41.9	0.5	48.6
	Overweight/obese	0.0	0.0	0.5	0.5
	Totals (*n* = 196)	45.9	53.1	1.0	100.0
Wave 1: Normal weight					
Wave 2 (6–7 years)	Underweight	1.1	2.2	0.0	3.4
	Normal weight	3.1	77.3	8.9	89.3
	Overweight/obese	0.0	2.2	5.2	7.4
	Totals (*n* = 3,087)	4.2	81.7	14.1	100.0
Wave 1: Overweight/obese					
Wave 2 (6–7 years)	Underweight	0.0	0.2	0.0	0.2
	Normal weight	0.0	20.9	9.5	30.4
	Overweight/obese	0.1	9.0	60.3	69.4
	Totals (*n* = 824)	0.1	30.1	69.8	100.0

Note: Percentages may not total exactly 100.0% due to rounding.

Overall, the K cohort showed considerable stability in BMI status across the three waves. The most prevalent Wave 1 category (normal weight) showed the greatest stability, with more than 80% remaining in that category at Wave 3. Of concern is that there was a much greater tendency for children of initially normal weight to move up to the overweight/obese category (14%) than to move down to the underweight category (4%). This, coupled with the fact that 60% of those who were initially overweight/obese in Wave 1 remained in that category by Wave 3, drove the sharp upswing in overweight/obesity by Wave 3 reported in section 9.2 (on page 93). Underweight was the least stable category, with fewer than half of those who were initially underweight still in that category four years later.

On a more optimistic note, 30% of those who were initially overweight/obese in Wave 1 had moved down to the normal weight category four years later. LSAC may prove to be particularly informative for policy-makers with regards to the physical, psychosocial and demographic promoters of healthy weight in today's environment, by following these promoters in the relatively large group of children who lose excess adiposity over time.

9.5 Persistence of overweight/obesity, by family socio-economic position and neighbourhood disadvantage

It is clear from the above that, despite the relatively strong tracking of BMI throughout childhood, individual children have widely varying trajectories, sometimes characterised by dramatic upward and downward shifts in relative BMI over time. The top panel of Table 9.5 shows the proportions of children who were never overweight/obese, and the proportions who were overweight/obese at one, two or (for K cohort children) all three waves. The lower panel of the table shows the proportions of children who were obese at zero, one, two or three waves. While overweight/obesity was commonly persistent (14% of the B cohort at both waves, and 12% of K cohort children at all three waves), persistent obesity affected only small numbers (2% of the B cohort at both waves, and 3% of the K cohort children at all three waves).

Table 9.5 Number of waves overweight/obese or obese, B cohort Waves 2–3 and K cohort Waves 1–3

	B cohort (Waves 2–3)	K cohort (Waves 1–3)
	%	
Number of waves overweight/obese		
0	67.5	67.3
1	18.4	12.6
2	14.2	7.7
3	–	12.3
Total	100.0	100.0
No. of observations	4,126	4,107
Number of waves obese		
0	91.5	90.6
1	6.3	4.0
2	2.2	2.2
3	–	3.2
Total	100.0	100.0
No. of observations	4,126	4,107

Note: Cases were only included if data were available at all waves.

Whether these small numbers with persistent obesity go on to suffer the burden of disease remains to be established. While obese individuals are known to experience greater cardiovascular, metabolic, musculoskeletal and other morbidities, an important question for policy-makers is whether and how this is related to lifetime exposure to obesity, as opposed to its immediate effects. Several published longitudinal studies suggest that resolution of childhood obesity reverses subsequent morbidity back to the levels of those who were never obese (Juonala et al., 2011; Viner & Cole, 2005; Wake et al., 2010). However, these conclusions were all limited by measuring obesity at only two time points (at exposure and outcome). It is likely that prolonged obesity may result in subsequent major physical and psychosocial morbidities and costs. LSAC, using its repeated biennial measurement of childhood BMI to determine lifetime obesity exposure and timing, will be well placed to address these issues as the children grow older.

Earlier cross-sectional analyses of Wave 1 LSAC data have already confirmed a substantial socio-economic gradient in obesity rates at the age of 4–5 years, with children in the lowest quintile of social disadvantage being 47% more likely to be in a heavier BMI category compared to those in the highest quintile (Wake et al., 2007).

Table 9.6 (on page 98) shows B cohort associations between socio-demographic markers (analysed separately by socio-economic position and by neighbourhood disadvantage, both measured at Wave 2) and the number of waves at which children were overweight/obese and obese. For both groupings and both markers, there were clear trends for those with the most persistent overweight/obesity to cluster in the lowest 25% group. These associations were seen for individual SEP and neighbourhood disadvantage, and for persistent obesity and persistent overweight/obesity combined. Thus, 4% of children in the lowest quartile of SEP, but only 0.4% of those in the highest quartile, were obese at both waves ($p < .001$). Similarly, though less strikingly, 5% of children in the lowest quartile of neighbourhood disadvantage, but only 2% of those in the highest quartile, were obese at both waves ($p < .01$).

Table 9.6 Number of waves overweight/obese or obese, by family socio-economic position and neighbourhood disadvantage, B cohort Waves 2–3

	Family socio-economic position			Neighbourhood disadvantage		
	Lowest 25%	Middle 50%	Highest 25%	Most disadvan-taged 25%	Middle 50%	Most advantaged 25%
		%			%	
Number of waves overweight/obese						
0	65.7	67.5	69.8	66.8	66.8	69.3
1	17.3	18.8	18.3	16.0	18.7	18.5
2	17.0	13.7	11.3	17.2	14.5	12.2
Total	100.0	100.0	100.0	100.0	100.0	100.0
No. of observations	941	2,114	1,069	400	2,571	1,155
Number of waves obese						
0	89.3	91.5	94.8	87.0	91.5	93.5
1	6.9	6.6	4.8	8.2	6.5	5.0
2	3.9	2.0	0.4	4.7	2.1	1.5
Total	100.0	100.0	100.0	100.0	100.0	100.0
No. of observations	941	2,114	1,069	400	2,571	1,155

Notes: Neighbourhood disadvantage categorised by SEIFA scores. SEP and SEIFA were measured at Wave 2. Overweight/obese: SEP: χ^2 (4, n = 4,124) = 14.8, p = .02; SEIFA: χ^2 (4, n = 4,126) = 8.4, p = .2. Obese: SEP: χ^2 (4, n = 4,124) = 35.0, $p < .001$; SEIFA: χ^2 (4, n = 4,126) = 23.1, $p < .01$.

In much the same way, Table 9.7 (on page 99) shows K cohort associations across the three waves. Gradients in this older group were even more striking. Thus, three-quarters of the children in the highest SEP quartile, but less than 60% of those in the lowest quartile, were not overweight at all three time points.

For both groupings and both markers, there were again clear trends for those with the most persistent overweight/obesity to cluster in the lowest 25% group. These gradients were even stronger when only persistent obesity was considered. Thus, 7% of children in the lowest quartile of SEP, but only 3% of those in the highest quartile, were obese at two or more waves ($p < .001$). Similarly, 8% of children in the lowest quartile of neighbourhood disadvantage, but only 4% of those in the highest quartile, were obese at two or more waves ($p < .01$).

9.6 Summary

This chapter has made use of the rich BMI data available in LSAC to investigate how children's BMI track across the preschool and early school years, and how patterns of change vary for children from different socio-economic backgrounds. The analysis shows a general decline in the percentages of children in the normal weight category, both across waves and between the two cohorts. The population levels of overweight/obesity also increased sharply in the middle childhood years.

At both the population and individual level, there was more between-waves variation in BMI for younger children compared to older children. While the majority of children were in the normal weight category at all waves, a large percentage of those who were overweight/obese remained in that category between waves. Approximately a third of the children who were overweight/obese when they were 4–5 years were in the normal weight category when they were 8–9 years. Unfortunately, this was more than offset by the greater absolute numbers of children moving up

Table 9.7 Number of waves overweight/obese or obese, by family socio-economic position and neighbourhood disadvantage, K cohort Waves 1–3

	Family socio-economic position			Neighbourhood disadvantage		
	Lowest 25%	Middle 50%	Highest 25%	Most disadvan-taged 25%	Middle 50%	Most advantaged 25%
	%			%		
Number of waves overweight/obese						
0	58.6	68.8	75.1	62.6	67.3	70.2
1	15.6	11.7	11.3	11.7	12.7	13.0
2	10.2	7.5	5.0	9.8	8.2	5.4
3	15.7	12.1	8.7	15.9	11.9	11.4
Total	100.0	100.0	100.0	100.0	100.0	100.0
No. of observations	864	2,122	1,114	568	2,403	1,136
Number of waves obese						
0	86.8	91.1	94.3	87.3	90.2	93.3
1	6.0	3.5	2.9	4.7	4.3	3.1
2	2.7	2.6	0.7	2.6	2.6	1.1
3	4.5	2.7	2.1	5.5	2.9	2.5
Total	100.0	100.0	100.0	100.0	100.0	100.0
No. of observations	864	2,122	1,114	568	2,403	1,136

Notes: Neighbourhood disadvantage categorised by SEIFA scores. SEP and SEIFA were measured at Wave 1. Overweight/obese: SEP: χ^2 (6, n = 4,100) = 69.1, $p < .001$; SEIFA: χ^2 (6, n = 4,107) = 22.7, $p < .01$. Obese: SEP: χ^2 (6, n = 4,100) = 40.8, $p < .001$; SEIFA: χ^2 (6, n = 4,107) = 25.9, $p < .1$.

from the normal weight category into the overweight or obese categories. However, with such a wide range of outcomes, LSAC is well placed to examine predictors of both worsening BMI and resolving overweight. Underweight was the least stable category, with most of these children moving into the normal weight category between waves. Persistent overweight/obesity clustered in the most disadvantaged 25% of children on measures of family socio-economic position and neighbourhood disadvantage, with the patterns being stronger for obesity.

These findings support a focus on early and effective prevention and intervention throughout the preschool years and transitions into school. This is particularly important for children experiencing either family-level or neighbourhood-level disadvantage. Future waves and analyses of LSAC data will be able to provide insight into the effects of persistent overweight/obesity on ongoing physical and psychosocial outcomes, as well as tracking changes in BMI through later childhood and adolescence.

9.7 Further reading

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