Individual, behavioural and environmental pathways to adolescent obesity

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Chapter Five
Discussion

This research confirms the multi-faceted nature of obesity, with many complex interactions of family, community, environment, social demographics, genetics, biology, behaviour, diet and psychology, all intricately interwoven in cause, effects and feedback loops. These interrelationships are shown to change over time, differ between boys and girls, and the pathways for normal weight, overweight and obese individuals are distinctly different from birth to adolescence.

Within the rich database of the Western Australian Pregnancy (Raine) Cohort numerous individual, behavioural and environmental variables were investigated with respect to weight status at age 14 years. This investigation involved four main stages: first to validate the adiposity proxy to classify children’s weight status at age 14 years, secondly to assess gender and weight status group differences in key variables at each follow-up; thirdly to develop a longitudinal model and assess obesogenic variables and their relationship to weight status at 14 years, and lastly to combine factors into a structural equation model to explore complex interrelationships.

Discussion in this chapter moves away from the simplistic notion of individual causes of obesity, to a multi-faceted perspective with relative contributions. The discussion begins with an overview of adiposity measures, followed by a synopsis of obesogenic variables guided by Bandura’s model of individual, behavioural and environmental factors. Lastly, findings are summated according to the longitudinal model of BMI, critical time periods, interrelationship modelling, and gender and weight status group differences.
Adiposity Measures

The similarities between common adiposity measures of weight, hip girth, waist girth, and the indices WHtR, BMI and WHR, were investigated in a large sample of adolescents using conventional Pearson Product Moment Correlation, the Bland-Altman method (Bland & Altman, 1986) and the Bland regression method (Bland, 2004). In addition, different weight status categorisation methods (Cole et al., 2000; Kahn et al., 2005; McCarthy & Ashwell, 2006; Taylor et al., 2000) were evaluated.

As demonstrated the indices of WHtR and BMI were strongly correlated, with the Bland-Altman method and Bland regression method confirming results. The subgrouping of the sample by gender and three weight status categories showed that both the BMI (Cole et al., 2000) and WHtR (Kahn et al., 2005) cut-offs provided similar groupings, which were strongly correlated and statistically significant. The BMI cut-offs (Cole et al., 2000) identified slightly fewer individuals as normal weight, more individuals as overweight, and less individuals as obese compared to the WHtR cut-offs (Kahn et al., 2005). Although the two category groupings (McCarthy & Ashwell, 2006) for BMI had a better Kappa value with WHtR, the number of differently categorised individuals was much higher.

Most critically, this analysis examined the similarity and inter-changeability of adiposity measures. Although the Bland-Altman method with z-scores reported strong agreement between some measures, the more appropriate statistical tool, Bland regression method, found large variation in limits that were unacceptable clinically. The adiposity measures examined in this study, although sharing strong relationships, appeared to provide different information. These findings highlight the need to interpret with caution most field-based measures of obesity.

Therefore, based on these findings and the availability of BMI measures, BMI was used as a proxy for adiposity (Chivers et al., in press). Despite some limitations as a measure of fatness (Dehghan et al., 2005; Freedman et al., 2007; Kahn et al., 2005; McCarthy & Ashwell, 2006; Taylor et al., 2002), BMI is still considered a reasonable marker (Bua et al., 2007; Cole et al., 2000; Dehghan et al., 2005; Guo & Chumlea, 1999; Katzmarzyk et al., 2004; Krebs et al., 2003; Taylor et al., 2002; Tremblay et al., 2002; WHO, 2006), and highly reliable (Bua et al., 2007; Guo & Chumlea, 1999; Lindsay et al., 2001).

**Individual Factors**

**Body Mass Index (BMI) - trajectories and adiposity rebound**

The BMI trajectories followed a distinct pathway from birth to 14 years for individuals within different weight categories. As suggested by others (Rolland-Cachera et al., 2006; Small et al., 2007), the timing of the adiposity rebound can be interpreted as a marker for later obesity. These results show more clearly than those reported by Rolland-Cachera (1984; 2006) the distinct and significantly different pathways followed by the three weight status groups for both the raw means and modelled data (LMM). There were statistically different pathways, in particular between the normal weight group compared to the overweight and obese groups. Major limitations were the absence of data at ages 4 and 5 years, and the smaller sample at age 2 years, which were reflected in the lack of statistical difference between the overweight and obese weight status groups only, although pictorially a difference was shown (Figure 2). However adiposity rebound has been reported in regards to macronutrients with a smaller sized sample ($n=112$) and time points 0.8, 2, 4, 6 and 8 years (Rolland-Cachera et al., 1995). We also found a statistical difference in BMI at nadir, with the normal weight group having a lower BMI at rebound compared to the overweight and obese groups.

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The limitation in the number of data points up to age 6 years and in particular between age 3 and 6 years may play a significant part in the adiposity rebound age and BMI nadirs reported. Although the ages for the obese and normal weight groups appear clear, those for the overweight group are not. The STRIP (Special Turku Coronary Risk Factor Intervention Project for Children) study reported by Lagstrom and colleagues (2008), collected annual measurements until age 13 years, and reported adiposity rebound at 4.3 years for overweight boys and 3.8 years for overweight girls. In reviewing this present study’s BMI trajectory plots (Figure 2), it is likely that there may have been a lower BMI point somewhere between assessments at 3 and 6 years of age. Irrespective, it is clear that the overweight adiposity rebound occurs at some point at, or after age 3 years, and before age 6 years in this cohort. This is well before that of the normal group, and those originally reported by Rolland-Cachera and colleagues (1984), yet similar to more recent studies (Lagstrom et al., 2008; Rolland-Cachera et al., 2006).

This identified timing of adiposity rebound supports others who found that the earlier the occurrence of the adiposity rebound the higher the BMI with age (Lagstrom et al., 2008; Rolland-Cachera et al., 1987; Rolland-Cachera et al., 2006). However, unlike Rolland-Cachera and colleagues (1987), children in the present study were pre-classified into weight status at age 14 years and then their respective mean value for adiposity rebound in the earlier years was calculated. Our methodology found that the higher the BMI at year one, the earlier the age of rebound, which may be reflective of children with high centile BMI or upward centile crossing according to BMI growth charts (Cole, 2004). Like others, we believe the occurrence of the earlier adiposity rebound is a marker for early determinants or mechanisms of obesity (Cole, 2004; Dubois & Girard, 2006; Rolland-Cachera et al., 1999; Small et al., 2007).

Following this line of thought, investigation of early feeding patterns was conducted (Chivers et al., 2010). A comparison of each early feeding group trajectory (Figure 3) showed a difference in BMI with those breastfed for more than 4 months having
a lower BMI at 14 years. Although a statistical difference between raw BMI with adiposity rebound measures for age or BMI at nadir were not found, predicted BMI based on the whole sample population accounting for age, gestational age, gender and weight status showed that breastfeeding plays an important role in the timing of the adiposity rebound. Both breastfeeding and the age other milk was introduced were important in the determination of BMI at adiposity rebound. These results support early feeding literature (Oddy et al., 2006b; Singhal et al., 2007) that suggest bottle feeding results in accelerated weight gain in the infant, compared to their breastfed counterparts, as depicted in the adiposity rebound nadir results. Early feeding patterns appear to be one of a number of early determinants or mechanisms for later obesity. These include environmental, behavioural and individual factors (such as diet, physical activity and genetics), that may program later weight status (Hallal et al., 2006; Skinner et al., 2004; Small et al., 2007). To date however the value of identifying the timing of adiposity rebound for use in a clinical setting is yet to be confirmed (Dietz, 2000), although it could be used as a tool to alert health professionals to children at risk.

Although these findings on adiposity rebound are similar to others (Lagstrom et al., 2008; Rolland-Cachera et al., 2006), the meaning of the distinct peaks and troughs in BMI in relation to child behaviour is as yet unclear. Analysis of the height and weight data found that the changes observed in BMI were principally related to changes in weight and not height. This can be accounted for by height and weight growth spurts that occur during childhood (Botton et al., 2008). While height trajectories were very similar for all three weight categories, the overweight and obese groups were gaining weight at a faster rate than their normal weight counterparts. This was most pronounced by 3 years of age, although statistically significant from age one. Adiposity rebound for the obese group occurred at around 2 years, the same as the beginning of the second critical period for adiposity proposed by Botton and colleagues (2008).

The longitudinal model of trajectories of BMI was different between males and females, and different for each weight category (Figure 14). This difference was in
both the rate of change over time (acceleration) and BMI at birth. The interaction effects showed that within the weight categories the pathways for males and females were significantly different, with females slightly leaner than males when young, with a cross over in later childhood/early adolescence. The obese group increased their BMI over time at a faster rate, and this difference began from birth. This analysis, which includes more frequent collection points and with a larger sample, is similar to the results reported by Blair and colleagues (2007) for their New Zealand cohort. These results indicate that the preschool years (before age 6 years) is a critical time period for the development of obesogenic behaviours.

The overlay of mean age-adjusted BMI at each follow-up on the modelled BMI trajectories provided an overview of goodness of fit of our proposed model (Figure 14), with residual diagnostics supporting this (Appendix E). The tight clustering of mean data points in the first few years again highlights the need for greater in-depth analysis of this important period with more frequent data collection points, perhaps at three-monthly intervals.

It is therefore apparent that in the Raine Study cohort, the increased rate in weight gain accounts for later adiposity. The underlying causes of the accelerated weight gain are still unclear, although early feeding appears to be an important factor. An examination of growth patterns may assist in the understanding of the development of obesity (Heude et al., 2006). Parents often observe children undergoing increased hunger and appetite, weight gain, followed by decreased appetite and height growth, or episodes of spurt and lag (Wilson, 1986). One explanation may be that established food behaviours do not follow the pendulum return of decreased appetite during growth for the overweight and obese groups. Physical and social aspects of the home environment may also influence food choices based on types of food available, parent food behaviours and feeding practices (Bryant, Ward, Hales, Vaughn, Tabak, & Stevens, 2008). There may also be an as yet determined developmental switch triggered by the environment, that is present or absent in the overweight and obese (Blair et al., 2007; Eriksson, Forsen, Tuomilehto, Osmond, & Barker, 2001), which may be related to epigenetic
mechanisms (Walley et al., 2006; Waterland et al., 2008). Genetically, a common variant in the FTO (fat mass and obesity associated) gene has been identified that increases the odds of obesity (Frayling et al., 2007). In addition, the level of physical activity and sedentary past-times could be important. Dubois and Girard (2006) concluded that influences of behavioural and social factors were critical to the possible onset of obesity in the early pre-school years. Regardless of cause, rapid weight gain after age one is associated with adverse health effects (Eriksson et al., 2001), and this critical period of development requires intensive investigation in regards to obesity.

Infant feeding\textsuperscript{20}.

Early infant feeding investigations using LMM indicated that the age breastfeeding stopped and the age other milk was introduced should be investigated simultaneously. Interestingly, those individuals who were breastfed for more than 4 months, but introduced to other milk at or before 4 months had the highest increase in BMI. Over the time period of interest, those individuals who were breastfed for more than 4 months and started other milk after 4 months did not increase their BMI.

Like Blair and colleagues (2007) for their New Zealand cohort, these data concur that the preschool years are a likely critical time period for the development of obesity (Chivers et al., 2010) and that early feeding plays an important role. These early feeding results extend the findings of Burke and colleagues (2005) on this cohort which showed higher BMI at age 8 years in children breastfed for less than 4 months. Cross sectional analysis of early infant feeding and weight status groups determined at 14 years showed that the proportion of overweight and obese was higher in those who had mixed feeding patterns. A difference was observed in BMI

peak at age 1 year for the different weight status groups, supporting the theory that early introduction of formula feeding is related to growth acceleration, and overweight or obesity (Oddy et al., 2006b), whereas exclusive breastfeeding meets the individual nutrient and energy requirements of each child (Butte, Lopez-Alarcon, & Garza, 2002). Modelling indicated that breast feeding for longer than 4 months, but introducing other milk before 4 months had the largest increase in BMI over time. This is supportive of the theory that bottle feeding reduces self-regulation as parental behaviour may override satiety (Gillman et al., 2001), whereas breast feeding provides protection against overfeeding (Oddy, Scott, Graham, & Binns, 2006c). Further, the suggestion that breastfeeding develops behavioural mechanisms for food acceptance and control of energy intake (Savage et al., 2007) is supported by the finding that BMI differences between early infant feeding groups remains over time until at least 14 years of age.

Recent reports have thrown into question whether the association between breast feeding and subsequent obesity is causal or in fact uncontrolled bias. This bias has been suggested to be mediated by selection and confounding socioeconomic environmental issues that determine parental family feeding and physical activity (Kramer et al., 2009; Michels et al., 2007). However, we were able to show that breastfeeding remained significantly associated with adolescent BMI when adjusted for maternal education, income and mother’s pre-pregnancy BMI (Chivers et al., 2010). Hence, with consideration of some SES confounding, the case is strengthened for the important role early infant feeding has on adolescent obesity.

**Diet.**

Gender differences in food choices in young adults (aged 17 to 30) (Wardle, Haase, Steptoe, Nillapun, Jonwutiwes, & Bellisle, 2004) were also found in the present study’s adolescent group. Males reported higher intake of fats while females reported higher intakes of vegetables. However, both fruit and fat intake were not found to be associated with weight status at 14 years, nor vegetable intake for males. These findings support Hu’s (2008) review of evidence which found that no
single dietary factor had a large effect on BMI. In contrast, there were weight status group differences in vegetable intake for females, and longitudinal modelling found that those who consumed fewer vegetables had a larger increase in BMI. This is similar to findings with adult women, where those who increased their intake of fruit and vegetable the most, decreased their risk for obesity (He et al., 2004).

Interrelationship investigations found that although adolescent fruit and vegetable intake was neither directly nor indirectly associated with BMI, there were relationships with other variables. Overall, healthy behaviours (e.g. being physically active) were related to increased fruit intake, while late stages of puberty were related to a decrease in vegetable intake. These relationship are not unusual, as in young adults, particularly women, healthy food choices are thought to be associated with a more positive attitude towards health, with these individuals more likely to put these beliefs into action (Wardle et al., 2004).

Surprisingly, fat intake was consistently unrelated to BMI. This may be due to measures used for fat intake in this study, which were not those typically reported, nor a complete representation of actual dietary fat intake. Dietary pattern analysis is becoming more popular (Ambrosini et al., 2009a; Hu, 2008c), although not available for analysis in the present study, it may be a more appropriate indicator for diet (Ambrosini et al., 2009a). However, the lack of association for fat intake with BMI may be related to specific dietary reporting issues. It is well known that individuals who are overweight or obese tend to under-report true intake because they are being recorded, are inaccurate in detailing items and amounts, and / or reluctant to admit what they are eating (Lissner, Heitmann, & Bengtsson, 2000). Closely associated is the issue of portion size (Rennie et al., 2005; Steenhuis & Vermeer, 2009), information which was not available in the present study, although the use of such data can be limited and restricted by many methodological issues (Hu, 2008c).
Developmental milestones and motor competence.

Early childhood is a particularly important developmental period for autonomous self, social and motor competence (Houck, 1999). Evidence from parent reported developmental milestones from ages 1 to 3 years suggested a weak relationship between the locomotor milestones of stand and totter and weight status. Interrelationships investigations found that these early milestones were the result of motor competence and did not have any causal pathways to other variables, nor BMI at age 1 year. Similarly, the Denver II Assessment results, over similar follow-up years, did not find any significant weight status differences, although individuals who were overweight or obese at 14 years, were more likely to have been rated uncooperative or suspect in these early years. These results are similar to Jones and colleagues (2009) who found no relationship between motor development, perceived competence and obesity in 2-6 year olds.

The IMQ results demonstrated some relationships with the overweight and obese individuals who were yet to master some fine motor skills. Interestingly, talking, which could be considered a fine motor skill, was delayed in those individuals who were overweight or obese at 14 years. Toddler speech may reflect a complex cognitive process and has been shown to predict a child’s capacity to self-regulate behaviour by school age. Further, developmental competence, as measured by the IMQ, precedes self concept and is enhanced by social competence (e.g. speech) (Houck, 1999).

Findings for locomotor skills suggest a possible link with later obesity. Locomotor skills in individuals overweight or obese at 14 years were more likely to be judged not like their peers for the IMQ, and below average for parent reported locomotor skills at 10 years. Longitudinal modelling showed a significant negative influence with BMI, with an increased BMI for those with poor locomotor skills. Locomotion, such as walking, is a major developmental milestone occurring during the first two years of life (Malina, 2004). Mastery of locomotor skills may be related to adolescent weight status through future physical activity levels, attitudes and self
concept. Certainly, evidence suggests that intervention at an early age for those with poor motor competence should occur (Houck, 1999), as pre-school children with poor coordination are less physically active (Williams et al., 2008). These early interventions may assist in increasing perceived competence and self concept, and help combat the suggested reciprocal relationship between motor competence and weight status (Okely et al., 2004).

Overall, these earlier motor skill findings were supported by the more accurate (reliable and valid) MAND results at both follow-up ages 10 and 14 years. A clear difference was found, with higher motor competence associated with lower BMI. Importantly, at 14 years, there were significant interrelationships, with low motor competence individuals more likely to make excuses for not increasing physical activity levels and have high screen use, the latter being similar to that found by Graf and colleagues (2004).

From a dynamic systems perspective, these factors probably relate to the specific environmental influences necessary for motor development, namely prior and new movement experiences (Malina, 2004). Those with better skills find it easier, and are more likely to engage in physical activity (Williams et al., 2008). However, although it has been shown that higher physical activity levels provides opportunities to improve motor skills (Reilly et al., 2006; Williams et al., 2008) we found no relationship between physical activity (step count) and motor competence. It is important to note that in contrast to these earlier studies, the physical activity measures differed, and the Raine Study cohort was older. Cohort age and measure of physical activity are important factors to consider when making comparisons (Williams et al., 2008), with differences across age having been shown in this cohort (Hands, Chivers, Parker, Beilin, Kendall, & Larkin, 2010b). Similar to Graf and colleagues (2004) we found a positive relationship between motor competence and aerobic fitness, concurring with a cross-sectional analysis using the Raine Study cohort (Hands et al., 2008). Perhaps the type of measure for physical activity is the key. In respect to the directionality question posed by Graf and colleagues (2004) “do overweight and obesity lead to poor physical performance or
is it the other way around?” (p. 25), the SEM results suggest motor competence predicts BMI. Like others (Williams et al., 2008), we demonstrate that a sedentary lifestyle (as measured by screen time) is interrelated with low motor competence and unhealthy weight.

**Physical fitness.**

Physical fitness relates to an individual’s ability to perform physical activity (Caspersen et al., 1985; Must & Tybor, 2005). The Raine study included measures of absolute aerobic fitness (PWC 170), muscle endurance (curl-ups), upper body strength (basketball throw), and flexibility (sit and reach, shoulder stretch) at 14 years. Gender differences were reported across all variables with males outperforming females in absolute aerobic fitness and endurance, while females had greater flexibility. Except for absolute aerobic fitness, no weight status group differences were found. The longitudinal model showed that the number of curl-ups and basketball throws were related to BMI. Those with higher BMI achieved fewer curl-ups, and this probably relates to actual fat mass restricting movement (Hands et al., 2008). Adolescents with higher BMI scored better in basketball throws and this may be related to the stability provided by body mass to perform this skill (Hands et al., 2008) or more muscle mass.

For both males and females, absolute aerobic fitness was greatest for obese, followed by those overweight, then normal weight. However, there was not a significant difference between the normal weight and overweight males. Longitudinal modelling replicated this trend with a positive relationship between absolute aerobic fitness and BMI. These results are not surprising and concur with others (Goran et al., 2000; Rowland, 1991). Obese individuals do not necessarily have an impaired cardio-respiratory response to exercise (Goran et al., 2000), but rather that increased fat levels are associated with increased cardiopulmonary exercise capacity (Rowland, 1991), particularly in a weight supported bike ergometer test. However, in non-weight supported activities (e.g. treadmill running) obese individuals require a greater proportion of their aerobic capacity to
participate (Goran et al., 2000), that is, for these tasks their *functional* fitness decreases with excess body fat (Rowland, 1991) and they are likely to find locomotor tasks such as running more difficult.

Pubertal stage has a confounding effect on the measure of aerobic fitness. ANOVA and SEM analyses both demonstrated a strong relationship between stage of pubic hair development and absolute aerobic fitness, with BMI. During puberty, increased body fat (Sloboda et al., 2007) and changes in physical characteristics (e.g. lean body mass, skeletal mass and body fat) occur (Hayward, 2003; McCarthy, Cole, Fry, Jebb, & Prentice, 2006). Regardless, interrelationship investigations at 14 years demonstrated that each of these factors was independently related to BMI both in an indirect and direct way.

**Puberty.**

Adolescence has been identified as a critical period for the development of obesity (Dietz, 1994), but also coincides with the timing of puberty. With increasing rates of childhood obesity, questions have been raised as to whether increased adiposity is responsible for earlier puberty, although evidence suggests an independent decline is also present (Aksglaede et al., 2009). However, it is well recognised that puberty is associated with increases in fat mass and muscle mass (Hayward, 2003; McCarthy & Ashwell, 2006; Sloboda et al., 2007).

In this study the overall timing of puberty as measured by first menstruation (menarche) and the Tanner self-ratings for pubic hair and breast development (Tanner, 1962) did not have a direct influence on individual BMI. The cross-sectional lack of association between BMI and age at menarche concur with previous findings in this cohort (Sloboda et al., 2007). However longitudinal modelling found that overweight females with later menarche had lower BMI, which may indicate some confounding with respect to the increase in body fat usually associated with menarche in females (McCarthy et al., 2006; Sloboda et al., 2007). Only female breast development was significantly associated with weight
status, with more obese and overweight individuals being more physically mature at 14 years. Longitudinal modelling of pubic hair development showed that those individuals who were obese and pre-pubertal had lower BMI, similar to the age at menarche finding.

Generally there was some evidence that individuals with higher BMI experienced pubertal changes earlier, which is consistent with previous findings (Styne, 2004). In respect to interrelationships at 14 years, puberty measured by pubic hair development was predictive of aerobic fitness (e.g. PWC 170) and also BMI, and is probably related to changes in physical characteristics (e.g. lean body mass, skeletal mass and body fat) (Hayward, 2003; McCarthy et al., 2006).

**Behavioural Factors**

**Physical activity.**

Physical activity is used to describe a body movement or behaviour of varying amounts as described by frequency, intensity, time and type (Caspersen et al., 1985). Physical activity can be measured in a number of ways, for example accelerometers, pedometers, heart rate monitors, direct observation and self report, with each method having its advantages and disadvantages (Molnar & Livingstone, 2000; Must & Tybor, 2005). In addition, attitudes and values to physical activity are seen as modifiable correlates of physical activity, such as encouragement, effects, importance, competence, excuses, intention, enjoyment, and encouragement (Sallis et al., 2000).

Historically, children’s development (and activity behaviour) is facilitated by positive early experiences, and can be delayed by negative experiences (Gandour, 1989). In the preschool years, early physical activity behaviours were assessed by how often children were taken to the park or playground (age 1 to 3 years). Generally males, compared to females, were taken to the park or playground more frequently, corresponding to participation levels in organised sport at age 6 years, but not later. It is well recognised that males tend to be more active than females
from an early age (Else-Quest, Hyde, Goldsmith, & Van Hulle, 2006) which may explain why caregivers are more likely to take males to the park to vent some of that excess energy. In the later years (ages 8 and 10 years) males continued to have higher activity levels compared to females. Females though had higher levels of participation in organised activity, but this probably related to the types of activities defined by this survey question, namely music, dancing, kindygym and other clubs. These gender differences are consistent with other studies (Dollman & Lewis, 2009; Hands et al., 2008; Hands et al., 2004; Martin et al., 2009; Thompson et al., 2009) and are probably also related to attitudes and values to physical activity (Li et al., 2005; Murcia et al., 2007; Sallis, 2000).

Adolescents who were obese at age 14 years were *never or seldom* taken to the park or playground as young children. Their parents reported less participation in organised activity at age 6 years, they comprised the highest proportion of inactive and lowest proportion of active at age 8 years, and had the lowest scores for light, moderate and vigorous activity at age 10 years. This appearance of tracking is supported by a concurrent study (Hands et al., 2010b) which depicts tracking of physical activity based on these variables in a longitudinal SEM model. These results support others who have highlighted the importance of early childhood activity participation in the development of physical activity behaviours in later childhood, adolescence and into adulthood (Janz, Dawson, & Mahoney, 2000; Tremblay & Willms, 2003).

In these early years, parents also play a key role in their child’s activity levels. The importance of parents as role models has been shown by others (Dollman & Lewis, 2009; O’Dea, 2003a). In the present study, at age 14 years, normal weight children had more active parents who also *helped them to exercise*. Interestingly, LMM found that those individuals who reported higher levels of encouragement from their parents had higher BMI, contrary to the positive role of parent encouragement in overcoming barriers to being physically active (O’Dea, 2003a). These differences may relate to the style of encouragement provided. Evidence in the physical education setting has shown that a style that develops structure,
autonomy support and involvement has positive outcomes, versus a controlled motivation with less autonomy (often used in the teaching setting for those less motivated) (Ntoumanis & Standage, 2009).

Overall pre-school physical activity behaviours did not seem to play an important role when considered with the longitudinal model of BMI, nor did it have interrelationships with other obesogenic variables. However, at age 10 years, a relationship was found between an increasing number of activities and decreasing BMI. Further interrelationship modelling indicated that physical activity in childhood operated indirectly by displacing screen time. Investigations on the displacement hypothesis have been mixed (Hands et al., 2010b; Hohepa et al., 2009; te Velde et al., 2007), however work with this cohort suggests early childhood was an important period for the development and establishment of healthy behaviours.

In this study, physical activity level was measured by pedometer step counts over a minimum 4-day period at age 14 years. Like others (Olds et al., 2004; Steinbeck, 2001), males had higher levels of physical activity (mean daily step count) than females overall, during the week and on weekends. The higher step counts are thought to be generated by being more involved in outdoor play and leisure activity, with outdoor activity associated with higher levels, intensity and frequency of physical activity (Klesges, Eck, Hanson, Haddock, & Klesges, 1990).

An association between physical activity and obesity is not consistently found (Hands et al., 2008; Thompson et al., 2009). In this study, only females showed a significant weight status difference with those who took more mean daily steps having lower BMI. There were no weight status group differences for males, with the overweight group having higher mean daily steps than the normal weight group. Though not significant overall, LMM analysis found subgroup interactions between the obese group and mean daily step count, with the more active obese individuals having a lower BMI. This suggests that physical activity may assist in preventing further weight gain (Fogelholm & Kukkonen-Harjula, 2000), or protect
against accelerated weight gain (Steinbeck, 2001). Interrelationship modelling also demonstrated an inverse relationship between physical activity at ages 6, 8, 10 and 14 years, supporting the inverse relationship between physical activity and BMI reported in young adults (Dragan & Akhtar-Danesh, 2007).

A relationship was found between physical activity and screen time at ages 6 and 8 years, but not at ages 10 and 14 years. In associated investigations with this same cohort sample (Hands et al., 2010b), a longitudinal SEM model demonstrated strong interrelationships between physical activity levels and screen time in the early years, indicating that during the early years screen time may displace physical activity. Evidence of physical activity level tracking from childhood into adolescence in this cohort study, along with other studies (Janz et al., 2000; Kelder, Perry, Klepp, & Lytle, 1994; Telama, 2009), provides additional support that early childhood may be a critical time for the establishment of more physical and less sedentary behaviours (Hands et al., 2010b).

In the present study, the direct influence of physical activity attitudes and values on weight status was examined along with the indirect influence through physical activity behaviour. Significant gender differences were found, consistent with findings for self-perception (Li et al., 2005; Murcia et al., 2007) and physical activity (Sallis et al., 2000). Overall males were more positive towards participation, while girls were more likely to make excuses to avoid participation. Weight status group differences were found, but again, similar to self-perceptions, healthy weight individuals had more positive responses and depicted greater confidence in being physically active. Recently Schmalz (2010) found in adults that perceptions of body weight were predictive of physical activity participation levels. More specifically, weight related stigma had an inverse relationship with perceived physical activity competence, which was also related to BMI. Overall in the present study, longitudinal modelling found either weak sub-group or no relationships with BMI, and similarly in interrelationship modelling. However, those with higher BMI were more likely to make excuses. Here, as the number of excuses increased, so did BMI, which is consistent with findings on perceived barriers and intentions to be active.
(Sallis et al., 2000) and weight related stigma (Schmalz, 2010). The low active (step count) and low motor competent (MAND) groups made more excuses for not participating in physical activity, providing further support that positive attitudes and values increase with physical activity participation (Li et al., 2005; Murcia et al., 2007), which in turn is related to healthy body weight.

Parent influences had an association with physical activity attitudes and values, although not always in the direction expected. These inconsistencies were also reported by Sallis and colleagues (2000) in their review of physical activity correlates. The involvement of peers was also significant. Individuals with active friends had lower BMI, supporting Tergerson and King’s (2002) study that showed having a friend to exercise with was important. Peer participation was not as important for males as it was for females, who valued the social aspect of physical activity participation. This was particularly true for overweight females aged 8 to 16 years (Zabinski, Saelens, Stein, Hayden-Wade, & Wilfley, 2003). Here, overweight children, particularly females, were more likely to report barriers to physical activity which included negative perceptions about their body; lack of interest, skills, facilities or knowledge; and negative social perspectives (e.g. lack of peers to be active with, teasing, peers not active). Overall, the shown gender differences in social aspects, were consistent with other studies (Hands et al., 2004; Tergerson & King, 2002).

Important differences in physical activity attitudes and behaviours were found between weight status groups. Obese individuals did not value physical activity opportunities, and were more negative about the positive influences of being physically active. The overweight and obese groups were more likely to be taunted by others about their weight or shape, and believed the role of physical activity was principally to control or lose weight. This suggests a different behavioural motivation for physical activity participation. Certainly having fun is more likely to promote a motivation to be physically active (Whitehead, 2008), but having fun may be less likely if an individual is self-conscious, teased, does not have peers to
be active with, lacks resources, or actual participation exhibits negative physical effects (difficult, dislike of how body feels, or uncomfortable) (Zabinski et al., 2003).

The most significant findings were related to perceived barriers or excuses for not increasing physical activity. More obese individuals were more likely to be self-conscious when being active, and therefore developed excuses such as having other interests, not finding physical activity fun, not being good at sport, that people might laugh at them, or that they had poor health. Social aspects and skills were both important for the overweight and obese individuals, with similar barriers reported in a similar aged cohort (Zabinski et al., 2003). Overall the derived scores showed that obese individuals scored less positively across all items. These results provide further evidence that lower self-perceptions are related to lower physical activity levels and unhealthy weight (Li et al., 2005; Murcia et al., 2007).

**Sedentary behaviours.**

Commonly, screen time, computer time and television watching are used as proxy measures of sedentary behaviour (Jebb & Lambert, 2000; Olds et al., 2004) as these are seen to be the main competitors to time spent participating in physical activity (Olds et al., 2004). Until age 14, gender did not play a role in the amount of time spent in screen based activity. However, at age 14 years more boys reported high levels of screen based activity, compared to girls. This gender difference probably relates to the type of free-time play, with males spending more time playing computer games, while females were more likely to be involved in socialising activities (like chatting on the phone) (Biddle et al., 2004a).

Although cross sectional analysis found more overweight or obese children had higher levels of screen based activities, this was not evident in longitudinal modelling, with all screen based activity models not significant. However there were some specific interactions noted in the estimates which depict specific effects for some subgroups. Consistently, for children classified as obese, those who were involved in less screen based activity (<2 hours per day) had a decrease in BMI
compared to those involved in the highest level of screen based activity (>5 hours per day). It would appear that overweight and obese children were more likely to be involved in more screen based activity, a finding reported in a recent study of 2-6 year olds (Jones, Okely, Gregory, & Cliff, 2009). Also, increased screen time may be associated with other negative health behaviours such as increased snacking, with higher snacking shown to occur in unhealthy weight families (Francis et al., 2003).

Interrelationship modelling found that at ages 6, 8, and 10 years higher levels of television watching were associated with increases in BMI. However this relationship was not present at 14 years. At ages 6 and 8 years, physical activity levels appeared to displace the amount of television being watched, with this inverse relationship shown in 2-6 year olds (Jones et al., 2009). It is hypothesised that time spent television watching, especially in the early years, is an indicator of opportunity for physical activity including active play (indoors and outdoors) and active transport (Dehghan et al., 2005), especially during the critical time after school and before dinner (Olds et al., 2004). Certainly in this age group others have shown that increasing time spent in sedentary activity is associated with increased body fat (Blair et al., 2007) and might be related to lowering of resting metabolism (Klesges et al., 1993; Molnar & Livingstone, 2000), and / or snacking behaviours and food choices whilst sedentary (Francis et al., 2003). It may also explain why at 14 years, television watching is no longer important in the overall model, as screen time may now be occurring outside this critical window and later at night. However in this study no information was collected on the time of day for screen time, hence this is speculation only.

There may also be other influences based on the types of programs, advertising, parental supervision and cognitive simulation (Must & Tybor, 2005). Rennie and colleagues’ (2005) review of determinants of obesity related to sedentary behaviours reported links to food advertising of food high in fat and or sugar, lack of advertising for healthy foods (eg. fruit and vegetables), and family lifestyle habits. More poignantly, they suggested without clear secular trends, it is unclear
whether increases in sedentary behaviours per se are obesogenic or it is due to the displacement of active behaviours. Results from this study are suggestive of the latter, particularly in light of evidence that the influence of sedentary behaviour disappears when adjusted for moderate and vigorous physical activity in 12-years-olds (Mitchell et al., 2009).

**Self concept.**

Self concept is important in understanding individual motivation and behaviour (Hagger et al., 2005; Harter, 1990; Weiss, 1987) with physical activity participation shown to increase when one has positive perceptions of their capacity to contribute (Murcia et al., 2007), and decrease with negative body esteem (Schmalz, 2010). These capacities support the development of perceived competence, which have been described as stemming from early childhood where objective self-awareness and self-conscious evaluations begin (Houck, 1999).

Overall, in this study, males reported higher scores than females across self-perception domains, consistent with a meta-analysis study (Wilgenbusch & Merrell, 1999) and Haggar et al. (2005). Normal weight individuals had higher scores in athletic competence, physical appearance and overall sense of self-worth, than those overweight or obese. Individuals overweight or obese had lower scores in self-worth, consistent with lower self-esteem reported in unhealthy weight children (Waters & Baur, 2003) and lower body esteem in adults (Schmalz, 2010). This construct is regarded as relatively stable and enduring (Hagger et al., 2005; Raudsepp et al., 2004) and is suggestive of an underlying difference in global self-worth for healthy weight versus unhealthy weight. Individuals overweight and obese may be less able to cope (e.g. with family stress), lack motivation (e.g. to be physically active), and may be less happy (e.g. peer related judgements) (Harter, 1990), than their healthy weight counterparts.

Investigation of these domains in the longitudinal model however did not find any significant relationship with BMI. Exploratory SEM also found no direct pathway
between self concept and BMI. However, it was shown that self concept may work in indirect ways through other variables such as attitude to participation and the valuing of physical activity, which impact on participation levels of physical activity (Schmalz, 2010). Certainly these findings support the role of a positive self concept (perceived athletic competence, association with a positive physical appearance, and overall global self-worth) in increasing participation in physical activity (Li et al., 2005; Murcia et al., 2007) which in turn is related to body weight (Dragan & Akhtar-Danesh, 2007). However in this study, without repeated measures of self concept, the direction of the relationship between BMI and self concept could not be discerned.

Related to self concept, parent reported social and behavioural progress at age 10 years found weak associations. Interestingly, more parents of obese girls were dissatisfied with their social progress, supported by a weak but significant interaction in the longitudinal BMI modelling. Overall parents of obese individuals were also dissatisfied with their behaviour progress, although no longitudinal relationship was found. It is unclear what inferences can be made here, particularly considering that these results are based on two survey questions alone. Yet these results may provide further support of the importance of individual motivation and behaviour in building one’s self concept for normal behavioural and social development (Hagger et al., 2005; Harter, 1990; Weiss, 1987).

Environmental Factors

**Socioeconomic status (SES).**

Socioeconomic status comprises a number of characteristics that influence behaviour, having both direct and indirect effects on obesity. These include wealth (family income), environment (SEIFA), educational attainment, knowledge (ethnicity, occupation) and life stress (Sanigorski, Bell, Kremer, & Swinburn, 2007). Results from this study support the SES gradients in fatness for Australian children reported in other studies (Dollman et al., 2007; Sanigorski et al., 2007), with those at the lower end more likely to be overweight or obese.
**Socioeconomic index for areas (SEIFA).**

Socioeconomic index for areas (Australian Bureau of Statistics, 2007a) was used as an environmental indicator of community SES as it permits the socioeconomic investigation beyond the individual (Bennett, Wolin, & Duncan, 2008). There were no reported gender differences for SEIFA, but significant weight status groups differences, like that reported for the Victorian cohort (Sanigorski et al., 2007) and similar to international trends in neighbourhood socioeconomic position (Bennett et al., 2008). Compared to normal weight individuals, overweight and obese individuals tended to have lower SEIFA scores and therefore lived in communities of more disadvantage. These disadvantaged communities have been shown to have a greater exposure to fast food (advertising and access), are less safe, and their community facilities are often poorly maintained (Dalton, 2007), aspects of the environment considered to not promote healthful behaviours, nor help avoid obesity (Sallis & Glanz, 2006). These findings provide support for the hypothesis that social context may play a more important role in obesity risk than other SES factors (Bleich, Thorpe, Sharif-Harris, Fesahazion, & LaVeist, 2010).

**Family Income**

Individuals from families with low income were more likely to be overweight or obese. While not evident in early childhood (birth to age 3 years), this relationship was strong from late childhood (6 to 14 years). Longitudinal modelling however did not find significant influences, although interrelationship modelling suggested family income did play a role with BMI, indirectly through influence on other obesogenic factors.

Exploratory interrelationship models at age 1 year, found high income was associated with increased time spent breast feeding, and may relate to both the opportunity for the mother to stay at home to care for her child and the educative value of breastfeeding one’s child for longer (Sloan, Gildea, Stewart, Sneddon, &
Iwaniec, 2007). Another confounder is that low income families tend to be overweight and obese (Australian Bureau of Statistics, 2007c), and mothers who are overweight and obese tend to breastfeed for shorter duration (Burke et al., 2005; Hediger et al., 2001).

At ages 6, 8, 10 and 14 years, income was positively related to activity, and inversely related to the amount of television watched. The number of reported organised activities may relate to the opportunities available due to the costs of activities, cost and availability of transport, availability of the parent to transport the child to the activities (working parents) and also attitudes toward the importance of activity participation (Olds et al., 2004). Similarly, if low income relates to reduced opportunity for participation in organised activities, then television watching may be an easy and affordable alternative.

**Parental Employment**

In recent times maternal employment has increased, with resultant changes in parental behaviour, home routines and attitudes (Fertig, Glomm, & Tchernis, 2009). A connection between maternal employment and childhood obesity has been suggested (Fertig et al., 2009; Hawkins, Cole, & Law, 2008). In the present study, children whose mother stayed at home were more likely to be obese, while those whose mothers were working were more likely to be of normal weight, with little difference in the overweight group. These results are generally similar with the Australian Bureau of Statistics (2007b) report which found the proportion of overweight was similar across SES. Interestingly, longitudinal modelling found that a working mother was protective for the obese group only. This suggests that for obese children, there is either a negative influence of the home environment (for non-working mothers), or a positive influence of the care environment (for working mothers), with more maternal work hours shown to be associated with lower BMI if a child spent time in child care (Fertig et al., 2009).
Further, the investigation of hours a mother worked showed very small decreases in child BMI for increasing hours. This concurs with Fertig and colleagues (2009), but is in contrast to Hawkins and colleagues (2008) who reported an increased likelihood of obesity for every 10 hours per week worked. These contrasting findings are probably related to sample size as 18,533 families were recruited for the Millennium Cohort (Hawkins et al., 2008), compared to 1,403 in the current study, and 2,500 children in the study by Fertig and colleagues (2009). It may be that mother’s work is a proxy for maternal education and reflective of their related effects (discussed below under Parental education). Such confounding effects, were also identified by Fertig and colleagues (2009) who showed differences between low and high educational attainment mothers, their work hours, and different effects for school and childcare. Overall, maternal employment has a complex relationship with other factors related to obesity.

**Parental education and father’s occupation.**

Parents with low educational attainment had higher proportions of obese children, concurring with another Australian study (Sanigorski et al., 2007). In the present study, in addition to parental education, father’s occupation was also related to weight status, with those involved in sales, plant operations and labouring having a higher proportion of obese children. Trades people had an even distribution of obese, overweight and normal weight for both educational attainment and father’s occupation. The mechanisms by which parent education and occupation may operate are unclear. Evidence has shown a positive association between educational level and healthy patterns of behaviour (activity level and cardiovascular fitness) (Cleland et al., 2009; Ferreira, van der Horst, Wendel-Vos, Kremers, van Lenthe, & Brug, 2007) and negative sedentary behaviours (television time) (Hesketh, Crawford, & Salmon, 2006). Paternal occupation mechanisms may be related to family income, role within the family, paternal food preferences (Sanigorski et al., 2007) or occupational culture. Overall though, more in depth considerations of what these operational mechanisms may be need further
investigation, to provide clarity and opportunities for more targeted and appropriate intervention programs.

**Ethnicity.**

Often social demographic characteristics such as ethnicity are used to identify disparities in health related outcomes (Bennett et al., 2008), although recent evidence suggests that such disparities are associated with the social context and not ethnicity (Bleich et al., 2010). Although sample size was low and highly skewed, in the present study father’s ethnicity was associated with weight status, with proportionally more Caucasians overweight and obese. Longitudinal modelling also found that parental ethnicity was associated with weight status, and Caucasians had a higher BMI. It could be argued that ethnicity may be a proxy for genetic differences (Bennett et al., 2008) or heritable individual genetic-environment susceptibility (Mutch & Clement, 2006; Walley et al., 2006). It might also be a proxy for parent behavioural qualities that may be attributed to ethnic related cultural practices and are therefore directly and indirectly related to patterns of behaviour (Gibson et al., 2007; Olds et al., 2004).

**Life Stress.**

The often assumed relationship between stress and obesity is not conclusive. Whether stress or its confounders are responsible is uncertain, with both biological and comfort food mechanisms considered (Bennett et al., 2008). Across the years of this study, money problems was the most associated life stress variable with weight status. Parents who reported money problems had fewer normal weight children. Another study with this cohort found financial stress during pregnancy was associated with a shorter duration of breastfeeding (Li et al., 2008), which itself is a risk factor for future obesity (Chivers et al., 2010). Longitudinal modelling also identified *problems with children* and *other problems* as significantly associated with weight status, both leading to an increased BMI. These two latter stress items may also be indicative of other behavioural mechanisms (such as the ability of the
parent to manage children’s behaviour i.e. parenting style), especially since investigation of three or more life stress events did not reveal any relationships, nor any interrelationships using SEM. This finding for overall stress corresponds with the lack of association between negative life events and BMI in another Western Australian cohort of 6-13 year old children (Gibson et al., 2007). Therefore family life stress may not play a significant role in weight status for children. However financial stress, which could occur across SES and be dependent upon level of household debt, may identify a stress burden which has an indirect role with other obesogenic factors related to adolescent obesity such as breastfeeding, financial costs associated with organised sport and quality of diet.

**Parental influences.**

Parental influences are embedded among many of the variables discussed and work both directly and indirectly on the child’s pattern of behaviour (Gibson et al., 2007; Klesges et al., 1990; Olds et al., 2004; Steinbeck, 2001). Probably most critically, parents serve as a role model to their children (Cleland, Venn, Fryer, Dwyer, & Blizzard, 2005; Gibson et al., 2007), particularly in the preschool years (Ventura & Birch, 2008; Wake et al., 2007). Parental exercise habits are positively associated with the 7-15 year old children’s activity levels and cardiovascular fitness even after adjustment for age, SES and school type (Cleland et al., 2005). It is proposed that parent influence on exercise may operate at three levels, firstly by modelling behaviour, secondly by providing encouragement and support (transport, equipment, funds), and thirdly through a genetic predisposition to being active (Cleland et al., 2005). Importantly, the role of parents is critical at the earliest stage of child development to support and promote healthy behaviours (Lindsay et al., 2006).

So far parental influence has been shown through early feeding practices, diet choice, participation in organised activity and sport, opportunity for participation (due to financial or time constraints), attitudes and values to active and sedentary
behaviours, encouragement to be active, culture (ethnicity), employment and education. Discussion of other factors now follows.

**Maternal smoking during pregnancy.**

Maternal smoking is a modifiable prenatal determinant of child obesity and is thought to reduce fetal growth (Gillman, 2008). The growing evidence that maternal smoking during pregnancy causes later obesity in the children (Gillman, 2008), was also supported by significant cross-sectional weight status group differences, particularly for those overweight. Longitudinal modelling confirmed that smoking during pregnancy reduces fetal growth in this cohort (lower birth weights), with BMI higher after birth. Whether maternal smoking is causative of, or a marker of other SES determinants and behaviours, was not able to be determined in this study.

**Parent BMI.**

The association between parent and child BMI is well documented (Bell et al., 2007; Huus et al., 2007) and the results of this study concur with previous research. Significant weight status group differences were found for mother’s BMI, with longitudinal modelling showing that as mother’s BMI increased so did the child’s BMI. A similar result was found for fathers, although the actual increase in BMI was smaller, when compared to mothers. Although there were no weight status group differences for parent birth weight, longitudinal modelling found for both mother’s and father’s birth weight, there was an incremental increase in BMI. Exploratory SEM at birth suggested that parent birth weight was correlated to child birth weight and gestational age. Both the LMM and SEM results indicate some underlying polygenic factor which suggests heritable individual genetic-environment susceptibility (Mutch & Clement, 2006; Walley et al., 2006).
Parenting styles.

The role of family characteristics on child obesity has been hypothesised over many decades. There is anecdotal evidence that parenting style, supportiveness and social cohesion may be important in respect to the development of obesity (Gibson et al., 2007; Wake et al., 2007) and that authoritarian parenting may have the highest risk of overweight (Rhee et al., 2006). This study investigated a total score for parenting and individual parenting styles relating to laxness, over-reactivity and verbosity. Overall, no gender or weight status differences in parenting styles were found at age 10 years, although longitudinal modelling indicated that with more negative parenting behaviours there was an increase in BMI for overweight individuals, followed by the obese group.

Adolescents rated their perception of parenting at age 14 years. Compared to males, more females reported positive parenting behaviours. Generally there were weak or no weight status group differences, which corresponds with results for the same parenting scale in 6- to 13-year-old Western Australian children (Gibson et al., 2007). Some negative parenting styles were associated with obesity. Obese males tended to be threatened or hit more often by parents, while obese females found parents were inconsistent in the enforcement of rules, and they felt less appreciated. However longitudinal modelling results suggested that the most adverse parenting behaviours (such as, threatened or hit and threaten punishment) were more likely to result in decreases in BMI, regardless of weight status.

Although these results concur with Gibson and colleagues (2007), a limitation to their study was the absence of child perceived parent support. This factor was evaluated at age 14 years in the present study, but it was not important for weight status. However this study did not differentiate between mother’s and father’s parenting styles nor investigate parenting and the preschool years, therefore no conclusion can be drawn on how early childhood parenting styles might relate to weight status in adolescence. Wake and colleagues (2007) found father’s parenting style was associated with preschool child BMI (Wake et al., 2007) with authoritarian
parenting (high demands for self-control but low levels of sensitivity (Rhee et al., 2006) associated with higher risk of obesity (Rhee et al., 2006; Wake et al., 2007). Perhaps this study’s weak findings relate to the low numbers of obese individuals in the cohort, but clearly lend support toward the positive role supportive, consistent and fair parenting has on childhood healthy weight possibly by providing children with positive incentives and guidance to develop effective self-regulation behaviours in respect to diet, exercise and sedentary activity (Rhee et al., 2006).

**Built environment.**

More recently there has been a growing interest in the built environment as a determinant of obesity in children, especially in respect to its association with diet and physical activity behaviours (Burdette & Whitaker, 2004; Maddison et al., 2009; Maziak, Ward, & Stockton, 2008; Norman, Nutter, Ryan, Sallis, Calfas, & Patrick, 2006; Page et al., 2010). There is evidence to suggest that the more time preschool children spend outdoors, use local parks and playgrounds, and have access to physical activity equipment, the more active they are (Norman et al., 2006). However research with adolescents reveal that these relationships are complex, and should be considered in context with SES factors (Boone-Heinonen, Evenson, Song, & Gordon-Larsen, 2010). Although built environment variables were not specifically collected in this cohort, and limitations based on Boone-Heinonen and colleagues (2010) are acknowledged, proxies such as early childhood home influences, and school influences were investigated.

**Early childhood home influences.**

In this study, having a swimming pool, home garden, or living near a park at ages 1, 2 and 3 years was hypothesised to provide a positive environment for physical activity and healthy weight. Except for living near a park or playground at age 1 year, all home influences had no significant relationship with weight status. These results may relate to the low sample size at follow-up ages 2 and 3 years, as well as the highly skewed data with a yes or no response. The latter issue was also identified as a limitation by Burdette and Whitaker (2004). The presence of a home
garden does not provide sufficient information on available space for physical activity, nor sufficient evidence for a relationship with yard space, as suggested for investigation by Burdette and Whitaker (2004). This is disappointing considering home yards provide active outdoor free-play opportunities (Veitch et al., 2010). Interestingly, at age 1 year, a higher percentage of healthy weight individuals did not live near the park or playground, which supports other studies that playground proximity is not related to overweight or obese (Burdette & Whitaker, 2004; Potestio et al., 2009; Timperio, Jeffery, Crawford, Roberts, Giles-Corti, & Ball, 2010). In considering these results, it should be noted that there is a poor level of agreement between objective and perceived proximity reports (Lackey & Kaczynski, 2009), and perhaps proximity to active spaces is related more to possible barriers to being healthy and active, with those exhibiting generally healthy behaviours also less likely to find proximity to a park or playground a barrier (Sallis, 2000).

This reasoning may explain why in longitudinal modelling we found an individual’s increase in BMI was greater for overweight and obese, compared to normal weight if they did not live near a park. Exploratory SEM at age 1 year also did not find any direct relationships between these early childhood influences, although preliminary investigations found that early walking was related to frequency of park visits, and frequency was associated with proximity. This relationship was hypothesised, but untested, by Burdette and Whitaker (2004). Certainly there is sufficient evidence to question the association and further investigations are warranted.

**School influences.**

There is limited literature discussing the impact of the school environment on obesity in childhood and adolescence. In this study, there were no gender differences for co-education, school affiliation, private versus public school, and representative sport opportunities at age 14 years. Weight status group differences were found for each school influence. More obese children attended coeducational schools which probably relates to a greater representation of such schools in the public system, and also overall more children from lower SES backgrounds (O'Dea,
Independent schools had the lowest overweight and obese individuals compared to Catholic and public schools, and obesity levels in public schools were double those in private schools. Longitudinal modelling did not show any significant trends. Overall these findings probably reflect differences in SES gradients typically seen across private and public school sectors in Australia (O'Dea, 2003b). Based on evidence that compulsory physical activity programs (Cleland et al., 2008b) and school physical activity environments (O'Malley et al., 2009) are not associated with obesity, school influences are likely to be related with SES variables such as family income. Preliminary SEM investigations found that school affiliation (independent, catholic, government) was related with family income, but that school affiliation did not influence BMI.

The sample for school representative sport was small (n=142) with a weak weight status group difference found, but no definitive trend. The total school facilities provided an indicator for environmental opportunity for organised sport and activity within the school environment but this was not significant. This result aligns with community environment studies that found little evidence of an association with either BMI (Norman et al., 2006) or physical activity (Maddison et al., 2009) in adolescents. This is contrary to positive community partnership results which demonstrated that community coalitions can increase the likelihood of adolescents being highly active (Leatherdale et al., 2010). In summary, school demographics are most likely the common factor in results found for public versus private schools. Overall, it would seem that the school environment does not directly influence obesity in childhood and adolescence.

**Synthesis of Overall Findings**

This section collates cross-sectional, longitudinal and interrelationship modelling evidence, with individual, behavioural and environmental perspectives. Research findings are brought together and discussed in respect to the original research questions listed at Chapter One.
**Longitudinal model of BMI.**

This study presented a longitudinal model of BMI from birth to adolescents depicting distinct pathways between males and females, as well as between individuals who were normal weight, overweight or obese (Figure 14) (Chivers et al., 2009). Details of this model have been discussed earlier in this chapter, with highlights presented throughout the chapter on the individual influences obesogenic factors had on this trajectory of BMI. Most importantly, this longitudinal model demonstrated that individual, behavioural and environmental factors were cumulative, and had both positive and negative effects on BMI.

These cumulative effects were sometimes specific to gender. Language development (Denver II and IMQ) that was *not normal* in females resulted in increased BMI, possibly reflecting a difficulty in self-regulation behaviour (Houck, 1999), or were more specifically related to the female gender in the development of self-concept (Okely et al., 2004). This was confirmed by an indifferent social progress rating for overweight and obese females at age 10 years, and an inverse relationship between self concept scores (SPPA) and BMI at age 14 years. In addition, increased physical activity levels (e.g. organised sport) had a more pronounced decrease on BMI for females, and may be related to the lower baseline levels of activity in which females are involved, compared to males (Olds et al., 2004; Steinbeck, 2001).

The different cumulative effects were also present for the weight status groups. Individuals who were obese and rated *not like their peers* in their early childhood locomotor skills (IMQ) and had lower activity levels (step count) in adolescence, increased their BMI, distinct from the normal weight and overweight groups. Improved motor competence score (age 10 and 14 years) was also protective, decreasing BMI by 2.2 kg/m$^2$ and 0.5 kg/m$^2$ respectively. This suggests a link between motor skill proficiency in mid childhood and later physical activity levels in adolescence, with an association between perceived competence and activity levels previously shown (Barnett, Morgan, van Beurden, & Beard, 2008). Individuals who
were overweight tended to be more affected by low motor competence in late childhood, by having both parents unemployed and by parenting style. More positive parenting scores in particular were most protective for those overweight, with significant decreases in BMI (2.2 kg/m²). This association with parental influences suggests that parental role modelling (Gibson et al., 2007), exercise habits (Cleland et al., 2005) and style (Rhee et al., 2006) may be more important for those children who are on the trajectory of overweight.

Overall, a continuum of positive and negative influences on BMI trajectory was shown, and has been discussed in detail previously. These key factors included maternal smoking during pregnancy, parental BMI, early feeding behaviours, aerobic fitness and basketball throw, sedentary behaviour, social progress, and attitudes and values to physical activity. For example, children from normal weight mothers (pre-pregnancy) decreased their BMI by 0.43 kg/m², and children who were breastfed for less than 4 months increased their BMI by 1.19 kg/m² (Chivers et al., 2010). The diversity in nature of effects in the longitudinal model of BMI confirms the complex and multi-faceted nature of adolescent obesity.

**Critical time periods.**

The developmental pathway to adolescent obesity was shown to be dynamic with periods of rapid change and periods of relative stability. There is evidence for three main periods to be a critical times for the development of obesity: perinatal, early childhood, and adolescence (Blair et al., 2007; Dietz, 1994; Lawlor & Chaturvedi, 2006). This study provided strong evidence to support a critical developmental period between birth and 8 years with three critical phases: perinatal, from birth to 3 years (early childhood), and 6 to 8 years (early adolescence). Unfortunately, data were only available until age 14 years for this study, and any adolescent and pubertal changes were unable to be examined in detail without another subsequent wave of data.
**Perinatal period.**

Several different mechanisms have been suggested to operate in the perinatal period (Dubois & Girard, 2006), with this study confirming the influences of maternal smoking and high birth weight on adolescent obesity. Maternal smoking during pregnancy was associated with lower weight babies, but from birth to adolescence these children had higher BMI, concurring with others (Dubois & Girard, 2006; Gillman, 2008). It is believed that growth restriction due to maternal smoking during pregnancy is then followed by postnatal catch up growth, which continues and is associated with later obesity (Dubois & Girard, 2006).

Higher birth weight was also associated with adolescent obesity. In particular overweight adolescents were more likely to have had higher birth weights compared to normal weight and obese adolescents. Higher birth weights are associated with later obesity (Dietz, 1997), with in utero conditions favouring high weight gain suspected to continue postnatal, suggesting the influence of an environmental factor (Dubois & Girard, 2006).

**Early childhood.**

The timing of adiposity rebound is a marker for later obesity (Lawlor & Chaturvedi, 2006; Rolland-Cachera et al., 1984) and in this study began as early as age 3 years, with children on a trajectory of overweight and obese between age 3 and 6 years (Chivers et al., 2009). Rapid growth and weight gain, as depicted in the longitudinal model (Figure 14) have long been suggested to be related to adult obesity (Law, 2001). It has been speculated that adiposity rebound may be an important marker as it is related to the expression of diet and activity behaviours (Dietz, 1997).

Early feeding behaviours, particularly exclusive breast feeding had an important relationship with BMI, which remained until age 14 years (Figure 3). Exclusive breastfeeding influenced the peak BMI at age 1 year, as well as the timing of, and BMI at adiposity rebound, and this influence remained until at least age 14 years (Chivers et al., 2010).
In respect to early motor development behaviours, this study showed that children aged 1 to 3 years were more likely to become overweight or obese if they were not assessed as developing normally. By age 10 and 14 years, low motor competence was associated with obesity, suggestive of a possible tracking of motor ability from early childhood. A relationship was also shown between motor ability and physical activity.

Early childhood physical activity behaviours (ages 1, 2, 3, 6 and 8 years), also demonstrated an association with later adolescent obesity. Physical activity behaviours have been shown to track across time, in concurrent work with this cohort (Hands et al., 2010b), as well as in other studies (Janz et al., 2000; Kelder et al., 1994; Telama, 2009). The Hands and colleagues study (2010b) also showed that screen time in early childhood (ages 6 and 8 years) might displace time spent engaged in physical activity. SES was important across years, but individual items for family life stress had particular and consistent effects at age 6 years.

Longitudinal modelling also demonstrated a shift in both males and females BMI trajectories between 6 and 8 years (Chivers et al., 2009). This is considerably earlier than the suggested increased fat deposition and obesity risk for females during adolescence (Dietz, 1994). Together, these results suggest age 6 years might be an important turning point that also happened to coincide with the beginning of full time schooling in the state of Western Australia.

**Early adolescence.**

The limit of the data was 14 years for this study, and hence examination of changing influence in early adolescence and beyond was not possible. However, in this period many important changes were occurring. These include physical changes associated with puberty and psychological development of self concept. Both these factors were found to have important co-relationships with other obesogenic factors. Certainly, evidence is suggestive of important mechanisms during this period that are different to earlier periods.
Overall it is clear that major changes in individual, behavioural and environmental factors are occurring in early childhood, and that these complex interactions between biological and behavioural mechanisms (Dietz, 1997) are responsible, at least in part, for adolescent obesity.

**Interrelationship modelling.**

To further elucidate developmental pathways to obesity this study used exploratory SEM modelling to investigate possible pathways to BMI and interrelationships between factors at follow-up ages 6 to 14 years. SEM is typically used to determine how well a theoretical model is supported by the data (Dragan & Akhtar-Danesh, 2007; Garson, 2007; Schumacker & Lomax, 2004). Since a detailed theoretical model was not hypothesised, the findings from this aspect of the study are speculative at this time. Further investigations with an independent sample would be required to confirm whether these models are supported by other data.

However the exploratory processes provided some valuable insights into possible interrelationships and pathways to BMI. From age 6 years screen time patterns were important in the direct prediction of BMI, but the amount of screen time was influenced by the child’s activity levels. By age 8 years, this relationship was reversed, with screen time behaviours now predictive of time spent in organised sport and activity, the latter now influencing BMI. This suggests that screen time patterns are being established by age 6 years, as recently reported for 2- to 6-year-old Australians (Jones et al., 2009). At age 10 years, the importance of motor competence is shown, having an influence on both activity levels, screen time patterns and BMI, findings supported in the present study by cross-sectional and longitudinal modelling results, along with others (Graf et al., 2004). By age 14 years the relationship between motor competence and BMI remained strong, influencing future activity levels and BMI. Overall, motor competence, as determined by early childhood development, may be an integral part of facilitating a healthier lifestyle. Those with better skills are more likely to engage in physical activity (Williams et al.,
2008), less likely to have high screen time patterns (Jones et al., 2009), be more fit (Hands et al., 2008) and hence have healthier diets (Hands et al., 2010a), and a higher self concept (Okely et al., 2004).

Some notable gender differences in pathways were also found. At age 6 years the pathway between activity and income was significant for males but not females. This finding is interesting but might be explained by the nature of the question, with activity representing music, dance, kindygym and other clubs. These activities may be considered feminine in nature with parents of boys not enrolling their sons in these types of activities. The tendency for boys to participate may be related to parent influenced gender linked stereotypes (Bussey & Bandura, 1992, 1999). In turn, parent influence may be associated with SES factors such as education, occupation and income. At age 10 years, the pathway between motor coordination and activity was more significant for males than females. This suggests that the relationship between better skills and more physical activity (Williams et al., 2008) is stronger for males. At age 14 years, although significant, the influence of fitness on BMI was greater for females than males, whereas mother’s BMI was stronger for males than females. Compared to females, the effect of puberty was highly significant for males, and relates to the physical characteristic changes which provide males with increased muscle strength (Hayward, 2003; McCarthy et al., 2006). The pathway between income and screen time was only significant for males, suggestive of SES influences in this behaviour. Specifically this may relate to the availability of screen based games and computers.

This exploratory process also identified other factors not important in strengthening the prediction of BMI in the overall models, this itself being of interest. In the first year of life, breastfeeding was the only strong predictor of BMI. This is not surprising considering the strong link between breastfeeding and obesity in this study (Chivers et al., 2010) and others (Butte et al., 2002; Gillman et al., 2001; Oddy et al., 2006c), which suggests that other factors (e.g. locomotor skills, diet, and physical activity) have a limited impact on BMI in the first year of life. Surprisingly, yet consistent with other results, diet variables at ages 8 and 14 years
did not have any relationships, and probably relate to limitations in the data used, such as lack of information on portion size (Rennie et al., 2005; Steenhuis & Vermeer, 2009) and or more comprehensive dietary pattern information (Ambrosini et al., 2009a; Hu, 2008c). At 14 years, the school environment, self concept and valuing of physical activity, did not have any pathways to BMI, however other factors were seen to influence them. For valuing of physical activity this may reflect a possible lag between thoughts and beliefs and measurable behaviours such as physical activity. As Houck (1999) describes, self concept capacities have already begun to develop in early childhood. For the school environment factors, exploratory results showed that school influence was related to family income, and was not related to BMI, which is similar to findings by others (Cleland, Crawford, Baur, Hume, Timperio, & Salmon, 2008a; O’Malley et al., 2009).

The exploratory processes undertaken for this part of the study provide important information on possible pathways and interrelationships between factors on BMI at several time points in childhood and adolescence. Directionality in pathways provides insights into possible mechanisms of action, and potential opportunities for intervention. SEM results provide evidence-based models available for testing in other datasets, in addition to raising new questions and hypothesis for future research.

**Gender differences.**

Consistent with previous literature, gender differences were generally common across many variables, and in some obesogenic influences over time (Longitudinal model of BMI). In relation to physical skills, males generally out performed females in performance type tasks such as dodge, object control, bike riding, muscle endurance and strength, while females outperformed males in skipping and fine motor skills. Females were more flexible, and involved in more activities (such as dance, gymnastics), while males played more sport, had higher activity levels at higher intensities and were more aerobically fit.
For self concept domains, females scored higher on behavioural conduct and close friend, while males scored higher in athletic competence, physical appearance, global self worth and romantic appeal. Compared to males, females academic performance, learning skills progress and behavioural progress was more likely to be rated highly by parents or caregivers. Compared to females, males were more positive about physical education classes, the effects of physical activity, and less likely to report excuses for not increasing physical activity in the future.

Until adolescence, screen behaviours were similar between males and females. However, at 14 years more males were now involved in high levels of screen time compared to females. This period was also associated with puberty, with more females in the later stages of pubertal development compared to males.

The longitudinal model of BMI clearly depicted gender as an independent moderator of effects with distinct trajectories and an overlap between ages 8 and 10 years (Chivers et al., 2009). Exploratory SEM models also demonstrated gender differences in pathways to BMI (discussed previously). These included significant differences between males and females in the following paths:

- family income and organised activity, age 6 years;
- motor coordination to activity, age 10 years;
- aerobic fitness to BMI, puberty to aerobic fitness, mother’s BMI and BMI, and income and screen time, age 14 years.

Overall, these findings confirm the importance in specifically identifying and acknowledging gender differences in obesity studies. This includes investigations of the possible influence on obesogenic factors and taking into account how these gender influences might change over time. Such basic knowledge is at the core of the development of appropriated and effective public health interventions.
Differences between overweight and obese adolescents.
The weight status group differences identified in this research revealed that overweight and obese adolescents’ responses were not always in the direction expected, nor always on a continuum from normal weight to obese. As far as is known, no such evidence has been presented within the literature, and reflects the complex and dynamic nature of the constructs of weight status.

The following findings highlight these non-typical trends:

- A high frequency of vegetable intake was greatest for those overweight, and least for those obese, and only for females.
- Obese individuals were more likely to have non-normal developmental milestones, but by late childhood motor abilities across weight status were along the continuum. However, longitudinal modelling found at ages 10 and 14 years low motor competence scores (MAND) resulted in increases in BMI for the overweight group only.
- Overweight and normal weight individuals were similar in their parent reported activity levels at ages 6, 8, 10 and 14 years, with obese individuals less vigorously active, and more inactive.
- Screen time was similar for the overweight and normal weight groups at ages 6, 8, and 10 years, with the obese group watching higher levels of 2 hours or more of television. However at 14 years, the overweight group were now similar to the obese group, watching higher levels of 2 hours or more of television, compared to the normal weight group.
- Stress items revealed that overweight children had a higher frequency of reporting family stress items pregnancy problems at follow-up age 6 years, and residential move at 8 years than the obese or normal weight adolescents.
- LMM found that where both parents were not employed BMI increased for the overweight group.
- The overweight group had highest proportion of mothers who smoked during pregnancy.
• A higher proportion of overweight adolescents attended Catholic schools, while a higher proportion of obese adolescents attended coeducational government schools.
• LMM at age 10 yrs showed that the overweight group increased BMI with more negative parenting, compared to the obese and normal weight group.

Certainly, findings across individual, behavioural and environmental factors question the practice of combining data for overweight and obese into one group, which may mask true differences. It also highlights that interventions may need to be different for overweight compared to obese individuals and also time-period sensitive.

Summary
Individual, behavioural and environmental factors are all intricately interwoven in the multi-faceted nature of obesity. These interrelationships and obesogenic influences have been shown to change over time, with this data confirming early childhood as a critical period for the development of obesogenic behaviours. Further, pathways differ for males and females, with obesogenic influences different across gender and changing over time. Longitudinal modelling demonstrated clear distinctions in the pathways of normal weight, overweight and obese groups, with obesogenic influences on BMI being both negative and positive. Influences were also shown to be different for individuals who are overweight or obese, and not necessarily on a continuum. Together these results demonstrated complex and dynamic interactions within individuals and among their environmental influences.
Fourteen years

“Adolescence is a new birth,
for the higher and more completely human traits are now born.”

By G. Stanley Hall