Feeding behaviour and its relationship to weight gain in infancy: behaviour and its relationship to weight gain

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Abstract

This thesis involved a longitudinal study of 30 healthy infants from 6 weeks to 15 months to investigate the relationship between feeding behaviour and weight gain in infancy. Poor infant weight gain is associated with adverse outcomes in childhood (e.g. Skuse, Pickles, Wolke, et al 1994) and adulthood (e.g. Fall, Vijayakumar, Barker, et al 1995). Previous research has investigated the relationship between feeding behaviour and concurrent weight, but with a few exceptions there has been little previous work on the relationship between feeding behaviour and weight *gain* in infants. Feeding behaviour was measured at four breastfeeds in 32 infants at six weeks and later in 30 of the same infants at 12 months during solids feeding. Birthweight was obtained from parents' child health records and weight was measured at 6 weeks, 3 months and thereafter every 3 months until 15 months. Sucking patterns during milk feeding were found to be independently associated with infant weight gain, but there was no independent association between solids feeding behaviour and weight gain. Other independent predictors of weight gain were; infant sex, milk intake during breastfeeding and age of introduction of solids. An analysis of associations between milk and solids feeding behaviour found some evidence of parallels within infants across the two different types of feeding and the implications of this are discussed. A new method for the analysis of breastfed infants' sucking patterns which resolves the serious problems of the already published methods was developed during the course of the study and an outline of this is provided. Previously unavailable data on (1) the behaviour of one year olds during solids feeding and (2) the components of variation in milk and solids feeding behaviour are discussed.

Feeding Behaviour and its Relationship to Weight Gain in Infancy

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Contents

Figures

Tables

Tables

Appendices

Declaration

No part of the work contained within this thesis has previously been submitted by the candidate for a degree at any university.

Statement of Copyright

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Chapter 1

Introduction

The main focus of this thesis is the relationship between feeding behaviour and weight gain in infancy. Poor infant weight gain is associated with adverse outcomes in childhood such as stunting of growth (Costello 1989) and developmental delay (Skuse, Pickles, Wolke, et al 1994), and with adverse outcomes in adulthood such as coronary heart disease and diabetes (e.g. Fall, Vijayakumar, Barker, et al 1995).

There is good evidence that weight gain in infancy is regulated; at birth, weight is influenced largely by the gestational environment with genetic influences playing only a very small role (Carr-Hill, Campbell, Hall, et al 1987) but investigations of growth in length during infancy have found evidence that it is 'target-seeking'. In other words, the growth patterns of infants gradually shift towards the trajectory that is 'genetically correct' for them in early life; short infants with a genetic potential to be tall (i.e. who had tall parents) show rapid catch-up growth soon after birth which lasts for the first year, and the opposite pattern of growth is found in infants who are long at birth but have a genetic tendency for smallness (Smith, Truog, Rogers, et al 1976). Further evidence of the regulated nature of growth is found in studies of catch up growth following acute malnutrition or illness (Tanner 1989).

The finding that infants start at a point at birth where weight is relatively uninfluenced by genetic factors but over the first year gradually move towards a track that is genetically 'correct' suggests infants regulate their nutrient intake to be in line with their growth needs. A series of experiments by Fomon and co-workers on bottle fed infants demonstrated that infants are able to adjust their intake volume in response to manipulations in the energy density of formula so that growth in length is not affected (Fomon, Filer, Thomas, et al 1975). Breastfed infants can also regulate their intake despite alterations in the timing of feeds by compensating for long intervals between feeds by consuming more milk at later feeds (Pinilla & Birch 1993). There are no studies of intake regulation in older infants during solids feeding, but calorie compensation studies of pre-school children demonstrate that children of 3-5 years are also capable of self-regulation of intake (e.g. Birch & Deysher 1985).

Thus there is evidence that intake and growth are regulated by the infant. The precise mechanisms for this regulation have been little researched in human infants, but it is highly probable that the infant's own feeding behaviour is involved in this process. As it is actually through its behaviour that the infant obtains nutrients for weight gain, it is likely that change in feeding behaviour is one of the means through which the infant modulates nutrient intake in line with the growth trajectory. There have been many studies of weight gain in infancy and the possible influences upon it (e.g. Kramer, Barr, Leduc, et al 1985); there have also been studies of feeding behaviour and concurrent weight (e.g. Pollitt, Gilmore & Valcarcel 1978a, Drabman, Cordua, Hammer, et al 1979, Nakao, Aoyama, Suzuki 1990), but few previous studies have investigated the relationship between feeding behaviour and weight *gain* in infants. There is however, evidence from previous research that sucking patterns are related to future adiposity (Agras, Kraemer, Berkowitz et al 1987, Agras, Kraemer, Berkowitz et al 1990).

This lack of attention given to weight gain in studies of infant and child feeding behaviour is rather surprising since one of the fundamental features of infancy and childhood is growth. Energy intake in infants, unlike adults who are no longer growing, must be regulated about a set trajectory rather than a set point; at birth about 30% of energy intake is devoted to growth (Prentice, Lucas, Vasquez-Velasquez, et al 1988) and while this drops considerably as growth velocity diminishes over the first year, a significant proportion of energy intake continues to be necessary for growth. Investigations of associations between feeding behaviour and concurrent weight in infancy have therefore missed an important dimension of the regulation of energy intake in infancy and childhood.

In addition to feeding behaviour, various other known or possible influences upon weight gain in infancy will be investigated including; the BMI of parents, the duration of breastfeeding and age of introduction of solids. To examine the relative influence of the two different types of feeding (milk and solids) on weight gain, data were collected on both. As these measures were to be made in the same infants across the two types of feeding it is also possible to investigate the associations between milk and solids feeding behaviour. Previous research on this relationship in rats (e.g. Hall & Williams 1983) has provided evidence that the two types of feeding are regulated separately, but no research has yet addressed this issue in humans.

Milk feeding behaviour was measured in breastfed infants while they were actually being breastfed. Previous research has concentrated almost exclusively on the measurement of sucking patterns while infants are fed from bottles (e.g. Kron, Stein

& Goddard 1963, Alexander & Roberts 1988), but as there are considerable differences between breast and bottle feeding (Akre 1989) it was felt important to investigate whether any associations between feeding behaviour and weight gain were apparent when infants were measured in their adaptive context for feeding i.e. on the breast. There are also fundamental problems with the traditional statistical techniques for summarising infant sucking patterns, especially as applied to breastfed infants, so a further aim of this study is to develop a new method for the analysis of breastfed infants' sucking patterns which resolves the problems associated with the existing methods.

Literature

From searches of the bibliographic databases Medline and PsycLIT it became clear that although there is relatively little published research directly relevant to this study, there are many hundreds of published studies which bear at least some relation to the issues under investigation. This review of published literature is therefore necessarily selective.

The importance of weight gain in infancy

Childhood outcomes of poor weight gain in infancy

Poor weight gain in infancy has been associated with adverse outcomes in childhood, such as developmental delay (Skuse, Pickles, Wolke, et al 1994) and stunting of growth (Costello 1989). In paediatric practice, poor weight gain is termed failure to thrive, although the defining criteria vary from clinician to clinician. The definition of failure to thrive is technical and complex and only a brief overview will be given here.

Failure to thrive is a disorder of infancy and early childhood, characterised by slow weight gain. Understanding of the condition has been hampered by the use of hospital based samples which are unrepresentative of infants with failure to thrive in the community (Skuse 1993). More recent epidemiological studies indicate the prevalence of failure to thrive in inner-city communities to be around 3.5 %, of whom just 6% had an organic disorder that could account for the poor weight gain (Skuse 1993).

There is consensus that failure to thrive is best defined in terms of anthropometric measures, but there is little agreement about precisely what degree of growth faltering constitutes failure to thrive and various measures of growth have been used including weight for length, and weight gain. Weight for age, one of the most commonly used measures, is based on growth standard charts, but these are based upon data collected cross-sectionally and are not entirely suitable as a reference for sub-normal weight gain over time. For example, a criterion such as falling below the 3rd centile on a standards chart will include false positives such as constitutionally small children and exclude false negatives such as children who fall from a high centile position but remain above the 3rd centile. Wright, Matthews, Waterston, et al (1994) devised a velocity measure known as the 'thrive index' to identify failure to thrive; the measure corrects for regression to the mean and generates a measure of weight gain that is the difference between a child's expected and actual weight gain.

Dowdney, Skuse, Heptinstall, et al (1987) conducted a retrospective investigation of the relationship between developmental delay and growth retardation among inner-city infants. From a cohort of 1233 Caucasian infants born in one health district in 1980, children who were below the 10th percentile on the British Standard Growth charts for height and weight in 1984 (after controlling for parental height and weight) were identified as cases of failure to thrive. Controls were chosen from the same health clinic to match for socio-economic status and matched for sex. Case children scored significantly lower than controls on measures of cognitive development (General Cognitive Index); the mean GCI for cases was 70.1 (SD 17.6) and 97.7 (SD 15.2) for controls. However, because the cases in this sample were selected on the basis of their attained growth in childhood, rather than their weight gain in infancy, it is difficult to draw any firm conclusions from this study on the importance of early weight gain for later development.

A later prospective study by Skuse, Pickles, Wolke et al (1994) specifically investigated the relationship between impaired growth during early infancy and mental development. This was based on the hypothesis that early infancy, a time of rapid brain growth and maturation, may be a sensitive period for development of mental function. From a cohort of infants born during one year in a single inner-city health district, cases were selected if their weight-for-age z scores fell below the 3rd percentile for at least 3 months during the first 12 months of life. Preterm and low birth weight infants were excluded, as were multiple birth infants. Fifty-two cases of growth faltering were identified which included three infants identified as having an organic disorder significant enough to be a major factor in the infants' poor growth. A comparison of cases versus a group of matched control infants showed no differences between the two groups on scores for mental or psychomotor development at 15 months. However a separate analysis showed the timing, duration and severity of growth faltering was associated with poor mental and psychomotor development; the earlier the faltering occurred, the poorer the mental development associated with it. This was true for faltering that occurred in the first 3 months of life but faltering that began after 3-6 months of age was not associated with developmental delay. A more recent community based, case-control study of failure to thrive and cognitive development in Israel, found infants with failure to thrive in the first 15 months scored had significantly lower scores on the Bayley scales of mental and motor development than matched controls (Wilensky, Ginsberg, Altman, et al 1996).

This evidence suggests there is a link between growth in early life and mental development, but it is important to remember that these studies alone are not sufficient to conclude that undernutrition is the primary cause of poor mental development. For example, there may be pre-existing problem with development; if manifested as reluctance to feed and poor oral motor skills this may predispose the child to undernourishment and growth faltering (Mathisen, Skuse, Wolke, et al 1989).

Poor weight gain in infancy and outcomes during adulthood

Over the past decade epidemiological evidence had accumulated on the hypothesis that several major diseases of adulthood have their origin in fetal and infant life (e.g. Barker 1995). The 'Early Origins Hypothesis' concerns the relationship between early growth and diseases such as coronary heart disease and diabetes; it contends that nourishment in utero and infancy, as indicated by fetal and infant growth, results in 'metabolic programming' which influences the development of disease. Barker (1995) has suggested the associations between infant weight and disease in later life may be due, in part, to resistance to growth hormone, a condition which has been associated with poor weight gain in infancy (Barker, Gluckman, Godfrey et al 1993). Growth hormone gradually plays an increasing role in the control of growth from late gestation. High circulating levels of growth hormone have been found in those resistant to this hormone and high concentrations of growth hormone may be associated with cardiac enlargement and atheroma in blood vessels, leading to later pathology. The discussion below will concentrate upon studies of the early origins hypothesis as it pertains to weight in infancy.

Studies of the relationship between infant growth (birth weight and weight at one year) and disease outcomes during adulthood have utilised the child health records of men and women born in Hertfordshire, between 1911 and 1930. Birthweight and weight at one year were systematically recorded for all infants born in Hertfordshire during this period. For the mortality studies 79% of the boys and 60% of the girls were traced. Standardised mortality ratios for coronary heart disease in men dropped from 102 in those who weighed 2.49 kg or less at birth to 66 in men who weighed more than 4.54 kg. For weight at one year, standardised mortality ratios dropped from 105 in men who weighed 8.16 kg or less to 42 in men who weighed more than 12.24 kg. The highest cardiovascular disease death rates were found in men with below average birth weights and below average weight at one year. Standardised mortality ratios for coronary heart disease in women dropped from 83 in those weighing 2.49 kg or less at birth to 49 in those weighing more than 4.54 kg. There was no association between weight at one year and death from coronary heart disease in women (Osmond, Barker, Winter, et al 1993) but there is evidence that weight at one year is associated with death from ovarian cancer (Barker, Winter, Osmond, et al 1995).

Impaired glucose tolerance and non-insulin dependent diabetes in middle and later life have also been found to be associated with lower birth weight and lower weight at one year in the Hertfordshire men (Hales, Barker, Clark, et al 1991). Further studies have shown low weight at one year, but not birth weight, is associated with elevated risk factors for coronary heart disease (plasma fibrinogen and factor VII concentrations) and increased prevalence of coronary heart disease (Barker, Meade, Fall, et al 1992, Fall, Vijayakumar, Barker, et al 1995). These associations between infant weight at one year, coronary heart disease in later life and risk factors for coronary heart disease were found within each social class (defined at birth and at the time of the study) and in non-smokers, former smokers and current smokers. In women, some cardiovascular risk factors are related to birth weight but not to weight at one year (Fall, Osmond, Barker, et al 1995).

There some problems with the evidence on the relationship between weight in infancy and coronary heart disease. First, in the morbidity studies (CHD prevalence, risk factors for CHD impaired glucose tolerance), only a small fraction of the original cohorts were investigated. Barker et al have suggested this would undermine the findings only in the unlikely event that the relationship between early growth and cardiovascular disease differed between those followed up and those lost to follow up.

Second, there are some internal inconsistencies in the findings; in the mortality studies, birthweight and weight at age one in men predicted death from coronary heart disease but for coronary risk factors and prevalence of coronary disease, only weight at one year was a predictor. The evidence for women is different again where only birthweight, not weight at one year, is related to mortality from CHD and cardiovascular risk factors. It has been suggested that the different patterns of association between men and women can be accounted for because male infants are more susceptible to weight faltering as they have a more rapid weight velocity than females (Osmond, Barker, Winter et al 1993). Third, in the mortality studies there is the possibility the associations may be confounded with social class. In the later studies on coronary heart disease risk factors and disease prevalence however, social class at birth, current social class and smoking were all investigated and the association between disease outcomes and infant weight held after controlling for these variables.

Although the relationship between infant weight and coronary heart disease is yet to be confirmed, evidence for the importance of weight at one year in men is particularly persuasive. In the mortality studies there is a strong and dose dependent relationship between weight at one year and death from cardiovascular disease; in the risk factor and cardiovascular disease prevalence studies the relationship with weight at one year is independent of method of infant feeding (whether bottle or breastfed), social class (assessed at the time of the study and at birth) and smoking.

Characteristics of infant weight gain and linear growth

During infancy weight gain is extremely rapid; by four months of age most infants have doubled their birth weight and by one year, most have tripled their birthweight (Cole 1995). This is good evidence that weight gain in infancy is regulated; it follows a highly predictable course where the rate of weight gain continuously decreases in infancy before it stabilises during the late pre-school years (Bogin 1988). Smith, Truog, Rogers et al (1976) investigated growth in length during infancy and found evidence that it is 'target-seeking'. Data from infants who were large or small at birth (above the 90th or below the 10th centile for length) and who moved up or down to the 50th centile by two years of age were examined. Short infants with a genetic potential to be tall (on the basis of their parents' height) showed rapid catch up growth soon after birth which lasted until around the first birthday. Infants who were long at birth but had a genetic tendency for smallness did not show any significant deceleration in growth rate until after the first 3-6 months but most had reached their new growth trajectory by 13 months. Thus the growth trajectories of these infants appeared to shift towards the track that is 'genetically correct' for them providing evidence of the regulated nature of growth in infancy (Tanner 1989). Further evidence is found in studies of catch up growth following acute malnutrition or illness (Tanner 1989). Typically growth is found to slow down or cease during such episodes, however, when the food supply or health is restored, the rate of growth is found to exceed that of age mates to compensate for earlier losses and eventual size is unaffected. This holds true only if the illness or malnutrition does not occur in very early in life, or for prolonged periods.

Weight in infancy and subsequent obesity

Two prior studies of the relationship between sucking patterns and anthropometric outcomes (Agras, Kraemer, Berkowitz, et al 1987, Agras, Kraemer, Berkowitz, et al 1990) have been prompted by an interest in understanding the aetiology of obesity. As obesity is extremely resistant to treatment once established, there has been considerable interest in preventing the development of the condition. Research on developmental changes in adiposity has shown that while there is some continuity in adiposity between adulthood and childhood the magnitude of correlations are small; correlations between age 1 and 21 are 0.25 for BMI (Rolland-Cachera, Deheeger, Guilloud-Bataille, et al 1987); and 0.14 for skinfold (Garn & La Velle 1985). In a longitudinal study that examined the relationship between levels of fatness in infancy and at 5 years of age, Poskitt and Cole (1977) found no evidence to suggest most overweight infants were still overweight at 5 years. The risk ratio for fat infants becoming fat adults, as compared to infants as a whole, is about 1.6-1.8 (Rolland-Cachera, Deheeger, Guilloud-Bataille, et al 1987, Garn & La Velle 1985). The small magnitude of the correlations between infancy and adulthood means that predictions about future fatness based on levels of fatness in infancy are generally poor. Rolland-Cachera et al found that less than half of infants were still in their original adiposity category in adulthood.

According to Rolland-Cachera et al, the timing of BMI fluctuations during childhood is more useful than fatness in infancy for predicting adult levels of fatness. Changes in adiposity during childhood appear to pass through several successive phases; during infancy adiposity rises rapidly reaching a peak at about 8 months of age (Cole, Freeman & Preece 1995); it then drops during the pre-school years before starting to climb again at about six years. This second rise in adiposity is termed the adiposity rebound and it is the timing of this that has been associated with levels of fatness in later life, not adiposity in infancy. In a similar analysis of a larger data set Gasser, Ziegler, Molinari, et al (1995) found that the correlations between age of rebound and adult BMI were only 0.3; age of rebound seems a poor predictor especially when one considers that the correlation for BMI at 6, the mean age of adiposity rebound, with BMI in adulthood is about 0.6. Although this indicates some continuity in tracking of BMI from childhood to adulthood, correlations between infancy and adulthood are substantially lower and even correlations of 0.6 do not allow for very accurate predictions (Gasser et al 1995). Returning to the issue of sucking as a predictor of fatness, it is interesting to note that in the research by Agras et al (1990) measures of sucking were not associated with adiposity beyond 3 years of age. Therefore it seems levels of adiposity in infancy are not closely associated with those in adulthood.

Non-behavioural influences upon weight gain in term infants

Influences on birthweight

Weight gain in infancy is associated with birthweight. Regression to the mean is important in this context: on average, a group of individuals who are at the extreme for a particular measure tend to move towards the mean when they are next measured. In terms of weight the implication of this is that small infants tend to grow up through the centiles towards the mean and large infants tend to grow down towards the mean. However, even after adjusting for regression to the mean about half of a cohort of 3418 infants in Newcastle-upon Tyne studied by Wright et al (1994) shifted by one major inter-centile space on a standard Tanner & Whitehouse weight chart between six weeks and 9-24 months.

In two national cohort surveys conducted in 1958 and 1970, based on over 26 000 births, the major influences upon birthweight in term infants were found to be maternal height, smoking during pregnancy, parity and pre-eclampsia during pregnancy. The former two variables appeared to have a much greater influence upon birthweight than the latter two (Peters, Golding, Butler, et al 1983). A smaller study of around 1450 women, which examined a wider range of variables on fetal growth (birthweight corrected for gestational age) including alcohol and caffeine consumption during pregnancy, socio-economic factors (e.g. social class, income, housing) and psychosocial stress (e.g. anxiety, depression, social support), confirmed that maternal height, parity, infant sex and maternal smoking were the only independent influences upon fetal growth for the whole sample (Brooke, Anderson, Bland, et al 1989).

Maternal social class, age at leaving school and receipt of help with hospital fares were associated with fetal growth in preliminary analyses but these did not remain statistically significant after controlling for maternal smoking. However, a recent UK study of a larger data set using a different index of social deprivation (which was based on area of residence index instead of social class) found birthweight was associated with social deprivation after controlling for physiological (duration of gestation, ethnicity, maternal height, infant sex and parity) and pathological effects (smoking and pregnancy weight gain) (Wilcox, Smith, Johnson, et al 1995).

Whatever the precise influences, these studies are in agreement that gestational environment is a major determinant of birthweight in term infants. To examine genetic influences on birthweight separately from environmental influences associated with family membership, Carr-Hill, Campbell, Hall et al (1987) analysed birthweight correlations among 505 grandmother-mother pairs. All data were based on first births in women aged 18-25. Information on birthweights was extracted from a data bank consisting of birth records collected since 1950. Linkage between grandmother-mother records was established by using date of birth for mothers and date of confinement for grandmothers. After controlling for most of the major determinants of birthweight found in previous studies (infant sex, maternal height, gestational age and pre-eclampsia), correlations between birthweights for mothers and daughters were between 0.14 and 0.17 suggesting only a very small role for genetic factors (other than those determining maternal height) in influencing birthweight. The major influences upon birthweight in term infants are maternal height, smoking, parity, infant sex, pre-eclampsia and possibly socio-economic circumstances.

Influences beyond birth:associations between infants and parents

Most studies reporting data on parent-child correlations in anthropometric measures on younger children concentrate on height, probably because of the association between height and health and nutrition during childhood (Eveleth and Tanner 1990). As there are very few data on parent-infant associations in weight and none on weight gain, this review will focus upon research on height and weight for height.

In childhood, weight is quite closely associated with height; in one large study about 60% of variation in weight was attributable to height (Rona & Chinn 1982). The correlation between infant length at birth and parental height was only 0.2 but by 18 months this correlation has reached 0.5. This is similar to the correlation between parents and their adult offspring.

One difficulty in looking at parent-child correlations in anthropometric measures is that while this is relatively unchanging in adults, children are changing rapidly. This can be illustrated by considering changes in BMI (kg/m^2): while adult BMI increases only slowly with age (Garrow 1981), in childhood BMI changes quite substantially. BMI increases rapidly for the first 8 months, gradually falling during the pre-school years before rising again at around six years of age, and again showing a steep rise around puberty (Cole, Freeman and Preece 1995). The timing of these changes may vary between individual children (Rolland-Cachera, Deheeger, Guilloud-Bataille et al 1987) so adjusting BMI for age is quite difficult and these developmental changes may influence the magnitude of anthropometric associations between parents and children (Tanner and Israelshon 1963).

Because of interest in the development of obesity, there are several reports of the relationship between parental anthropometric measures and child weight for height. In a report based on data collected for the National Study of Health and Growth, Rona and Chinn (1982) investigated the associations between parental anthropometric and social characteristics and measures of weight (adjusted for height and age) in children aged 5-11 years. The total study population comprised over 5000 children with about 1600-1700 children in each of the three age groups (5-7, 7-9 and 9-11 years). Heights and weights of children were measured for the study but for parents were based on reported values. Both maternal and paternal height and weights were related to children's weight for height at all ages. The amount of variation in child weight for height explained by the inclusion of parental weight for height increased from around 1 percent in the youngest age group to 3 percent in older children. By contrast the association between birthweight and current weight for height was strongest in the younger age groups but tended to disappear in older children. In general the social factors measured in this study (fathers employment status and social class, number of children in the family, maternal age and maternal age at the end of full-time education) were not consistently related to child weight for height: the only independent effect was an inverse association between family size and weight for height in girls.

In summary there is evidence of associations between infants and parents in anthropometric measures. The size of these associations are influenced by the age and stage of development of the child but in general, are small in very early infancy and increase as development proceeds.

Influences beyond birth: socio-economic factors

As reported above, research carried out in the UK demonstrates that child weight (adjusted for height and age) is unrelated to parental socio-economic factors (Rona and Chinn 1982). Evidence from the Department of Health Survey (1989) conducted in children aged 10-11 and 14-15 years also show no consistent class differences. By contrast, research from the USA suggests anthropometric measures for the child are related to family social characteristics: Agras et al (1990) found less parental education was independently associated with greater BMI at six years of age although no associations with parental social characteristics were found before six years. An investigation of anthropometric differences also conducted in the USA found that regardless of ethnic group, overweight 11 year old girls were more likely to come from a low income family (Morrison, Payne, Barton, et al 1994). Therefore it seems that in British populations, associations between social class during childhood and obesity that emerge during adulthood (Braddon, Rodgers, Wadsworth et al 1986) do not actually begin to develop until after childhood.

Milk feeding

Breastfeeding

After delivery the level of circulating placental sex hormones that inhibit lactation during pregnancy diminish rapidly and 30-40 hours after parturition the breasts begin to fill with milk. The suckling infant plays an important role in promoting milk production by stimulating the secretion of prolactin from the anterior pituitary. Prolactin is one of the two key hormones involved in lactation; it is in response to prolactin that milk-protein and lactose is synthesised in the alveolar cells. Prolactin also plays a role in water and salt conservation thereby reducing the demands of lactation (Akre 1989).

Suckling also induces the release of the other key hormone oxytocin from the posterior pituitary. Oxytocin is involved in the milk ejection or 'let-down' reflex by causing the myoepthelial cells surrounding the alveoli to contract, forcing milk from the alveoli to the milk ducts. In some women the strength of the contractions can force milk out of the nipple at the beginning of a feed especially when the breasts are full. In the main however, milk is removed from the ducts by the negative pressure and the tongue movements of the suckling infant (Arke 1989).

Influences on lactation

Lactation is maintained by frequent suckling and emptying of the breasts which stimulates lactogenic hormones and prevents the build up of peptides in the breast which are thought to surpress lactation (Akre 1989). Disorders which severely inhibit or prevent lactation are rare; milk ejection can be temporarily delayed by stress, pain or the effects of engorgement but with careful management none of these conditions should prevent successful breastfeeding. Physiological conditions which severely compromise the production of milk are also rare yet 'milk insufficiency' is one of the main reasons cited by women in industrialised countries for giving up breastfeeding (White, Freeth & O'Brien 1992). Women in developing countries who often suffer from poor nutrition and health, and are frequently engaged in strenuous physical labour usually manage to breastfeed their infants and it is thought this is because lactation results in improved metabolic efficiency which in combination with the nutrient reserves deposited during pregnancy, help to compensate for the increased nutritional requirements (Prentice, Paul, Prentice, et al 1986). Therefore, except when undernutrition is extremely severe, milk production is largely unaffected by environmental conditions.

Nevertheless there are wide individual differences in the volume of milk production between women which appear unrelated to maternal age, parity, weight or BMI in well nourished populations (Dewey, Heinig, Nommsen, et al 1991a). Data on breastmilk volume is not a precise guide to actual infant energy intake as the macro nutrient composition of breastmilk is highly variable both between mothers and within mothers from day to day (Butte, Garza & Smith 1988). For these reasons the energy intake of infants receiving the same volume of breastmilk may vary widely (Lucas, Gibbs, Lyster, et al 1978). This variability in the energy density of breastmilk is mostly due to variation in the fat content of milk (Nommsen, Lovelady, Heinig, et al

1991); very little variation has been found in the lactose content of milk either between or within subjects.

No maternal factors (diet, parity, adiposity, age) have been found to be consistently related to the energy density of milk in well nourished populations in the first few months of lactation but after six months there is evidence that the energy density of milk is positively associated with maternal adiposity (Nommsen, Lovelady, Heinig, et al 1991). In a sub-sample of women who completed dietary intake records, maternal protein intake was also found to be associated with higher milk energy content. Nommsen et al suggest this changing sensitivity to maternal factors across the course of lactation may be due to the utilisation of fat stores accumulated during pregnancy and this masks any relationship in the early months. Only when these fat stores have been diminished does the effect of differing levels of adiposity and of diet become apparent.

Measurement of breastfeeding patterns

There are problems in defining what actually constitutes a ‘feed’ and criteria for this are rarely specified in studies of feeding patterns. In research over extended periods, it is mostly the mother who records feeding patterns but for this to be accurate, clear guidelines about what to record must be provided. Recording may be inaccurate if, for example, some mothers distinguish between 'feeding' and 'comfort sucking' and do not record the latter. In data collection this can be overcome by using a behavioural definition, such as asking the mother to record every time the baby attached to, and released the nipple. In analysing the data, the difficulty is one of deciding how to group together different bouts of sucking into feeds and there exists no widely accepted criteria for this.

Measurement of breastmilk intake

The most straightforward method of measuring intake in breastfed infants is by test weighing, which involves weighing the infant immediately before, and then after a feed. There are several sources of error in test weighing. Probably most important is the precision of the balances used (Drewett, Woolridge, Greasley, et al 1984). Studies where accurate estimates of milk intake are required utilise electronic integrating balances which take 20 replicate measurements of weight to reduce inaccuracies caused by the movements of the infant. Another source of error in test weighing is insensible water loss during feeding. This can vary depending on the temperature and humidity of the feeding environment (Butte, Wong, Klein, et al 1991), but there are methods to correct for it where very accurate determination of milk intake is required. A more difficult issue is that mothers may forget to test weigh their infants or there may be inaccuracies for other reasons, for example if the mother feeds her infant outside the home. There is only limited previous research on the accuracy of maternal test weighing records but in a study of 10 highly educated and motivated women, Dewey & Heinig (1987) found no evidence to suggest the requirement to test weigh altered the frequency of feeding. However, in a comparison of 5 day test weighing and the deuterium dilution method to estimate the breastmilk intake (which does not rely upon test weighing), Butte, Wong, Klein et al (1991) found that mean estimates of breastmilk intake were consistently lower in the test weighing records. Mean estimated milk intake was 752 g/day from test weighing records and 858 g/day for the deuterium dilution method. When corrected for environmental water influx and insensible water loss the difference between the methods decreased to 766 g/day and 807 g/day respectively, but this difference remained highly statistically significant. There were also wide individual differences in the size of the discrepancy between the two methods of intake estimation suggesting there were individual differences between women in the accuracy of their test weighing records.

The energy content of breastmilk, unlike formula varies quite widely between women (Akre 1989). Test weighing only provides a measure of volume intake, so breastmilk must be sampled to obtain an estimate of the actual energy intake. As the composition varies over the course of a day and over the course of a feed it is very difficult to obtain samples of breastmilk that allow its energy content to be precisely estimated (Nommsen, Lovelady, Heinig, et al 1991). The 'gold standard' method of estimating breastmilk intake is the deuterium dilution method. This involves administering small amounts of deuterium oxide to infants which allows water entering and leaving the body water pool of the infant to be estimated (Butte, Wong, Klein et al 1991). From this the milk intake can be derived. Although this method solves the problems discussed above, it does not provide an estimate of intake at individual feeds. It also requires specialised technical facilities and is very expensive.

Sucking

Sucking is a reflex triggered by the application of pressure to the palate of the infant. It is present in a reasonably developed and co-ordinated from at about 34 weeks gestation (Ernst, Rickard, Neal, et al 1989). The movements involved in sucking have been described by Woolridge (1986) based on previous cineradiographic work by Ardran, Kemp & Lind (1958a) and ultrasound studies by Weber, Woolridge & Baum (1986). A single suck consists of a raising up of the anterior tip of the tongue, accompanied by a momentary release, followed by a raising of the lower jaw. Beginning at the anterior tip, the tongue compresses the nipple against the hard palate in a peristaltic or 'wave-like' action moving in a posterior direction. This compressing continues to the base of the tongue squeezing milk from the nipple. The suck ends as the base of the tongue is depressed creating negative pressure which helps to draw the nipple back into the mouth for the next suck.

Three mechanisms are believed to be responsible for the transfer of milk from the breast: peristaltic action of the tongue compressing the nipple against the hard palate, negative pressure within the oral cavity which aids the progress of milk into the nipple from the ducts and particularly at the beginning of the feed, the mother's milk ejection reflex. Externally a suck is distinguished by the downward movement of the lower jaw and the upward movement of the larynx which accompanies the tongue actions (Johnson & Salisbury 1975).

Traditionally researchers have tended to study sucking under controlled laboratory conditions using artificial feeding devices. The focus of interest was usually not on feeding per se, but on sucking as a predictor of developmental outcomes (Kron, Ipsen & Goddard 1968, Wolff 1968). Thus data would typically be collected outside usual feeding context for a limited period or 'test feed' which would not usually last more than 2-3 minutes.

A distinction was normally drawn between nutritive sucking involving the delivery of fluid to the infant (e.g. Kron, Ipsen & Goddard 1968, Johnson & Salisbury 1975), and non-nutritive sucking where infants suck 'blind' on pacifiers or adapted nipples (e.g. Drier & Wolff 1972, Dreier, Wolff, Cross et al 1979). These two modes of sucking are associated with two distinct sucking patterns or rhythms: the nutritive sucking pattern involved a relatively slow continuous sequence of sucks at a rate of about 1/sec, and a non-nutritive pattern consisting of a distinct burst/pause cycle, with a burst of sucks in rapid succession (at a rate of about 2/sec) followed by a pause before the next burst of sucking.

This distinction between nutritive and non-nutritive sucking appears to be of little relevance when the sucking of infants is measured on the breast. In studies using both direct observation of feeds and intra-oral pressure measures of sucking, there was no evidence to warrant a distinction between nutritive and non nutritive sucking (Drewett & Woolridge 1979, Bowen-Jones, Thompson & Drewett 1982). The rate of sucking on the breast was found to follow a smooth gradient ranging from about 1 suck per second to 2 sucks per second. Furthermore, sucking largely seemed to follow a burst-pause pattern for most of the feed i.e. there appeared to be two types of intervals or gaps between sucks; short intervals within a sucking burst, and long gaps or pauses occurring between sucking bursts. The only exception to the burst-pause pattern is at milk ejection or 'let-down' which occurs at the beginning of the feed when sucks tend to occur in a continuous stream (Woolridge 1986). When the relationship between milk flow and sucking rates was examined by test weighing babies every three minutes during the feed, rate of sucking showed a negative association with milk flow; high rates of milk flow were associated with a slow rate of sucking and a low rate of milk flow was associated with a faster sucking rate (Bowen-Jones et al 1982).

Techniques for the measurement of sucking during bottle feeding have been in use since the early 1960s and have been widely tested by researchers as detailed in the many publications about sucking patterns on bottles (e.g. Kron, Stein & Goddard 1963, Wolff 1968, Alexander & Roberts 1988). Sucking on bottles is usually recorded using a pressure transducer attached to an artificial nipple via a cannula; such devices allow for the recording of sucking pressure as well as sucking patterns. By contrast, techniques for the measurement of sucking patterns during breastfeeding are far less developed and only a handful of studies have so far been published on this issue. A technique which is rather similar to that used during bottle feeding involves the measurement of intra-oral pressure within the infant's mouth (Woolridge & Drewett 1986). This involves taping a fine cannula to the mother's breast so that the cannula enters the infant's mouth when latched onto the breast. The cannula is attached to a pressure transducer which measures pressure changes within the infant's mouth in the same way as during bottle feeding. Aside from the major disadvantage that it is very intrusive, this method is only suitable for laboratory use and tends to generate a lot of missing data as the cannula is prone to obstruction.

Much less intrusive and more suitable for use in the field is recording of sucking by direct observation. In observation there are essentially two techniques for recording sucking behaviour: (1) feeding can be videoed and information about sucking behaviour can be entered into computer at a later date for analysis or (2) information about sucking behaviour can be entered 'live' onto a portable computer as breastfeeding is in progress. The latter method of recording has the advantages that it is less likely to cause embarrassment to mothers and, as the movements involved in sucking are quite fine and subtle, 'live' observation is better than video recordings for discerning sucking actions. The reliability of 'live' observation was found to be satisfactory in a study that compared records of sucking obtained by using pressure transducers with those obtained through live observation (Woolridge & Drewett 1986). Details of another technique for the measurement of sucking during breastfeeding, involving the use of a strain gauge attached to the infant's chin, have only recently been published (Ramsay & Gisel 1996).

Milk feeding and weight

Mother-infant interaction during feeding and weight gain

Most studies of mother-infant interaction during feeding have been concerned with charting the development of the mother-infant relationship rather than with feeding per se. In these studies feeding has merely provided a convenient arena in which to examine mother-infant interaction (e.g. Ainsworth and Bell 1969) and some observational studies of 'meal times' do not involve any recording of actual feeding (e.g. Stein, Woolley, Cooper et al 1994).

More relevant investigations have examined the avenues for the infant to exert control during feeding. For example, during a feed the infant may accept or refuse the nipple, suck or not suck, and leave or push out the nipple. This suggests there are important differences in the extent to which infants can exert control and these differences appear to be related to the mode of feeding. Crow, Fawcett, Wright (1980) observed feeding in both breastfeeding and bottle feeding mothers-infant dyads. The frequency of baby related maternal behaviours during feeding (after adjusting for the frequency of infant behaviours) was negatively associated with birthweight but only in the bottle feeding dyads; no such associations were found for breastfeeding mother-infant pairs. In a group of day old, bottle-fed newborns, Pollitt, Gilmore & Valcarcel (1978b) found that weight gain over the first month of life was negatively associated with the frequency and duration of mothers' attempts to 'clean' and 'groom' their infants during bottle feeding. A follow-up study with a sub-group of the same infants found that maternal behaviour during bottle feeding at one month was also associated with weight gain over the first month (Pollitt & Wirtz 1981).

This suggests that maternal behaviour during feeding may be associated with infant weight and weight gain over the first month. There are, however some problems with the evidence. Firstly these associations have only been found in bottle fed mother-infant pairs, and at present there is no evidence to suggest such associations are present in breastfed infants. Secondly, there are considerable difficulties in conducting observations of the quite subtle aspects of behaviour necessary to establish who 'controls' a feed (e.g. making judgements about control) particularly when it is impossible to make such observations while 'blind' to the mode of feeding. Thirdly, there are difficulties in disentangling the respective contribution of mother and infant to these associations. Pollitt et al suggest their findings indicate a lack of 'synchrony' in the behaviour of mother and infant, for example, that the mother is stimulating the infant at inappropriate moments. Crow et al (1980) suggest that mothers of small infants are responding to the size of their infants and possibly attempting to increase their infants intake through stimulation during feeding. The point is that neither of these studies have directly examined the feeding behaviour of smaller, more slowly growing infants. It is quite possible these infants display little interest in feeding; mothers may be responding to these subtle cues of lack of interest in feeding by attempting to stimulate the infant and so encourage feeding. Bottle feeding mothers are perhaps more likely to do this as they clearly have feedback about how much their infants are consuming in a way that breastfeeding mothers do not.

One means of distinguishing maternal and infant contributions is to compare mother-infant and nurse-infant feedings. A study of this sort by Thoman, Turner, Leiderman et al (1970) provides some evidence that the influence of maternal factors on the feeding interaction is partly attributable to differences in the infant. Such an analysis is of course impossible with breastfeeding infants. Another technique for disentangling maternal and infant contributions might involve a fully sequential analysis of mother-infant interaction to uncover precisely what, if any, cues mothers are responding to when they stimulate their small infants. This procedure was followed by Kaye (1977) who used two observers to record sucking and the behaviour of the mother (including gaze direction and 'jiggling' her infant). This appeared to show mothers were more likely to 'jiggle' their infants in response to certain subtle infant cues such as 'pauses' in sucking.

In summary, there is little evidence that maternal behaviour during feeding is associated with weight gain in breastfed infants. Techniques that might allow maternal and infant contributions to the feeding interaction to be disentangled are not suitable for fieldwork with breastfeeding mothers.

Feeding patterns and weight

Findings on the relationship between feeding frequency and weight gain have consistently found no relationship between the two. Studies by De Carvalho, Robertson, Merkatz et al (1982) and Butte, Wills, Jean, et al (1985) found no relationship between feeding frequency during breastfeeding and weight gain in the first months of life. This lack of a relationship could be due to the fact that these two studies recorded feeding frequency over just one day for most infants. However, Dewey, Heinig, Nommsen et al (1991b) recorded feeding frequency over 4 days when infants were aged 3 months and also found no relationship with growth velocity to 12 months of age.

There is, however evidence to suggest that feeding frequency in early life is related to levels of adiposity in later infancy. Based on maternal reports of feeding frequency over a seven day period at 2 and 4 weeks of age, Agras et al (1987) found less frequent (but larger) feeds were associated with greater skinfold thickness at 1 year of age, and greater a BMI at two years of age.

Few studies based on Western samples have examined the relationship between weight gain and feed duration. De Carvalheo, Robertson, Merkatz et al (1982) found a negative correlation between total duration of feeding per 24 hours over the first 14 days of life and percentage weight gain from birth to one month. In the only other study to examine this relationship, Butte, Wills, Jean et al (1985) report no relationship between feeding duration and weight gain but, as mentioned above, this study only measured feeding patterns over one day at each data collection point.

In summary it appears there is no clear relationship between feeding patterns and weight gain. This is not surprising since, although the mother responds to the signals of her infant, she has overall control over the initiation and cessation of feeds. Interpretation of infant signals by the mother may depend on temporal factors: immediately after a feed, or later when a feed is due again, crying is likely to be interpreted as a signal of hunger but at other times different interpretations, such as pain or discomfort, may be derived (Richards, 1975). This process of interpretation is likely to limit the extent to which infants can regulate milk intake and weight gain through their feeding patterns. It is possible that feeding is also initiated and prolonged for reasons other than ingestion of calories, for example, mothers may nurse their infants to calm them and because it is something from which mother and infant derive enjoyment.

Breastfeeding, bottle feeding and weight

There are many studies comparing the growth of breastfed and bottle fed infants. In developing countries where contamination of water supplies and feeding utensils is a major problem, the research is consistent in finding that breastfed infants gain weight faster than bottle fed infants (Dettwyler & Fishman 1992). In western countries where contamination is not a problem the results of studies are quite mixed. Earlier studies conducted in the period 1950-1970 tend to suggest that formula fed infants gain weight more rapidly than breastfed infants. However, such studies were conducted at a time when the composition, preparation of formulas and the age of introduction of solids was very different from those currently recommended (Whitehead, Paul and Cole 1989). More recent studies still present problems of interpretation as nationally there are major social differences between women who breastfeed and those who choose to bottle feed which may independently influence the weight gain and growth of breast and formula fed infants.

In an attempt to overcome these problems of interpretation, Dewy, Heinig, Nommsen et al (1992) compared the patterns of weight gain in a cohort of formula and breastfed infants matched for parental socio-economic status, education and the timing of the introduction of solids foods. Measurements of energy intake were taken every 3 months until infants were aged 18 months using four day weighed records of dietary intake and breastmilk. Weight, length and skinfold thickness were measured on a monthly basis to 18 months and then at 21 and 24 months. Weight differed significantly between the two feeding groups from 7 to 24 months but there were no statistically significant differences for height. An analysis of weight gain for each three month period showed that weight gain was similar for the first three months but differed between the two groups from 3 to 12 months. In a subsequent report based on the same sample of infants, weight for length and skinfold thickness was found to be higher in the formula fed infants from around seven months onwards. When energy intake was controlled however, feeding mode was no longer a statistically significant predictor of anthropometric differences suggesting that differences between the groups were not due to mode of feeding.

Milk intake and weight

Studies that record milk intake for a sufficient duration show there is a significant relationship between milk intake and weight gain. Whitehead & Paul (1981) measured milk intake volume over a 4 day period at monthly intervals from 6 weeks to 8 months (or until the cessation of breastfeeding if this was before 8 months) and found milk intake was correlated with weight gain until 6 months. In a very thorough study, Dewey, Heinig, Nommsen, et al (1991b) found a significant relationship between energy intake from breastmilk measured over 4 days at age three months and weight gain between 3 and 6 months. This study is the only one reported here to have adjusted test weighing records for insensible water loss during feeding and to have estimated the energy density of milk directly from 24 hour milk samples supplied by the mother. Perhaps the most surprising aspect of this study, given the precision with which it was undertaken, is the finding that the correlation between energy intake and weight gain was only 0.3.

Sucking behaviour and weight

In one of the first studies of the relationship between sucking behaviour and weight in infancy, Nisbett & Gurwitz (1970) looked at taste and sucking effort in infants of different birthweights and weight for length ratios. In the first experiment, 42 infants classified as heavy (3620-4960g) medium (2890-3540g) or light (2500-2880g) were offered a standard infant formula and a sweetened formula at two feeds. Heavy infants consumed significantly more of the sweet formula but there were no statistically significant differences in intake between the other two groups. In a second experiment reported in the same paper, Nisbett & Gurwitz looked at the effect of varying the size of the hole in the bottle teat (through which the milk flows) on intake at a feed. Infants were classified as heavy, medium or light according to weight for length ratios. There were no significant differences between the groups on the first testing day but on the second the milk intake of the heavy infants was depressed by 20% when they were fed using a teat with a small hole. Intake of the two lighter groups was unaffected by this manipulation.

This suggests differences in feeding behaviour may be attributable to infant weight. In the first experiment, however, the only outcome measure was intake and it should be noted that the two lighter groups also increased their intake for the sweetened formula. In both experiments the duration of feeding would be likely to have a substantial impact on the infant's intake but no data are reported regarding the duration of feeding, or what factors led to the cessation of feeding (i.e. whether this was determined by the experimenters, hospital policy, the mother's interpretation of her infant or by a specific infant behaviour).

For these reasons there are problems in using intake as a sole outcome measure. Pollitt, Gilmore & Valcarcel (1978a) looked at the concurrent relationship between measures of sucking behaviour and weight in a group of 40 infants at two days of age and then again at one month. Infants were fed for a limited duration from bottles attached to pressure transducers which allowed recording of sucking behaviour. Mean amplitude of sucking and intake per minute of the feed were correlated with weight at 2 days of age (r= 0.58 and r= 0.48 respectively). At one month, mean amplitude of sucking was correlated with weight at one month (r= 0.47). Although there were significant sex differences in these feeding behaviour variables, an analysis of covariance showed that infant sex did have not an independent effect on sucking behaviour.

The study by Pollitt et al only reported their results on the relationship between feeding behaviour and concurrent weight. Agras, et al (1987) looked prospectively at the relationship between early feeding behaviour and later outcomes. The sucking behaviour was measured at two and four weeks of age in a sample of ninety-nine infants. Information about infant feeding (age of introduction of solids, duration of breastfeeding and frequency of feeding) and parental demographic and anthropometric information was also recorded. Follow-up anthropometric measures of infant height, weight and adiposity (triceps skinfold thickness) were collected on 81 infants at 1 year of age, and 79 at 2 years. Greater skinfold thickness at 1 year of age was predicted by shorter pauses between burst of sucking and lower level of parental education; greater sucking pressure and maternal reports of fewer feeds per day in the first 20 weeks of life predicted greater skinfold thickness at 2 years of age. The number of feeds per day predicted BMI at 1 year of age and at 2 years; sucking pressure and energy intake were associated with BMI at borderline levels of significance. An analysis of intercorrelations among the factors which predicted levels of fatness at 1 and 2 years of age showed that a particular sucking pattern predicted later levels of fatness; this consisted of sucking at high pressure, with long sucks and sucking bursts, short intervals between sucks and sucking bursts and higher energy intake at a feed. Number of feeds per day and parental education were not associated with these variables.

A follow-up study of 54 of these children showed that early sucking patterns predicted fatness to 3 three years of age but not to 6 years (Agras et al 1990). Greater sucking pressure together with delayed introduction of solid foods predicted greater BMI at 3 years but none of the sucking behaviour variables were related to BMI at 6 years. Instead a combination of less parental education, greater BMI at birth, fewer feeds per day in early life and breastfeeding beyond 5 months of age predicted greater BMI at 6 years of age.

In these studies the authors were interested in predicting the development of fatness they do not report any analyses of weight gain. Secondly, skinfold thickness has a high measurement error rate because its range is very small during infancy and childhood (Agras et al 1990). There are also problems with the measurement of feeding behaviour in these studies; the authors report that the majority of infants in this study were actually breastfed yet sucking behaviour was measured while these infants were fed commercially prepared formulas from bottles and under laboratory conditions. It is possible that feeding behaviour was affected by being studied under these conditions. Sucking on the breast differs from that on the bottle in terms of motor actions (Nowak, Smith & Erenberg 1994) and sucking patterns (e.g. Drewett & Woolridge 1979). By the time these infants were several weeks old, they would have gained considerable experience in breastfeeding so taking measures of sucking using artificial feeding devices may have altered their usual sucking patterns. There are no published studies of how breastfed infants respond to being offered bottles, but there is anecdotal evidence to suggest some breastfed infants feed very poorly from bottles or refuse them completely (Kissling 1993). Regarding the use of formula, previous research in breastfed infants has shown sucking behaviour is affected by quite subtle tastes in breastmilk (Mennella & Beauchamp 1991). On bottles, it has been shown infants alter their sucking patterns in response to different tastes and concentrations of taste solutions (Crook 1978).

Why sucking?

There are several reasons to concentrate largely on sucking behaviour as a predictor of weight gain. First, as discussed above, there is evidence from prior research that sucking behaviour in early life is associated with certain anthropmetric measures later in infancy and early childhood. Second, other variables, some of which have been more thoroughly investigated than sucking behaviour, have been somewhat disappointing as predictors; milk intake, for example, is very difficult to measure in breastfed infants and even with precise measurement correlates quite weakly with weight gain (Dewey et al 1991b). Third, sucking in the human infant has parallels with tongue movements in rats during ingestion and microstructural studies of tongue movements in rats have been extremely useful in analysing the regulation of intake in the rat (e.g. Davis & Levine 1997, Davis & Smith 1992).

Although it is sometimes assumed that infants respond passively to their environment and have little direct control over their regulation of intake and growth there is considerable evidence to the contrary. Studies of catch-up growth, in which growth velocity has been reduced as a result of illness, but increases following recovery (to the point where there is no lasting affect on long-term growth) demonstrate the regulated nature of human growth (Tanner 1989). Evidence that infants are actually capable of regulating their intake comes from a number of studies. One of the earliest was a series of experiments by Fomon and co-workers on bottle fed infants. These studies involved manipulation of the concentration of infant formula followed by observation of caloric intake and infant growth over a number of weeks. Infants fed the dilute version of the formula were found to compensate by consuming greater volumes of formula than infants receiving the concentrated version. After a number of weeks, full caloric compensation was achieved and there was no difference in calorie intake between the two groups despite the fact that they received formulas of substantially differing energy density (Fomon, Filer, Thomas et al 1975).

In summary there is evidence that intake and growth is regulated by the infant. The precise mechanisms for this regulation have been little researched in human infants however, as infants are capable of changing their intake in response to manipulation of the energy density of milk and the timing of feeds, it is highly probable that sucking behaviour is involved in this process.

Solids feeding

Measurement of eating behaviour in children

Compared with the number of studies on adults there have been relatively few studies of solids eating behaviour over the weaning period. It is difficult to get access to pre-school children as many mothers[1] now return to work before their infant's first birthday and substitute care arrangements may be complex and variable. If observations of feeding are made on more than one occasion the infant may be fed by different carers and this is likely to introduce a greater degree of variability into eating behaviour. The little research that has been carried out, mainly on children aged two years and above, suggests there are a wide range of factors that may affect the eating behaviour of young children, and these influences may vary depending on the particular age range investigated. Other important issues in studying the eating behaviour of young children are considered below.

Type of food

Food intake in infants of weaning age (4-6 months) does not appear to be affected by the addition of salt (Sullivan & Birch 1994), yet children of two to three years of age prefer high levels of salt when presented in an appropriate food context (Beauchamp & Cowart 1990). Thus there are developmental changes in responses to salty tastes.

Preference for sweet taste are present at birth and remain constant throughout early childhood (Cowart 1981). Infants from 5-6 months ingest more of a solution as its

[1] In the context of this discussion of solids feeding, the term 'mother' is used as it is usually the mother who is the primary carer and therefore most involved in infant feeding.

level of sweetness increases (Desor, Maller & Greene 1977) and 2-6 year old children eat significantly more of sweetened than unsweetened spaghetti (Filer 1978). Children prefer high levels of sweetness and saltiness in their foods and drinks (Desor & Beauchamp 1987) so it is likely children's eating behaviour is influenced by the level of sugars and salt in foods and drinks.

Feeding behaviour of pre-school children is also influenced by the post ingestive consequences of foods. For example, 3-5 year old children consume less food following a high density preload than a low density preload (Birch & Deysher 1985). After a series of feeding trials where a low energy density food was repeatedly paired with one flavour (a 'low calorie flavour') and a high energy density version of the same food was paired with another flavour (a 'high calorie flavour'), when subsequently presented with a food of isocalorie density, Birch & Deysher found that children consumed less if it had the 'high calorie flavour' than if it had the 'low calorie flavour'. This demonstrates that children learn to associate flavours with foods of different energy density and adjust their eating behaviour accordingly. Not only are levels of food intake influenced by such manipulations but young children also learn to prefer flavours associated with foods of high calorie density over flavours associated with low calorie versions of the same foods (Birch, McPhee, Steinberg & Sullivan 1990).

As with adults, there is also some evidence that children's eating behaviour is affected by sensory specific satiety, i.e. that increasing the variety of foods at a meal increases intake. In their investigation of sensory specific satiety, Birch & Deysher (1986) found that children's preferences for different foods, only some of which were consumed, dropped for the foods they had eaten but not for the other foods. The drop in preference was only statistically significant at the preference assessment immediately following food ingestion and not at a second preference assessment 20 minutes after ingestion. Hence food acceptability alters temporally as a result of food ingestion and is specific to the foods consumed. A child who is offered a variety of foods at a mealtime is likely to consume more than one who is not.

Food texture also influences eating behaviour. Gisel (1991) investigated chewing behaviour in children in each of six age groups (6, 8, 10, 12, 18 and 24 months) who were videoed while being presented with standard foods of puree, viscous and solid textures. Time taken to swallow food (from placing the food in the mouth) and the number of chews for each presentation of food were recorded. Time taken to swallow foods was significantly different for foods of different textures: children took the least time to swallow puree foods, more time was required for foods with viscous texture and foods with solid texture took longest to swallow.

In studies involving pre-school children food neophobia can have a large impact upon children's willingness to eat novel foods. Research by Birch, McPhee, Shoba, et al (1987) with 2-5 year olds showed that neophobia was particularly high in the youngest children they studied so research involving the presentation of novel foodstuffs to young children is very difficult. Familiarity is an influence upon the food preferences and food intake of young children. This was investigated in two year old children by Birch & Marlin (1982) using a range of initially novels foods given to children to taste over a number of days and the number of exposures to particular foods varied. When tested subsequently, children's preferences were found to be highly correlated with the frequency of exposure to a particular food; thirteen of the fourteen children studied consistently chose the foods they were more familiar with.

Research by Harris and Booth (1987) demonstrates that food familiarity can interact with taste preferences. Two groups of one year olds were investigated; one group was reported by the parents to be fed (unsalted) potato on a regular basis, the other group received (unsalted) potato only infrequently. All infants were offered two versions of mashed potato, one salted (100 mg NaCl/100g potato), the other with no added salt. Frequent potato eaters consumed more of the unsalted version of potato whilst infrequent potato eaters consumed more of the salted version.

Parents and the eating context

A fundamental difference between the feeding behaviour of infants and young children, and that of adults is that the former are unlikely to feed themselves independently. There are no systematic studies investigating the influence of parental spoon feeding on the eating behaviour or food intake of infants and very young children, but taste preference researchers have recognised for some time that food intake may be more influenced by parental spoon feeding behaviour than by the food preferences of the infant (Filer 1978).

Klesges, Coates, Brown, et al (1983) investigated the relationship between children's level of adiposity and parent-child interactions at mealtimes. Fourteen children aged 1-3 years were observed at family mealtimes in the home using partial time sampling procedure (observe for 10 seconds and record for 10 seconds). Eating behaviour recorded included: the percentage of time spent eating, playing with food, crying, talking, requesting food, refusing food, spitting out food, away from table and engaged in other activity. Food related interactions between the index child and other family members were also recorded, including encouragement and discouragement to eat, food offers and modelling of eating. Significant positive correlations were found between the children's relative weight and the number of parental encouragements to eat, food prompts and offers. As the age range of children in this study was very wide, there are some difficulties in interpreting these results; younger children are less competent at self feeding and are more likely to elicit parental assistance and encouragement to eat, so the results of this study are confounded by age.

Evidence of the need to take age into account when designing studies of eating behaviour in children is provided by a larger study conducted by Koivisto, Fellenius and Sjoden (1994). The food intake of fifty 3-7 year old children was measured using seven-day weighed records of dietary intake. Videos of eating behaviour and parent child interaction during mealtimes were taken on two days. A coding system similar to that used by Klesges et al (1983) was used to analyse mealtime behaviour. After controlling for meal duration, energy intake was found to be negatively related to the frequency of parental assistance and negative statements about the child; positive associations were found between energy intake and the child 'taking food on the recommendation of the parent,' but after controlling for age these correlations were no longer statistically significant. As one would expect, age is related both to energy intake and parental interventions in children's eating.

Agras, Berkowitz, Hammer et al (1988) investigated the social transmission of parental eating styles to children. Instead of studying the direct effects of parental modelling on eating, or directive behaviour, they examined the relationship between the eating behaviour of children and of their parents as they ate separately. The eating behaviour of twenty nine children aged 18 months and their parents was recorded in a controlled laboratory situation. Although all family members ate alone, mothers were present when observations were conducted on their children to minimise the artificiality of the situation and disturbance to the child. A large number of eating behaviours were coded and energy intake was determined by providing subjects with a standard 'buffet' style array of foods which were weighed before and after the observation. Three eating behaviours were significantly associated in parents and children: active feeding time, bite frequency and calorie intake. Children with higher calorie intakes tended to have mothers who ate rapidly and fathers whose meal duration was longer.

Therefore parental behaviour may influence children's eating through social transmission which does not depend on direct modelling of behaviours, and in the case of fathers, occurs even when they are not present. There is evidence that other aspects of the eating environment may also have a strong influence on children's eating behaviour. Birch, Zimmerman & Hind (1980) investigated the effects of differences in the social context of food presentations on the formation of preferences in children aged 3-5 years. An initially neutral snack food was identified for each child at preference assessments prior to the main experiment. Each child was presented with this food in one of four different contexts: (1) as a reward for performing a particular action (2) non-contingently presented with adult attention (3) in a non social context (4) at a normal snack time. Statistically significant increases in preferences were found for the snack foods presented as rewards and non-contingently with adult attention. No consistent changes in preferences were observed for foods presented in the other contexts.

Other influences

As mentioned above, developmental differences influence eating behaviour in infants and young children. Even within samples of similar age there may be large variability due to differences in maturation and experience. For example, some infants of a year of age may be entirely spoon fed by the mother, some may be largely self-feeding, while most probably experience some mixture of the two. In comparing aspects of eating behaviour such as rate of food ingestion between subjects, it is important to consider how this might be influenced by the amount of assistance the child receives with feeding. Thus, in young children, eating behaviour may be a reflection of parental behaviour as well as the infant's appetite or satiation processes. Even when children become capable of feeding themselves independently, there will be different levels of competence in feeding skill which may affect intake and behaviour. In a study of the development of spoon using skills in one to two years olds, Connolly & Dagleish (1989) noted that although the developmental sequence of specific abilities followed a similar course in all infants, there was some variability between infants in the appearance of different skills.

Energy intake in infants and young children is also variable. In a semi-longitundinal study, Black, Coles, Wiles (1983) examined developmental changes in day to day variation of energy intake in two groups of infants aged 2-18 months. Four day weighed intake records were kept by mothers at monthly intervals in one group to 7.5 months and at 10, 12, 15, and 18 months in the other group. Breastmilk was recorded by test weighing. While infants were still fully breastfed, day to day variation was relatively low (within subject coefficient of variation of 10-11). As infants were weaned, variation in energy intake rose slightly, but by 15-18 months, it had increased markedly to reach levels comparable with adults (within subject coefficient of variation at eighteen months was 18). There were also individual differences in the degree of variability between infants; while some infants were quite consistent in their energy intake, others fluctuated quite widely.

Meal to meal variability in energy intake was examined by Birch, Johnson, Anderson (1991) in fifteen children aged 2-5 years. While intake was being recorded all children consumed the same foods which were supplied by the investigators. Birch et al recorded high variability in energy intake from meal to meal (mean coefficient of variation within subjects was 33.6) but variation from day to day (mean coefficient of variation 10.4) was considerably lower. Day to day variation in this study was also lower than that reported by Black et al on slightly younger children. This disparity could be due to the use of standardised meals by Birch et al which removes an important source of variation in energy intake.

One cause of variability in energy intake in young children is frequent illnesses. In the recent National Diet and Nutrition Survey of children aged 1.5 to 4.5 years, eleven percent of children were reported by their parents to be unwell but with appetite unaffected by their illness and sixteen percent of children were reported to be unwell and have decreased appetite as a result. For both groups of children energy intake was affected by the reported illness: for children with affected appetite, energy intake was about thirteen percent lower than children who were well, and even for children whose appetite was reported to be unaffected by illness, energy intake was six percent lower than for well children (Gregory, Collins, Davies et al 1995).

Influences on weight

Duration of breastfeeding

In a large observational study of 358 infants from birth to 12 months of age Kramer, Barr, Leduc et al (1985) found evidence that the duration of exclusive breastfeeding was associated with the infant's weight at 12 months of age: each additional week of exclusive breastfeeding was associated with lower weight at 12 months. The relationship between duration of breastfeeding and weight has been researched more frequently in developing countries though without much progress in clarifying the issue. In a review of the literature which considered only studies which used infants who were breastfed for over one year, Grummer-Strawn (1993) concluded that most studies had major design flaws and failed to address the issue of reverse causality (i.e. that poor growth could be a cause of prolonged breastfeeding).

Age of introduction of solid foods

In the observational study of 358 infants from birth to 12 months of age reported above, Kramer, et al (1985) found evidence that the age of introduction of solid foods was associated with weight measured at 6 and 12 months of age. After controlling for other independent predictors, birthweight, infant sex, duration of breastfeeding and age at time of visit, Kramer et al found a negative association between age at introduction of solids and weight: infants who were older when they were introduced to solids tended to be lighter. Measures of skinfold at 12 months were also associated with age of introduction of solids and birthweight.

Forsyth, Ogston, Clark, et al (1993) examined the relationship between the timing of the onset of weaning and weight in the UK. The 671 newborn infants recruited to the study were divided into three groups according to the timing of the introduction of solid foods; under eight weeks, 8-12 weeks and over 12 weeks. Each mother-infant pair was visited at home by a health visitor on eleven occasions (at 2 weeks and 2, 3, 4, 6, 9, 12, 15, 18, 21 and 24 months of age) to collect information about feeding, and weight was measured at 1, 2, 3, 6 12 and 24 months. After adjustment for other factors associated with weight (infant sex, method of infant feeding, birth weight and maternal height) infants introduced to solids before 12 weeks were heavier up to 26 weeks of age, but thereafter no statistically significant difference in weight was found between the three groups. The weight difference between infants introduced to solid foods before 12 weeks and those introduced after 12 weeks had been apparent from four weeks of age; as this was before the introduction of solids for almost all of the infants, it would appear that infant size influences the timing of the introduction of solids rather than the reverse.

The only randomised control study of the effect of age of introduction of complementary food on infant energy intake and growth (Cohen, Rivera, Canahuati, et al 1995) found no evidence for an association between age of introduction of solid foods and weight gain. This study was conducted among a low-income urban population living in Honduras. Exclusively breastfeeding mothers and their infants were randomly assigned to one of three groups when their infants were aged four months: continued exclusive breastfeeding to 6 months, introduction of solid foods at 4 months with no specifications about nursing frequency and introduction of solid foods at 4 months with instructions to maintain nursing frequency at pre- solid foods levels. To prevent infant illness arising from contamination of foods, all mothers in the solid foods groups were supplied with pre-packaged baby foods. There were no statistically significant differences between the groups either in total energy intake assessed at 16, 21, and 26 weeks, or infant weight gain from 4-6 months.

Eating behaviour and weight

A number of studies suggest that there is a relationship between eating behaviour and weight in adults, although the findings are not consistent. Spitzer and Rodin (1981) reviewed the literature and concluded there were two major differences between obese and normal weight individuals in their eating behaviour; firstly the obese were more likely to consume large amounts of highly palatable foods, secondly the obese were less likely to slow down their rate of eating during the course of a meal.

Most studies of children's eating behaviour and weight concentrate on school age children who are capable of independent eating. There are a few studies with younger children and none of these have concentrated on age groups that are predominately spoon fed by their carers. While studies of older children are not strictly relevant to the present study some of these will be reviewed to illustrate the difficulties involved in carrying out research in this area.

Drabman, Cordua, Hammer, et al (1979) investigated the influence of weight on the eating behaviour of children from three age groups (18-24 months, 3-4 years and 5-6 years). Weight was classified as overweight or normal weight on the basis of observer judgements. Observations were conducted in the naturalistic setting of the school cafeteria using time sampling intervals of 30 s observations and 30 s breaks, to avoid subjects becoming aware that their behaviour was being recorded. All subjects ate the standard school lunch. Variables recorded were number of bites, chews, sips of drinks and talks with other children. Regardless of age, the children judged to be overweight took more bites per 30 s interval and fewer chews per bite than the normal weight children.

Studies using weights and heights recorded from recent health records have also found evidence of a relationship between eating behaviour and concurrent weight. Keane, Geller & Scheirer (1981) measured the eating behaviour of 11 year olds under controlled conditions. Half the children were overweight (23% to 65 % overweight for height and age) and half were normal weight (-7 % to 7 % overweight for height). All children ate a standardised meal and eating behaviour was recorded using time sampling. The behaviour coding scheme was similar to those used by Drabman et al (1979). Overweight children were found to have a shorter meal duration and take more bites per minute than normal weight children. Similar findings are reported by Barkeling, Ekman & Rosser (1992) who measured the rate of consumption under experimental conditions of 11 year olds who were of normal weight (BMI 15-20 kg/m^2) or overweight (BMI 24-33 kg/m^2) using a concealed balance connected to a computer which allowed the amount of food taken from the plate to be recorded automatically. Overweight children ate faster than normal weight children overall and the overweight children did not slow down their rate of food eating towards the end of the meal. An important aspect of this study is that food ingestion was recorded automatically and so the results are less likely to be affected by experimenter bias than studies using purely observational methods of recording eating behaviour

One striking finding in most studies of both children and adults is the large variability in eating behaviour found within groups classified according to weight or level of adiposity. Spitzer & Rodin (1981) point out that more variability may be accounted for by individual differences within groups than by systematic differences between groups. Partly because of this variability, a more appropriate approach to investigate the relationship between weight and eating behaviour is to treat weight as a continuous variable. Nakao, Aoyama & Suzuki (1990) examined the relationship between eating behaviour and measures of weight and adiposity in eleven normal weight, pre-school, Japanese children. A behaviour sampling coding scheme was used which involved recording one action per minute for each of the eleven children until each child ceased eating. Children were observed eating in a group over 18 consecutive days at 40, 52 and 59 months of age. Concurrent relationships between eating behaviour and weight and BMI were found at 52 and 59 months: meal duration was the strongest and most consistent predictor variable. Interestingly, the relationship between weight and eating behaviour was not present at 40 months when these children were not consistently self-feeding, but only emerged later once self-feeding was fully established.

One other study with weight as a continuous variable did not find any evidence of a relationship between weight and eating behaviour. Israel, Weinstein & Prince (1985) used a similar observation method and behaviour coding system to that used by

Drabman et al (1979) to investigate the eating behaviour of 60 children aged 7 to 12 years under naturalistic conditions. Percentage overweight for height, age and sex was calculated from measured weights and heights. Twelve of these children were between 15% and 30% overweight and a further eight were more than 30% overweight. Children in this study did not eat a standardised meal. Three summary variables were calculated, the number of bites per 30 s interval, chews per bite and interruptions (a composite variable calculated by summing the number of instances of toying with food, pausing, talking and sipping). None of these eating behaviour variables was consistently correlated with weight. A group based analysis comparing the eating behaviour of normal weight (-5% to + 5 % overweight) and overweight children (> 15% overweight) revealed no systematic differences between the groups. The disagreement between this and other findings may be explained by the fact that this is the only reported study in which subjects did not eat a standardised meal while their eating behaviour was recorded.

In summary most naturalistic and laboratory based studies suggest there is a relationship between eating behaviour and weight in children. The most consistent finding is that overweight children eat at a faster rate (bite rate or food ingestion rate) than children of normal weight. Only two studies have examined the relationship between eating behaviour and weight in pre-school children. One of these by Nakao et al studied Japanese children in the first stages of independent feeding with chop sticks so it is difficult to generalise these findings to samples of Western children. The other study by Drabman et al involved children aged 18 months to 2 years, but as this sample was restricted to self-feeding children the results may not be typical of children of this age. The evidence on meal duration is mixed; only two studies provide evidence suggesting overweight children have shorter meals than normal weight children, while others studies found no association between meal duration and weight. The research on adults is also equivocal but suggests meal duration is strongly influenced by food preference (with subjects taking longer to eat preferred foods than non preferred foods); studies that report differences between normal and overweight subjects tend to allow free selection of foods while those reporting no differences use standardised meals (Spitzer & Rodin 1981).

Milk and solids feeding

Relationship between milk and solids feeding: animal studies

There is little previous research on the feeding behaviour in humans which has investigated milk and solids feeding in the same infants, or examined the relationship between milk and solid feeding behaviour. The issue has been widely investigated in rats and much of the research has been concerned with the development of the regulation of energy intake (e.g. Hall & Williams 1983). Researchers have attempted to establish whether the system underlying the regulation of energy intake in milk and solids feeding is common to both types of feeding, or whether the regulatory systems are distinct. These investigations have been largely been experimental and concerned mostly with the underlying regulation of energy intake. The present investigation in human infants is observational and principally concerned with observable associations between milk and solids feeding, and so is clearly distinct from much of the research on rats. Nevertheless, as the research reported in the animal literature is the only major body of research to consider milk and solids feeding and their relationship, this work will be briefly reviewed.

There are two broad possibilities regarding the relationship between milk and solid feeding: (a) the motivational system underlying milk feeding and solid feeding is continuous based on the same neural structures and organisation (b) there are two distinct motivational systems underlying milk feeding and solid feeding. The animal literature compares the evidence on this relationship in terms of motor responses, external control of behaviour, internal control of behaviour, neural substrates and experiential factors.

First, in terms of motor responses the feeding behaviour of adult and suckling rats is clearly distinct. Adult rats lick, chew and mouth their food, actions which predominantly involve the front of the mouth, but in suckling pups the front of the mouth plays only a small role in the ingestion of milk. Second, there is evidence that the role of external control differs for milk and solids feeding. Suckling is guided and stimulated by odour cues; removing these odour cues from the nipples disrupts suckling but not later ingestive behaviour for solid foods. (Teicher & Blass 1976). If odour cues are removed around the time of weaning suckling is usually disrupted, but weaning onto solid foods proceeds normally (Alberts 1976). Third, regarding the internal control of feeding behaviour, comparison of milk and solid feeding is difficult because food availability is quite different in the two situations. Under naturalistic conditions the availability of milk during suckling is limited because it is released only infrequently by the mother, and intake depends upon the rat pup responding rapidly to a milk ejection and exerting sufficient negative pressure to withdraw the milk. In the usual laboratory environment food is continuously available for adult rats. When the availability of milk during suckling is manipulated to be more like the availability of food for adult rats (this is done by using oral cannula which continuously deliver milk into the oral cavity), rat pups show no control of intake and will continue to suckle until reaching extreme states of gastric fill (Hall & Rosenblatt 1977). Such evidence suggests that the mechanisms controlling intake differ for milk and solids feeding. Fourth, pharmacological evidence on the differential effects of drugs on milk and solid feeding shows different neural substrates are involved in the two types of feeding. For example, amphetamine depresses feeding in adult rats but in pups has the opposite effect, increasing the amount of time they engage in suckling (Raskin & Campbell 1981). Finally, suckling experience is not essential to successful feeding on solids; deprivation of all suckling experience in rat pups does not inhibit later solid feeding, however, deprivation of suckling that persists for longer than the first few days after birth completely disrupts suckling behaviour (Hall & Williams 1983). This suggests experiential factors play a different role in milk and solid feeding.

In addition to the evidence suggesting suckling and solid feeding are regulated by distinct systems, further research indicates the existence of an ingestive system that is distinct from suckling but continuous with later ingestion is present during early infancy. From birth rat pups will ingest food from the floor of their cages in a motor sequence like that of adults (Hall & Bryan 1980). Under these conditions where food is provided in a manner similar to that of adults, food intake and ingestive responses appear to be sensitive to the pups nutritional state. As reported above in the oral cannula studies, this is not the case when milk is continuously available to suckling pups. The coexistence of an independent ingestive system from birth more akin to the adult ingestive system provides further support for the view that suckling is not an early precursor of solid feeding, but part of an independent motivational system.

The relationship between milk and solids feeding: human studies

Though it is not possible to compare milk and solid feeding in humans in the same amount of detail there are a few studies which suggest these are also motivationally distinct in humans. Obviously the motor actions involved in suckling in human infants and solids feeding are different. Suckling consists of up and down tongue and jaw movements which removes milk by compression of the nipple and exertion of negative pressure to keep the nipple in the oral cavity (Woolridge 1986). In solids feeding the upper lip is involved in removing food from the spoon and rotary jaw movements in the chewing of food. In a similar study to that of Hall & Bryan above, Sheppard & Mysak (1984) examined the development of oral reflexes and chewing behaviour in normal human infants from 1 week to 35 weeks of age. Chewing was elicited by placing a cube of banana on the gums. From one week of age infants responded to the banana cube with chewing-like actions. Although these were not typical of mature chewing in a functional sense they were distinct from other oral reflexes possessed by the infant. These actions consisted of up and down movements of the lower jar, lateral tongue movements and movement of the banana from the side of the mouth to the centre (although not all mature oral-motor movements were present until after 26 weeks of age). Given the appropriate stimulus conditions, it appears that some early precursors of mature ingestive behaviours can be elicited soon after birth and these appear to coexist with the usual ingestive responses associated with infancy.

Research also suggests that the effects of illness are different for milk and solids feeding. Brown, Stallings, Kanashiro, et al (1990) investigated the effects of common illnesses on energy intake in low income Peruvian infants during the first year of life. Home visits were conducted every three weeks to collect information about illnesses and full day visits (lasting from 6 am until the child's final evening meal of the day) took place monthly to record food and breastmilk intake. Comparisons of energy intake between the days when infants were ill and symptom free days showed that energy intake from breastmilk remained constant but energy intake from other sources decreased by 20-30 percent on the days infants were ill.

Further evidence on human infants concerns patterns of food intake. In infants under 3 months there is evidence of a preprandial pattern of feeding where volume of milk ingested at feeds is positively related to the preceding interval (Matheny, Birch & Piccano 1990). When adult humans are studied under conditions where they are deprived of temporal and other cues, a situation that more closely reflects milk fed infants, feeding patterns appear to differ from that of infants. Under these conditions adults adopt a postprandial feeding pattern where intervals between meals are related to size of the preceding meal (Le Magnen 1985). Thus in adults, there is evidence meal size influences the interval following the meal, but in infants, feed size is influenced by the interval preceding the feed.

Summary

Weight gain in infancy is important for later health; it is associated with developmental outcomes in early childhood and with major causes of morbidity and mortality in adulthood. There have been many investigations of the influences upon weight gain in infancy such as energy intake, parent characteristics, etc. but these have generally not examined the influence of the infant's own behaviour during feeding on their weight gain. Studies which have investigated feeding behaviour have not generally attempted to relate it to weight gain.

The main aim of this thesis is to examine the relationship between the infant's own feeding behaviour and weight gain. To this end, longitudinal measures of feeding behaviour were taken during milk and solids feeding. The purpose of measuring both types of feeding in the same infants was to examine the relative influence of each on weight gain, and also to investigate the relationship between milk and solids feeding behaviour. As this is the first study to measure milk and solids feeding behaviour in the same infants, this work on the relationship between the two types of feeding is exploratory but it provides insights into the relationship between the two. In addition to feeding behaviour, other variables known to be, or possibly associated with, infant weight gain were measured to control for their effects. These are, milk and food intake, parent BMI, infant sex, milk feeding patterns over the day, age of introduction of solids and duration of breastfeeding.

Birthweight was obtained from child health records and infants were weighed at 6 weeks, 3 months and approximately every 3 months thereafter. Traditionally, weight gain has been summarised by examining differences between weights at two points in time (e.g. Dewey et al 1991a), however there are several disadvantages with this: (1) it does not make parsimonious use of the data (2) it cannot accommodate uneven intervals between measurement occasions (3) it cannot deal with missing data. To avoid these difficulties weight data were analysed using a growth curve model (Berky & Reed, 1987) specified as a random coefficient regression model in ML3 (Prosser, Rasbash & Goldstein 1991). This provides a more efficient use of the data and allow greater flexibility in data collection.

Previous research on milk feeding behaviour has concentrated almost exclusively on the measurement of sucking patterns while infants are fed from bottles (e.g. Kron et al 1963, Alexander & Roberts 1988). In this study it was decided to concentrate solely on breastfed infants. Given the detailed and time consuming nature of the observations undertaken, it was impossible to study sufficient numbers of both breast and bottle fed infants. In this study milk feeding behaviour was recorded in breastfed infants while they were actually being breastfed. While this introduces certain difficulties and complexities it is important to investigate associations with weight gain using measurements of milk feeding in its adaptive context.

Infant feeding behaviour during milk feeds consists largely of sucking, although data were also collected on feed duration and milk intake. One major difficulty is that traditional statistical techniques are inadequate for summarising breastfed infant sucking patterns because they do not allow for change in the global structure of sucking patterns during the course of a feed. This is an especially important consideration in breastfed infants as the composition and flow rate of milk change systematically during the course of a breastfeed (Akre 1989). A second concern applies regardless of the method of feeding and is related to how the traditional methods summarise the local burst-pause structure of sucking patterns (these issues are discussed in chapter 4). To overcome these problems the extensive data set on sucking patterns collected during this study was used to develop a new method for the analysis of breastfed infants' sucking patterns.

In the analysis of feeding behaviour this study deliberately concentrates on *infant* behaviour, not mother-child interaction during feeding (though some aspects of maternal behaviour during feeds was summarised where this played an intrinsic role in food ingestion). While it is recognised that feeding in infancy is a social process involving an interaction between mother and infant, given the general paucity of research in this area coupled with the complexity of the subject matter, it was considered prudent to concentrate in detail on just one aspect of feeding behaviour.

As no extensive data has previously been published on feed to feed variation, measurements of feeding behaviour were made at four milk feeds and four solids feeds for each infant. This data was examined using analysis of variance to allow the proportion of variation in each aspect of feeding behaviour attributable to individual differences to be compared to the proportion attributable to feed to feed fluctuations. For solids feeding, an aim of this study was to provide normative data on the feeding behaviour of one year olds under naturalistic conditions and thereby obtain a more detailed description of their feeding behaviour than has so far been available. As they are not yet capable of independent self-feeding, it has sometimes been assumed that infants of this age are somewhat passive during mealtimes, although there is very little previous research in this age group. The method of data collection allowed the feeding behaviour during the sweet and savoury portions of the meal to be distinguished as sweet taste is a particularly important influence on the feeding behaviour of infants and young children (Desor & Beauchamp 1987).

Chapter 2

Methods

Overview of design

This was a longitudinal study of normal breastfed infants from six weeks to fifteen months of age. It was decided to concentrate solely on breastfed infants because it was impossible to study sufficient numbers of both breast and bottle fed infants given the detailed and time consuming nature of the observations undertaken. Furthermore as breastfeeding is currently regarded as providing the best source of nourishment for infants (British Paediatric Association 1994) and being important for public health (Howie, Forsyth, Ogston, et al 1990) to study breastfeeding seemed an appropriate choice. Mothers and their infants were recruited through Community Midwives and Health Visitors. Subjects were visited at home on 9 separate days, consisting of an initial recruitment visit (one day), feeding observation visits (four days) and infant weight visits (four days). Feeding observation visits took place when infants were approximately six weeks and twelve months of age, with four feeds observed on each occasion. Infants were weighed at 6 weeks, 3, 6, 9, 12 and 15 months, and birthweight was recorded from parent-held child health records.

Subjects and recruitment

It was planned to recruit 30-36 breastfeeding mothers and their infants from the North Durham area. Recruitment criteria specified that infants should be aged 4-6 weeks, breastfed, healthy and of no less than 37 weeks gestation. As the initial approaches to subjects were to be carried out by Community Midwives and Health Visitors employed by the local Health Trust, it was necessary to obtain ethical approval for the study from North Durham Health Authority Ethics Committee. (Ethical approval is required for all research involving patients of the Trust).

The Ethics Committee was supplied with copies of study information sheets to be given to subjects (see appendix 1), details of the procedure for obtaining subject consent together with the background to the study, design, measures used and objectives. The agreement of a Health Trust consultant to act as a clinical supervisor was sought prior to the application for Ethics Committee authorisation. Approval was granted subject to reviews of progress every six months, and in accordance with Committee policy it was agreed that details of potential subjects would be given to the researcher only after their agreement had been sought by the health workers.

Midwives and Health Visitors gave the information sheet about the study to all breastfeeding mothers who met the recruitment criteria. Though recruitment was not meant to be selective, it is inevitable that an element of self-selection occurs in recruiting for a long-term study of this kind. Details of mothers expressing an interest in taking part were passed to the researcher by health workers, and these mothers were then contacted by telephone or letter to give a brief outline of the study and arrange a preliminary home visit to explain the study in greater detail. At the preliminary home visits mothers were told the study would last until their infants were 15 months of age and initially involve the researcher visiting them at home to observe four breastfeeds over two days when their infants were aged about six weeks. The test weighing procedure to record breastmilk intake was described and mothers were shown the charts for keeping 48 hour diaries of infant activity and recording breastmilk intake (see appendix 2 '48 Hour Baby's Day Record and appendix 3 '48 Hour Record of Baby's Feeding'). The later part of the study, involving home visits every three months to weigh infants and videoing of infant feeding at one year of age, was also described. Mothers were informed that the purpose of the research was to investigate feeding behaviour and weight gain during the first 15 months of life. Any issues raised by mothers were discussed at this stage and signed consent was sought (see appendix 4).

If mothers consented to the study a questionnaire was then used to record details of a) the educational and employment history of mothers and fathers, b) parental weight and height and c) type of delivery and feeding history of the infant concerned (see appendix 5 'Infant Feeding - Questionnaire One'). Infant birth weight, together with any subsequent weights taken by Midwives and Health Visitors were recorded from patient held records and arrangements were made to carry out the two days of feeding observations.

Design

The study employed a longitudinal design following infants from six weeks to fifteen months of age. A summary of the design and timing of data collection points is given in Table 2.1.

Table 2.1

Summary of data collection

Age	Data Collected
4-6 weeks	Recruitment and preliminary visit Questionnaire one
6 weeks (range 5-7 weeks)	Observations of 4 feeds 48 hour milk intake 48 hour activity record Infant weight
3 months (range 15-19 weeks)	Questionnaire two - feeding history Infant weight
6 months (range 26-30 weeks)	Questionnaire two - feeding history Infant weight
9 months (range 37-41 weeks)	Questionnaire two - feeding history Infant weight
12 months (range 50-54 weeks)	Video of 4 meals Intake records of videoed meals Infant weight
15 months (range 62-66 weeks)	Questionnaire two - feeding history Infant weight

Most observational studies of infant feeding use newborns who are studied while still in hospital. However, feeding patterns and sucking behaviour during the neonatal period are likely to differ from those in later infancy. For the first few days after delivery, mother and infant are still adapting to each other, the milk supply is not yet established (Arkre, 1989) and the infant feeding behaviour can be affected by events during labour and delivery (Kron 1966, Wolff 1968). Therefore it was decided to carry out observations of feeding when infants were six weeks of age to avoid the complexities of the newborn period. Breast feeding would also be well established by this time, so the research would be less likely to interfere with the feeding relationship. A second reason for choosing six weeks was to exclude infants who were receiving solid foods as it is likely this could influence sucking behaviour. Data from the national Infant Feeding 1990 survey show that most mothers introduce solids between 12 and 16 weeks and only 2% of breastfeeding mothers gave their baby solids before 6 weeks (White, Freeth & O'Brien 1992).

The timing of data collection at twelve months for the recording of solids feeding was chosen because it was expected that solids feeding would be well established by this time and infants would be receiving a substantial proportion of energy intake from non milk sources. The only recent data available are on somewhat older infants who were studied in the recent national diet survey; this shows that by 18-30 months of age infants receive

26% of total energy intake from milk and milk products (Gregory, Collins, Davies et al 1995).

Six week feeding observation visits

To obtain information on within and between subject variation in feeding behaviour, repeated measures of feeding behaviour were conducted. Four feeds were chosen as the maximum likely to be acceptable to mothers. It was planned to carry out all four feeding observations over two consecutive days when infants were aged between five and seven weeks. For the purposes of the observations a single feed was defined by the mother so observations of feeding were continued until the mother indicated that the feed had ended.

Observations were to be undertaken in the subject's own home on days that were convenient for the mother. Some care was required to ensure the researcher actually arrived in time to observe the feeds as most breastfeeding mothers report that their infants are fed on demand and some infants can be quite erratic in their patterns of feeding. On the morning of the first feeding observation, mothers were telephoned at about 9:00 am to obtain an approximate estimate of the time the infant would next be fed. As a safety margin, the researcher attempted to arrive at least 30 minutes before the feed was due. This also gave time for the mother and infant to adjust to the presence of the researcher and allowed time to set up the equipment. In the event of infants demanding to be fed earlier than anticipated, mothers had been advised in advance to feed their infants and not wait for the arrival of the researcher. This helped to control against gross differences in hunger between infants. Recording of feeding behaviour began when the breast was first offered to infants. Mothers were asked to feed their infants 'as you usually would' and no steps were taken that might have altered the usual feeding environment (such as excluding visitors or turning off the T.V., etc.). In this way, it was hoped to foster a relaxed atmosphere, therefore minimising the disturbance of being observed to both mother and infant.

Information about feeding behaviour was recorded directly onto a laptop computer (Toshiba T1000) using a program specially designed for recording behaviour (Marsh 1988). The program allowed a different behaviour code to be entered by pressing a different key (see Table 2.2). The behaviour code, the date and the time was recorded each time a key was pressed. Time was recorded nominally accurate to 10 ms though the actual precision of a human observer is lower. In pilot research it was observed that occasionally, due to movements of the infant, sucking was lost to view and it was necessary to ask the mother to adjust the position of the infant. To distinguish between (1) periods when feeding behaviour was temporally out of view and (2) pauses during feeding when the infant remained attached to the breast, the duration of instances when feeding was lost to view was also recorded on computer. A list and description of all infant and mother behaviours recorded during the observations can be found in Table 2.2.

This direct observation method of recording is less intrusive than using pressure transducers which involve placing a fine cannula in the infant's mouth or attached to the mother's nipple and this method is also technically difficult to carry out in the field. It requires sterilisation of equipment and is liable to give a high number of missing data points when the cannula become blocked by the infant's mouth or cheek. Direct observation was considered to be less embarrassing to mothers than using a video camera. Also, as the movements involved in sucking are quite subtle, 'live' observation is probably superior to video for recording sucking. The validity of the direct observation method has been previously established in a study that compared records of sucking obtained by using pressure transducers with records obtained by direct observation (Woolridge & Drewett 1986). I was widely experienced in the observational method of recording breastfeeding behaviour having previously trained by observing 28 feeds in 13 infants aged six weeks.

Table 2.2

Behaviours recorded during breastfeeds

Subject	Label	Description
Mother	offer	positions nipple ready for infant to accept and/or brings nipple to infant's mouth.
	take off	withdraws nipple from infant's mouth
Infant	accept	moves head to grasp nipple in mouth and/or opens mouth to accept nipple
	refuse	keeps mouth closed as nipple approaches and/or as nipple touches mouth
	release	releases or expels the nipple from mouth
	suck	repetitive act of releasing lower jaw accompanied by upward movement of the larynx[1] (coded separately for right and left breast)
miscellaneous	invisible	infant's mouth cannot be seen
	visible	(record only after a period when the infant's mouth cannot be seen) infant's mouth can be seen

Following the first feed, I usually remained in the home until the next feed if the mother thought this would be within two hours. If it was inconvenient to stay or the mother thought it would be more than two hours until the next feed, I usually left and returned 30-40 minutes before the next feed was due.

[1] From Johnson & Salisbury (1975)

Over the two days of the feeding observations, mothers were also asked to keep a continuous 48 hour diary of their infant's behaviour on a chart previously designed for this purpose by Barr, Kramer, Boisjoly et al (1988). (See appendix 2). Mothers started keeping these diaries from the beginning of the first observed feed, noting the time and duration of all infant activities from the following categories; i) feeding, ii) sleeping, iii) crying, iv) fussy, v) awake and content. In a study that compared parent diaries of crying and fussing with continuous audio tape recording of infant vocalisation made over a 24 hour period, the correlations between diaries and tape recordings was $r = 0.64$ for the frequency of crying and fussing and $r = 0.45$ for the duration of crying episodes (Barr et al 1988).

During this 48 hour recording period of the present study, mothers also test weighed their infants at all feeds using Seca Model 724 balances which are nominally accurate to 20 g in the 0-10 kg weight range and to 50 g in the 10-50 kg range. More accurate balances were available but were not used because feeding *behaviour* rather than intake was the main focus of the study and it was feared that the use of more accurate balances, which are very heavy and cumbersome, would reduce maternal compliance with the study. Mothers were provided with verbal and written instructions (see appendix 3) on the correct procedure for test weighing and this was carried out under the supervision of the researcher at all observed feeds. The two balances used in this study were checked every three months. The quantity of expressed breastmilk or formula taken at any additional feeds was recorded by mothers using the graduations on infant feeding bottles.

Infant weight and feeding history visits

Additional home visits were conducted at 3, 6, 9, and 15 months to weigh infants. If compliant, infants were weighed twice on each visit to check the nominal precision of the scales. At each of these visits a feeding history questionnaire (see appendix 6 'Questionnaire Two - Feeding History') was used by the researcher to ascertain the duration of breastfeeding, age at introduction of solids, and age when first offered three solids meals per day. Mothers were also asked to recall all the foods their infants had been given in the previous 24 hours to provide information on the range of foods offered to infants.

Twelve month feeding visits

Only solids feeding behaviour was recorded at twelve months of age. From a pilot study it was clear there would be difficulty in conducting accurate direct observation of continuous solid feeding because, unlike sucking behaviour, it involves recording a wide range of actions. Therefore, recording of solids feeding was carried out using video cameras instead of direct observation. No difficulties were anticipated in distinguishing the movements involved in solids feeding on video as these are quite pronounced and easy to discern.

To obtain information on variability in solids feeding behaviour it was again planned to record feeding at four meals (two lunches and two teas). These recordings were to take place on two consecutive days within fourteen days of the child's first birthday. On the day of the first recording mothers were telephoned to find out if infants were well and the time they would be having lunch that day. I arrived 20-30 minutes before this time to set up the equipment. Mothers were asked to feed their children 'as you usually would'. Videoing started when food was placed in front of the infant and continued until the mother removed any remaining food at the end of the meal or indicated that the child had finished eating. To maintain a relaxed, informal atmosphere and avoid infants becoming aware there was something special about the situation, which may have altered their usual feeding behaviour, no special actions were taken (such as excluding other members of the family or turning off T.V.s) to alter the customary feeding environment of the child. In attempting to normalise the situation as much as possible, it was hoped to minimise the disturbance of being videoed for the mother as well.

Records were taken of the type of foods and drinks offered to infants and the volume of food consumed was calculated by weighing bowls or plates before and after the meal using an Ohaus strain gauge electronic balance (model CT1200-S, nominally accurate to 0.1 g). Energy intake was not determined as this requires each ingredient to be separately weighed. This would have imposed a considerable burden upon mothers and may have led to restriction of the types of foods mothers offered to infants. Infants were weighed at some time during the two days of recording.

Measurement Issues

Measurement issues in breastfeeding

In measuring sucking patterns while infants are on the breast rather than during bottle feeding, some additional complexities are encountered. Firstly there are problems regarding the definition of breastfed infants. Very few infants described as exclusively breastfed in Western countries are, in fact, exclusively breastfed in the sense that they have never received any formula. By one week of age, 46% of breastfed infants in the UK had received at least one bottle of formula milk (White, Freeth & O'Brien, 1992). Breastfed infants may also receive expressed breastmilk from a bottle and so a distinction is needed between what a baby is fed, whether breastmilk or formula, and the method of feeding, whether breast or bottle. In longitudinal work an additional complexity is that breastfeeding rates change over time quite dramatically as, for example, solids foods are introduced, or for other reasons. Of mothers who began breastfeeding in 1990 (defined as putting the baby to the breast on at least one occasion), 38% had stopped completely by the time their infants were 6 weeks of age (White, Freeth & O'Brien, 1992). Secondly as will be described in more detail in Chapter 4, techniques for the recording of sucking on the breast are less developed than those for bottle feeding. Finally, while social interaction between mother and child is an important component of both breast- and bottle feeding, only breastfeeding involves physiological interaction as an intrinsic feature of the process; this makes breastfeeding an inherently more complex process to study than bottle feeding.

Weight gain as an outcome measure

Although it is probably true to say that weight gain is a relatively unspecific measure of growth as it reflects changes in length, body fat and muscle tissue (Wright, Matthews, Waterston, et al 1994), there are several reasons to warrant its use as an outcome measure in this study. First, weight gain is widely accepted as a measure of health and well-being in infancy (Power 1995) and its measurement is accurate and straightforward. A combined weight/height measure such as BMI necessitates the measurement of infant length; accurate measurement of length requires training and even then it is still prone to inter-observer variation (Wright et al 1994). Other measures of infant adiposity such as skinfold are prone to considerable measurement error which substantially reduces their reliability (Gasser, Ziegler, Molinari, et al 1995).

Second, there are problems regarding the acceptability of length measurement to subjects; the measurement of length in infancy may cause considerable distress to infants because it involves quite vigorous physical manipulation of the infant to achieve an accurate measure. In a longitudinal study, where it is necessary to obtain repeated measures of infant anthropometry, requiring infants to undergo this procedure on a routine basis may risk elevating subject attrition.

Chapter 3

Subjects

Recruitment

Of the 38 mothers who were contacted to take part in this study, one refused to participate at the initial telephone call and two declined at the preliminary visit because they thought the study would be too time consuming. Three mothers dropped out between the preliminary visit and the first feed observation, one because she had stopped breastfeeding by six weeks and two because of problems with breastfeeding. Thirty-two mother-infant pairs took part in the first feeding observations.

Subject characteristics

Subject characteristics are shown in Table 3.1. The sample was predominately middle class with 64% of mothers and fathers belonging to social classes I & II. This is the expected pattern because breastfeeding is strongly associated with occupational class in the general population (White, et al 1992). Also in keeping with national social trends, the sample were highly educated: 60 % of mothers and fathers remained in full-time education until aged 19 years or over. Half the mothers in this sample were aged 30 or over, 15 were in the 20-25 age range and only one in the 20-24 age range. For 18 mothers this was a first baby, for 9 this was a second baby and 5 mothers already had two or more other children.

Birth and early feeding history

Thirteen infants were female and nineteen were male. All were of at least 37 weeks gestation estimated from date of last menstrual period and ultrasound scans. Nineteen mothers had an unassisted delivery, seven had an assisted vaginal delivery and six had caesarean deliveries. Mean birth weight of the infants was 3635 g (range, 2722-4848 g, SD 463 g). Birth weight data are summarised in Table 3.2.

Table 3.1

Parental social class and age at leaving full-time education

Social Class[1]	Mothers	Fathers[2]
I & II	19 (59%)	21 (68%)
IIINM & M	9 (28%)	4 (13%)
IV & V	4 (12%)	6 (19%)
Age at leaving full time education		
16 or under	4 (12%)	10 (32%)
17 or 18	8 (25%)	3 (10%)
19 or over	20 (62%)	18 (58%)

[1] Defined using the Standard Occupation Classification (1990). OPCS

[2] One mother declined to give any information about the father of her child

Table 3.2

Summary of infant birth weights

Weight(g)	Number of Infants
2500-2999	1
3000-3499	12
3500-3999	13
4000 or more	6

Two mothers stayed in hospital for more than seven days following delivery, one because of complications following caesarean delivery and one because her baby had mild jaundice. All mothers breastfed their babies while in hospital, although 12 infants were also offered at least one bottle of formula milk while in hospital. Fourteen mothers had experienced at least one problem with breastfeeding while in hospital and sixteen reported breastfeeding problems since returning home. A summary of the type of problems is given in Table 3.3.

Table 3.3

Number of mothers reporting different breastfeeding problems in hospital and since returning home

Hospital	No.*	Home	No.*
Sore nipples	5	Sore nipples	10
Baby not latching	7	Baby not latching	3
Baby hungry	2	Baby hungry	1
Engorgement	2	Blocked ducts	2
Baby ill	1	Baby vomiting	2
Mother and baby ill	1	Slow weight gain in baby	1
		Breast infection	1

* *Some mothers reported more than one problem*

Since returning from hospital, only three infants were reported to have received formula on more than 1 or 2 occasions. Two of these were offered a 'top-up' bottle of formula at the night-time feed only and one received 'top up' bottles of formula at most feeds. At the time of recruitment, 27 mothers reported feeding their infants on demand, 4 said they fed their baby to a schedule, and one mother had started to wake her baby for a feed at 3 hourly intervals on the advice of her doctor.

Six week feeding observations

During the period of the breastfeeding observations, one mother reported that her infant had a slight cold and another infant was taking antibiotics prescribed for an infected rash. One male infant was seeing a community paediatrician because of poor weight gain (this infant weighed 4850 g at birth). At a subsequent visit to collect equipment two weeks after the feeding observations, one mother recalled that her infant had shown some signs of illness which began late on the evening of the second observation day. Two days after the observation period, this infant had been admitted to hospital for surgery to correct a pyloric stenosis.

Two mothers reported breastfeeding problems at the time of the observations; both were experiencing nipple soreness and one of these women used a nipple shield on one breast when feeding her baby at the observed feeds. Four infants received some formula over the two days of the feeding observations but only one these consumed more than 130 ml per 24 hours of formula on the observation days.

Occasionally, mothers forgot to test weigh their infants at some of the feeds and some weights were also missing from one infant due to equipment failure. As ignoring these missed feeds would have systematically underestimated breastmilk intake for the 48 hour period, the volume of milk ingested at these missed feeds was estimated by interpolating the intake from similarly timed feeds on the other day of test weighing. Intake was estimated in this way for 36 missed feeds out of a total of over 600 feeds. No infants had been given any solid foods at the time the first feeding observations were conducted.

Infant weight

With the exception of birthweights, all data on infant weight were obtained by weighing the infant at home with Seca balances which had a digital display (model no. 724, accurate to 20g for weights below 20 kg and 50g for weights between 10-20 kg). Birthweight was obtained from parent-held child health record books. The mean age at visits when infants were weighed and the age range in weeks are given in Table 3.4. Complete weight data was obtained for all but two subjects: one baby was not weighed at twelve months because he was living away from home during this period, and another baby moved with his parents to the USA at three months and no further weights were available for this baby.

Table 3.4

Timing of visits to weigh infants

Visit	Mean Age	Minimum Age (weeks)	Maximum Age (weeks)
6 weeks	6	5	7
3 months	17	11	20
6 months	29	26	30
9 months	40	37	42
12 month	53	50	57
15 months	65	60	67

The mean and median birthweights and subsequent weights are given in Table 3.5 together with the standard deviation (SD) scores calculated using the new British

1990 growth reference for weight (Freeman, Cole, Chinn, et al 1995). SD scores provide an assessment of an infant's weight gain by comparing their current weight with that predicted from their previous weight on the basis of reference data from the UK 1990 reference and correlational data from the Cambridge Infant Growth Study (Whitehead, Paul & Cole 1989). SD scores adjust for regression to the mean i.e. the tendency for light infants on average, to grow faster than heavy infants.

For the infants in the present study the mean standard deviation scores from birth to 15 months was 0.53 for boys and -0.63 for girls. Figure 3.1 shows SD scores plotted to 15 months. It is clear there is a considerable discrepancy in the SD scores between male and female infants with the mean score for females being markedly lower. Although this could be due to small sample of infants included in this study, sizeable sex discrepancies in SD scores based on the 1990 standards have been noted in very large data sets reported elsewhere (e.g. Wright, Corbett & Drewett 1996) and the new standards are undergoing revision to correct for sex differences.

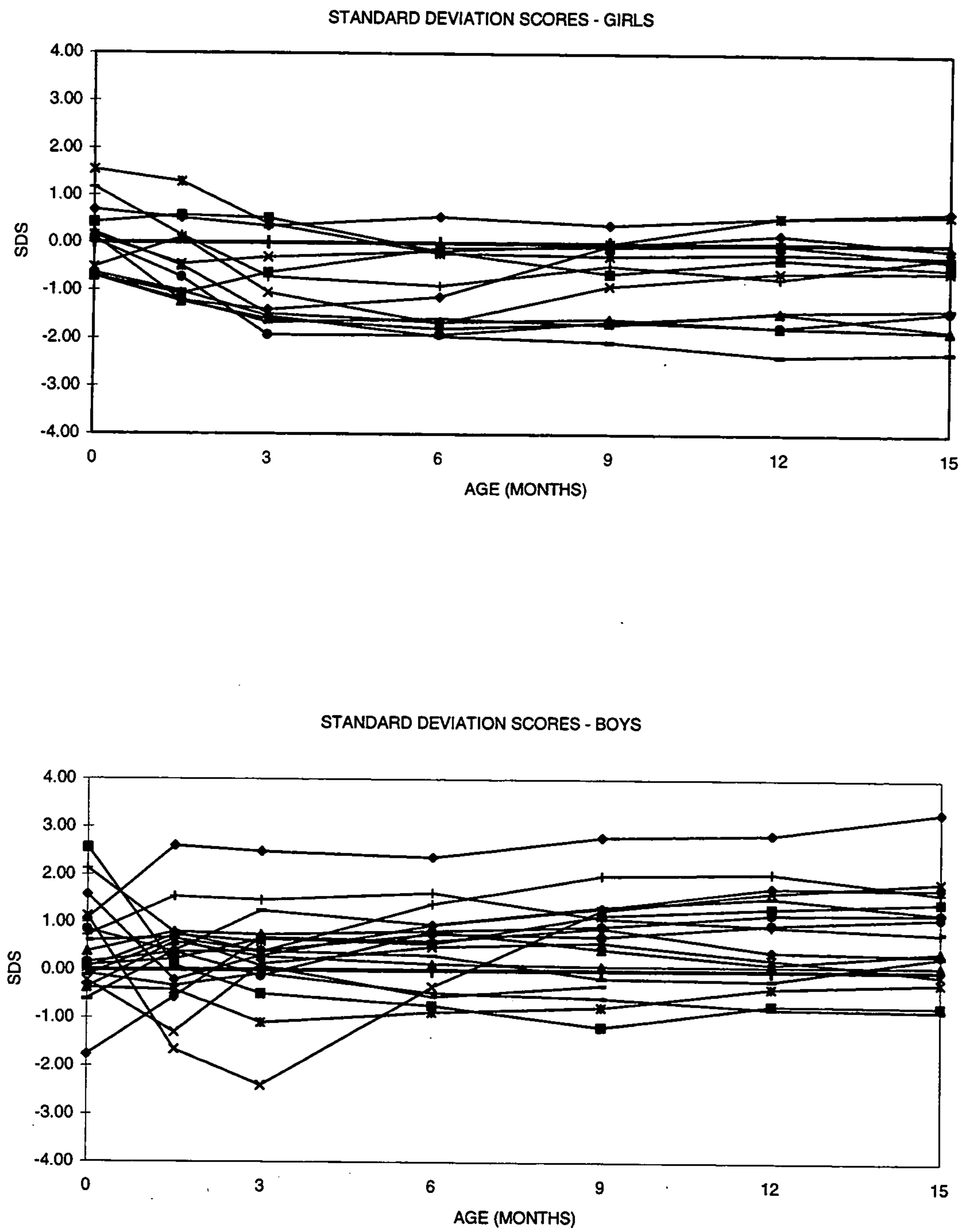
Table 3.5

Weights and weight SD score by age and gender

	n	Mean weight	Median weight	Median weight SD score
BOYS				
Birth	19	3.76	3.63	0.16
6 weeks	19	5.01	5.10	0.38
3 months	19	7.13	7.19	0.38
6 months	18	8.76	8.77	0.58
9 months	18	9.95	10.15	0.81
12 month	17	11.03	11.17	0.94
15 months	18	11.73	11.60	0.80
GIRLS				
Birth	13	3.45	3.46	0.12
6 weeks	13	4.46	4.36	-0.49
3 months	13	6.06	5.94	-1.05
6 months	13	7.19	7.17	-1.12
9 months	13	8.14	8.36	-0.63
12 month	13	9.05	8.97	-0.61
15 months	13	9.63	9.92	-0.51

Figure 3.1

Standard deviation scores to fifteen months



Parent anthropometry

Data on parental weights and heights were collected from maternal reports. Where there was any uncertainty of the mother's weight or that of her partner, the mother was asked to check the accuracy and the researcher later telephoned to obtain the weight. Evidence from previous studies suggest individual's self-reports of weight (Palta, Prineas, Berman et al 1982) and reports of family members' weights are reasonably accurate (Sorensen, Stunkard, Teasdale, et al 1983). Mean weight and height was 63.7 kg (SD 9.3 kg) and 1.65 m (SD 0.05 m) for mothers, and 78.1 kg (SD 8.2 kg) and 1.8 m (SD 0.06 m) for fathers. Mean body mass index (kg/m^2) was 23.28 (SD 2.74) for mothers and 24.05 (SD 2.45) for fathers. Table 3.6 shows the numbers of mothers and fathers within BMI category according to internationally accepted categories for classification of BMI (Breeze, Maidment, Bennett, Flately, & Carey, 1992). None of the parents in this sample were clinically obese (BMI > 30).

Table 3.6

BMI classification of mothers and fathers

BMI (kg/m^2)	Mothers	Fathers
<20 'Underweight'	4 (12.5 %)	0
20-25 'Desirable'	20 (62.5 %)	21 (65.6 %)
25-30 'Overweight'	8 (25.0 %)	11 (34.4 %)

Solids feeding

At each of the weight visits, a short feeding history questionnaire was completed with mothers to find out the duration of breastfeeding and age of introduction of solid food.

Table 3.7 shows the number of infants for whom breastfeeding had been discontinued since previous visit. Mothers were asked whether they were still breastfeeding at all and those who had ceased were asked to recall their infant's age in weeks when they had last been breastfed. Five mothers had discontinued breastfeeding by the second visit, three because they had breastfed for as long as they had wanted, one because she was going back to work and one because she found breastfeeding was taking too long. Most infants discontinued breastfeeding between the six and nine month visit, but six infants were still being breastfed when the last visit took place.

Table 3.7

Number of infants stopped breastfeeding since previous visit

Age at Visit	Number stopped since previous visit
6 weeks	0
3 months	5
6 months	5
9 months	11
12 months	4
15 months	1
Breastfeeding at last visit	6

Table 3.8 shows the number of infants who had been introduced to solid food since the previous visit. Introduction of solids was defined the earliest time when infants had continually received solids foods. Three mothers had initially tried offering solids foods but then withdrew them (one because her baby developed gastro-enteritis and two because their babies where initially uninterested) before reintroducing solid foods later. For these three infants, the age of introduction of solids was taken from the time solids were reintroduced. Mothers were asked whether their infants had received any solid foods (defined as any foods other than milk such as cereal, rusk or any other solid food) and to state the age in weeks when their infants had first been introduced to solid food. Mothers were also asked how many mealtimes per day their infants were given solid food: if this was three or more, a note was made of age in

weeks when infants had first started having three meals of solid food per day. Sixteen infants were given solid food by the three month visit; of these seven received their first solid food between 8 -11 weeks. Six infants were older than sixteen weeks when they first received solid food but all infants had been introduced to solid food by 26 weeks of age.

Table 3.8

Age at introduction of solid food and first being given three meals per day

Age at Visit	Solid Foods	Three Meals per Day
6 weeks	0	0
3 months	16	4
6 months	16	23
9 months	0	4
12 months	0	0
15 months	0	1

Twelve month visit

By the time their infants were 12 months old many mothers in this sample had returned to work and this created some difficulties in finding a suitable time to video four solids meals, nevertheless, videos of four meals were taken in all but three infants in the sample (one infant was videoed at three meals, one family had moved abroad before the infant's first birthday, and one family was unable to take part because of severe illness in a sibling around the time of the index child's birthday). All infants were aged between 50-57 weeks when videoing of meals was carried out.

Where possible, videos were made of the mother feeding her infant. For mothers who were working full-time this could only be achieved by carrying out videoing at weekends. Although several mothers agreed to this, others refused to allow videoing at weekends. In such cases there were two possible options, (1) to video while a substitute carer was feeding the infant or (2) asking mothers to undertake the videoing themselves. As it was feared that requiring mothers to use a video camera while they were also busy feeding their infants might unduly interfere with feeding, the former was the preferred option. Three infants were fed by a person other than the mother at some or all of the meals and two infants were videoed by their mothers (one had moved to another part of the country and agreed to video her infant using her own video camera, and one mother who was working full-time videoed her infant herself for three of the four meals).

All infants except one were videoed at two lunch time and two teatime meals. Three infants were not placed in a highchair at mealtimes but were fed by their mothers while they moved around the room. On the days videoing was to take place, mothers were telephoned in the morning to find out if their infants were well, and videoing was postponed if infants were reported to be exhibiting signs of illness. Despite this precaution, the incidence of minor illnesses in this age range is high and four mothers reported their infants had a slight cold on the days prior to the videoing and in some cases this may have affected the infant's appetite. After the videoing, one mother said that her baby had been diagnosed as suffering from an ear infection the following day and with hindsight she felt this had affected her baby's appetite.

Conclusion

The mothers involved in this study were predominately of middle-class occupation and had completed relatively more years in full-time education. Although this is in keeping with national breastfeeding trends of the general population (White, et al 1992), these sample characteristics must be taken into account in drawing conclusions from the work reported in subsequent chapters. Data on obstetric history and parity are simply reported but no analyses of these characteristics was undertaken because the design of this study is not suitable for such investigations. Problems with breastfeeding, infant illnesses and the practice of giving supplementary bottles to infants were frequent in this sample and data on these are also reported. As such practices and difficulties are commonplace in the general population of breastfeeding mothers and their infants (White, et al 1992), to have excluded mothers on such grounds would have substantially reduced the size of the sample and rendered it less representative of the general population of breastfeeding mothers.

The timing of the collection of infants weight is also described. It was planned that infants should be weighed within 2 weeks of the target age for the visit and on only 2 occasions did weighing take place more than two weeks outside this target. These unevenly spaced measurement occasions are unlikely to cause any difficulties as data are to be analysed using ML3, a multi-level modelling package which can accommodate data of this sort (Prosser, Rashbash & Goldstein 1991).

Chapter 4

Summarising Infant Sucking Patterns

Previous work on sucking behaviour has two main inadequacies which this study has sought to overcome. Firstly, there is little previous work on variability in sucking behaviour and secondly, there are problems with the statistical methods traditionally used to summarise sucking behaviour.

Variability in sucking behaviour

The few papers that report data based on repeated observations of feeding behaviour tend to pool the estimates of sucking behaviour across measurement occasions with no attempt to examine feed to feed variability. Three studies have attempted to deal with this issue more systematically. Pollitt, Gilmore and Valarcel (1978a) examined correlations between measures of sucking behaviour conducted on two occasions when infants were aged two days. Zero-order correlations between the sucking measures on the two occasions ranged from 0.27 to 0.83. In a similar study design, Ramsay & Gisel (1996) report correlations of between 0.60 and 0.89 for measures of sucking behaviour taken on two occasions when infants were about two days of age. These two papers seem to suggest that infants are relatively consistent in their sucking patterns when compared over no more than a few days. However, both looked at feeding on only two occasions, which is unlikely to generate precise estimates of within subject variation. Kron, Ipsen & Goddard (1968) collected more extensive information of within subject variability by measuring sucking in eight newborns at eighteen consecutive feeds. Measurements began when infants were 12-16 hours old. An analysis of within subject variability relative to between subject variability was carried out to examine the components of variation in the sucking measures obtained at each feed. The measures of interest were mean sucking pressure at a feed and rate of sucking per minute of the feed. The analysis of variability showed that 68% of variation in sucking pressure was attributable to between subject differences and 61% percent of variation in the rate of sucking per minute was due to between subject differences.

As these measures were based on test feeds of a limited duration, carried out in controlled laboratory conditions on bottle fed infants, it is uncertain to what extent they apply to breastfed infants measured under naturalistic conditions where variability is likely to be greater. Milk intake varies quite widely from feed to feed within breastfed infants (Matheny, Birch & Picciano 1990), and sucking behaviour might also vary quite widely. This study was designed to provide information on within and between subject variation in sucking patterns in breastfed infants measured under natural conditions. Repeated observations of four feeds (carried out over two) days was chosen as the maximum number likely to be acceptable to mothers.

Summarising sucking behaviour

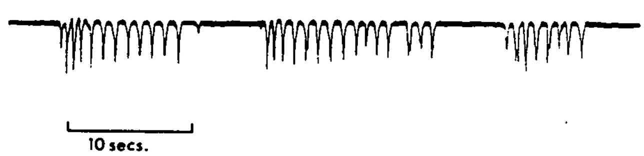
There are two problems in summarising the sucking patterns of infants which have not been adequately addressed in previous work; the first is concerned with accurately describing the local structure of sucking patterns; the second is with describing global change in sucking patterns over the course of a feed

Summarising the local structure of sucking patterns

Human infants suck in a distinct 'burst-pause' fashion, that is to say, they do not suck in a smooth or continuous fashion but typically have a burst of about 8-15 sucks in rapid succession, followed by a pause of several seconds duration before the next burst of sucking (Johnson & Salisbury 1975, Drewett & Woolridge, 1979). This is illustrated in Figure 4.1 which shows a series of sucks as changes in intra-oral pressures recorded using a pressure transducer. This burst-pause pattern of sucking is largely evident throughout the feed.

Figure 4.1

An example of sucking recorded using a pressure transducer[1]



[1] Reproduced with permission from Drewett & Woolridge (1979)

A point event record of sucking, such as that collected in the present study, records two types of intervals; short intervals from one suck to the next within a burst, and long intervals from one burst to the next. As each suck has a duration (i.e. the time taken for a suck) the short intervals within a burst may be assumed to correspond to suck *durations.* The long intervals between bursts correspond to *pauses* between bursts of sucking. To summarise the local burst-pause structure of the infant's sucking behaviour, a means of distinguishing the suck *durations* (short intervals) from the *pauses* (long intervals) is required. In previous research the usual approach has been to separate the two by using a cut-off point: Drewett & Woolridge (1979) used a cut-off of 1.3 s derived from inspecting the sampling distributions of the intervals, whilst Pollitt, Gilmore & Valcarcel (1978a) chose a cut-off of 2 s but do not give any details of their rationale for this choice. The drawback in using a cut-off point is that the distributions of the suck durations and the pauses actually overlap so there is, in fact, no point that can accurately separate the two intervals. There is little agreement among researchers about the positioning of the cut-off point and summaries of the structure of sucking patterns are likely to be considerably influenced by its positioning.

Global sucking patterns over the course of a feed

Previous work in bottle fed infants tends to avoid the issue of change in sucking patterns over a feed by measuring sucking behaviour for brief periods of about two minutes duration (e.g. Dubignon, Campbell, Curtis, et al 1969). This simplifies the analysis but information is lost on how infants change their sucking patterns over the course of a feed, as, for example, they become progressively satiated. An alternative method has been to record sucking behaviour for the whole of a feed and simply ignore changes over a feed (Agras, Kraemer, Berkowitz, Korner & Hammer 1987). Only one study, by Kron, Stein & Goddard (1963) has identified this issue of change in sucking patterns. Kron et al measured sucking behaviour over a nine minute period in infants who were bottlefed and state that a 'trend analysis' for sucking pressure, nutrient ingestion and sucking rate per minute of the feed revealed no significant differences between each of the nine minutes. No details of the analysis or the results are given in the paper.

In breastfed infants the issue of change over the course of a feed is likely to be of greater importance than in bottle fed infants. In addition to progressive satiation, the availability, composition and flow rate of milk change systematically during a breastfeed (Akre 1989). As some of these features have been found to influence sucking patterns (Drewett & Woolridge 1979, Bowen-Jones, Thompson & Drewett 1982), it is important that changes in sucking during a feed are investigated, and if necessary, that summary measures of sucking in breastfed infants allow for them.

Modelling sucking behaviour during breastfeeding

An appropriate statistical model for summarising sucking patterns of breastfed infants was formulated in collaboration with Dr A.G. Chetwynd and Professor P. J. Diggle (Chetwynd, Diggle, Drewett & Young 1996). Below is a brief description of the model and an explanation of how the problems described above were resolved. A fuller description is given in appendix 7..

There are difficulties in defining what actually constitutes a 'feed' and different definitions have been offered including; (1) any episode of sucking when more than 5 minutes has elapsed since the previous episode (Drewett, Woolridge, Jackson et al 1989), and (2) episodes of sucking lasting for pre-defined duration (e.g. Ramsay & Gisel, 1996). Because changes in infant sucking patterns during the course of a sucking episode were of major interest in this study, for all infants it was decided to analyse sucking patterns collected when the infant was fed at the first breast only. This avoided the need to impose external time limits on the recording period. Therefore, for the purposes of analysing infant sucking patterns a 'feed' corresponds to all episodes of sucking that took place while the infant was feeding at the first breast. In this sample, half the infants were fed on just one breast (i.e. the first breast they were offered) at all observed feeds. The other half were fed at both breasts at some or all of their feeds.

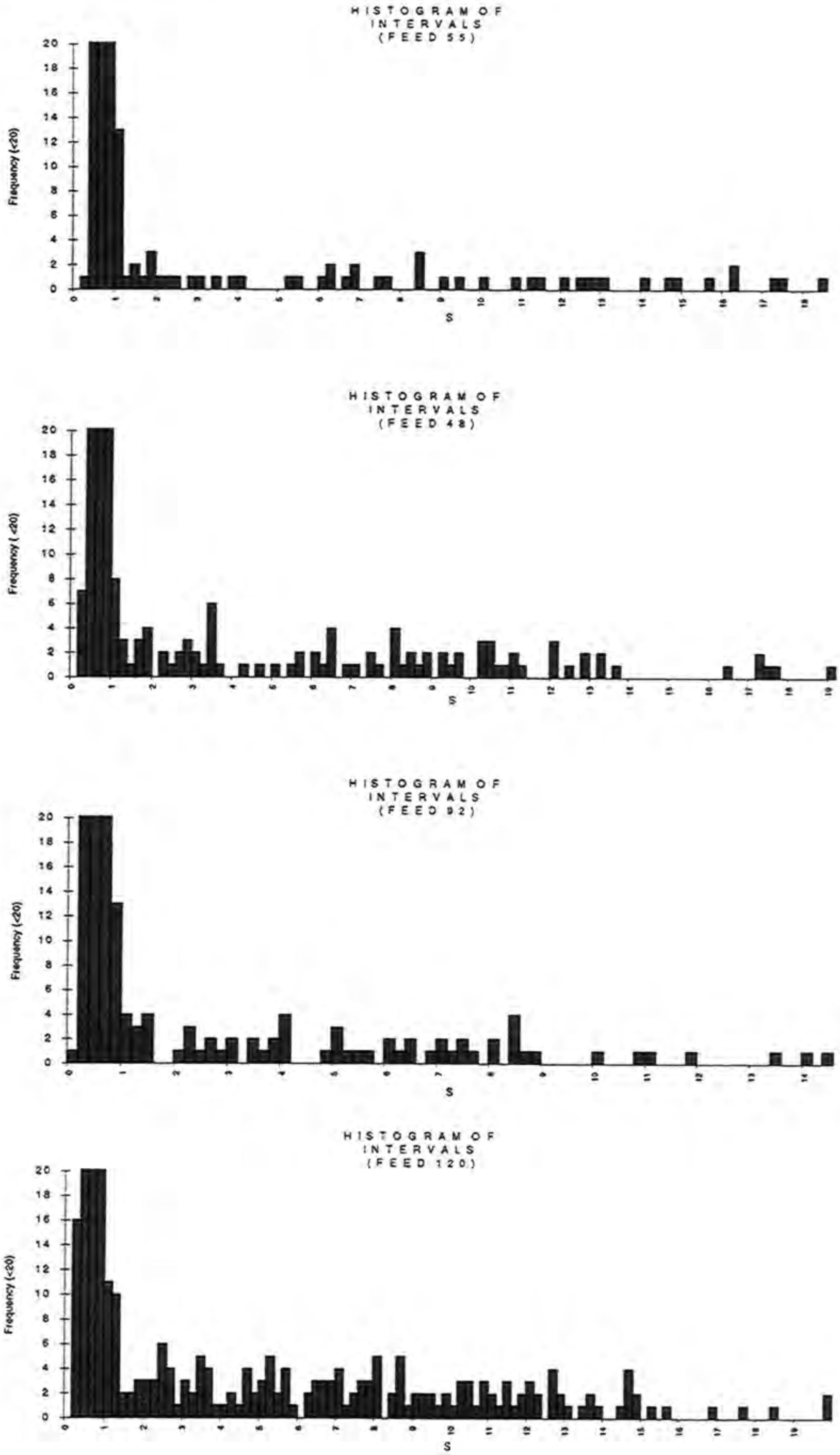
From inspection of the sucking records for all 128 feeds, there were four gaps in the sucking records greater than sixty seconds duration; these were probably due to the infant falling asleep during the feed. It was decided to remove these four gaps prior to data analysis.

To describe the local burst-pause pattern, four assumptions were made:

(1) a suck has a duration
(2) most short intervals in the point event record are suck durations
(3) bursts of sucks are separated by pauses
(4) long intervals on the point event record are made up a pause between bursts of sucking, plus the duration of the final suck in the preceding burst (see figure A7.2 in appendix 7).

As explained above, traditional analyses assume that suck durations can be distinguished from pauses by their length. Figure 4.2 shows histograms of intervals taken from point event records of four feeds in four different infants (only frequencies ≤ 20 are shown so that the tails of the distributions can be displayed). As can be seen, there is some overlap in the distributions of the suck durations and pauses so an analysis which uses a cut-off point based on the length of intervals to distinguish the two events cannot provide a correct summary of the burst-pause pattern.

Figure 4.2 *Histograms of Intervals*



The approach adopted here was to use a *2 component mixture model* (Titterington, Smith & Markov, 1985) to describe the burst-pause pattern. This recognises there are two overlapping distributions and models them simultaneously. The shape of the mixture model distributions makes assumptions about the underlying distributions; these assumptions were based on examination of the distribution of pilot data.

The suck durations were modelled as a 2 parameter normal distribution, summarised by its mean and standard deviation. In Figure 4.2 for example, the suck durations have a mean of about 0.7 s with a standard deviation of about 0.1 s. However, it is clear there are long tails to the right of the distributions which do not fit under the normal distributions. The tail is mostly made up of pauses and these were modelled as an exponential distribution which is summarised by a single parameter, its mean.

The next stage is to estimate the proportion of intervals from each distribution. This is modelled as a geometric distribution with one parameter which defines the probability of a suck duration being followed by a pause. For ease of interpretation this is transformed to the mean number of sucks per burst, which is the number of suck durations (i.e. equivalent to the number of sucks) divided by the number of pauses (i.e. equivalent to the number of bursts).

Thus, the sucking parameters estimated for the mixture model were:

(a) mean number of sucks per burst

(b) mean suck duration

(c) standard deviation of the mean suck duration

(d) mean pause duration

To summarise changes in the sucking behaviour over a feed, each of the four estimated sucking parameters above was allowed to vary over time (strictly, over the proportion of sucks elapsed). Mean suck durations, their standard deviations and pause durations must be positive so these were modelled as a log-linear time trend which constrains all parameters to be positive. The probability of a suck being followed by a pause (from which the number of sucks per burst is derived) must be positive and take a value between 0 and 1. This was modelled as a logistic linear time trend which constrains parameters to take positive values between 0 and 1. See appendix 7 for details of the transformation to 'start' and 'end' of feed values.

Model fitting was carried out separately for each feed. The sucking parameter estimates for each feed were estimated by maximum likelihood using S+. Likelihood ratios, D were used to explore possible simplifications of the model. Under the null hypothesis D is distributed as χ^2.

Results

To explore the effects of allowing each of the parameters to vary, an exhaustive series of comparisons were carried out feed by feed. To begin, the static model with all 4 parameter estimates held constant over the feed was compared with the four possible 5 parameter models, each with one of the suck parameters allowed to vary. From this comparison the best fit was a model in which the suck duration was allowed to vary: this produced a better fit than the static model for 122 of the 128 feeds ($D > 3.84$, $p < 0.05$). This new 5 parameter model, with suck duration allowed to vary, was accepted as the new baseline model and the comparison process was repeated with the three possible 6 parameter models, each with two sucking parameters allowed to vary. For 89 out of 128 feeds a better fit was provided by a model in which the duration of the pauses and the duration of the sucks was allowed to vary over a feed.

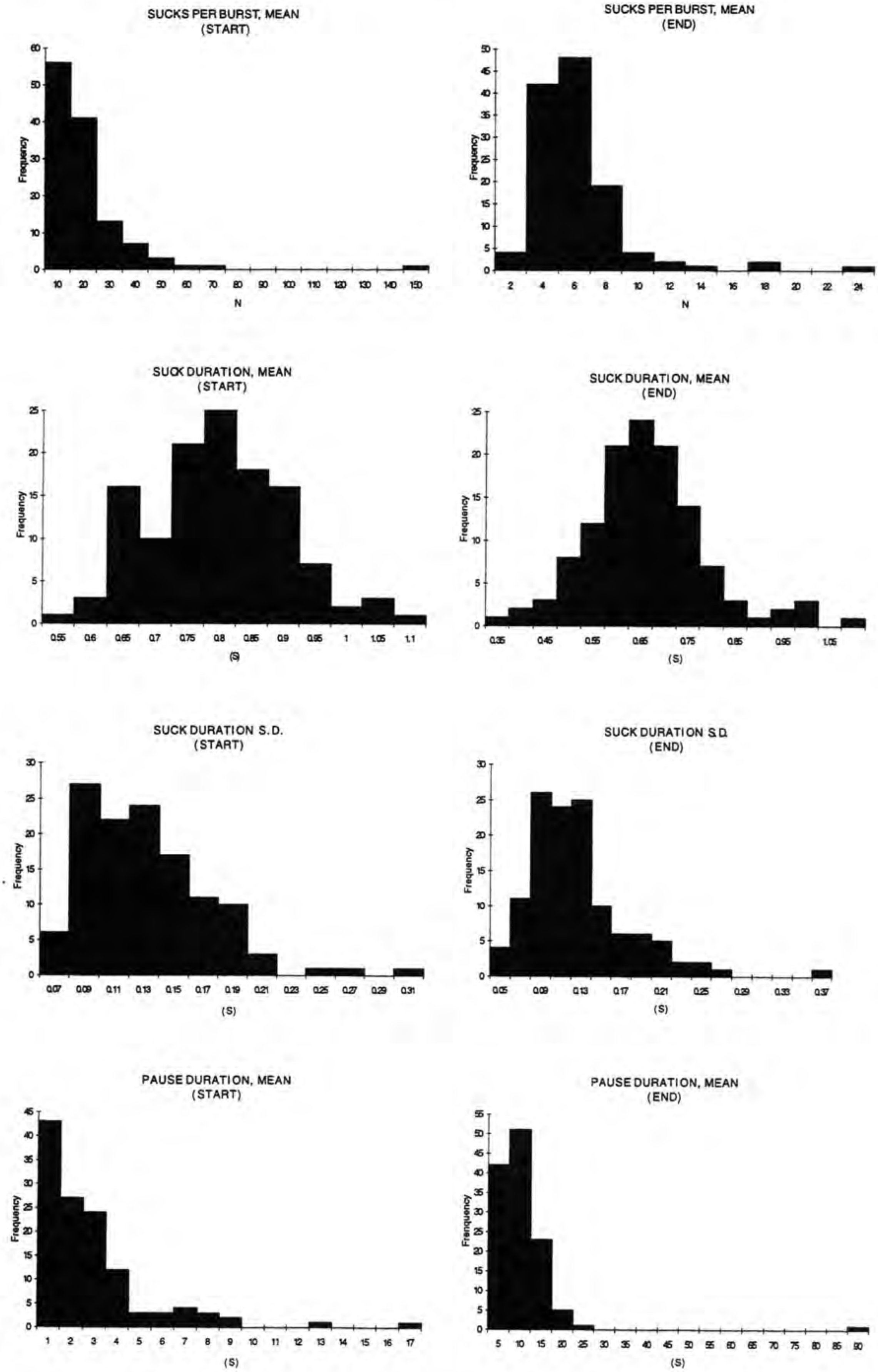
This process was repeated, parameter by parameter, to examine the effect of allowing all the parameter estimates to vary. The results of this are summarised in Table 4.1. For 70 of the 128 feeds the best fit was provided by a 7 parameter model which had three of the sucking parameters varying over a feed, but for 55 out of 128 feeds a better fit was provided by an 8 parameter model which had all of the parameters varying. As the aim was to produce a single model which could characterise all of the feeds adequately, and avoid the complexities of using different models for different feeds, the 8 parameter model, which had all the suck parameter estimates varying was accepted as the most appropriate model for summarising the sucking patterns of breastfed infants. The parameter estimates for each individual feed are given in appendix 8. From these estimates it is apparent that the model has broken down for 5 feeds: in feeds 16, 66, 74, and 77 the model has treated each short interval as a long interval, and for feed 91 the model has estimated the first burst as 1000 sucks long. These 5 feeds have been removed from subsequent analyses. Histograms of the mean sucking parameter estimates at the start and end of a feed for all of the remaining 123 feeds are given in Figure 4.3 and mean parameter estimates averaged across all the feeds are given in Table 4.2.

Table 4.1

Summary of parameters varying

Parameters Varying	Number of parameters	$D > 3.84$ $p < 0.05$
Suck durations	5	122/128
+ Pause duration	6	89
+ S.D. of suck durations	7	70
+ Sucks per burst	8	55

Figure 4.3 *Histograms of New Model Mean Parameter Estimates*



As can be seen from the mean parameter estimates in Table 4.2 the characteristic pattern is for the number of sucks per burst to drop from 15 to 5 sucks over the course of a feed, however; there is some variation about this pattern. As can be seen in Figure 4.3, sampling distributions for the number of sucks per burst at the start and end of a feed are quite asymmetrical, particularly for the start of the feed, and there are some outliers. The estimates for the suck durations and their standard deviations show much less variation; there are no outliers and the distributions are symmetrical. The suck durations drop from a mean of about 0.77 s to 0.64 s. The inter-quartile range of the difference between the duration of the suck duration at the start and end of the feed is 0.01 to 0.24. This demonstrates that a slight decrease is consistent across feeds. The change from start to end of a feed for the standard deviation of the suck durations is not consistent (interquartile range is -0.03 to 0.04). For the pause durations, the mean parameter estimates rise over the feeds, but there is considerable variation in the estimates across the feeds and the sampling distributions are highly asymmetrical. Figure 4.4 provides a graphical illustration of the average changes in the sucking parameter estimates during the course of a feed.

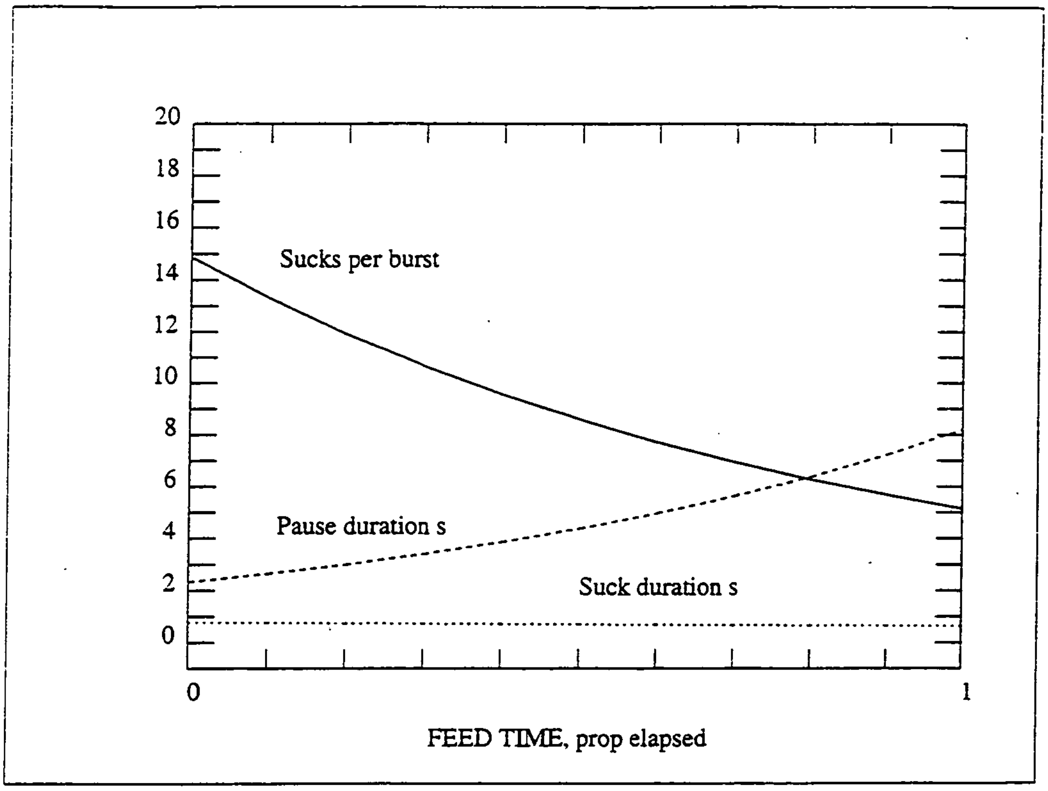
Table 4.2

Mean parameter estimates and their standard deviations from the time trend model averaged over 123 feeds

	Start Estimate	S.D.	End Estimate	S.D.
Sucks per burst, mean	14.87	16.28	5.14	2.97
Suck duration, mean	0.77 s	0.10 s	0.64 s	0.12 s
S.D. of suck duration, mean	0.12 s	0.04 s	0.12 s	0.05 s
Pause duration, mean	2.33 s	2.49 s	8.20 s	8.47 s

Figure 4.4

Average changes in the sucking parameter estimates during the course of a feed.



Variability in sucking behaviour

Data on sucking patterns collected at four feeds were analysed using ML3, a multi-level modelling package (Prosser, Rashash & Goldstein 1991), to examine the components of variation in sucking behaviour. Multi-level modelling is a statistical technique which recognises data that are hierarchically structured. In the sucking data considered here, each infant is located at one level in the hierarchy and is associated with the four feeds (at which sucking behaviour was measured) which are located at a lower level in the hierarchy. Because multi-level modelling recognises the hierarchial structure of the data it allows the between subject and within subject components of variation in the sucking data to be estimated. The analysis here is identical with a variance component analysis of variance, which is a special case of a multi-level model.

Results

Table 4.3 shows the estimates of between and within subject variance components for each of the eight sucking parameters. The final column shows the proportion of variation between subjects (i.e. attributable to stable individual differences) for each sucking parameter. For all sucking parameters, there is proportionally less variation between subjects than variation within subjects. For the number of sucks per burst, feed to feed fluctuations within infants are greater at the start of a feed than at the end, so individual differences form a proportionally small component of variation at the start of a feed for this parameter. For suck durations there is no difference in the proportion of variation between subjects for the start and end parameters. The standard deviation of suck durations show greater fluctuations from feed to feed at the end of a feed than at the start. However, the parameters showing the greatest fluctuation from feed to feed are pause durations; for these parameters individual differences are proportionally much smaller than feed to feed fluctuations.

Thus in terms of the new model parameters, these infants are fluctuating quite widely in their sucking behaviour from feed to feed. The duration of the pauses are especially variable within infants. Parameter estimates showing the least variation within infants are the number of sucks per burst at the end of a feed, the suck durations at the start and end of a feed, and the standard deviation of the suck durations at the start of a feed.

Table 4.3

Estimates of within and between subject variance components for mixture model parameters

	Between Subjects	Within Subjects	Proportion Between
Sucks per burst (start)	67.83	199.1	0.25
Sucks per burst (end)	3.543	5.303	0.40
Suck duration (start)	0.005	0.006	0.45
Suck duration (end)	0.007	0.009	0.45
S.D. of suck duration (start)	0.001	0.001	0.42
S.D. of suck duration (end)	0.001	0.002	0.19
Pause duration (start)	0.896	5.326	0.14
Pause duration (end)	5.935	65.92	0.08

Comparison of new model sucking parameter estimates with estimates derived from traditional methods

The sucking parameter estimates derived from the new model were compared with parameter estimates based on a traditional method of summarising sucking to provide some assessment of the validity of the new model. The traditional method involved using a 1.3 s cut-off to distinguish between the suck duration and pauses. The feeds were then split into thirds based on the proportion of time elapsed since the start of the feed. A set of variables equivalent to the new model parameter estimates were computed for the first and last portions of the feeds. A multi-level correlation which takes into account the hierarchical structure of the data was used to correlate the traditional variables with the sucking parameter estimates obtained from the new model. This was carried out in ML3.

Results

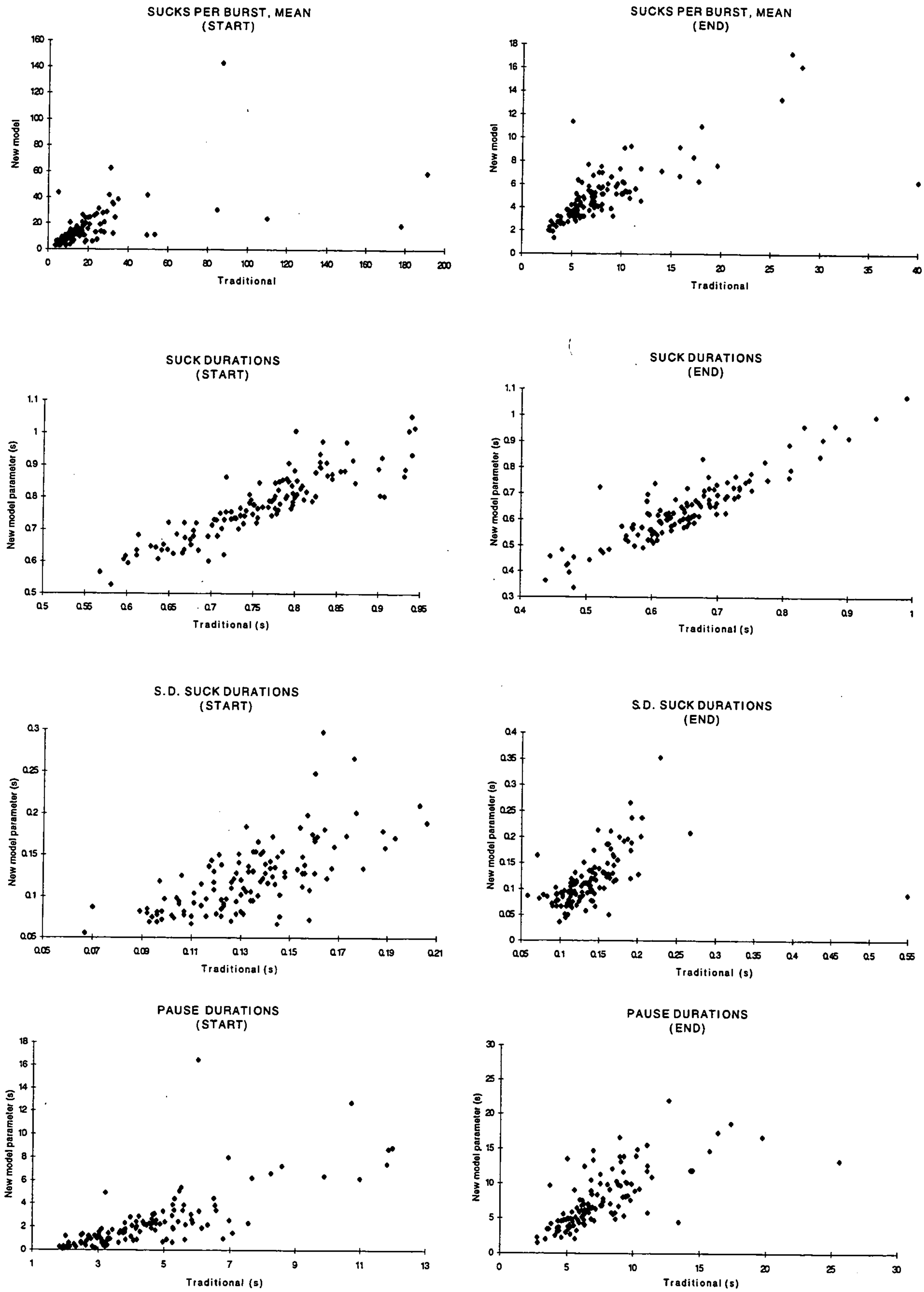
Table 4.4 gives the correlation coefficients between the traditional variables and the new model parameters. Scatterplots of new model parameters against traditional sucking variables are given in Figure 4.5. For the number of sucks per burst the level of agreement between the new model and the traditional method is acceptable, although from the scatterplots it is clear there are several gross outliers, particularly for the start of feed estimate, and it seems most of the outliers occur in feeds which have an exceptionally long burst of sucking at the start. For the suck durations the level of agreement is excellent and there are no outliers. The level of agreement for the standard deviation of the suck durations is generally acceptable although there are some outliers. Finally for the duration of the pauses, the level of agreement between the new model parameters and the traditional method is quite good but again, there are some outliers in the scatterplots.

Table 4.4

Multi level correlations between sucking parameters estimates from the traditional analysis and the new model ($p < 0.001$ in all cases)

	Start	End
Sucks per burst	0.53	0.72
Suck duration	0.90	0.90
S.D. of suck duration	0.68	0.42
Pause duration	0.76	0.68

Figure 4.5 *Scatterplots of new model parameter estimates against sucking parameters estimated by traditional methods*



General discussion

From the comparison of the two models it can be seen that the new model provides a good description of the sucking patterns of breastfed infants during a feed and successfully overcomes the problems associated with the more traditional methods. The local structure of sucking patterns are described without resorting to the use of a cut-off point, and the model can accommodate changes occurring during a feed.

The parameter estimates of the new model are a reasonably good approximation to parameters estimated by more traditional means. The most problematic parameters seem to be the number of sucks per burst at the start of a feed and the standard deviation of the suck duration at the end. In the case of the former parameter, the scatter plots in Figure 4.5 show that all but one of the outlying points appear to caused by the traditional estimate (i.e. the outliers are on the *x* axis). This suggests the number of sucks per burst may be difficult to estimate in feeds which begin with a long burst of sucks. Possible resolutions of this problem are hard to envisage without introducing a still more complex model but could possibly take the form of a model which is not constrained to fit a burst-pause structure at the outset of a feed. From estimates of the within and between subject variance components, the duration of the pauses are especially variable within infants. It seems unlikely this is due to problems in the modelling of these parameters as there is a reasonably good correlation between the estimates from the new model and those from the traditional analysis. Further investigation of the source of these pauses seems warranted. They could, for example, reflect the infant's level of satiation or behavioural state, or some combination of both and the influence of these state variations on sucking patterns could be studied experimentally.

An important feature of this study has been the examination of between and within subject sources of variation in sucking behaviour as this allows one to say whether feed to feed fluctuations within infants account for more variation than individual differences between infants. Overall, most variation in sucking patterns is due to feed to feed fluctuations within infants; when measured under naturalistic conditions, breastfed infants are not very consistent in their sucking behaviour. The parameter estimates with the lowest feed to feed variation within infants were the number of sucks per burst at the end of a feed, the suck durations and their standard deviations at the start of a feed. However, even for these parameters proportionally more variation was due to feed to feed fluctuations than individual differences between infants. Direct comparisons with previous findings on variability in sucking behaviour are difficult because of differences in measurement conditions, study design and analysis. In a study which examined between and within subject variation in infant sleeping, feeding and crying patterns, St James-Roberts and Plewis (1996) also found fluctuations within infants accounted for the largest proportion of the variability. The results of the present study support the view of St James-Roberts and Plewis (1996) that occasion to occasion fluctuations in behaviour within infants may be a prominent characteristic of infancy. At a practical level these results strongly suggest future work with breastfed infants should incorporate repeated measures on subjects.

From this extensive data set, it is clear that a better description of the feeding behaviour of breastfed infants is provided by a time trend model. Static summary measures are not adequate for describing the sucking patterns of this population over a feed. In providing a means of summarising the microstructure of feeding behaviour in infancy, this model provides a starting point for investigating the infant's regulation of intake during feeding. Although there is some variation in the direction of change, the general trend is for the suck durations and the number of sucks per burst to drop over the course of a feed, and for the duration of the pauses to rise. There are several factors in the mother and infant that could be responsible for one or more of these changes: infant factors include changes in the level of satiation or behavioural state; maternal factors include the rate of milk flow, the availability and the composition of breastmilk. In allowing changes in the infant's behavioural responses over the course of a feed to be described, this model could be used in future experimental work to investigate the regulation of intake in breastfed infants. This could be done by manipulating levels of satiation through the use of calorie preloads and examining the effect of this upon sucking patterns.

Chapter 5

Milk Feeding Behaviour and Weight Gain

Analysis of weight data

Models of weight gain

A major aim of this study is to examine the relationship between feeding behaviour and weight gain. One procedure for the statistical treatment of the weight data would be to examine differences in weight over two points in time (e.g. Dewey, Heinig, Nommsen, et al 1992). However, weight gain can be described by fitting a curve to the data (Cole, 1993) and in doing this the parameters of the curve provide a smoothed representation of changes in the weight or height of the child over time. The major advantages of modelling weight in this way instead of examining differences between two points in time are: (1) all the data points contribute to the final model so all the information in the data is fully utilised, (2) modelling allows the use of data which has been collected at unequal intervals, which means every subject does not have to be measured at precisely the same age and (3) it also allows the use of data from subjects who have some missing measurements. In summary, modelling uses the data more effectively and allows greater flexibility in data collection. In longitudinal research this is a major benefit.

Weight gain in infancy occurs in a predictable pattern. In the first few months of life the rate of weight gain is very rapid but over the first year it decreases. In other words, the velocity of infant weight gain is largely smooth and decreasing (Tanner 1989); this differs from the rest of childhood when the velocity is generally constant. Separate models are usually applied to these distinct phases of weight gain.

Many types of linear and non linear models of infant growth have been proposed: non-linear models usually provide the best fit to the data but are less widely used because of their complexity (Berkey & Reed 1987). Large measurement error affects the goodness of fit for all models as the size of residuals increase with poor quality data (Simondon, Simondon, Delpeuch et al 1992), and modelling weight is more difficult than height because weight may decrease over short periods, for example during illness. The goodness of fit of these models are also affected by abnormal patterns of growth and the age range studied.

The simplest model of weight gain is a polynomial:

$$Y = \beta_0 + \beta_1 t + \beta_2 t^2$$

(Here Y is the expected weight, t is time and $\beta_0 \ldots \beta_2$ *are the regression coefficients).*

However polynomials do not provide adequate models for infancy when the rate of weight gain is not constant but is particularly rapid in the first few months of life. The shape of the curve based on the above equation does not correspond to this pattern of weight gain. The behaviour of polynomials at the extremes of the age range is also unpredictable. An improvement upon this is the model devised by Count (1943) which contains a term for the logarithm of age to model the early phase of very rapid weight gain:

$$Y = \beta_0 + \beta_1 t + \beta_2 \ln (t + 1)$$

(One is added to age so that the model can be used to describe weight gain from birth, when t = 0).

An extension of this model was devised by Berky & Reed (1987) to describe periods of weight gain acceleration, which are a feature of the first few weeks of life following initial weight loss during the first week of life:

$$Y = \beta_0 + \beta_1 t + \beta_2 \ln(t+1) + \beta_3 (t+1)^{-1}$$

The first order Reed model contains an additional term, the reciprocal of age. This term allows these periods of growth acceleration to be described. Simondon et al (1992) compared five models of growth with weight data from birth to thirteen months of age from a sample of rural Congolese infants. The first-order Reed model provided the best fit to their data. As the present study examines weight gain over a similar period, it was decided to use this model to describe the weight gain patterns of the infants in this study.

Modelling weight

Weight data were analysed in ML3e (Prosser, Rasbash & Goldstein 1991), a multi-level modelling package which allows regression with repeated measures. Multi-level modelling is a statistical technique which recognises that data with repeated measures are hierarchically structured. In the present data, each infant, located at one level in the hierarchy, is associated with a series of weight measures at another level in the hierarchy. Recognition of this hierarchical structure is important because on average, any measures from the same individual will be more alike than measures taken from different individuals. Thus, multi-level modelling takes account of variation at both levels in the hierarchy; i.e. from individual to individual (between subjects) and from one measurement occasion to another in the same individual (within subjects). Failure to recognise this structure can result in standard errors being underestimated.

Weights were entered in data files as weight in kilograms and infant age in days was transformed to age in months (30 days). Modelling first involved fitting fixed (average) curves to the data. Statistical significance was tested as each age term was added to the model using the likelihood statistic, D (see appendix 9). Values of D are distributed as χ^2 under the null hypothesis with degrees of freedom equal to the difference in the number of parameters between two models, one of which is nested in the other.

Results

Table 5.1 shows the likelihoods and values of the likelihood ratio statistic, D, as each age term was added to the model. The addition of the reciprocal term for age, derived from the first order Reed model (Berkey & Reed 1987), to the model containing the linear and log terms produced a highly significant difference in the likelihood ratio statistic ($D = 13.3$, $p < 0.0003$, df 1). Therefore, the best fit to the data was provided by the first order Reed model, represented for fixed parameters by the equation:

$y_{ij} = \beta_{0j} + \beta_1 t + \beta_2 \ln(t+1) + \beta_3 (t+1)^{-1} + e$

(Here y_{ij} is the ith weight from the jth infant, and β_{0j} is an intercept estimated separately for each).

Table 5.1

Likelihoods, likelihood ratio statistics (D) and degrees of freedom for fixed parameters

	Likelihood	D	df	p
intercept	1063.8			
+ linear term	601.4	462.4	1	<0.00001
+ log term	508.7	92.7	1	<0.00001
+ reciprocal term	495.4	13.3	1	<0.0003

Random variation in changes over time

This basic model was elaborated to model random variation at level 2 (between subjects) in each of the age terms. This allows the curves to vary from infant to infant. The Reed model with all parameters random at level 2 is:

$$y_{ij} = \beta_{0j} + \beta_{1j} t_{ij} + \beta_{2j} \ln(t_{ij}+1) + \beta_{3j} (t_{ij}+1)^{-1} + e_{ij}$$

where the subscript i represents the measurement occasion and j refers to the individual infant. An ij subscript denotes a term which varies from one measurement occasion to the next within infants, and a j subscript represents a term which varies between infants but remains constant from one measurement occasion to the next within infants. As the coefficients β_{0j} to β_{3j} are likely to be correlated, their covariances are estimated as well as their variances.

Results

Modelling random variation at level 2 produced a highly statistically significant value of D (D = 245.7, df 9, $p < 0.0002$)[1] so a better fit was provided by the model in which each of the age terms varied at level 2. Thus, there was considerable variation between infants in their patterns of weight gain. Table 5.2 shows the fixed and random parameter estimates for the Reed model fitted to the weight data after modelling random variation at level 2.

Standardised residuals for each of the terms varying at level 2 (the intercept, linear age, log of age and the reciprocal of age), were calculated to examine whether this model was appropriate for the data. The assumption is that the residuals for the terms β_{0j}, β_{1j} , β_{2j} and β_{3j} are normally distributed. Normal probability plots of the residuals associated with these terms generally conformed to a straight line indicating these were close to a normal distribution. Normal probability plots of residuals associated with terms varying at level 2 can be found in appendix 11.

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1 The degrees of freedom correspond to the number of parameters estimated at level 2. For example, the addition of the linear term involves estimating the variance associated with the linear term and its covariance with the intercept; the addition of the log term involved estimating three more parameters, the variance associated with log age and the covariances for the log term associated with the intercept and the linear term, and so forth.

From Table 5.2 the estimate for the level 1 variance is 0.044 kg, which gives a standard deviation of 0.210 kg. This is somewhat in excess of the of the nominal measurement error of the balances used in this study (see Chapter 2).

Level 1 standardised residuals i.e. residuals associated with the term e_{ij} were also calculated. A plot of these against age can be found in appendix 12. As can be seen from this plot there is no systematic variation in the residuals with age. A normal probability plots of level 1 standardised residuals can be found in appendix 13. This generally conforms to a straight line indicating the residuals were close to a normal distribution.

Figure 5.1 displays the empirical (plotted) weight gain data and the fitted curves based on the Reed model with the three age terms varying at level 2. It can be seen the fitted model provides a good description of the empirical data.

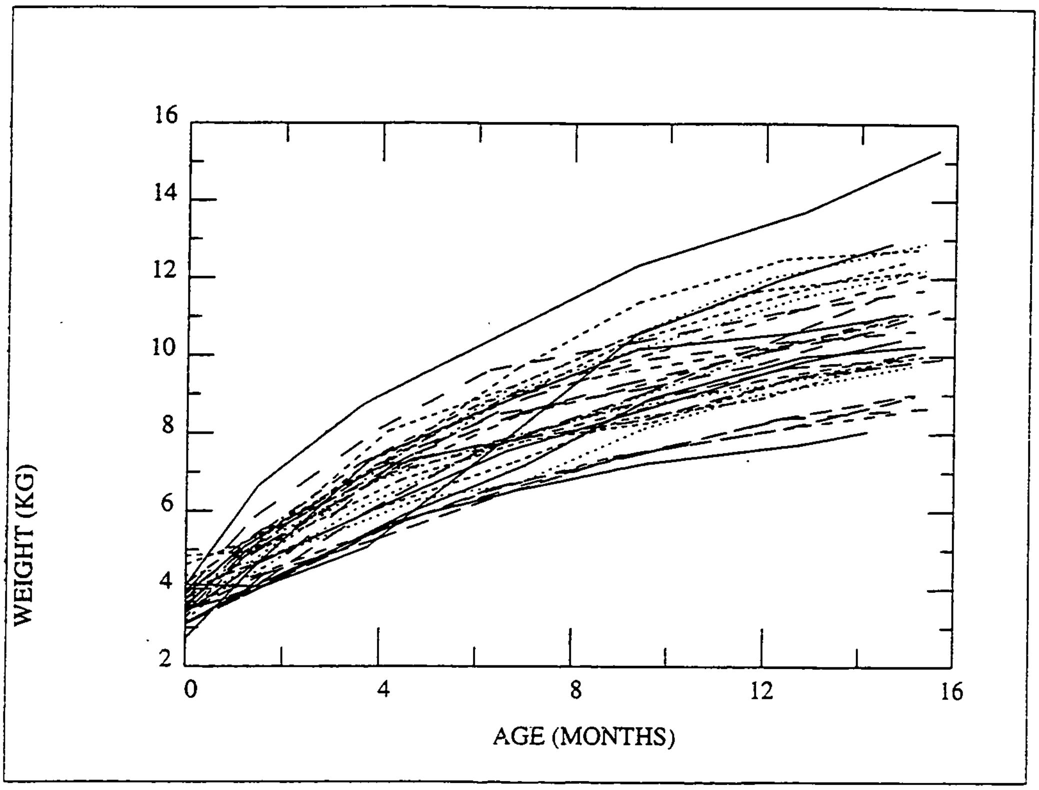
Table 5.2

Parameter estimates for the Reed model after modelling random variation at level 2.

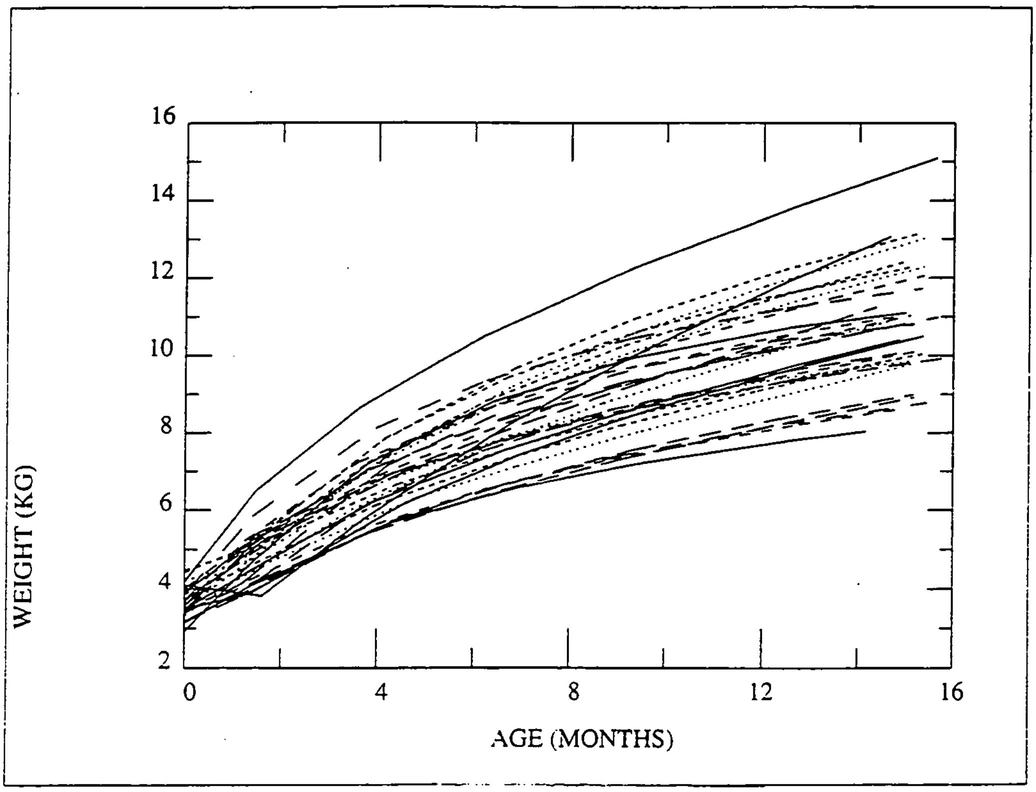
	Estimate	Standard Error
Fixed Parameters		
Intercept	0.205	0.525
Linear	0.045	0.032
Log	3.524	0.337
Reciprocal	3.433	0.534
Random Parameters		
Level 2 (between subjects)		
Variances		
Intercept	5.888	2.222
Linear	0.022	0.008
Log	2.417	0.916
Reciprocal	5.973	2.305
Covariances		
Intercept/linear	0.218	0.119
Log/intercept	-3.432	1.382
Log/linear	-0.178	0.081
Reciprocal/intercept	-5.847	2.250
Reciprocal/linear	-0.197	0.119
Reciprocal/log	3.419	1.400
Level 1(within subjects)		
Variance		
Intercept	0.044	0.006

Figure 5.1

Empirical weight data



Fitted curves based on the Reed model after modelling random variation at level 2.



Infant sex and weight gain

To model the effect of sex on weight gain, two additional fixed terms were added to the model; a main effect term for infant sex and an interaction term for sex with linear age (sex had been coded in the data file as female = 0 and male =1). This model for infant weight gain is now represented by

$$Y = \beta_0 + \beta'_0(\text{sex}) + \beta_1 t + \beta'_1(t \times \text{sex}) + \ldots$$

$$= \beta_0 + \beta'_0(\text{sex}) + (\beta_1 + \beta'_1 \text{sex})\, t + \ldots$$

If the infant is female, sex = 0, so β'_0 (sex) and β'_1 (sex) are both 0. The females average curve is therefore

$$Y = \beta_0 + \beta_1 t + \ldots$$

If the child is male, β'_0(sex) and β'_1(sex) alter the intercept and linear term respectively, giving different average pattern of weight gain for males and females.

Statistical significance was tested for the effect of infant sex using the likelihood ratio statistic, D. This is distributed as χ^2 under the null hypothesis with degrees of freedom equal to the difference in the number of parameters between two models. The value of the likelihood ratio statistic, D was 18.8 (df 2, $p < 0.00009$) indicating that infant sex was a highly statistically significant predictor of weight gain.

Interactions with log age and the reciprocal of age were also considered. There was no evidence that either the log or the reciprocal interactions produced a further statistically significant improvement in the model.

The fixed effect term for sex indicates males were heavier than females overall, and the interaction term with linear age indicates that males gained weight at a faster rate than females. Parameter estimates for the Reed model fitted to the weight gain data, taking into account infant sex after also modelling random variation at level 2, are shown in Table 5.3.

Table 5.3

Parameter estimates for the fitted model controlling for infant sex with random variation at level 2.

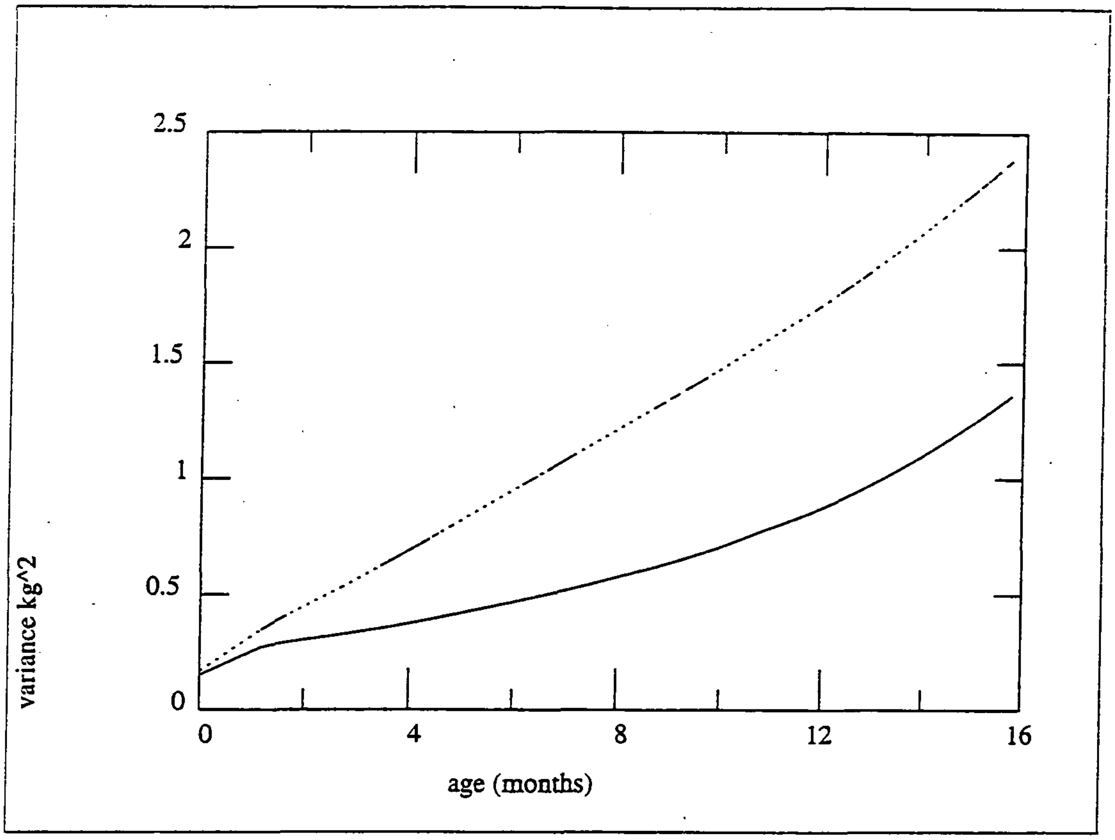
	Estimate	Standard Error	r
Fixed Parameters			
Intercept	-0.081	0.539	
Linear	-0.019	0.038	
Log	3.524	0.337	
Reciprocal	3.436	0.534	
Sex	0.475	0.130	
Sex × Age	0.109	0.025	
Random Parameters			
Level 2 (between subjects)			
Variances			
Intercept	6.179	2.314	
Linear	0.027	0.010	
Log	2.425	0.921	
Reciprocal	6.003	2.335	
Covariances			
Intercept/linear	0.262	0.131	.64
Log/intercept	-3.589	1.422	-.93
Log/linear	-0.212	0.088	-.05
Reciprocal/intercept	-6.015	2.312	-.99
Reciprocal/linear	-0.232	0.128	-.58
Reciprocal/log	3.435	1.413	.90
Level 1(within subjects)			
Variance			
Intercept	0.044	0.006	

Because level 2 variance is calculated around mean curves specified by the fixed effects parameter estimates, with the addition of infant sex to the model we now have separate mean curves for males and females, which reduces the unaccounted for level 2 variance.

The proportion of level 2 (between subject) variance accounted for by infant sex was calculated (see appendix 10). Figure 5.2 shows the level 2 residual between subject variation plotted against age for the weight model with just the three age terms (broken line) and for the model containing infant sex and its interaction with the linear term as an additional predictor variable (solid line). As can be seen infant sex accounts for about 39 percent of the variation in weight between subjects at 3 months of age, and 52 percent at 8 months and 45 percent at 15 months. This figure also clearly shows that the level 2 (between subject) variances increase over time. This is an important characteristic of weight gain. Details of the way the level 2 (between subject) variances are calculated are given in appendix 10.

Figure 5.2

Level 2 (between subject) variation against age for age model (broken line) and for the model with age plus infant sex (solid line).



Conclusion

The first order Reed growth model provided a good fit to the weight gain data. Infant sex was a highly statistically significant predictor variable indicating the male and female infants differed in their patterns of weight gain. More importantly, modelling random variation at level 2 provided a statistically significant improvement in the fit of the model. Modelling variation between subjects is more than an exercise in statistical technique; analysing the data in this way allows the slopes of the curves to vary from infant to infant and so provides a description of the data that was maximally sensitive to the individual differences in weight gain. Considerable variation in patterns of weight gain between infants was seen. A major aim of the following section and the next chapters will be to explain this variation by examining infant feeding behaviour.

Milk feeding behaviour and weight gain

We can now consider the relationship between feeding behaviour during milk feeds and weight gain over the first 15 months of life. It will be recalled from Chapter 1 that previous research has suggested there is a relationship between early feeding behaviour, weight gain to one month of age, and measures of adiposity up to three years (Pollitt, et al 1978a&b, Agras et al 1987, 1990). This research was carried out on bottle fed infants measured under laboratory conditions. The present study is the first to investigate associations between sucking behaviour measured under natural conditions and weight gain in breastfed infants. As previous studies have also found a relationship between milk intake and weight gain (e.g. Dewey, Heinig, Nommsen et al 1991b), and conflicting evidence on the relationship between feeding patterns and weight gain (e.g. DeCarvalheo, Robertson, Merkatz et al 1982), the associations between these variables and weight gain were also investigated in the present study.

As discussed in Chapter 4 the sucking data in the present study has been summarised using a mixture model. In dispensing with the need to use a cut-off point to distinguish suck durations from pauses, this model provides a more accurate description of the local structure of sucking patterns. The model also provides a description of global changes in the structure of sucking patterns; this is particularly important in breastfed infants as the composition and flow rate of milk, which remain constant during a bottle feed, change during the course of a breastfeed.

To simplify the analyses, milk feeding behaviour was considered in three different stages; stage one is concerned with the whole day feeding behaviour variables recorded in diaries by mothers; stage two with the feeding behaviour variables recorded by the observer; and stage three with the sucking behaviour variables also recorded by the observer.

Whole day feeding behaviour variables

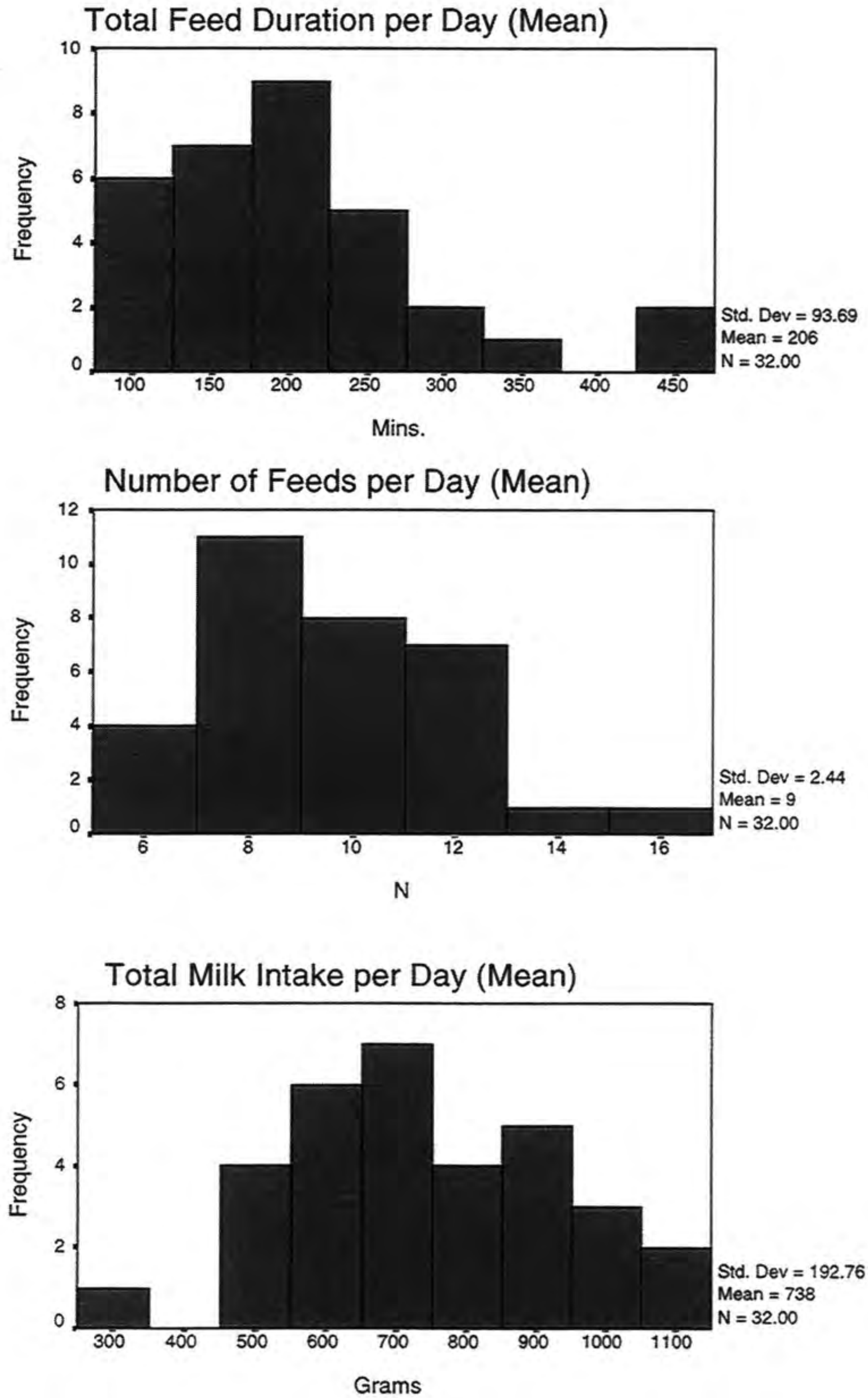
Whole day feeding behaviour variables were averaged over the two days of observations to give a mean value per 24 hours. Three whole day feeding variables were examined; total duration of feeding per 24 hours, number of feeds per 24 hours and total milk intake per 24 hours. Total milk intake comprised breastmilk plus any expressed breastmilk or formula the baby received over the 48 hour period. Histograms of these are given in Figure 5.3. The sampling distributions for total feed duration and number of feeds per day are quite asymmetrical but that for total milk intake is approximately normally distributed.

The analyses to examine the relationship the whole day between feeding behaviour variables and weight gain were carried out in ML3e. Starting with the basic weight model each feeding behaviour variable was added as a main effect term and in interaction with age. Because there are three age terms in the basic weight model (age, log age and the reciprocal of age), all feeding behaviour variables were combined with each of these so three separate analyses were carried out for every feeding behaviour variable. Statistical significance was tested for the combined main effect and interaction with age for each feeding behaviour variable using the likelihood ratio statistic, D. This is distributed as χ^2 under the null hypothesis with degrees of freedom equal to the difference in the number of parameters between two nested models.

A separate analysis was carried out for each whole day variable. Although each predictor variable was added to the model as a main effect and as an interaction with the three age terms, the main effect is of little interest in itself as it merely controls for overall weight differences between infants: a statistically significant main effect term for milk intake would only indicate that infants with bigger milk intakes are heavier overall which is to be expected given the greater body maintenance requirements of heavier babies (Tanner 1989). Of much greater importance would be a statistically significant interaction term between milk intake and age as this would indicate infants with greater milk intakes are gaining weight at a faster rate.

Figure 5.3

Histograms of whole day feeding behaviour variables



Results

No statistically significant effects were found for total duration of feeding or number of feeds per day. A statistically significant effect was obtained for total milk intake per 24 hours in interaction with log age (D = 7.2, df 2, $p < 0.03$) or with the reciprocal of age (D = 11.0, df 2, $p < 0.004$). Total milk intake in interaction with linear age was not statistically significant.

As the two statistically significant terms were both interaction terms with the same variable, total milk intake, it is possible that they are not independently associated with weight gain. The effect of including such correlated terms in the same model is to reduce the precision of the regression coefficients and increase their standard errors (Healy 1995a&b). To investigate this the model was further examined. The reciprocal interaction was added first as this produced the greatest value of D in the likelihood in the separate analysis. The addition of the log interaction did not produce a further statistically significant difference in the likelihood. Thus only the reciprocal of age was independently associated with weight gain, so the reciprocal is used in subsequent analyses. The parameter estimates for this model are given in Table 5.4 below.

Table 5.4

Parameter estimates with total milk intake as a main effect and with the reciprocal of age

	Estimate	Standard Error	z	p
Intercept	-1.579	0.7022		
Linear	-0.0147	0.0376		
Log	3.526	0.3404		
Reciprocal	5.249	0.7229		
Sex	0.472	0.1323		
Sex × age	0.102	0.0251		
Total milk	0.002	0.0006	3.3	< 0.01
Total milk × reciprocal age	-0.0024	0.0007	3.4	< 0.01

For one subject, the total milk intake recorded by the mother was exceptionally low suggesting the record for this infant may have been inaccurate. An analysis for total milk intake excluding this subject was therefore also carried out. With this subject excluded total milk intake terms remained a statistically significant predictor of weight gain (D= 25.6, df 2, p< 0.0001).

Feeding behaviour variables recorded by the observer

The four feeding behaviour variables recorded by the observer were number of sucks per feed, feed duration, breastmilk intake at a feed and the number of feeds at which infants were fed from two breasts. The number of sucks per feed, feed duration and breastmilk intake at a feed were averaged over the four feeds to give a mean value for each infant. Histograms of all four variables are given in Figure 5.4.

Following the same procedure as described above main effect and interaction terms for the 4 feeding variables with each of the 3 age terms were added to the model. No statistically significant effects were found for number of sucks per feed, feed duration or the number of feeds at which infants were fed from two breasts. There was a statistically significant effect for milk intake at a feed with the reciprocal of age (D = 13.4, df 2, $p < 0.002$) or with log age (D = 9.6, df 2, $p < 0.009$).

To investigate whether these terms have independent effects both were added to the model. The reciprocal interaction was added first as this produced the greatest difference in the likelihood in the separate analysis. The addition of the log interaction did not produce a further statistically significant difference in the likelihood. Thus only the reciprocal of age interaction with milk intake at a feed was independently associated with weight gain. The reciprocal is used in the subsequent analyses. The parameter estimates for this model are give in Table 5.5 below.

Figure 5.4
Histograms of feeding behaviour variables recorded by the observer

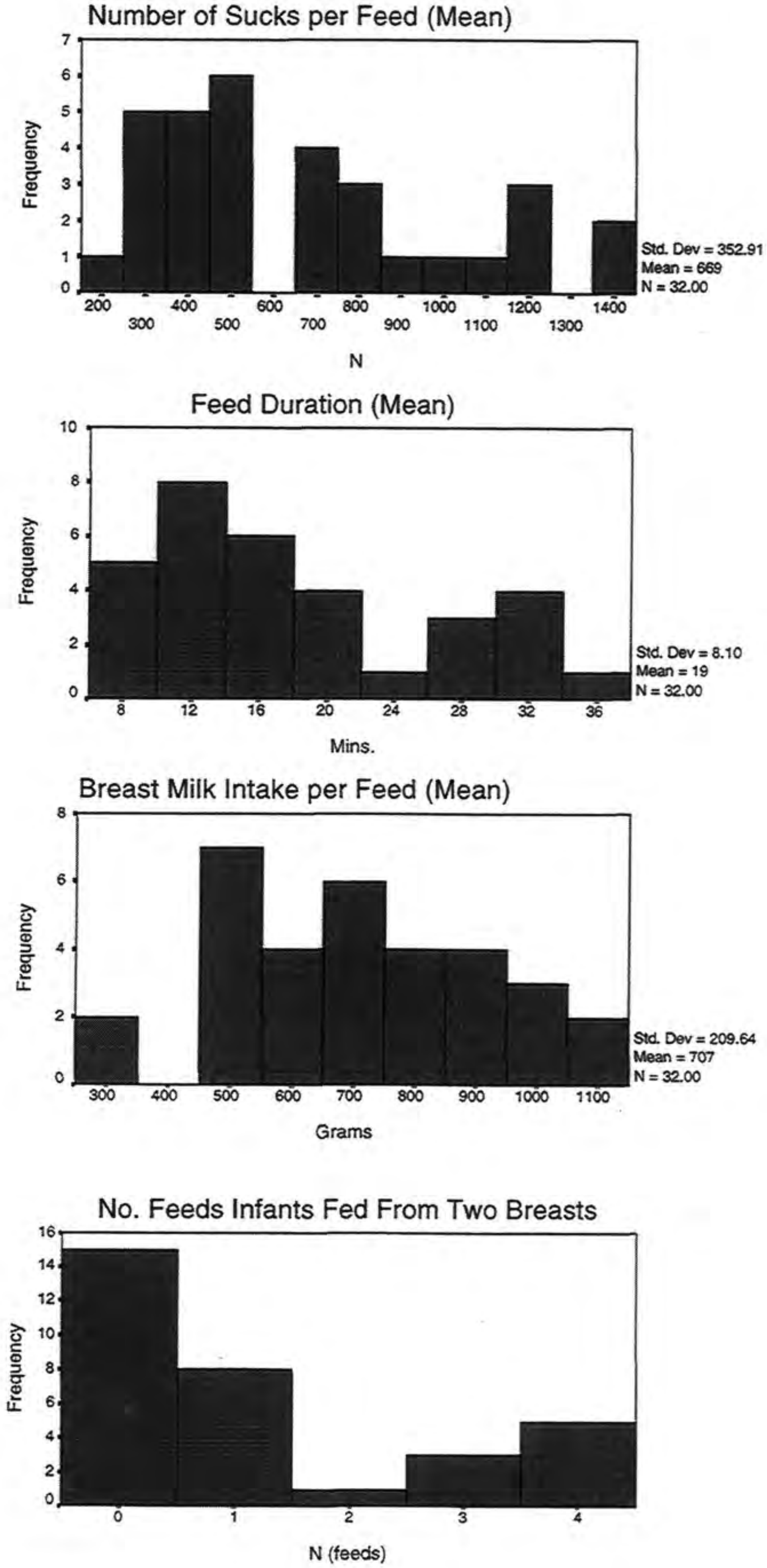


Table 5.5

Parameter estimates with milk intake at a feed as a main effect and with the reciprocal of age

	Estimate	Standard Error	z	p
Intercept	-1.138	0.5956		
Linear Term	-0.0065	0.0369		
Log Term	3.524	0.3342		
Reciprocal Term	4.716	0.6049		
Sex	0.4603	0.1386		
Sex × age	0.0873	0.0251		
Feed milk	0.0116	0.0032	3.6	< 0.01
Feed milk × reciprocal age	-0.014	0.0034	4.1	< 0.01

As total milk intake per 24 hours and milk intake at a feed were correlated ($r = 0.66$, $p < 0.001$), further analyses were carried out to examine the effect of adding both terms to the same model. Milk intake at a feed was added to the model first as this variable produced the largest likelihood difference in the separate analysis. The addition of total milk intake then reduced the likelihood only slightly ($D = 2.2$, $p > 0.05$). Milk intake averaged over the 4 observed feeds was used in subsequent analyses.

Size of effects

To examine the effect sizes on weight gain, the parameter estimates for milk intake at a feed in Table 5.5 were used to calculate associated weight gains. The coefficient for milk intake at a feed is negative, as is often the case for reciprocal terms, but the combined effect of the main effect and reciprocal of age produces a positive association between milk intake at a feed, m, and weight gain:

$$Y = \ldots + 0.0116\,m - 0.014\,m.1/(age+1) + \ldots$$

$$= \ldots \quad [0.0116 - 0.014\ 1/(age+1)]\,m + \ldots$$

Every 100 g of milk at a feed predicted an increase in attained weight of 810 g at three months of age, 1010 g at eight months and 1080 g at fifteen months.

Conclusion

In keeping with previous findings, milk intake was found to be a significant predictor of weight gain during the first year of life. An interaction with the reciprocal term produced a greater difference in the likelihood than with the linear or log term. As the reciprocal term influences the shape of the curve most in the first few months of life, it is not surprising to find that milk intake measured at 6 weeks best predicts weight gain in the first few months of life.

In an analysis with both milk intake measured at the four feeds when the observer was present, and total milk intake per 24 hours recorded over the two days by mothers test weighing their infants, milk intake at the four feeds was most strongly associated with weight gain. In some senses this finding is surprising as one would expect intake at a feed to be more variable than intake over 24 hours, and therefore to give a poorer estimation of the infant's habitual intake. However, this expectation depends upon the mother remembering, and correctly adhering to, the very onerous task of weighing her infant before and after each feed, and there is evidence from previous research by Butte, Wong, Klein et al (1991) that maternal test weighing records may be inaccurate. The present study suggests accurate records at 2 meals per day are better predictors. In finding no relationship between feeding frequency and feed duration in early life and weight gain these results provide additional evidence that there is no simple relationship between feeding patterns and weight gain. There was also no significant association between weight gain and the number of times infants were fed on two breasts at a feed rather than one.

Weight gain and sucking behaviour

In these analyses the mixture model parameter estimates used to summarise sucking (number of sucks per burst, suck duration, the standard deviation of suck durations and pause duration) were used to explain weight gain. It will be recalled that these parameters give *start* and *end* feed estimates of sucking behaviour. Thus a total of eight sucking estimates were examined in these analyses. Prior to the analyses, each estimate was averaged across the 4 feeds to give mean estimates for each infant.

The same procedure as described above was followed where each sucking estimate was entered as a main effect and as an interaction with each of the three age terms. Initially, each sucking estimate was entered into to the model separately. Statistical significance was tested using the likelihood ratio statistic, D.

Results

Significant predictors of weight gain were: the number of sucks per burst (end estimate), mean suck duration (start and end estimate) and mean pause duration (end estimate). The number of sucks per burst (start estimate), standard deviation of the suck durations (start and end estimates), and mean pause duration (start estimate) were not statistically significant predictors of weight gain.

Dealing firstly with sucks per burst (end); statistically significant values of D were obtained for linear age (D = 12.1, df 2, $p<0.002$), log age (D = 17.2, df 2, $p< 0.0002$), and the reciprocal of age (D = 16.7, df 2, $p<0.0003$). As log age produced the greatest value of D in the separate analysis, this term was added first to the basic weight model to test for independent effects. The linear and reciprocal terms were then added, in turn, to the model already containing the log term: for the linear term this produced a value for D of 0.27 (df 1, $p > 0.05$), for the reciprocal term D was 0.25 (df 1, $p > 0.05$). As neither the linear or the reciprocal term produced a better fit in the model, the log term was used for subsequent analyses involving the sucks per burst estimate (end).

For suck duration (start and end estimate) only the interactions with the reciprocal of age terms were statistically significant; suck duration (start) gave a D of 7.0 (df 2, $p<0.04$) and suck duration (end) a D of 7.1 (df 2, $p<0.03$). The start and end terms were added to the same model to examine if they were independently associated with weight gain. The end estimate, which produced the largest value of D in the separate analyses was added first. The addition of the start of feed estimate produced a D of 3.8 ($p > 0.05$). As the start of feed estimate for suck duration did not produce a further statistically significant difference in the likelihood the end of feed estimate is used in subsequent analyses involving suck duration.

For pause duration (end), a statistically significant D was obtained for linear age (D = 14.0, df 2, $p < 0.001$), log age (D = 14.6, df 2, $p <0.0007$) and the reciprocal of age (D = 12.8, df 2, $p<0.002$). The procedure described above was followed to examine whether the three terms had independent effects. The term which produced the greatest D, log age, was added first to the model. The addition, in turn, of linear age (D = 0.33, $p > 0.05$) and the reciprocal of age (D = 0.05, $p>0.05$) to the model already containing log age did not produce a further statistically significant effect. Therefore, for the duration of the pauses (end), the interaction with log age is used in subsequent analyses.

Finally, to investigate whether the three statistically significant sucking estimates, sucks per burst (end), pause (end) and suck duration (end) were independent predictors of weight gain, these were added together to the basic weight gain model and a z statistic for each was calculated. This was done by dividing the parameter estimate for each interaction term, adjusted for the effects of the others, by its standard error: only the interaction term for the number of sucks per burst with log age reached statistical significance ($z = 2.1$, $p < 0.05$). To check if this was indeed the best predictor, sucks per burst was paired in turn with each of the other sucking estimates and the values of D examined: neither the suck duration, nor pause duration produced a statistically significant values of D so number of sucks per burst at the end of a feed was the best predictor of weight gain. The parameter estimates for model of weight gain with number of sucks per burst as the predictor are given in Table 5.6.

Table 5.6

Parameter estimates with number of sucks per burst at the end of a feed as a predictor of weight gain

	Estimate	Standard Error	z	p
Intercept	-0.314	0.573		
Linear age	-0.020	0.037		
Log	4.056	0.361		
Reciprocal	3.436	0.547		
Sex	0.472	0.131		
Sex × age	0.113	0.021		
Sucks per burst (end)	0.046	0.030	1.5	> 0.05
Sucks per burst (end) × log	-0.104	0.022	4.7	< 0.01

Size of effects

Although sucks per burst was the only sucking estimate independently associated with weight gain, as the results of the analyses above demonstrate, weight gain during the first year of life is also associated with the duration of the pauses at the end of a feed, suck duration at the start and end of a feed, and the number of sucks per burst at the end of a feed. To examine the influence of all of these on weight gain, expected weight was calculated from the regression coefficient estimates.

The association between sucks per burst (end), b, and weight gain was negative:

$$Y = \ldots + 0.046\,b - 0.104\,b\,(\log \text{age} + 1) + \ldots$$

$$= \ldots [0.046 - 0.104\,(\log \text{age} + 1)]\,b + \ldots$$

At three months of age every additional suck per burst at the end of a feed was associated with a reduction in attained weight of 99g, at eight months and fifteen months the associated reductions were 183 g and 243 g respectively.

The association between the duration of the pauses at the end of a feed, p, and weight gain was positive:

$$Y = \ldots + 0.03549\,p - 0.04041\,p\,(\log \text{age} + 1) + \ldots$$

$$= \ldots [0.03549 - 0.04041\,(\log \text{age} + 1)]\,p + \ldots$$

Every additional second in the duration of a pause was associated with an increase in attained weight of 91 g at three months, 124 g at eight months and 147 g at 15 months.

The relationship between suck duration, d, and weight gain was also positive:

$$Y = \ldots + 3.205\,d - 4.007\,d\,1/(age + 1) + \ldots$$

$$Y = \ldots + [3.205 - 4.007\;1/(age + 1)]\,d + \ldots$$

Every additional 0.1 s in the mean duration of a suck was associated with an increment in attained weight of 220 g at three months, 276 g at eight months and 295 g at 15 months.

However sucks per burst (end) is correlated with both suck duration (end) ($r = -.44$, $p < 0.02$) and pause duration (end) ($r = .74$, $p < 0.001$), so after entering sucks per burst it must be rembered that the other sucking behaviour estimates make no statistically significant independent contribution.

Conclusion

Weight gain to 15 months of life is predicted by four sucking behaviour estimates. Three of these are end of feed estimates and one is a start of feed estimate: for number of sucks per burst and the duration of the pauses, the end of feed estimates were statistically significant; for the suck durations, both start and end of feed estimates were statistically significant, although the end of feed estimate was the better predictor of the two. The number of sucks per burst at the end of a feed was the only independent predictor of weight gain when entered in combination with the other sucking estimates.

Sucks per burst at the end, milk intake at a feed and weight gain

From Chapter 1 it will be recalled that previous research has shown energy intake from breastmilk is associated with future weight gain (Dewey, Heinig, Nommsen, et al 1991b) although the correlation between the two is low. The present study also found that milk intake at a feed is associated with weight gain in early life. To examine whether sucks per burst (end) had an independent effect upon weight gain after controlling for milk intake, the two variables were entered together to the basic weight gain model. The addition of sucks per burst (end) to the model already containing milk intake at a feed gave a D value of 14.6 (df 2, $p < 0.0007$). Number of sucks per burst at the end of a feed is a highly statistically significant predictor of weight gain even after controlling for milk intake. The parameter estimates for milk intake at a feed and number of sucks per burst at the end of a feed are given in Table 5.7.

Table 5.7

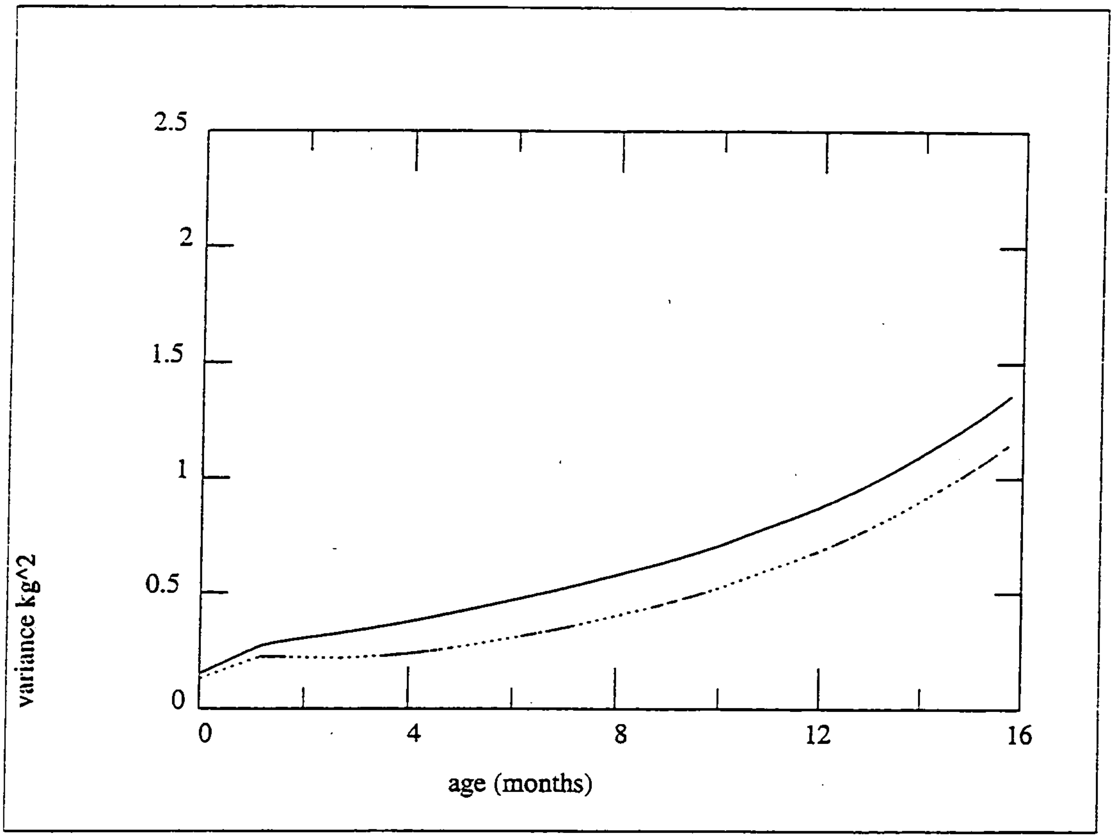
Parameter estimates for milk intake at a feed and number of sucks per burst

	Estimate	Standard Error	z	p
Intercept	-1.126	0.6357		
Linear age	-0.0092	0.0367		
Log	3.973	0.3624		
Reciprocal	4.389	0.6059		
Sex	0.454	0.1382		
Sex × age	0.094	0.0210		
Milk	0.0092	0.0030	3.1	< 0.01
Milk × reciprocal age	-0.0100	0.0029	3.4	< 0.01
Sucks per burst	0.0439	0.0307	1.4	> 0.05
Sucks per burst × log age	-0.0889	0.0205	4.3	< 0.01

The level 2 (between subject) variance accounted for by the two predictor terms sucks per burst of the end of a feed and milk intake at a feed was calculated. Figure 5.5 shows the level 2 variation plotted against age for the model with age plus infant sex (broken line), and for the model also containing these two statistically significant predictor terms, milk intake at a feed and sucks per burst (solid line). As can be seen, the predictor terms account for about 35 percent of the otherwise unaccounted for variation in weight between subjects at 3 months of age, 30 percent at 8 months and 15 percent at 15 months.

Figure 5.5

Level 2 (between subject) variation against age for age model (broken line) and for the model with sucks per burst and milk intake at a feed (solid line).



General discussion

This is the first study to examine the relationship between the sucking patterns of infants on the breast and weight gain. When the sucking patterns of infants are measured in their adaptive context and summarised using techniques that allow for change during the course of a feed to be described, the sucking pattern associated with higher rates of weight gain to fifteen months consists of fewer sucks per burst, longer pauses between bursts and longer sucks. Weight gain is particularly associated with the pattern of sucking at the end of a feed. Of all the sucking variables, the number of sucks per burst was most strongly associated with weight gain and this association remained strong even after controlling for milk intake.

Given the evidence of previous studies that the ability to predict patterns of weight gain from measures of milk intake is limited, the findings of the present study are important in demonstrating that it is possible to predict weight gain using a behavioural measure of feeding behaviour which is simple and inexpensive to collect. The present study suggests such measures may provide an alternative to costly and cumbersome procedures involving the measurement of intake in breastfed infants.

In Chapter 4 it was seen that the issue of change in sucking patterns over the course of a feed is particularly important in studying breastfeeding. These results extend previous findings on the relationship between sucking behaviour and weight to infants measured while feeding on the breast, and provide new evidence suggesting sucking patterns at the end of a feed are particularly important for predicting later weight gain. Previous work has found relationships between (1) sucking pressure and concurrent weight during the first month of life (Pollitt, et al 1978a) (2) infant behaviour during a feed and weight gain to one month life (Pollitt, et al 1978b) and between (3) sucking pressure, shorter intervals between bursts at 2-4 weeks and levels of fatness up to three years of age (Agras et al 1987, 1990). The present investigation is the first to use summaries of sucking that capture changes occurring over the course of a feed. In finding that sucking patterns at the end of the feed were better predictors than sucking patterns at the beginning, these results indicate that processes occurring during the course of a feed may be important for predicting weight gain.

The sucking behaviour estimates used in this study were derived from measures taken while the infant suckled from the first breast. Although some infants were fed from more than one breast during some feeding episodes, the finding that weight gain was unrelated to the number of feeds at which infants were fed from two breasts suggests these conclusions on sucking patterns and weight gain would be unaffected by including measures from the second breast.

Chapter 6

Solids Feeding Behaviour and Weight Gain

The few previous investigations of eating behaviour in preschool children have largely been confined to children capable of independent self-feeding. As the child's first experiences with 'adult foods' begins with being spoon fed by a carer, there are good grounds to investigate eating behaviour before independent self-feeding is fully established. One of the aims of this chapter is to provide descriptive data on eating behaviour of one year olds. There is, for example, no previous research on meal to meal variability in eating behaviour in this age group. Research with slightly older children has found considerable meal to meal variability in energy intake (Birch, Johnson, Anderson et al 1991) and, as eating behaviour is likely to vary similarly, an important feature of the present study was to provide data on meal to meal variability. Four meals were chosen to maintain consistency with the observations of milk feeding behaviour conducted in the same infants at six weeks of age.

The literature reviewed in chapter 1 suggests there is a relationship between eating behaviour, concurrent weight and levels of adiposity in both child and adult subjects. None of these studies have looked prospectively at the relationship between eating behaviour and future weight gain so, on the basis of just these studies, it is difficult to identify whether eating patterns are a cause or a consequence of current weight. The present study aims to investigate this relationship prospectively and therefore provide a better basis to interpret the associations.

There are special difficulties in researching the eating behaviour of children which this study has sought to overcome. First, as the context of the meal may have important influences upon the behaviour of young children, mealtimes were recorded in a familiar environment to minimise the disruptive effect of the observation. Second, problems arising from food neophobia were anticipated (Birch 1990) so instead of offering standardised meals, infants were recorded while being fed whatever foods the carer had chosen to give them on that day. Previous research also suggests food tastes, particularly sweetness (e.g. Desor, Maller & Greene 1977), may influence eating behaviour in young children. To investigate this the coding scheme allowed eating behaviour during the savoury and sweet portions of meals to be analysed separately. Because the foods given to infants were not restricted, it was especially important to examine the effects of gross differences in the types of foods given to infants. Third previous research has tended to recruit children over quite broad age ranges (e.g. Koivisto, Fellenius & Sjoden 1994b, Klesges, Coates Brown et al 1983) but as infancy is a time of very rapid developmental change, findings from these studies are likely to be confounded by age differences. To avoid these difficulties, observations of eating in the present study were limited to within three weeks of the infant's first birthday. This timing was chosen to achieve a balance between ensuring infants would have attained a reasonable level of experience in eating solid foods and also ensuring that they were still predominately spoon fed by carers.

Development of infant eating behaviour coding scheme

A provisional coding scheme was developed from previous work on child eating behaviour. The scheme was principally based on work by Agras, Berkowitz, Hammer et al (1988) and Harris, Thomas & Booth (1990). The overall objective was to produce a scheme that allowed accurate recording of ingestive behaviour. Early in the design stage it was decided to deliberately limit the coding scheme to events that were easily observable and unequivocal, avoiding the need to make judgements about behaviour as far as possible. No coding was made of verbal behaviour of the mother or infant as the focus of the study was ingestive behaviour.

A pilot group of four 12 months old infants was recruited solely for the purposes of developing the coding scheme: none of the infants in the pilot study were included in the main study. Videos of 2 mealtimes were made on each of these infants. A provisional coding scheme was used to code infant eating behaviour and this was done directly into a laptop computer using a programme specially designed for recording behaviour (see chapter 2 for details). The behaviour categories for the provisional coding scheme are given in Table 6.1.

Table 6.1

Pilot coding scheme behaviour categories

Subject	Behaviour category
Infant	feeds self
	eager accept
	passive accept
	refuse
	reject
	miss
	chew
Mother	offer spoon
	bring spoon
	retract

To examine the reliability of the provisional coding scheme, these pilot videos were viewed separately by two independent observers and the coding records were analysed in SPSS. Counts of each behaviour category, by each observer, were calculated for each feed. Pearson correlation coefficients were calculated for the frequency scores. Inspection of these and the corresponding scatterplots showed there were some problems with the codes. First, the inter-observer correlation for the number of chews/meal was very low ($r = 0.38$). This was probably due to difficulty of discerning chewing for foods with a soft or puree consistency. As one year olds consume a large number of these foods it was decided to drop this category from the scheme. Second, inter-observer correlations for behaviour categories relating to maternal food offer categories ('offer spoon,' r = 0.62 and 'bring spoon,' r = 0.79) and the parallel infant acceptance behaviours ('eager accept,' r = 0.58 and 'passive accept' r = 0.62) were only moderate. Scrutiny of scatter plots indicated these behaviours were absent for many feeds so even the Pearson correlations quoted above are likely to be artificially inflated. The distinction between the behaviours to which these codes refer are probably too subtle for the behaviours to be accurately recorded. As the recognition of a particular behaviour and the decision to code it depends on the clarity of the behaviour (Dowdney, Mrazek, Quiton et al 1984), it was decided to dispense with this distinction and combine the maternal categories 'offer spoon' and 'bring spoon' to produce a single category 'gives' to code the mother giving food to the infant. The correlation for the new combined category 'gives' was 0.99 ($p < 0.001$). Similarly it was decided combine the infant categories 'eager accept' and 'passive accept' to produce a single category 'accept' to code infant food acceptance: the correlation for this new combined category was 0.99 ($p < 0.001$).

The correlation for 'refuse' was zero. This was probably because the definition of this behaviour had been unclear in the provisional coding scheme. As this behaviour is very important in signalling infant satiety during spoon feeding, it was decided to retain 'refuse' in the scheme and improve its behavioural definition. No instances were recorded of the category 'miss' so it was decided to drop this category.

Inter-observer reliability of main solids feeding behaviour data set

Coding of all videos in the main data set using the coding scheme described in Table 6.2 was carried out by a single observer (Observer 1). To assess inter-observer reliability for this data set, a video of one feed from each infant was selected at random to be independently viewed and coded by a new observer (Observer 2). Observer 2 had been previously trained in the use of the coding scheme by using it to code the pilot videos that had been collected for the purpose of developing the scheme.

Training involved the two observers viewing the pilot videos together, and discussing which code should be applied to a particular behaviour. This process was followed for two whole mealtime videos. Observer 2 then viewed two additional videos and any remaining ambiguities were clarified in subsequent discussion and review of the relevant videos with Observer 1. Coding of videos from the main data set was carried out independently by the two observers.

Table 6.2

Behaviour categories and descriptions for the final coding scheme.

Subject	Category	Description
Infant	feeds self	grasps spoon/food, brings it towards mouth without assistance and places in mouth
	accept	takes spoon/food into mouth after parent has placed it in or near the infant's mouth
	refuse	infant has attended to spoon/food but fails to open mouth or closes mouth as spoon/food approaches and before spoon/food is fully in mouth (may also turn head, push spoon away, cover mouth)
	reject	expels spoon from mouth and/or spits out food
	drink	infant has a drink of liquid from cup or bottle
Mother	gives	brings spoon/food to infant's mouth
	retract	withdraws spoon/food/cup after failure to gain child's attention or refusal by child

Summaries of solids eating behaviour to be reported here consist of simple counts of behaviour scores, or of counts of behaviour per minute for the meal. Assessment of inter-observer reliability involved calculating correlation coefficients on these counts.

For each category, histograms of behaviour frequency were first inspected to examine the sampling distribution of the data and whether there were any zero counts for any of the behaviours. This happens, for example, when a baby was entirely spoon fed by the mother and no instances of 'feeds self' were recorded. Zero counts were often found for 'feeds self,' 'miss,' 'refuse,' reject' and 'retract'. As mentioned above, the Pearson correlation coefficient can be misleading if there are zero counts as the strength of association is artificially inflated (Bland 1995). An alternative measure of association is Kendall's tau-b; in this statistic, tied values for variable x are dropped and therefore do not contribute to the final measure of association. Kendall's tau-b correlation coefficients were calculated for all behaviours feed by feed. Pearson and Kendall correlation coefficients for all behaviours are shown in Table 6.3.

From the Kendall correlation coefficients in Table 6.3 (and from inspection of scatterplots), it appears that the inter-observer reliability for recording the frequency of behaviours at a particular meal and for total meal duration is generally good.

One problem with the correlation coefficient for a reliability study is that it only measures strength of association and gives no information about whether there are any systematic differences between observers in their coding of behaviours. The tendency of one observer to 'pick-up' or attend to more of a particular behaviour than another observer is a major obstacle to achieving reliability in observational studies (Dowdney 1984). To examine whether there were any systematic differences between observers, a sign test was used feed by feed, on the behaviour counts.

Table 6.3

Pearson and Kendall correlation coefficients for coding by two independent observers

Subject	Category	Pearson r	Kendall tau-b
Infant	feeds self	.99	.93
	accept	.99	.98
	refuse	.93	.71
	reject	.91	.84
	drink	.98	.85
Mother	gives	.99	.94
	retract	.62	.71
Feed Duration		.99	.96

The results of the sign test are shown in Table 6.4. No statistically significant differences were found for the behaviours ‘accept,’ ‘drink,’ ‘feeds self,’ ‘refuse,’ duration and ‘gives.’ Significant differences in direction of recording were found for the behaviours 'reject' and 'retract': observer 1 systematically recorded more instances of both behaviours than observer 2. It was decided to drop the behaviours 'reject' and 'retract' from all subsequent analyses.

Table 6.4

Sign test on behaviour scoring frequencies

Subject	Category	- diffs*	+ diffs	ties	p (2-tail)
Infant	feeds self	12	7	11	>.1
	accept	9	4	17	>.1
	refuse	15	8	7	>.1
	reject	10	2	18	<.05
	drink	9	6	15	>.1
Mother	gives	14	9	7	>.1
	retract	25	1	4	<.01
Feed Duration		2	2	26	>.1

(* - differences indicate that the count was higher for observer 1 than observer 2)

As mentioned earlier, the behaviours 'feeds self' and 'refuse' had a high number of zero counts for some meals To test the inter-observer agreement for whether or not a behaviour occurred at all, Kappa statistics were calculated for these two behaviours feed by feed. The value of Kappa was 0.83 for 'feeds self' and 0.54 for 'refuse.' According to Fleiss (1981)[1] these values of Kappa represent excellent ($k > 0.75$) to fair agreement ($k > 0.4$).

[1] Cited in Armitage & Berry 1994

As described above the final coding scheme contained five subject behaviour codes. Four of these were infant behaviours ('feeds self,' 'accept,' 'refuse,' and 'drink') and one code was for carer behaviour ('gives'). In addition, solid food intake at a meal (weight in grams) and meal duration were also recorded.

Two composite variables were calculated from the infant behaviour codes. First, because it was possible some infants might feed themselves without assistance from a carer for some meals, while other infants might be entirely spoon fed by the carer, a composite variable, 'bites' was calculated so that there was one ingestive behaviour variable for which all infants had a score. 'Bites' was equal to the total number of food ingestions and was calculated by summing the count of 'accept' and the count of 'feeds self.' Second, when infants are spoon-fed by carers an important means by which infants can exert control over food intake is to refuse food that is offered. To represent this aspect of infant behaviour, an index of food acceptance behaviour is required. This index was calculated as the ratio of 'accepts' to the sum of 'refuses' plus 'accepts' i.e.

$$\frac{\text{food accepts}}{\text{food refusals} + \text{food accepts}}$$

This composite variable was termed the 'accept proportion'.

Results

Variance components in solids eating behaviour

Data on eating behaviour at four meals were analysed using ML3, a multi-level modelling package (Prosser, Rashash & Goldstein 1991) to examine the components of variation in behaviour.

Table 6.5 shows the estimates of the means, between subject variance and within subject variance for each of the nine solids meal behaviour variables. From the means for 'gives' and 'accept' it can be seen infants are accepting only a proportion of food offered to them and just under half of all food ingestions are self-feeding. Mean meal duration was a little under 19 minutes and infants took an average of 4 sips of drink during a meal. The final column shows the proportion of variation between subjects. For all except two of the variables, close to half the variation in eating behaviour is due to between subject differences. For the number of 'accepts,' relatively more variation is due to between subjects differences than to within subject differences. The variable showing most variation within subjects is the number of 'refuses.'

Table 6.5

Means and estimates of within and between subject variance components for variables at solid meals

	MEAN	VARIANCE between subjects	within subjects	*proportion between*
Accept	29.85	192.00	167.70	0.74
Accept proportion	0.69	0.02	0.02	0.51
Bite	50.55	294.30	304.40	0.49
Drink	4.47	9.67	11.50	0.46
Feed self	20.71	365.70	260.50	0.58
Give	45.33	361.80	394.50	0.48
Refuse	13.33	49.83	105.30	0.32
Duration (mins)	18.84	43.75	44.65	0.49
Intake (g)	146.60	1876.00	2058.00	0.48

Correlations among solid meal variables

The following analyses examined the between subject correlations for the solids eating behaviour variables. To give a mean for each infant, eating behaviour variables were averaged over the number of feeds observed. Four infants were not offered any food by their carer at one meal, but fed themselves. For these four the variables 'gives,' 'accept' and 'refuse' were averaged over the other three meals. Two infants did not feed themselves at any of the observed meals as they were discouraged from doing so by their carers, so these infants were excluded from the analyses for the variable 'feeds self.'

The correlations among the mean solid meal variables between subjects are given in Table 6.6. There were three statistically significant associations with mean intake at a meal. Infants who consumed a greater amount of food tended to be those who were offered food more frequently, accepted food more frequently and had a higher 'accept proportion.' There were no statistically significant relationships between mean intake and the mean counts of 'refuse,' 'bites,' 'self feed,' 'drinks,' or with meal duration.

Strong positive associations were found between the mean count of 'gives' and 'accepts,' and the mean count of 'gives' and 'refuse'. Counts of 'feeds self' were negatively related to mean number of 'accepts' and 'gives.' Mean duration of meals was strongly (positively) associated with mean count of 'feeds self.'

Table 6.6

Between subject correlations among solid meal eating behaviour variables

	Accept Proportion	Bite	Drink	Feed self	Give	Refuse	Duration	Intake
Accept	.29	.31	.05	-.45*	.92†	.41*	.04	.64†
Accept Proportion		.34	-.28	.10	-.03	-.59*	-.11	.47*
Bite			.18	.70†	.29	.13	.70†	.28
Drink				.13	.16	.33	.52*	-.10
Feed self					-.42*	-.19	.63†	-.22
Give						.72†	.19	.51*
Refuse							.36	.14
Duration								-.08

* p<0.05, † p<0.01

Savoury and sweet foods

The above variables were calculated separately for the times when infants were being fed savoury and sweet food. One infant was never offered a sweet food at his observed meals and so this child is excluded from this analysis. Six other infants were only offered sweet foods at some of their meals and two infants were given sweet and savoury foods simultaneously at some of their meals (so variables for the savoury and sweet portion of the meals could not be separately calculated). For these infants, subject means for the sweet and savoury portion of the meals are calculated only for some meals. For all behaviour variables there were some meals at which there were zero occurrences of a particular variable; all means were based on meals where there was a least one occurrence of the variable.

Means and standard deviations of each eating behaviour variable for the savoury and sweet portions of the meals are shown in Table 6.7. Table 6.7 also shows the subject level correlations between the sweet and savoury portion of the meal for each variable. After averaging within subjects, several variables had scores of zero for some infants; 'feeds self' had a value of zero for nine infants and three infants had zero scores for 'drinks' and 'refuse.' As the Pearson correlation can be artificially inflated by a high number of zero values, Kendal's tau-b correlation coefficient is reported for these variables. The Pearson correlation coefficient is reported for all other variables.

Statistically significant positive associations were found for the number of 'accepts,' 'feeds self,' 'gives,' 'bites,' 'refuse' and 'accept proportion' during the sweet and savoury portion of the meal. Only intake and 'drinks' were not associated during the sweet and savoury portion of the meal. Infant behaviour during the savoury portion of a meal is positively related to that during the sweet portion with the exception of food intake and 'drinks.'

Table 6.7

Means standard deviations and correlations for sweet and savoury portions of the meals

	Mean	S.D.	Correlation	p
Accept (savoury)	17.19	9.98	.51	<0.01
Accept (sweet)	16.82	12.89		
Accept proportion (savoury)	0.64	0.20	.41	<0.05
Accept proportion (sweet)	0.75	0.20		
Bite (savoury)	43.49	20.28	.39	<0.05
Bite (sweet)	26.22	12.28		
Drink (savoury)	3.32	3.99	.15	>0.05
Drink (sweet)	2.21	2.95		
Feed self (savoury)	14.38	15.38	.39	<0.01
Feed self (sweet)	9.45	5.96		
Give (savoury)	29.11	16.21	.57	<0.01
Give (sweet)	22.48	14.56		
Refuse (savoury)	10.19	8.18	.34	<0.05
Refuse (sweet)	4.93	4.67		
Duration (savoury)	13.43	7.35	.48	<0.01
Duration (sweet)	8.57	6.37		
Volume intake (savoury)	84.86	37.92	.29	>0.05
Volume intake (sweet)	75.75	36.93		

Conclusion

This study represents one of the largest data sets collected on the eating behaviour of one year old infants. From the results described above it is clear these infants accept only a proportion of food that is offered to them by carers. This provides evidence that spoon-fed infants are not passive recipients of all that is offered to them but actively control food ingestion even though they are dependent upon carers for feeding. The high proportion of food ingestions as a result of infant self-feeding further supports the view that one year old infants play an active role in mealtimes. Although the frequency of self-feeding is quite high, the majority of food ingestions are still due to spoon-feeding by carers. It is also important to point out that data on 'feeds self' does not provide information about how successful infants are at actually getting food into their mouths when feeding themselves.

This study is the first to systematically investigate patterns of variation in eating behaviour and therefore provides previously unavailable data on the components of variation in one year old infants. Overall, around 50% of the variation in eating behaviour is due to fluctuations from meal to meal within infants. The variable showing most variation is the number of 'refuses' with around seventy percent of variation due to differences within infants from meal to meal. These results demonstrate that estimates of eating behaviour could be substantially improved in future studies by measuring eating behaviour on more than one occasion.

From the correlations among the eating behaviour variables above, surprisingly there are no correlations between intake and 'refuses.' Less surprising was the finding that intake is positively associated with variables related to spoon-feeding ('offers,' 'accepts' and the 'accept proportion'). No such association was found between self-feeding and intake but self-feeding was associated with longer meal duration. Comparing behaviour during the savoury and sweet portions of meals, eating behaviour correlations were modest for most variables: infants who score high during the savoury portion of a meal also tend to score high during the sweet portion. Clearly there are parallels in eating behaviour which hold true whether or not the food is sweet or savoury, however, the small magnitude of the relevant correlations ($r = 0.4$-0.5), suggests these parallels are far from strong. This would suggest the eating behaviour of one year olds is influenced by whether food is sweet or savoury and this needs to be taken into account.

Eating behaviour during solid meals and weight gain

The following analyses examined the relationship between solids eating behaviour at 12 months of age and weight gain to 15 months. The eight solids eating behaviour variables were averaged over the four observed feeds to give a mean value for each infant. This subject level mean for each variable was added to the model as a main effect and an interaction with each of the three age terms (age, log age and the reciprocal of age), so three separate analyses were carried out for each eating behaviour variable. Statistical significance was tested for the main effect and interaction combined using the likelihood ratio statistic, D. This is distributed as χ^2 under the null hypothesis.

In the regression of weight on solids eating behaviour, the only variable with a statistically significant effect was the 'accept proportion.' A statistically significant effect was obtained for this in interaction with log age ($D = 7.24$, df 2, $p < 0.03$) and with the reciprocal of age ($D = 7.24$, df 2, $p < 0.03$) but not with linear age ($D = 4.91$, df 2, ns). To investigate whether these effects were independent, the effect of adding both to the model was examined. The interaction with log age was entered first as this term produced a marginally greater difference in D when analysed separately. The addition of the reciprocal of age interaction did not produce a further statistically significant effect so the interaction for 'accept proportion' with log age was selected to model this effect. Parameter estimates for the regression of the 'accept proportion' on weight are given in Table 6.8.

Size of effects

To examine the effect of the 'accept proportion' on weight gain, the parameter estimates from the regression model for the 'accept proportion,' p were used to calculate predicted weight (y):

$$Y = \ldots \; -0.346\,p \; + \; 1.006\,p\,(\log \text{age} + 1) \; + \ldots$$

$$= \ldots \; [-0.346 + 1.006\,(\log \text{age} + 1)]\,p \; + \ldots$$

At twelve months of age every 0.1 increase in the 'accept proportion' predicted an increase in attained weight of 220g, and at fifteen months an increase in attained weight of 230g.

Table 6.8

Parameter estimates with the 'accept proportion' as a main effect and with the log of age

	Estimate	Standard Error	z	p
Intercept	0.139	0.621		
Linear term	- 0.012	0.038		
Log term	2.823	0.425		
Reciprocal term	3.462	0.549		
Sex	0.473	0.140		
Sex × age	0.099	0.025		
Accept proportion	- 0.346	0.425	0.8	>0.05
Accept proportion × log age	1.006	0.354	2.8	<0.01

Rate of eating behaviour

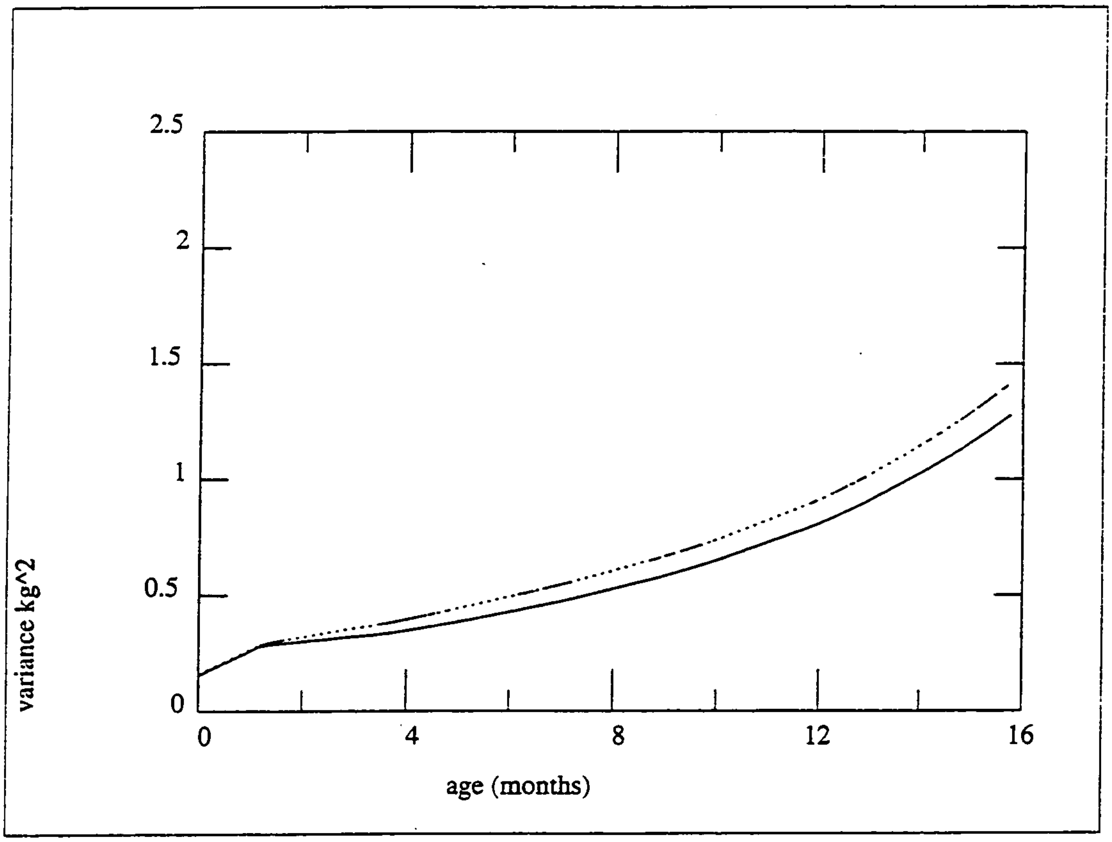
In the above analyses the solid eating behaviour variables were treated as simple counts. As described in the literature review in chapter 1 previous research has found that the *rate* of eating is associated with concurrent weight. To examine whether the solids eating behaviour variables were related to the rate of eating, the above analyses were repeated after controlling for meal duration. This analysis is equivalent to entering the eating behaviour variables as rates (i.e. number of occurrences adjusted for meal duration).

The addition of meal duration (main effect and all age terms) produced a D of 1.9 (df 4, $p > 0.05$). This is not statistically significant but this model provided a new baseline for examining the effect of the other eating behaviour variables adjusted for meal duration. After examination of the effect of adding all eating behaviour variables the only one to produce a further statistically significant effect was the 'accept proportion' in interaction with log age ($D = 7.21$, df 2, $p < 0.03$) and the reciprocal of age ($D = 7.13$, df 2, $p < 0.03$). Thus even after controlling for meal duration, the only significant predictor of weight gain from solids eating behaviour at 12 months was the 'accept proportion.' This was confirmed by an additional analyses in which actual rates, calculated for all eating behaviour variables across the whole meal (i.e. counts adjusted for the number of minutes in the meal), were entered to the model. No further statistically significant predictors of weight gain were found.

The level 2 (between subject) variance accounted for by the predictor term 'accept proportion' was calculated (see appendix 10). Figure 6.1 shows the level 2 variation plotted against age for the basic weight model (broken line) and for the model containing the 'accept proportion' (solid line). As can be seen this predictor term accounts for about 11 percent of the variation in weight between subjects at 3 months of age, 15 percent at 8 months and 10 percent at 15 months.

Figure 6.1

Level 2 variation against age for the basic weight model (broken line) and the 'accept proportion' (solid line)



Food type, eating behaviour and weight gain

As the 'accept proportion' may vary with the type of foods (whether sweet or savoury) given to infants, an analysis of the 'accept proportion' for just the savoury part of the meal was carried out.

All three interaction terms were statistically significant: for linear age D = 6.62 (df 2, $p < 0.04$) for log age, D = 8.69 (df 2, $p < 0.02$) and for the reciprocal of age D = 8.25. (df 2, $p < 0.02$). To examine whether all these were independently associated with weight gain, the term which had produced the greatest effect in the separate analyses, the interaction with log age was added first to the basic weight model. The linear and reciprocal age terms were then added in turn to the model already containing the log term. Neither the linear or the reciprocal produced a further statistically significant effect. The log interaction with the 'accept proportion' was accepted as the best predictor variable during the savoury portion of the meal.

Conclusion

This is the first study to examine the relationship between eating behaviour and weight in infants who are still predominately reliant upon carers for feeding. One eating behaviour variable, the 'accept proportion' was associated with weight gain to fifteen months: infants with a high 'accept proportion' had higher rates of weight gain than those with a low 'accept proportion'. This remained true after controlling for meal duration (equivalent to an analysis with eating behaviour variables entered as rates) and when eating behaviour only during the savoury portion of the meal was considered. No other eating behaviour variable was associated with weight gain.

General discussion

This study represents one of the largest data sets collected on the eating behaviour of infants who are still predominantly spoon-fed. When observed at mealtimes in naturalistic conditions, with no restrictions on foods offered, one year old infants appear to exert some control over food ingestion through refusing food that is offered. The data on self-feeding behaviour also illustrates these infants are attempting to assume an active role in food ingestion: of the entire group only two infants did not engage in any self-feeding behaviour and around 40 percent of all food ingestions were the result of self-feeding.

Around half the variation in the measures of eating behaviour was meal to meal variation within subjects. This finding has important implications for future studies as it suggests there is a need for replicate observations even if eating is measured under similar conditions at each feed. Evidence on the influence of food type on eating behaviour is mixed: eating behaviour during the savoury and sweet portions of meals was correlated but the magnitude of these correlations were moderate suggesting that although there is some constancy within individuals across food type, eating behaviour is also influenced by whether infants are offered savoury or sweet food.

One index of the infant's eating behaviour, the 'accept proportion' was found to be associated with weight gain. This suggests that infants who are still predominantly spoon fed may regulate their weight gain through their food acceptance behaviour. This aspect of infant behaviour remained a statistically significant predictor of weight gain when just the savoury portion of the meal was considered demonstrating that this measure was not a proxy for food type.

Food acceptance, as measured by the 'accept proportion' may be an important means by which the infant exerts control over weight gain. It is likely the relationship between the 'accept proportion' and weight gain is mediated by food intake and it should be noted that the 'accept proportion' and the volume of food intake were positively associated in this study. Unless the mother actually forces food into the infant's mouth, it is the infant that ultimately controls whether food is accepted or refused when offered by the mother. Further evidence for the view that the 'accept proportion' is predominantly influenced by infant behaviour is the finding that there was no association between 'gives', a measure of maternal behaviour and the 'accept proportion'. There was also no evidence that rate of food ingestion itself, either in terms of spoon-feeding by carer, self-feeding or a combination of both is associated with weight gain. Nor was there any association between meal duration and food intake. When one considers that meal duration and rate of food ingestion in spoon feeding is likely to be influenced by the carer, the infant and a range of other factors that might have little association with motivation to ingest food, perhaps it is not surprising there was no relationship among these variables.

Chapter 7

Milk Feeding, Solids Feeding and Weight Gain

Two lines of evidence will be considered in this chapter. Firstly evidence from Chapters 5 and 6 will be brought together to consider milk and solids feeding behaviour as combined predictors of weight gain. An additional aim will be to examine the relationship between feeding behaviour and weight gain after controlling for the influence of parent BMI, the duration of breastfeeding and the age of introduction of solids. Secondly, an analysis will be undertaken to investigate the patterns of association between milk and solids feeding behaviour.

Feeding behaviour and weight gain

In previous chapters the relationship between feeding behaviour and weight gain has been examined separately for milk feeding and solids feeding. Several milk feeding behaviour variables and one solids feeding behaviour variable were found to be associated with patterns of weight gain. The aim of the present chapter is to examine the combined influence of these on weight gain.

The literature review in Chapter 1 suggests there are other possible influences on weight gain during the early years of life. These include parent BMI (e.g. Rona & Chinn, 1982), duration of breastfeeding and the age of introduction of solids foods (Kramer, Barr, Leduc et al, 1985). It is possible that some of these variables may be correlated with aspects of feeding behaviour so another aim of the present chapter is to examine the influence of feeding behaviour on weight gain after controlling for these influences.

It will be recalled from Chapter 5 that milk intake at a feed and the number of sucks per burst at the end of a feed were independently associated with weight gain to 15 months. In Chapter 6 it was seen that the 'accept proportion' during solids feeding was also associated with weight gain to 15 months. The following analysis examined the relationship between milk and solids feeding behaviour variables entered together in the same model, and weight gain to 15 months.

The milk feeding behaviour variable, sucks per burst with log age was added first to the basic weight model as this produced the largest effect in Chapter 5. The value of D for this variable was 16.3 (df 2, $p < 0.0003$). The addition of the 'accept proportion' with log age produced a D of 4.4 (df 2, $p > 0.2$) which was not statistically significant. The order of entry for these terms was reversed to check for their independent effects. When entered first to the basic weight gain model the value of D for the 'accept proportion' was 7.2 (df 2, $p < 0.03$); adding sucks per burst to this produced a D of 13.3 (df 2, $p < 0.002$), clearly therefore, sucks per burst was producing the greatest difference in the likelihood ratio.

The parameter estimates for the regression of weight on milk and solids feeding behaviour are given in Table 7.1. Inspection of this demonstrates that the interaction for the 'accept proportion' with log age was statistically significant ($z = 2.2$, $p < 0.05$) but the main effect was not ($z = 0.4$, $p > 0.05$), therefore, the main effect and interaction taken together do not produce a statistically significant difference in the likelihood.

Table 7.1

Parameter estimates with sucks per burst and the accept proportion

Parameter	Estimate	Standard Error	z	p, df 2
Intercept	-0.181	0.6783		
Linear term	-0.015	0.0383		
Log term	3.536	0.4393		
Reciprocal term	3.455	0.5624		
Sex	0.468	0.1398		
Sex × age	0.106	0.0209		
Sucks per burst	0.0414	0.0322	1.3	>0.05
Sucks per burst × log age	-0.0899	0.0221	4.0	<0.01
Accept proportion	-0.179	0.4316	0.4	>0.05
Accept proportion × log age	0.642	0.2954	2.2	<0.05

Conclusion

When milk and solids feeding behaviour predictor variables are added together to the basic model it is clear that feeding behaviour during milk feeding is the best predictor of weight gain. Adding the 'accept proportion' to a model already containing sucks per burst does not produce a further statistically significant difference in the likelihood. When added to the model containing sucks per burst, the main effect and interaction for the 'accept proportion' combined was not statistically significant, though the interaction for the 'accept proportion' was significant. This suggests infants with a greater 'accept proportion' are gaining weight at a faster rate, but as the main effect was not statistically significant there is no evidence these infants are heavier per se.

Age of introduction of solids, duration of breastfeeding and weight gain

Age of first introduction of solids foods (in weeks) and duration of breastfeeding (up to 15 months, in weeks) were each entered to the basic weight model as main effects and as an interaction terms with the three age terms (see Chapter 3 for the descriptive statistics on these variables). There were no statistically significant effects for duration of breastfeeding. Age of introduction to solids food was associated with weight during the first fifteen months and all age terms were statistically significant: the value of D for linear age was 9.4 (df 2, $p< 0.01$), for log age D = 10.3 (df 2, $p< 0.006$) and for the reciprocal of age D = 9.4 (df 2, $p< 0.01$). To examine whether these three terms were independently associated with weight gain, log age interaction was added first to the model as this produced the greatest difference in the likelihood in the separate analysis, and the effect of entering the other terms in turn, was examined; neither had a statistically significant effect. The log age interaction with age of introduction of solids food is used in subsequent analyses. The parameter estimates for this are given in Table 7.2.

Table 7.2

Parameter estimates for age of first introduction to solids food

Term	Estimate	Standard Error	z	p, df 2
Intercept	0.433	0.6192		
Linear term	-0.005	0.0371		
Log term	4.063	0.4176		
Reciprocal term	3.425	0.5356		
Sex	0.334	0.1333		
Sex × age	0.086	0.0261		
Age of introduction to solids food	-0.030	0.0198	1.5	>0.05
Age of introduction to solids food × log age	-0.039	0.0179	2.2	<0.05

Parental BMI

Maternal BMI and paternal BMI (see Chapter 3 for descriptive statistics) were entered as main effects and interactions with each of the three age terms. Paternal BMI was not a statistically significant predictor of weight gain. Maternal BMI was associated with weight to 15 months of age: the statistically significant interactions were for log age which produced a D of 12.8 (df 2, p <0.002) and for the reciprocal of age which produced a D of 14.2 (df 2, p <0.009). To examine whether these age terms were independently associated with weight gain the reciprocal interaction was added first to the model as this produced the biggest effect in the separate analysis. When log age was then added to this model it had no significant effect. The reciprocal interaction for maternal BMI is used in subsequent analyses. The parameter estimates for this model are given in Table 7.3.

Size of effects

To examine the effect of maternal BMI and age of first weaning on weight gain the parameter estimates given in the tables above were used to calculate predicted weight. The association between maternal body mass index (BMI) and infant weight (y) specified by the parameter estimates was negative:

$$Y = \ldots / \ -0.0669\,\text{BMI} \ + \ 0.1515\ \text{BMI}\ [1/(\text{age}+1)] \ldots +$$

$$= \ldots / \ \{-0.0669 + 0.1515\ [1/(\text{age}+1)]\}\ \text{BMI} \ \ldots +$$

At three months of age every 1 kg/m^2 in maternal BMI predicted an attained weight that was lower by 29 g; at eight months and fifteen months the predicted attained weights were 50 g and 57 g lower respectively.

The association between infant weight (y) and age of first solids food (s) was also negative:

$$Y = \ \ldots / -0.03027\,s \ - 0.03955\,s\,(\log \text{age} + 1) + \ \ldots$$

$$= \ \ldots / \ [-0.03027 - 0.03955\,(\log \text{age} + 1)]\,s + \ \ldots$$

Every 1 week delay in the introduction of solids foods predicted an attained weight that was lower by 85 g at three months of age: at eight and fifteen months of age the predicted attained weights were 117 g and 140 g lower respectively.

Table 7.3

Parameter estimates for maternal BMI

Parameter	Estimate	Standard Error	z	p,df 2
Intercept	1.446	1.296		
Linear term	-0.012	0.038		
Log term	3.521	0.349		
Reciprocal term	-0.092	1.295		
Sex	0.531	0.124		
Sex × age	0.099	0.025		
Maternal BMI	-0.067	0.050	1.3	>0.05
Maternal BMI × reciprocal of age	0.151	0.050	3.0	<0.01

Conclusion

Statistically significant predictors of weight gain were maternal body mass index and age of first weaning. There was no statistically significant association between duration of breastfeeding and weight gain. Maternal body mass index is negatively related to infant weight gain: heavier mothers appear to have infants who gain weight more slowly than infants of lighter mothers.

Final model of weight gain

The possible independent predictors of weight gain to 15 months are: sucks per burst at the end of a feed, maternal body mass index, milk intake at a feed and age of first weaning. To construct the final model of weight gain these variables were added to the basic weight model one by one, beginning with the variable which produced the largest effect in the separate analyses and ending with the variable which produced the smallest.

Sucks per burst with log age was entered first, producing a D of 17.2 (df 2, $p < 0.0002$), followed by maternal BMI with the reciprocal of age which produced a D of 9.4 (df 2, $p < 0.01$). Although the difference in the likelihood for maternal BMI was statistically significant, inspection of the model parameter estimates showed the z statistic for the interaction with the reciprocal of age did not reach statistical significance ($z = 1.3$, $p > 0.05$); only the main effect for maternal BMI was contributing to the effect for the two terms. This suggests infants of mothers with high BMI were heavier overall but were not actually gaining weight at a statistically significant faster rate. Because it was not significant, the interaction term for maternal BMI with the reciprocal of age was removed from the model, while the main effect was retained. Milk intake at a feed was then added to the model already containing sucks per burst (main effect and interaction) and maternal BMI (main effect). This produced a D of 10.8, (df 2, $p<0.005$). Age of first introduction of solids food was added to this model and gave a D of 11.0 (df 2, $p < 0.005$). This analysis is summarised in Table 7.4 which gives the likelihoods and likelihood ratio statistics as each term was entered into the model. The fixed and random parameter estimates for this final model of weight gain to 15 months of age are given in Table 7.5.

Table 7.4

Likelihoods. likelihood ratio statistics and degrees of freedom for terms included in final model

	Likelihood	D	df	p
Sex Sex × age	230.84			
+ Sucks per burst Sucks per burst × log age	213.63	17.21	2	<0.0002
+ Maternal BMI	207.44	6.18	1	<0.02
+ Milk Milk × reciprocal of age	196.62	10.82	2	<0.005
+ Age of introduction to solids food Age of introduction to solids food × log age	185.62	11.00	2	<0.005

Table 7.5

Final model parameter estimates for sucks per burst, maternal BMI, milk intake at a feed and age of first weaning

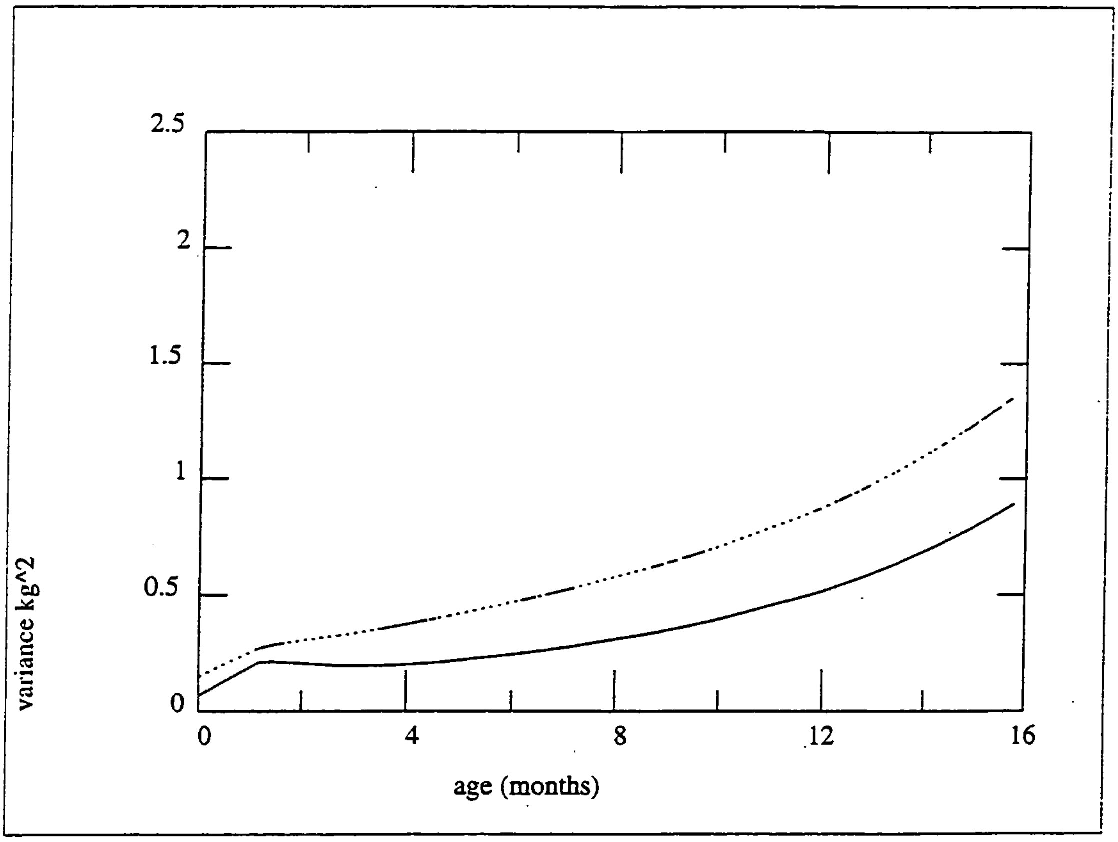
Fixed Parameters	Estimate	Standard Error
Intercept	-1.693	0.810
Linear	-0.001	0.035
Log	4.339	0.388
Reciprocal	4.218	0.576
Sex	0.397	0.122
Sex × age	0.080	0.021
Sucks per burst	0.010	0.027
Sucks per burst × log age	-0.091	0.019
Maternal BMI	0.068	0.022
Milk	0.007	0.003
Milk × reciprocal of age	-0.009	0.003
Age of introduction to solids food	-0.042	0.017
Age of introduction to solids food × log age	-0.026	0.013
Random Parameters Level 2 (Between Subjects)		
Variances		
Intercept	6.7	2.566
Linear	0.027	0.01
Log	2.648	1.02
Reciprocal	6.441	2.566
Covariances		
Intercept/linear	0.283	0.14
Log/intercept	-4.003	1.59
Log/linear	-0.224	0.094
Reciprocal/intercept	-6.537	2.559
Reciprocal/linear	-0.263	0.138
Reciprocal/log	3.884	1.582
Random Parameters Level 1 (Within Subjects)		
Intercept	0.043	0.006

Level 2 standardised residuals for the final model were calculated to examine whether this model was appropriate for the data. Normal probability plots of the residuals generally conformed to a straight line indicating these were close to a normal distribution. These plots can be found in appendix 14. Level 1 standardised residuals for the final model were also calculated and a plot of these against age can be found in appendix 15. It can be seen that there is little systematic variation in the level 1 residuals with age. A normal probability plot of the level 1 standardised residuals can be found in appendix 16. This largely conforms to a straight line indicating the level 1 residuals were close to a normal distribution.

The level 2 (between subject) variance accounted for by this final model of weight gain was calculated (see appendix 10). Figure 7.1 shows the level 2 variation plotted against age for the basic weight model (broken line) and for the model containing predictor terms, sucks per burst, maternal BMI, milk intake at a feed and age of introduction of solids (solid line). These predictor terms account for about 50% of the variation in weight between subjects at 3 months of age, 49% at 8 months and 36% at 15 months.

Figure 7.1

Level 2 variation plotted against age for the basic weight model (broken line) and for the final model (containing, sucks per burst, maternal BMI, milk intake at a feed and age of introduction of solids (solid line).



Discussion

The best prediction of infant weight gain during the first fifteen months of life is provided by a model that includes the number of sucks per burst at the end of a feed, maternal BMI, milk intake at a feed and age of introduction of solids. Together these variables explain a considerable percentage of the variation in patterns of weight gain to fifteen months but especially in the early months. The milk feeding behaviour variable, sucks per burst remains a good predictor of weight gain after adjusting for other known influences.

This is the first study to investigate the relationship between feeding behaviour and weight gain using measures of feeding behaviour derived from both milk and solids feeds. In separate analyses, aspects of both milk and solids feeding behaviour were statistically significant predictors of weight gain; however when both were added to the same model only milk feeding behaviour was an independent predictor of weight gain.

There are several possible reasons why solids feeding behaviour may not be an independent predictor of weight gain. Firstly there are difficulties relating to the measurement and summary of solids feeding behaviour. It is likely that solids feeding behaviour is influenced by extraneous variables to a greater extent than milk feeding behaviour. In the literature review in Chapter 1 it was seen that there are a wide range of factors which may strongly influence feeding behaviour in older infants. One of these, food taste (i.e. whether food was sweet or savoury) was examined in Chapter 6. When feeding behaviour during just the savoury portion of the meal was considered, the 'accept proportion' was a better predictor of weight gain than the analyses involving the whole meal. It is also likely that the summary measures of sucking behaviour are more sensitive and discriminating than the measures used to summarise solids feeding behaviour.

Secondly, it is possible that measures of milk and solids feeding behaviour represent a common characteristic of the child. If this is the case, one would not expect the two to be independent predictors of weight gain: milk feeding behaviour is an excellent predictor but measures of the solids feeding behaviour do not provide any additional information about the child. The relationship between milk and solids feeding behaviour will be further explored in the following section.

Milk and solids feeding behaviour

Very few previous investigations have examined milk and solids feeding in the same infants and no previous research in humans has specifically addressed the relationship between milk and solids feeding. A considerable number of studies have examined the relationship between milk and solids feeding in other species (mainly rats) but these have been mostly experimental and largely focused on the mechanisms underlying the regulation of feeding (e.g. Hall & Williams 1983). The present investigation, which is observational and concerned with overt feeding behaviour rather than underlying regulatory processes, is very different from this previous research. Because of these considerations and the fact that there are few obvious parallels between the two types of feeding to provide a basis for comparison, the analyses reported here are exploratory.

Aims

These analyses examine the patterns of association between milk feeding behaviour measured at six weeks and solids feeding behaviour measured at 12 months of age. A related aim was to investigate whether any associations found remain statistically significant after adjusting for other possible influences on feeding behaviour such as infant sex, parental BMI, and age of introduction of solids (these will be collectively termed general characteristics).

The following analyses were carried out in SPSS using regression analysis with solids feeding behaviour as the dependent variable. A preliminary analysis showed there were no statistically significant associations between solids feeding behaviour summarised as simple counts and sucking behaviour. In all analyses reported, solids feeding behaviour is summarised as rates; i.e. the number of occurrences divided by the number of minutes in the meal.

To simplify the description of the results it will be reported in stages; stage one involves the relationship between solids feeding behaviour and general characteristics (infant sex, paternal BMI, maternal BMI, duration of breastfeeding and age of introduction of solids foods); stage two involves the relationship between solids feeding behaviour and milk feeding patterns and stage three examines the relationship between solids feeding behaviour and sucking behaviour.

General characteristics and solids feeding behaviour

Solids feeding behaviour variables were regressed on the variables infant sex (female = 0, male = 1) paternal BMI, maternal BMI, duration of breastfeeding and age of introduction of solids foods. There were no significant associations between any of the solids feeding behaviour variables and infant sex, paternal BMI, maternal BMI and duration of breastfeeding. A statistically significant association was found between one aspect of solids feeding behaviour, the 'accept proportion' per minute and the age of introduction of solids. The parameter estimates for this are given in Table 7.6.

Table 7.6

Parameter estimates for regression of accept proportion (per minute) on age of introduction of solids

Variable	Constant	Slope	SE	t	p<	r
Age of introduction of solids	0.12	-0.004	0.002	-2.164	0.04	0.38

Milk feeding patterns and solids feeding behaviour

To examine if solids feeding behaviour was related to patterns of milk feeding, solids feeding behaviour (rates) were regressed on the whole day milk feeding variables (total duration of feeding, total milk intake and total number of feeds per 24 hours) and feed variables (milk intake at a feed and feed duration). There were no statistically significant associations between solids feeding behaviour and total duration of feeding, total milk intake per day and feed duration. Two statistically significant associations were found; (1) intake per minute during solids feeds was associated with number of feeds per 24 hours during milk feeding and (2) bites per minute during solids feeds was associated with milk intake at a feed. The parameter estimates for these associations are given in Table 7.7 below.

Table 7.7

Parameter estimates for the regression of solids feeding behaviour on milk feeding patterns

Regression	Constant	Estimate	SE	t	p<	r
Intake (g per minute) on feeds per day	18.687	-1.103	0.332	-3.32	0.003	0.54
Bites per minute on milk feed intake g	2.514	0.011	0.005	2.22	0.04	0.39

Milk feeding behaviour and solids feeding behaviour

Solids feeding behaviour variables were regressed on sucking behaviour parameter estimates. There were no statistically significant associations between solids feeding behaviour and number of sucks per burst, the standard deviation of suck duration, pause duration and suck duration (start estimate) Statistically significant associations were found between four solids feeding behaviour variables and suck duration (end estimate) during milk feeding. The solids feeding behaviour variables were; number of accepts per minute, gives per minute, the 'accept proportion' per minute and intake (g) per minute.

To examine if these milk feeding characteristics were independently associated with solids feeding behaviour further analyses were carried out. For the 'accept proportion,' suck duration was added first as this produced the best fit in the separate analyses. This gave a F value of 6.26 ($p< 0.02$). The addition of age of introduction of solids did not produce a further improvement in the fit of the model. Therefore suck duration was the most strongly associated with the 'accept proportion.'

This same procedure was followed for intake per minute during solids feeds. Number of feeds per day was added first as this produced the best fit in the separate analyses. This gave a F value of 11.03 ($p<0.003$). Adding suck duration to this model did not produce a better fit, therefore the best predictor of intake per minute during solids feeding is the number of feeds per day during milk feeding. The parameter estimates for these analyses age given in Table 7.8.

Table 7.8

Parameter estimates for the regression of solids feeding behaviour on milk feeding behaviour

Regression	Constant	Estimate	SE	t	p<	r
Accepts per minute on suck duration (end)	-2.252	5.926	1.769	3.35	0.003	0.53
Accept proportion per minute on suck duration (end)	-0.044	0.164	0.065	2.50	0.02	0.42
Gives per minute on suck duration (end)	-1.160	5.765	2.545	2.26	0.04	0.39
Intake g per minute on number of feeds per day	18.69	-1.10	0.33	-3.32	0.003	0.54

The relationship between milk and solids feeding behaviour and concurrent infant weight

It is possible that these associations between milk and solids feeding behaviour are maintained via an association with infant weight at the time feeding behaviour was measured and therefore that the associations between milk and solids feeding behaviour are not independent effects. Further analyses were conducted to examine whether these associations between milk and solids feeding behaviour remained statistically significant after controlling for concurrent infant weight on the two occasions at which feeding behaviour was measured. This was investigated by regressing solids feeding behaviour on weight at 6 weeks, weight at 12 months and milk feeding behaviour. No further statistically significant improvements in the fit of the models were found. Therefore, there was no evidence to suggest the associations between milk and solids feeding could be accounted for by a common association with concurrent weight at the time feeding behaviour was measured.

General discussion

In this exploratory analysis there were no statistically significant associations between solids feeding behaviour summarised as simple frequency counts and milk feeding behaviour. However, there were several statistically significant associations between some solids feeding behaviours summarised as rates and milk feeding behaviour. Three solids feeding behaviour variables were consistently related to one aspect of sucking behaviour, suck duration at the end of a feed. Infants with longer sucks at the end of a feed on the first breast were given food at a higher rate during solids feeding, accepted food at a higher rate and had a higher 'accept proportion' per minute during solids feeding. One independent association was found between feeding patterns at six weeks and solids feeding behaviour: infants with more feeds per day during milk feeding consumed less food per minute during solids feeding. These apparent parallels in feeding behaviour across two different types of feeding are independent of infant weight measured at the time feeding behaviour was recorded. Therefore it is unlikely the associations between milk and solids feeding behaviour are operating via a common association with concurrent weight.

Though these analyses are exploratory, the consistent finding that suck duration is associated with solids feeding behaviour supports the conclusion that these associations are not chance effects. In breastfed infants, rates of sucking within bursts are strongly associated with rates of milk flow: higher rates of milk flow are associated with lower rates of sucking (Lucas, Lucas & Baum 1979). In terminology consistent with the present study, longer suck durations are likely to be associated with a faster rate of milk flow. From the associations found in the present study, infants who are rapidly ingesting milk at the end of a feed at six weeks of age tend to be given and accept food at a faster rate, and have a higher proportion of food acceptances per minute during solids feeding at twelve months.

In summary, these results suggest that babies who are avid feeders at 6 weeks, stimulating a high rate of milk flow even towards the end of a breastfeed, continue to be avid feeders at 12 months, ingesting solids food more readily and at a faster rate. This continuity between milk feeding and solids feeding is likely to be supported at several different levels. Firstly, experiences during early suckling may be generalised to later solids feeding; infants with a rapid rate of ingestion during milk feeds may have learnt a particular style of feeding which they continue to exhibit during solids feeding. This view attributes the observed continuity between milk feeding and solids feeding to the effects of experience and learning during suckling. Secondly, the observed continuities could be supported by features of the feeding situation that are common to both types of feeding and a particularly important factor in this is the mother. Through her behaviour the mother supports a particular style of feeding in her child. Thirdly, it is possible these continuities are due to an underlying characteristic of the child that is common to both types of feeding; for example, measures of sucking and solids feeding may both be behavioural expressions of a underlying factor such as appetite which is carried across the two types of feeding.

As seen in the literature review in Chapter 1, research with rats suggests milk feeding and solids feeding should be seen as two separate systems with regard to the underlying organisation and regulation of the two types of feeding. In finding some apparent behavioural continuities within subjects across the two types of feeding these results could be seen as conflicting with previous research. However, the existence of these continuities in observable behaviour do not necessarily imply that the actual system controlling the regulation of intake is common to both types of feeding. Rather these finding may indicate only that there are similar influences operating upon the two types of feeding. It is important to remember that the mechanisms involved in the regulation of intake have not been directly studied here.

In the results described earlier it was seen that although both sucking and solids feeding behaviour are predictively associated with weight gain, only sucking behaviour was independently associated. This suggests milk and solids feeding may, at least in part, reflect a common characteristic of the child. It also points to weight gain as one possible explanation for the association between milk and solids feeding. Although there is no evidence to suggest either sucking or solids feeding behaviour is associated with concurrent weight, there is strong evidence that both are related to the child's pattern of weight *gain*. These associations suggest that the child's feeding behaviour may be partially a reflection of their underlying weight gain trajectory.

Chapter 8

Discussion and Conclusions

Findings in brief

The longitudinal study reported in this thesis examines the relationship between feeding behaviour and weight gain in infancy. Using a simple and non-invasive observational technique of data collection, this study demonstrates that it is possible to predict patterns of weight gain in infancy from sucking patterns, when these have been appropriately summarised. Solids feeding behaviour is also associated with weight gain but not independently of milk feeding behaviour. The association between milk feeding behaviour and weight gain is in keeping with previous findings on feeding behaviour and weight, and on sucking and subsequent adiposity.

In addition to feeding behaviour, other known or possible influences upon weight gain in infancy were investigated. Infant sex, milk intake and the age of introduction of solids were also independently associated with weight gain, while milk feeding patterns, duration of breastfeeding and paternal BMI were not. Maternal BMI was associated with infant weight but not with weight gain.

In the course of this study, a new method for the analysis of breast fed infants' sucking patterns has been developed. This was devised using an extensive data set from 128 breastfeeds in 32 infants and represents a considerable improvement upon previous methods derived from measures of infants on bottles during short 'test-feeds'; firstly, it resolves the problems associated with the use of artificial cut-off points and therefore provides a more accurate summary of the local structure of sucking patterns; secondly, it allows changes in sucking patterns over the course of a feed to be described. This is of particular importance for breastfed infants measured under naturalistic conditions.

This study was also the first to take detailed measures of behaviour during milk and solids feeding in the same infants. Previous research on the two types of feeding in rats suggests the mechanisms underlying milk and solids feeding are distinct and separate. The present research, however, provides some evidence of parallels in observable behaviour within infants across the two types of feeding. Furthermore, in the analysis that examined both milk and solids feeding behaviour as predictors of weight gain, evidence of an association between the two types of feeding behaviour was found as only milk feeding behaviour was an independent predictor.

From this extensive data set on the sucking patterns of breastfed infants and the behaviour of one year old infants during solids feeding, it is possible to derive previously unavailable descriptive information on feeding under naturalistic conditions. The sucking patterns of breastfed infants change systematically during the course of a feed; suck durations and the number of sucks per burst drop over the course of a feed and there is a rise in the duration of pauses. In developing a new method for summarising sucking patterns this study has provided a foundation for future experimental work to investigate the possible influences on these changes, and thereby develop an understanding of satiation processes in infancy. The data on solids feeding demonstrates that although 12 month old infants were still largely dependent upon their carers for spoon feeding, they are still capable of exerting control by refusing food and they played an active role in mealtimes by engaging in self-feeding behaviour. Correlations of behaviour during the sweet and savoury portions of the meal were modest, demonstrating that while there were some continuities within infants, eating behaviour is also influenced by the type of food given.

For both milk and solids feeds, data were collected to investigate the components of variance in feeding behaviour. For milk feeds there was proportionally more feed to feed variation than subject to subject for all parameter estimates. For the solids feeding behaviour, variation was divided fairly equally between and within subjects except for two variables; the proportion of variation between subjects for the number of refusals was 32%, and for the number of accepts, 74%. Overall, at least for these summary variables, the results demonstrate that milk feeding behaviour is more variable from feed to feed than solids feeding behaviour. Nevertheless, there is considerable fluctuation from feed to feed during both types of feeding suggesting that the accurate characterisation of an infant's individual feeding behaviour could be improved by collecting data at more than one feed.

Infant sucking patterns during breastfeeding

Sucking behaviour was recorded solely through observation because at the time this study was designed other methods were too intrusive to be used in fieldwork. Subsequently, an alternative method which uses a strain gauge has been reported (Ramsay & Gisel 1996) but as yet there are no reports of this being suitable for use in the field and it has only been validated in bottle fed infants. One problem associated with using direct observation for the recording of sucking is that because the frequency of sucking is greater than one suck per second, it is possible this frequency is greater than can be accurately recorded by a human observer. This is likely to have implications only for the recording of suck durations and since the same observer and method of recording was used for all infants at all feeds it is most unlikely the accuracy of recording differed systematically among infants. The accuracy of pause durations and sucks per burst would not be compromised by the method of recording used.

The new method for the analysis of breast fed infants' sucking patterns summarised sucking behaviour in terms of 4 parameters; sucks per burst, suck duration and its standard deviation, and pause duration. This model uses a 2 component mixture model to describe the local burst-pause pattern and so resolves the problems associated with the use of artificial cut-off points in the traditional summary methods. The new method also describes change in sucking parameters over the course of a feed. Each of the four parameters has a start and end of feed estimate and because all the curves are two parameter curves, these estimates describe the whole feed.

The general pattern of change over a feed is for the number of sucks per burst and the duration of sucks to drop over a feed, and for pause durations to rise. Across all the feeds this pattern is most consistent for the duration of sucks. In modelling a time-trend for all sucking parameters this model is over-elaborate for some feeds, but the alternative of having different models for different feeds (i.e. some with one parameter varying over time and some with more) seemed a less satisfactory choice than a single model which fitted all feeds. The pattern of change observed in the model parameters is consistent with previous research on changes in sucking patterns during the course of a breastfeed; in a study which examined sucking patterns for different periods of a feed, Drewett & Woolridge (1979) found that towards the end of a feed the suck duration drops and the pause duration increases. These changes have in turn been associated with a drop in the rate of milk flow as the feed progresses (Woolridge, Baum & Drewett 1980, Woolridge & Baum 1988).

Estimates for pause durations caused some problems; they are the most variable within subjects and their sampling distributions are asymmetric. This may indicate a problem with the model which could stem from the fact that it is constrained to a burst-pause framework throughout the feed; inspection of sucking records demonstrate there are some feeds in which the infant does not adopt a burst-pause pattern but sucks in a continuous fashion until a considerable proportion of the feed has elapsed. In the model this is treated as a very long burst. The match between statistics derived from traditional and new summary methods was good for suck duration, pause duration and number of sucks per burst at the end of a feed, but for sucks per burst at the start of a feed and the standard deviation of suck durations at the end, the match was only moderate. These difficulties with sucks per burst also appear to occur in feeds which begin with a long burst of sucks so it again appears to be the case that problems arise because the new model is constrained to fit a burst-pause pattern throughout the feed. Further research could investigate the effect of revising the model so that it was not constrained to fit a burst-pause pattern at the outset of a feed. This would involve a 'cut-point' model, however they are notoriously difficult to estimate if the cut-point is not known as would be the case for sucking data.

As mentioned above, the general pattern of change observed in sucking patterns is compatible with the limited amount of previous research on this issue. As the new model is able to accommodate these changes, further research on the influences upon these changes is now possible. For example, experimental investigations of the influence of hunger/satiation on sucking patterns could be conducted by using high and low calorie preloads to manipulate infant levels of satiation. If satiety does play a role in changes in sucking patterns over the course of a feed, all else being equal infants receiving a high calorie preload would be expected to exhibit sucking patterns similar to those of infants at the end of a feed under naturalistic conditions. Through experimental research of a similar nature it would also be possible to examine the influence of other features which change over the course of a feed, including infant factors such as fatigue and behavioural state. Maternal factors such as rate of milk flow and composition could also be investigated.

It might also be possible to investigate the role of infant sucking characteristics in maternal milk production and maternal perceptions of their infant's hunger; the role of sucking may be direct, i.e. the infant adopts a less vigorous or stimulating style of sucking as a result of supplementation and this in turn provides less stimulation for the production of milk; or indirect, for example, the mother may interpret changes in the infant's sucking patterns during a feed as indicating their infant is less motivated to breastfeed and, as a result, provide shortened or reduced opportunities for breastfeeding. Such an investigation might be useful in understanding problems such as 'perceived insufficient milk syndrome' which is frequently mentioned by mothers as a reason for giving up breastfeeding (White, Freeth & O'Brien 1992).

Milk feeding and weight gain

In this study milk feeding behaviour was found to be consistently and strongly associated with weight gain to fifteen months. Three of the four sucking behaviour variables associated with weight gain came from end of feed parameter estimates; fewer sucks per burst, longer pause duration and suck duration at the end of a feed were all associated with greater weight gain. Longer suck duration at the start of a feed was also associated with greater weight gain. The only other aspect of milk feeding found to be associated with weight gain was milk intake; there was no evidence from this study that feeding patterns (feeding frequency and feeding duration) are associated with weight gain; the associations are with sucking patterns.

As there is very little previous research on the relationship between feeding behaviour and weight gain in infancy, it is difficult to compare these findings with previous research. Earlier work has concentrated upon bottle fed infants, employing different measurement and analytical techniques to the ones used here and has derived different variables. The study by Agras et al (1987) investigated different outcome variables and Pollitt et al (1978a) only investigated concurrent associations between weight and sucking behaviour (though Pollitt et al 1978b have found a relationship between weight gain to one month and two aspects of infant feeding behaviour, frequency of eye opening and refusing the bottle). These differences preclude a detailed comparison of the findings, nevertheless the work by Agras et al found suck duration was positively associated with skinfold thickness at one and two years. This is broadly consistent with the present study which found suck duration, both at the start and end of a feed, was positively associated with weight gain.

Possible mechanisms for the associations with weight gain

Although it is most likely these associations between sucking patterns and weight gain are mediated through calorie intake, it is possible they are also mediated via other mechanisms such as energy expenditure or energy absorption. These two possibilities are discussed below.

Energy expenditure

In a series of experiments with newborns Blass & Ciaramitaro (1994) investigated the associations between nutritive sucking, non-nutritive sucking and various outcomes including motor activity, heart rate and crying. They found evidence that the effect of nutritive and non-nutritive sucking varied with the behavioural state of the infant; in agitated infants non-nutritive sucking reduced activity and heart rate, but in calm infants non-nutritive sucking had no effect on heart rate. In already calm infants nutritive sucking (for sucrose) produced further calming and heart rate lowering effects. Interestingly the magnitude of these effects were greater than those for presentations of sucrose alone (i.e. without any sucking stimulus). Thus in calm infants, while non-nutritive sucking has no effect on heart rate, it can potentiate the effects of sucrose stimulation. Woodson, Drinkwin & Hamilton (1985) found similar results in their investigation of the effects of *ad libitum* non-nutritive sucking on behavioural state and motor activity; suckling stimulation was found to reduce overall motor activity. Hence, there is evidence that sucking may serve to reduce infant activity, heart rate and crying. It is also possible that sucking may influence energy expenditure and in turn weight gain.

Nevertheless, it is important to point out these are only short term associations; there is conflicting evidence about the role of energy expenditure for the regulation of weight gain over longer periods of time during infancy. In a study of energy expenditure and energy intake in infants born to lean and over weight mothers, Roberts, Savage, Coward et al (1988) found total energy expenditure at three months of age was considerably lower in infants who became overweight by one year of age. At three months no significant differences in energy intake had been observed between infants who later became overweight and those that did not. However, a more recent and much larger study of normal healthy infants by Davies, Day and Lucas (1991) found no evidence of an association between energy expenditure in infancy and subsequent weight gain.

In summary although there may be an association between sucking and reduced activity over short periods of time, evidence from a larger study conducted over an extended period of time casts doubt on the conclusion that energy expenditure is associated with weight gain during infancy. In a study on infant activity patterns over longer periods, St. James-Roberts & Plewis (1996) found that infant activity patterns were regulated over relatively long periods of time in infancy. So even if sucking is associated with reduced energy expenditure in the short-term, if energy expenditure during early infancy is regulated over say, a 24-hour period, then overall energy expenditure and weight gain will be unaffected. A direct test of the relationship between sucking patterns and energy expenditure over long periods would be possible using the deuterium dilution method.

Energy absorption

One other possibility for the influence of sucking patterns on weight gain is the role of suckling stimulation in energy absorption. The tactile stimulation produced by suckling stimulates the secretion of gastric hormones involved in the development and functioning of gastrointestinal tract. This association is believed to operate via the vagal nerve (Uvnas-Moberg, Widstrom, Marchini, et al 1987).

Associations between sucking (on a pacifier) and weight gain have been extensively studied in preterm infants. A number of initial studies provided evidence that non-nutritive sucking during tube feeding facilitated weight gain and development, leading to earlier discharge from hospital (e.g. Field, Ignatoff, Stringer et al 1982, Bernbaum, Pereira, Watkins et al 1983). Later randomised control studies of the association between non-nutritive sucking and weight gain, which have carefully controlled for confounding variables such nutrient intake, have found no such effect for non-nutritive sucking on growth in very low birth weight infants (Ernst, Rickard, Neal et al 1989).

One problem with this conclusion is that the infants studied by Ernst et al (1989) were all aged below 30 weeks gestation. According to Bernbaum et al (1983), the sucking reflex is rarely fully developed and co-ordinated before 34 weeks gestation so there is a possibility that the infants studied by Ernst et al (1989) were just too immature to suckle properly and were not able to benefit from whatever gastric effects sucking stimulation produces. In a comparison of sucking in term and preterm infants, Jain, Sivieri, Abbasi, et al (1987) found preterm infants sucked at lower pressures and spent less time engaged in sucking for a given time period than term infants. In a study of full and preterm infants Marchini, Lagercrantz, Feuerberg et al (1987) found evidence of raised plasma insulin levels in response to non nutritive sucking in full-term infants but there were no statistically significant changes in preterm infants. According to Marchini, et al (1987) one possible influence on the magnitude of the hormonal and gastric responses may be variations in the intensity of suckling.

In summary there is only limited evidence that the association between suckling and weight gain can be accounted for via mechanisms other than intake. Though sucking produces short lived reductions in activity and heart rate, studies of the role of energy expenditure in weight gain over longer periods have found no consistent evidence of an association. Other work suggests non-nutritive sucking may play an important role in augmenting nutrient absorption and promoting weight gain, but most of this work has been conducted on very premature infants and the results have not been consistent. Very little work investigating the role of sucking in the gastrointestinal function of full term infants has been conducted, and as the techniques associated with these sorts of investigations are too invasive to be employed solely for research purposes, it seems unlikely any firm conclusions can be reached on these matters.

Energy intake

It is quite probable that the association between sucking patterns and weight gain is operating at least partially through milk intake. At a gross level, infants would not gain weight were there no nutrients available for tissue growth. At the finer level of explaining individual differences in weight gain patterns, except for energy expended on activity, basal metabolism and thermogenesis, all metabolizable energy intake is utilised to fuel growth (Davies 1992). In the present study, milk volume intake and sucking behaviour were independent predictors of weight gain, i.e. the effect of one remained after statistical control for the other, suggesting the two are unrelated. However, as this study used only a volume measure of intake it is likely there was some error associated with the measurement of milk intake; furthermore, because the energy content of breastmilk is quite variable (Akre, 1989), it is likely the data on milk intake gave only a rough indication of actual calorie intake. Therefore it is quite possible feeding behaviour is related to weight gain through an association with calorie intake.

What evidence is there that sucking patterns are associated with breastmilk intake and composition? Unfortunately, there is little work relating sucking characteristics to breastmilk intake or to breastmilk composition. In infants measured on bottles, the sucking patterns associated with higher intake of milk include a greater proportion of time spent sucking during a feeding trial (Pollitt et al 1978a) and greater sucking pressure (Dubignon & Cooper 1980). There is no evidence that the fat content of expressed breastmilk is associated with the sucking patterns of infants measured on bottles (Woolridge, Baum & Drewett 1980). Investigations involving repeated test weighing during feeding, suggest that the rate of sucking and burst-pause pattern of sucking are associated with the rate of intake over the course of a feed; as the rate of milk flow decreases, suck durations and the number of sucks per burst drop while pause durations rise (Drewett & Woolridge 1979).

How might the particular sucking patterns found to be associated with weight gain in this study also be associated with increased intake? In the present study infants with longer suck durations at the start and end of a feed had higher rates of weight gain and from the research discussed above we know that longer suck durations are associated with higher rates of milk flow. It is plausible that infants who experience a relatively high rate of milk flow at the end, as well as the start of a feed, are likely to be those with a greater intake of milk. The other aspects of the sucking patterns found to be associated with weight gain, fewer sucks per burst and longer pauses at the end of a feed, are not so obviously related to higher milk intake. In fact the pattern of fewer sucks per burst and longer pauses are usually associated with lower rates of milk flow (Drewett & Woolridge 1979). Therefore while the data on suck durations would suggest a high rate of milk flow, the burst-pause pattern suggests the opposite. This could only be accommodated if different components of the sucking pattern are differentially influenced by the many covariates that change systematically during the course of a feed. If this is true it may suggest it is a mistake to assume that different components of sucking are uniformly influenced by the covariates. For example, suck duration may respond to changes in milk flow, but the global burst- pause pattern might be influenced by other factors, such as satiation and fatigue. As stated elsewhere in this chapter what is required are investigations of how sucking patterns vary as functions of the covariates.

For breastfed infants to regulate their intake they must regulate the maternal milk supply and one theory as to how infants do this concerns breast emptying (e.g. Akre 1989, Daly and Hartmann 1995). Milk production is increased if the breasts are emptied regularly. There is good evidence that infants do not ingest all the milk available at a feed (Dewey et al 1991a) and this may be in part due to milk availability; at the start of a feed when the breasts are full and the rate of milk flow is fast, relatively little effort is required by the infant to ingest milk, but towards the end of a feed when the breasts are relatively empty and the rate of milk flow is slow, more effort is required. Those infants who are more efficient at emptying the breast at the end of a feed may be more capable of augmenting their mother's supply of milk and so gain most weight. Not only might such infants increase the supply of milk, but as the fat content of milk increases as the feed progresses (Akre 1989), they will ingest proportionally more milk with a high fat content. In relation to the sucking patterns found in the present study we have seen that the main feature distinguishing between infants with high and low rates of weight gain were sucking patterns at the end of a feed. Systematic research investigating the associations between sucking patterns, calorie intake and volume intake is needed in order to make firm conclusions about of these findings.

Such research would require accurate measurement of breastmilk intake by test weighing and breast milk composition through sampling of the milk; both of these are difficult to carry out and may well influence the variables under investigation. One alternative may be to determine intake using the deuterium dilution method (e.g. Butte et al 1991) but this would only allow investigations of associations between sucking patterns and milk intake over a minimum period of several days, and not associations between sucking patterns and intake over a feed.

Solids feeding and weight gain

In this study of the relationship between eating behaviour and weight gain in infants who are still largely dependent upon carers for feeding, one eating behaviour variable, the 'accept proportion' was found to be associated with weight gain to fifteen months. The results showed infants with a high proportion of food acceptances had higher rates of weight gain than those with a lower proportion. This finding was unaffected by controlling for meal duration. When eating behaviour during only the savoury portion of the meal was considered, the association between the 'accept proportion' and weight gain was slightly stronger than in the equivalent analysis for the whole meal. None of the other eating behaviour variables were associated with weight gain.

Of studies comparing the eating behaviour of children classified according to weight, all report that overweight children eat at a faster rate than normal weight children (Drabman, Cordua, Hammer et al 1979, Keane, Geller, Scheirer et al 1981 and Barkeling, Ekman, Rossner et al 1992). Among studies with weight as a continuous variable, Nakao, Aoyama, Suzuki et al (1990) found eating behaviour was not related to weight or BMI at 40 months when children were still dependent upon carers for feeding, but by 50 and 59 months when the children had become relatively competent at feeding themselves, feed duration was related to weight and BMI. The only other study with weight as a continuous variable involved much older children of 7 -12 years and found no significant associations between feeding behaviour and anthropometric variables (Israel, Weinstein, Prince, 1985). Associations have therefore been found between eating behaviour and weight, but not consistently.

There are some problems in comparing the present study with previous research in this area. First, previous studies have tended to concentrate on the relationship between feeding behaviour and concurrent weight. Second, as mentioned above, several of the previous studies have used a different form of analysis involving comparisons between groups rather than using weight as a continuous variable. Third, most of these studies have measured feeding behaviour by presenting subjects with standardised foods whereas the present study used foods selected by the mother. Fourth, these studies have tended to use samples of children who have been feeding themselves, and most also involved children who were considerably older than those under present investigation.

Age and self-feeding competence of the subjects may be of particular importance in understanding the results of the present study. The only previous study involving children under two years of age is that reported by Drabman et al (1979) on children who were selected only if they were capable of feeding themselves without assistance.

The infants in the present study were still largely dependent upon carers for feeding so it is possible that what is being measured here is not the same as in previous studies; because the infants in the current study are only partially self-feeding the rate of food ingestion is not determined solely by the child according to his or her motivational state, but instead is influenced jointly by mother and child. The 'accept proportion,' which is a measure of how often infants accept rather than refuse food when it is offered to them, was found to be positively associated with weight gain. Unlike the rate of eating, the 'accept proportion' is under the sole control of the infant, and with the exception of force-feeding, it is the infant who exercises ultimate control over whether or not to accept food when it is offered.

It might be reasoned that where the infant is able to exert even more control is in self-feeding and so this should provide an even better reflection of his or her motivational state. But even for this variable, there was no significant association with weight gain. From watching numerous videos of infants feeding, it is clear that instances of self-feeding are not only motivated by the desire to ingest food; for example, there were many instances of what could be interpreted as 'playing with food' where infants take a piece of food and repeatedly place it in and take it out of their mouths; and some self-feeding ingestions involved minute quantities of food. Such acts seem motivated not so much by a desire to ingest the food, but by the sheer enjoyment of the very act of 'feeding oneself' without assistance.

Mechanisms for the association

The 'accept proportion' was found to be positively associated with the amount of food ingested suggesting that it is through their food acceptance/rejection behaviour that infants control their intake and therefore regulate their weight gain. The 'accept proportion' was not associated with the number of times infants were offered food by their mothers, lending further support to the view that in predominately spoon fed infants, the 'accept proportion' is largely a reflection of the infant's motivation.

Discussion of mechanisms raises the question of exactly what characteristic of the infant the 'accept proportion' is measuring. In a review of feeding behaviour research in adults, Spitzer & Rodin (1981) suggest measures such as rate of feeding are partially a reflection of hunger. As we have seen in spoon fed infants, however, measures of rate are somewhat different; they reflect the behaviour of both mother and infant and as far as can be seen from this study rate measures are not related to weight gain. In spoon fed infants the 'accept proportion' is a predictor of weight gain, and may be a more appropriate measure of hunger.

Support for the view that the 'accept proportion' is not just a reflection of food preferences comes from the finding that the association between the 'accept proportion' and weight gain was present when just the savoury portion of the meal was considered. Therefore the 'accept proportion' is not merely a proxy for food palatability.

Future investigation

Further investigation is required to systematically investigate precisely what the 'accept proportion' is measuring. If it is a measure of hunger or appetite one would expect that it will vary as a function of stage in the meal (as the infant becomes progressively satiated and appetite diminishes). Future research examining changes in feeding behaviour over the course of a meal may well be useful, but modelling these changes is unlikely to be feasible as there are insufficient events during solids feeding upon which to construct a formal model. Even with sucking where there are approximately 500 events per meal, modelling change over time is not easy. It may be possible, however, to investigate changes more informally by splitting the meal into distinct portions. To rule out other possible influences on feeding it would be necessary to assume greater control over the foods offered to infants by ensuring the energy density, texture and palatability to infants were controlled as any of these factors may affect feeding behaviour (Birch & Deysher 1985, Gisel 1991, Desor & Beauchamp 1987). Alternatively, research involving manipulation of infant levels of satiation with the use of food preloads to examine the subsequent effects upon infant feeding behaviour would address the same issues.

Milk feeding, solids feeding and weight gain

When both sucks per burst and the 'accept proportion' were included as predictor variables in the same model, the number of sucks per burst remained a statistically significant predictor of weight gain but the 'accept proportion' was not. Hence, of the two feeding behaviours, only milk feeding behaviour was an independent predictor of weight gain. This model accounts for a considerable amount of the variation in patterns of weight gain, but especially in the early months of life.

The most parsimonious model of weight gain therefore, is one that includes milk feeding behaviour but not solids feeding behaviour. When added to the model already containing milk feeding behaviour, solids feeding behaviour provides no additional explanatory value. The question then arises, why is milk feeding behaviour independently associated with weight gain but solids feeding behaviour is not? It is reasonable to infer that solids feeding behaviour was not an independent predictor of weight gain because milk and solids feeding behaviour are measuring the same underlying characteristic. Further evidence that milk and solids feeding behaviour may be measuring the same characteristic of the child comes from the analyses in Chapter 7 that directly investigated the associations between milk and solids feeding. Here it was seen that one milk feeding behaviour variable was associated with three of the solids feeding variables, providing further evidence of a link between the two.

It is largely speculative to say exactly what characteristic of the child sucking behaviour is measuring but it may be a reflection of the infant's appetite. Agras et al (1987) termed the pattern of sucking they found to be associated with adiposity an 'avid feeding style.' Because this style was apparent from early life they suggest it may be a reflection of the infant's genetic predispositions. In examining weight gain not adiposity, the situation for this study may well be different but evidence from previous research was presented in Chapter 1 suggesting that weight gain and growth is regulated and influenced by genetic characteristics (e.g. Fomon, Filer, Thomas et al 1975, Tanner 1989, Smith, Truog, Rogers et al 1976). To sustain weight gain along a genetically influenced trajectory the infant must have some means of regulating energy intake. In the present study we have seen that the infant achieves this regulation through his or her feeding behaviour. It is contended that the characteristics found to be associated with weight gain in the present study are likely to be a reflection of the infant's appetite, which in turn is under the influence of the infant's genetic growth trajectory. It is quite possible however that learning and maternal influences may also play a significant role in these associations.

If measures of milk and solids feeding behaviour are indeed measuring the same underlying characteristic of the infant, clearly milk feeding behaviour is a better predictor of weight gain. Several difficulties were encountered in the measurement and summary of solids feeding behaviour and these could mean it is less sensitive to important aspects of the infant's behaviour. In Chapter 1 it was seen that a wide range of extraneous variables are believed to influence solids feeding behaviour. These include food tastes (e.g. Cowart 1981), sensory specific satiety (Birch & Deysher 1986), food textures (Gisel 1991) and the eating environment (Birch, Zimmerman & Hind 1980). While it is true that milk feeding behaviour is also influenced by extraneous variables, such as the flavours of foods consumed by mothers tainting breastmilk (Mennella & Beauchamp 1991) and the introduction of solids foods (Drewett, Payman & Whitley 1987), it is possible that extraneous influences play a greater role in solids feeding. One piece of evidence in line with this assumption is that intake during solids feeding is more variable than during milk feeding (Black, Cole, Wiles, et al 1983). There are also motor, perceptual and cognitive developmental changes to consider which mean an infant of one year may be more prone to distractions than one of six weeks.

There has been less systematic research carried out on solids feeding behaviour than there has of sucking behaviour. As a result, measures of behaviour during solids feeding are less developed and have been less widely tested than those for sucking. There are also issues relating to how measures of behaviour are summarised. In the present study it was found that a single breast feed is likely to consist of about 500-600 sucks whereas a solids feed may consist of only 50-60 acts of food ingestion. Sucking behaviour is particularly amenable to time series modelling techniques because of the large quantity of data involved. In solids feeding there are considerably fewer data so the reliability of the estimates generated by models are likely to be so low that the use of such techniques cannot be justified. For these reasons it is very difficult to extract information on changes in feeding behaviour over the course of a meal during solids feeding. In addition, the follow-up measure of weight gain continued for only three months after solids feeding behaviour was measured and it is possible that a longer period of follow-up would strengthen the association between solids feeding behaviour and weight gain.

Although there are problems associated with the measurement of solids feeding behaviour which weaken the association with weight gain, it must be remembered that solids feeding behaviour was associated with weight gain when analysed separately so despite these problems, measures of solids feeding behaviour were sensitive to aspects of the infant that play a role in the regulation of weight gain. This lends some validity to the measures of solids feeding behaviour used in this study.

Other influences on weight gain

The other variables independently associated with weight gain were infant sex, milk intake during breastfeeding and age of introduction of solids. Maternal BMI was independently associated with infant weight but not with weight gain. There were no significant associations between weight gain and paternal BMI, milk feeding patterns, duration of breastfeeding or solids food intake.

The influence of the infant's sex on weight gain is unsurprising as it is well documented in previous research (Tanner 1989). The positive association between milk intake and weight gain is also in keeping with most previous research on this issue (Dewey et al 1991b). Age of introduction of solids was found to be negatively associated with weight gain and similar findings have been found in infants up to six months of age in previous observational research (Forsyth, Ogston, Clark et al 1993).

Duration of breastfeeding up to 15 months was not significantly associated with weight gain in these infants. As previous research on the relationship between milk feeding patterns and weight gain has generated inconsistent findings (e.g. Dewey 1991b, Butte, Wills, Jean et al 1985), the lack of a significant association between weight gain and milk feeding patterns (duration and frequency of milk feeds) in this study provides further evidence that there is no simple relationship between the two.

Finally, the lack of a significant association between volume of solids food intake and weight gain is most probably because; (1) intake was measured at only four meals which is a rather limited sample given that meal to meal variability in intake is rather high in young children (Birch, Johnson, Anderson, et al 1991) and; (2) the measure used in this study was the weight of food, not energy intake.

Variability in feeding behaviour

One of the contributions of this study is the partitioning of the variation in feeding behaviour into the proportion of variation attributable to individual differences between subjects, and the proportion due to meal to meal fluctuations within subjects. Little previous research on feeding behaviour has addressed this issue; several previous studies have made observations on only part of a feed or meal (e.g. Israel et al 1985) and of those that have involved observations of entire meals or feeds, none have took measures at more than two (e.g. Koivisto, Fellenius & Sjoden 1994b, Agras et al 1987, Agras et al 1988). For milk feeding behaviour the variation attributable to individual differences ranged from 45% for suck duration to less than 1% for pause duration at the end of a feed. For solids feeding behaviour there was greater stability; variation attributable to individual differences ranged from 74% for number of acceptances to 32% for number of refuses. Clearly milk feeding behaviour was the more variable. Further investigation of the sources of variability in both milk and solids feeding are required. In comparing the components of variation for milk and solids feeding it is important to remember that the methods of deriving these summary statistics for the two types of feeding have been very different. For milk feeds, start and end of feed estimates are given but for solids feeds the estimates are averaged over the entire feed. This may be one reason for the higher level of feed to feed fluctuation seen in milk feeding behaviour. As discussed above, there also appear to be some residual difficulties with the modelling of milk feeds, particularly the pause durations.

Using a similar method of analysis to investigate infant behaviour patterns, St James-Roberts & Plewis (1996) found day to day variation was the largest single source of variation in behaviour patterns. Given the findings of both studies it would seem variation is a major feature of infant behaviour and this needs to be seriously considered in future studies. There is certainly a need for better understanding of the sources of these fluctuations and further investigation of what number of feeds should be sampled to achieve the most reliable but cost effective measures of feeding behaviour.

Solids feeding behaviour

This study has provided important information on the feeding behaviour of one year olds under naturalistic conditions. In distinguishing between food ingestions according to whether they were maternal or self-feeding it was possible to identify the extent of self-feeding among these infants. Around 40% of food ingestions were self-feeding although there were considerable individual differences with some infants receiving very little assistance while others were almost entirely fed by their mothers. This confirms the findings of previous research on the development of spoon using skills in infants which found some variability between infants in levels of skill (Connolly & Dagleish, 1989).

While 40% of food ingestions were acts of self-feeding this tells us little about the efficiency of self-feeding behaviour at this age. Although infants were engaging in a substantial number of self-feeding acts, in several cases it appeared that little food was actually ingested and in this sense the figure of 40% may underestimate the reliance of these infants on caretakers for their feeding. The success of self-feeding will also depend on the sorts of foods offered to infants; foods of puree or semi-solid consistency were clearly more of a challenge than solid foods which could be eaten with fingers.

A fundamental difference between the feeding behaviour of year old infants and older children or adults is that most year olds are not yet feeding themselves independently. From this study it seems that although these infants are still dependent upon their carers, they are exercising control over their food ingestion by refusing food. In older children the rate of food ingestion appears to be an important feature of eating behaviour (e.g. Drabman et al 1979, Barkeling et al 1992) but in these younger infants the 'accept proportion' appears to be more important. This is not surprising when one considers that the rate of food ingestions is determined jointly by the mother and infant but it is the infant alone that determines whether or not to accept food when it is offered (except in force feeding). Future research investigating at what stage during a meal infants start to refuse food and what factors influence mothers' responses to food refusals would be useful. Given that the mean number of food refusals during the savoury portion of meals was ten, the occurrence of food refusal does certainly not indicate the end of a meal. This is relevant to understanding how control over the termination of feeding is achieved; whether or not they are able to exert such control is likely to have important implications for infants in learning to respond to their own internal cues of satiety. As far as this study is concerned it appears that most of these infants were able to exercise some control in that they refused food on a considerable proportion of the occasions when it was offered.

In keeping with previous research on the role of food taste on feeding behaviour (Desor & Beauchamp 1987), behaviour during the sweet and savoury portion of the meals was only moderately correlated suggesting the taste of food may play an important role in feeding behaviour. Although these correlations were modest, feeding behaviour during the sweet and savoury portions of the meal was correlated for seven out of the nine variables studied. Clearly then there is an element of constancy within individuals in their feeding behaviour despite the influence of food taste.

One area for future work on solids feeding is the development of summary methods that allow changes in say, the rate of food ingestion during the course of a meal to be described. As mentioned above it is difficult to envisage the use of formal modelling techniques because there are too few instances of ingestive behaviour to obtain reliable estimates, and not all food ingestions are equivalent; some are self-feeding and some are feeding by mothers. One way to resolve the latter difficulty might be to use automated data collection techniques, such as those employed by Barkeling et al (1992), which use computerised scales to sequentially record the amount of food removed from the plate.

Relationship between milk and solids feeding behaviour

In the analysis of the relationship between milk and solids feeding behaviour, suck duration at the end of a feed was consistently found to be associated with solids feeding behaviour; infants with longer suck durations at the end of a breastfeed were given food at a faster rate during solids feeding, accepted food at a faster rate and had a higher 'accept proportion' per minute of a feed. These associations remained after controlling for infant weight at the time of the measurement of feeding, indicating that it is unlikely the relationship between milk and solids feeding behaviour is due to a common association with concurrent weight.

Previous research, mainly conducted on rats, has provided evidence that the systems underlying milk and solids feeding are separate in terms of motor responses, the role of external influences, regulation mechanisms and neural substrates (e.g. Hall & Williams 1983). The little research relevant to this issue that has been conducted in humans also points to a similar conclusion (e.g. Woolridge 1986, Brown, Stallings, Kanashiro 1990). The most likely conclusion of the present study, which, it is important to remember has not investigated any actual mechanisms involved in the regulation of feeding, is that the apparent continuities between milk and solids feeding behaviour found here are a reflection of influences that are common to the two types of feeding. Therefore, the continuities found in the present study are not necessarily in conflict with the thesis that milk and solids feeding are regulated by two separate systems because continuities would be expected if the two systems are subject to similar influences. Support for this conclusion comes from the particular pattern of associations found; infants who were still ingesting milk at a relatively fast rate towards the end of a feed (as indicated by long suck durations) appear to be ingesting food at a higher rate, and more readily during solids feeding.

One important characteristic of infants which may support this apparent continuity is their weight gain trajectory. In as far as this growth trajectory influences the infant's appetite or avidity of feeding so we see the continuities in behaviour observed in the present study.

Overall conclusions

From previous research we know weight gain in infancy has important implications for later development. This study has contributed to an understanding of the influences on weight gain and has shown it is possible to predict weight gain from measures of feeding behaviour using a carefully formulated method for summarising that behaviour. This method for the analysis of breastfed infants' sucking patterns allows for changes in sucking over the course of a feed and should provide a foundation for future experimental work on the processes that influence sucking patterns. The collection and analysis of the repeated measures feeding behaviour data indicate that feed to feed fluctuations account for a considerable proportion of the variation, particularly for milk feeds, and there can be little doubt that the characterisation of an individual's feeding behaviour could be substantially improved by averaging replicated measures.

This study provides evidence that milk and solids feeding behaviour are associated, indicating that measures of milk and solids feeding may be tapping into the same characteristic. It has been suggested that this characteristic is the infant's appetite, and that in turn, this is influenced by the genetic growth trajectory of the infant. With further research it should be possible to test whether these measures are indeed a reflection of appetite. Future research examining associations between feeding behaviour and growth in height may also be informative; if growth in height were found to be related to feeding behaviour this would provide firmer evidence that these associations are mediated by genetic influences. For similar reasons it would also be instructive to investigate associations with parent height.

Further elaboration of the model to prospectively investigate other possible influences on weight and growth would be useful. Parental influences are an obvious candidate; previous research has found that parental behaviour during mealtimes is associated with the feeding behaviour of their 18-month old children (Agras et al 1988) and there is some evidence that maternal behaviour during bottle feeding is associated with infant weight gain very early in life (e.g. Pollitt & Wirtz 1981). Other more contextual features such as the elevated levels of conflict, disorganisation and negative attitudes during mealtimes have also been found to be associated with infant and child weight in certain groups of children (Stein, Woolley, Cooper, et al 1994, Heptinstall, Puckering, Skuse, et al 1987). It would be particularly useful to examine such influences prospectively.

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Appendices

Appendix 1

Study Information Sheet

Bridget Young
Department of Psychology
University of Durham
South Road
Durham DH1 3LE

RESEARCH ON INFANT FEEDING

I would like to invite you and your baby to take part in a study of how the feeding behaviour of infants changes during the first year of life. Through this study, I hope to gain a greater understanding of several important issues that are poorly understood at present.

Taking part in this study will initially involve my visiting you at home to explain the study and discuss any points you would like to raise. If you wish to participate I will ask you to sign a consent form. Obtaining signed consent is routine for all studies, it does not oblige you to participate, and you will be free to withdraw from the study at any time.

I would then like to arrange to come to your home and observe two feeds when your baby is aged about 5-6 weeks, and then again when your baby reaches 6 and 12 months of age. Information about the behaviour of your baby during the feeds will be recorded using a portable computer. I will also ask you to keep some records about your baby's feeding yourself, and to weigh your baby with me on each visit.

Please note that I will not be asking you to change your baby's feeding in any way and that all information collected during this study will be kept confidential.

Many thanks,

Bridget Young.

Appendix 2

48 Hour Baby's Day Record

"48 HOUR BABY'S DAY RECORD"

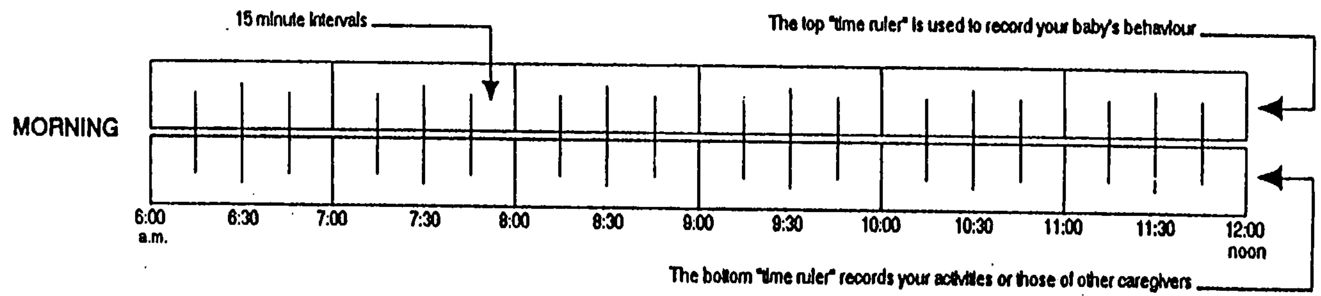
Contains:

1. Two baby's day records for filling in;
2. Instructions for completing the record;
3. An <u>example</u> record, to show what a completed record might look like.

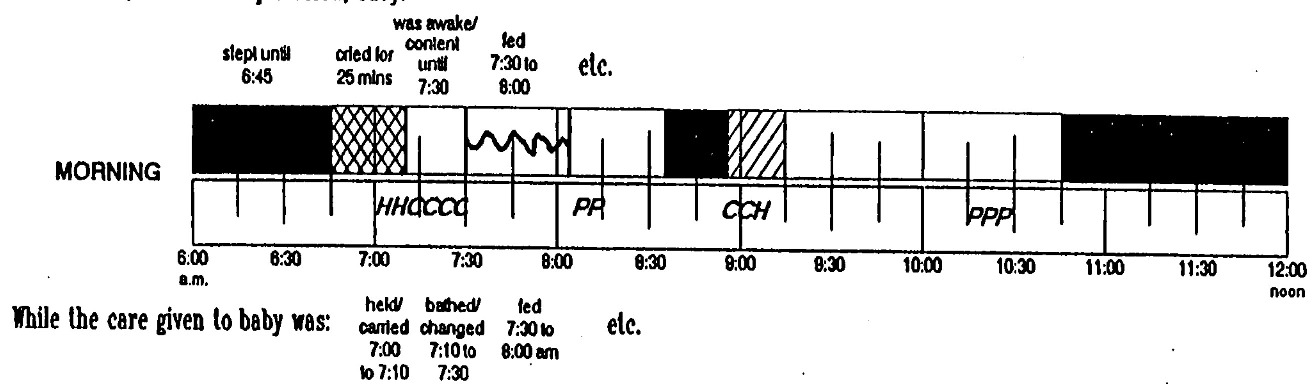
If there are any queries about filling the record in please telephone Bridget Young on (0207) 283213.

INSTRUCTIONS FOR COMPLETING THE "BABY'S DAY" RECORD

This record is designed to enable you to record your baby's behaviour and your activities with your baby over a continuous twenty-four hour period. As you can see, the day is divided into four blocks of six hours each. For example:



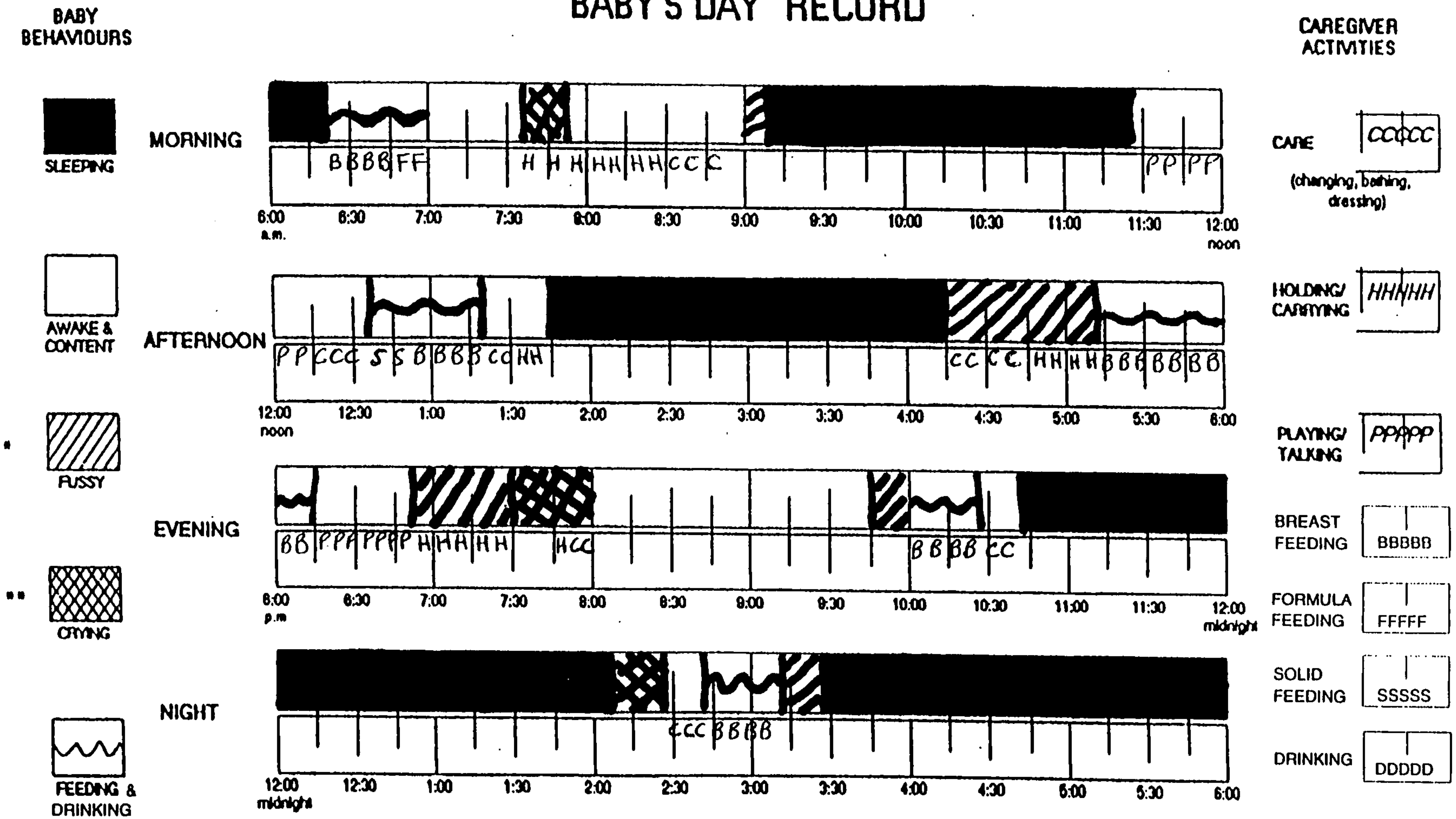
The record is filled in by shading on the "time rulers".
For instance, in the example below, baby:



The attached example record shows a full 24 hours record filled in and explains the symbols. Note that activities or behaviours don't need to last 15 minutes in order to be filled in. The length of the shading-in tells us how long they lasted for. If you can be accurate to within about 5 minutes - and omit activities/behaviours which last less than 5 minutes - that will be accurate enough.

Baby's full name: EXAMPLE Baby's age: ______ weeks/months (please indicate weeks or months) Today's Date: __ : __ : __

"BABY'S DAY" RECORD



* FUSSY: your baby is unsettled, irritable, restless or fractious and may be vocalizing but not continuously crying

** CRYING: periods of prolonged distressed vocalization.

Baby's full name: ______________________ Baby's age: ________ weeks/months (please indicate weeks or months) Today's Date: ___ : ___ : ___

"BABY'S DAY" RECORD

BABY BEHAVIOURS

- SLEEPING
- AWAKE & CONTENT
- * FUSSY
- ** CRYING
- FEEDING & DRINKING

MORNING

6:00 a.m. | 6:30 | 7:00 | 7:30 | 8:00 | 8:30 | 9:00 | 9:30 | 10:00 | 10:30 | 11:00 | 11:30 | 12:00 noon

AFTERNOON

12:00 noon | 12:30 | 1:00 | 1:30 | 2:00 | 2:30 | 3:00 | 3:30 | 4:00 | 4:30 | 5:00 | 5:30 | 6:00

EVENING

6:00 p.m | 6:30 | 7:00 | 7:30 | 8:00 | 8:30 | 9:00 | 9:30 | 10:00 | 10:30 | 11:00 | 11:30 | 12:00 midnight

NIGHT

12:00 midnight | 12:30 | 1:00 | 1:30 | 2:00 | 2:30 | 3:00 | 3:30 | 4:00 | 4:30 | 5:00 | 5:30 | 6:00

CAREGIVER ACTIVITIES

CARE (changing, bathing, dressing)	CCCCC
HOLDING/ CARRYING	HHHHH
PLAYING/ TALKING	PPPPP
BREAST FEEDING	BBBBB
FORMULA FEEDING	FFFFF
SOLID FEEDING	SSSSS
DRINKING	DDDDD

* FUSSY: your baby is unsettled, irritable, restless or fractious and may be vocalizing but not continuously crying

** CRYING: periods of prolonged distressed vocalization.

Baby's full name: ______________________ Baby's age: ________ weeks/months (please indicate weeks or months) Today's Date: __ : __ : __

"BABY'S DAY" RECORD

BABY BEHAVIOURS

- SLEEPING
- AWAKE & CONTENT
- * FUSSY
- ** CRYING
- FEEDING & DRINKING

MORNING

6:00 a.m. | 6:30 | 7:00 | 7:30 | 8:00 | 8:30 | 9:00 | 9:30 | 10:00 | 10:30 | 11:00 | 11:30 | 12:00 noon

AFTERNOON

12:00 noon | 12:30 | 1:00 | 1:30 | 2:00 | 2:30 | 3:00 | 3:30 | 4:00 | 4:30 | 5:00 | 5:30 | 6:00

EVENING

6:00 p.m | 6:30 | 7:00 | 7:30 | 8:00 | 8:30 | 9:00 | 9:30 | 10:00 | 10:30 | 11:00 | 11:30 | 12:00 midnight

NIGHT

12:00 midnight | 12:30 | 1:00 | 1:30 | 2:00 | 2:30 | 3:00 | 3:30 | 4:00 | 4:30 | 5:00 | 5:30 | 6:00

CAREGIVER ACTIVITIES

- CARE (changing, bathing, dressing) — CCCCC
- HOLDING/ CARRYING — HHHHH
- PLAYING/ TALKING — PPPPP
- BREAST FEEDING — BBBBB
- FORMULA FEEDING — FFFFF
- SOLID FEEDING — SSSSS
- DRINKING — DDDDD

* FUSSY: your baby is unsettled, irritable, restless or fractious and may be vocalizing but not continuously cryin

** CRYING: periods of prolonged distressed vocalization.

Baby's full name: ______________________ Baby's age: ________ weeks/months (please indicate weeks or months) Today's Date: __ : __ : __

"BABY'S DAY" RECORD

BABY BEHAVIOURS

- SLEEPING
- AWAKE & CONTENT
- * FUSSY
- ** CRYING
- FEEDING & DRINKING

MORNING

6:00 a.m. | 6:30 | 7:00 | 7:30 | 8:00 | 8:30 | 9:00 | 9:30 | 10:00 | 10:30 | 11:00 | 11:30 | 12:00 noon

AFTERNOON

12:00 noon | 12:30 | 1:00 | 1:30 | 2:00 | 2:30 | 3:00 | 3:30 | 4:00 | 4:30 | 5:00 | 5:30 | 6:00

EVENING

6:00 p.m | 6:30 | 7:00 | 7:30 | 8:00 | 8:30 | 9:00 | 9:30 | 10:00 | 10:30 | 11:00 | 11:30 | 12:00 midnight

NIGHT

12:00 midnight | 12:30 | 1:00 | 1:30 | 2:00 | 2:30 | 3:00 | 3:30 | 4:00 | 4:30 | 5:00 | 5:30 | 6:00

CAREGIVER ACTIVITIES

- CARE (changing, bathing, dressing) — CCCCC
- HOLDING/ CARRYING — HHHHH
- PLAYING/ TALKING — PPPPP
- BREAST FEEDING — BBBBB
- FORMULA FEEDING — FFFFF
- SOLID FEEDING — SSSSS
- DRINKING — DDDDD

* FUSSY: your baby is unsettled, irritable, restless or fractious and may be vocalizing but not continuously cryi[ng]

** CRYING: periods of prolonged distressed vocalization.

Appendix 3

48 Hour Record of Baby's Feeding

48 Hour Record of Baby's Feeding

Instructions for recording your baby's intake
The amount of breast milk your baby is getting can be measured by weighing him/her before a feed begins and then weighing him/her again when the feed has ended. Subtracting the weight recorded before the feed from the weight after the feed makes it possible for me to estimate your baby's milk intake.

To get an accurate measurement of how much breast milk your baby is getting it would be very helpful if you could note the following points;

1) Please try to record your baby's milk intake at as many feeds as possible. If you forget or are unable to weigh your baby at a feed, please make a note of this on the intake record before you fill in the details of the next feed.

2) If your baby needs to have a nappy change at any time during a feed you will need to weigh him/her before changing and then weigh him/her again after changing. This is in addition to the usual procedure of weighing before and after the feed.

3) Please try to make sure your baby is wearing the same clothing when weighed after feeds as he/she was wearing when weighed before the feeds. If you take any clothing off your baby during a feed, this can be placed on the scales with your baby when you weigh him/her at the end of the feed. If you put any additional clothing on your baby during a feed, it would be best if you could remove this before he/she is weighed at the end of the feed.

4) If you give your baby any expressed breast milk please record this in the final two columns of the chart. Indicate that your baby had expressed breast milk by writing 'EBM' in the 7th column and use the measures given on your feeding bottles to estimate how much breast milk your baby has taken.

Please also record any drinks and/or formula feeds given to your baby in the appropriate columns on the chart. Use the measures given on feeding bottles to estimate your baby's intake of drinks and formula. It would also be helpful if you could name or describe any additional drinks that you give to your baby.

Use a separate chart for each 24 hour period.

Record of Baby's Breast Milk, Formula and Drinks Intake

Name:______________________________ Date__________________

Time	Weight (grams)				Formula	Expressed Breast Milk (EBM)or Additional Drinks	
(delete am or pm)	before feed	before changing	after changing	after feed	amount (delete mls or ozs)	description or name	amount (delete mls or ozs)
am/pm					mls/ozs		mls/ozs
am/pm					mls/ozs		mls/ozs
am/pm					mls/ozs		mls/ozs
am/pm					mls/ozs		mls/ozs
am/pm					mls/ozs		mls/ozs
am/pm					mls/ozs		mls/ozs
am/pm					mls/ozs		mls/ozs
am/pm					mls/ozs		mls/ozs
am/pm					mls/ozs		mls/ozs
am/pm					mls/ozs		mls/ozs
am/pm					mls/ozs		mls/ozs
am/pm					mls/ozs		mls/ozs
am/pm					mls/ozs		mls/ozs
am/pm					mls/ozs		mls/ozs
am/pm					mls/ozs		mls/ozs

Appendix 4

Parental Declaration of Informed Consent

Parental Declaration of Informed Consent

I am willing to take part in the infant feeding project. I have been informed that I am free to withdraw at any time and that all information collected will be kept confidential.

Child's Name [ ]
first name

[ ]
second name

Parent's Signature [ ]

Date [ ][ ] [ ][ ][ ] [ ][ ]
day *month* *year*

Appendix 5

Infant Feeding - Questionnaire One

INFANT FEEDING - QUESTIONNAIRE ONE

1. TODAY'S DATE — day / month / year

2. ABOUT YOU

(a) Surname

(b) Other name(s)

(c) Date of birth — day / month / year

3. ABOUT YOUR BABY

(a) Surname

(b) Other name(s)

(c) Date of birth — day / month / year

4. How old is your baby now? — weeks

5. Is this your first baby ?

no — *please answer (a) below*

yes

(a) Please give the ages of all your other children.

male children (years)

female children (years)

ABOUT THE BIRTH

6. What was your expected date of delivery?

☐☐ ☐☐☐ ☐☐
day month year

7. Was there any uncertainty about your dates?

no ☐

yes ☐

if yes, please explain about this below

8. How many weeks pregnant were you when your baby was born?

☐ weeks

9. What type of delivery did you have?

normal ☐

forceps ☐

vacuum extraction ☐

caesarean ☐

10. How long after the baby was born did you stay in hospital?

☐ hours OR ☐ days

ABOUT FEEDING YOUR BABY

11. While you were in hospital did you always feed the baby yourself or did the nurses ever feed him/her?	always fed baby myself	☐
	nurses sometimes fed baby	☐
12. How did you yourself feed your baby while in hospital?	breast only	☐
	bottle only	☐
	combination of breast and bottle feeding	☐
13. Did you have any problems feeding your baby while in hospital?	no	☐
	yes	☐ *please go to (a) below*
(a) What problems did you have? (Tick one or more)	sore or cracked nipples	☐
	baby not latching on to breast	☐
	baby hungry	☐
	baby vomiting	☐
	other[s] (please tick and describe below)	☐

14. Have you had any problems feeding your baby since you left hospital?

	no	☐
	yes	☐ *please go to (a) overleaf*

(a) What problems did you have? (Tick one or more)

- sore or cracked nipples ☐
- baby not latching on to breast ☐
- baby hungry ☐
- baby vomiting ☐
- other[s] (please tick and describe below) ☐

15. Since you left hospital has your baby ever been given any milk from a bottle?

- no ☐
- yes ☐

please go to (a) below

(a) How often has your baby been given a bottle?

- once or twice only ☐
- sometimes ☐
- quite often ☐
- nearly always ☐

16. Do you feed your baby on demand or do you tend to keep to set feeding times?

- on demand ☐
- set times ☐
- other arrangement (tick and describe below) ☐

17. Has your baby ever had any foods apart from milk such as cereal, rusk or any other kind of solid food?

- no ☐
- yes ☐ *please go to (a) below*

(a) How old was your baby when he/she first had solids?

☐ weeks old

18. In general, how would you describe your baby's appetite?

- very good ☐
- good ☐
- satisfactory ☐
- poor ☐
- very poor ☐

19. How often do you encourage your baby to feed for longer?

- never ☐
- rarely ☐
- sometimes ☐
- quite often ☐
- nearly always ☐

If you do encourage your baby to feed for longer could you please describe how you do this below.

THE NEXT SECTION CONTAINS SOME GENERAL QUESTIONS ABOUT YOURSELF AND YOUR FAMILY. ALTHOUGH SOME OF THESE QUESTIONS MAY NOT SEEM VERY RELEVANT TO INFANT FEEDING, THEY ARE ALL CONCERNED WITH THINGS THAT ARE RELATED TO A MOTHER'S DECISIONS ABOUT FEEDING HER BABY.

20. Apart from yourself and your new baby, how many of you usually live in this house together? (Please enter the number in each box)

partner	☐
male children	☐
female children	☐
grandparents	☐
others	☐

21. Have you ever smoked cigarettes?

no	☐
yes	☐ *go to (a)*

(a) Do you smoke at all nowadays?

no	☐ *go to (b)*
yes	☐

(b) Have you smoked at all in the past two years?

no	☐
yes	☐

22. ABOUT YOUR WEIGHT AND HEIGHT, AND THE BABY'S DAD'S WEIGHT AND HEIGHT

(a) What weight are you?	☐☐ ☐☐ *stones* *pounds*	☐ *kilos*
(b) What height are you?	☐ ☐☐ *feet* *inches*	☐ *metres*
(c) What weight is the baby's dad?	☐☐ ☐☐ *stones* *pounds*	☐ *kilos*
(d) What height is the baby's dad?	☐ ☐☐ *feet* *inches*	☐ *metres*

ABOUT YOUR EDUCATION AND EMPLOYMENT

23. How old were you when you finished full-time education ?

- 16 or under ☐
- 17 ☐
- 18 ☐
- 19 or over ☐

24. What qualification(s) have you obtained at school or college?

- no formal qualifications ☐
- CSE (or equivalent) ☐
- 'O' level (or equivalent) ☐
- 'A' level ☐
- degree ☐
- other (please specify below) ☐

25. Have you ever worked in paid employment?

- no ☐
- yes ☐ *please tell me about this below*

26. What is (was) your current (or last) form of paid employment?

Write in job title

27. Is (was) this employment full-time or part-time?

- full-time ☐
- part-time ☐

28. What do (did) you actually do?

Describe your job

[ ]

29. What firm or organisation do (did) you work for?

Give the name of employer or state 'self-employed'

[ ]

30. Are (were) you a manager or supervisor of any kind?

- yes, manager ☐
- yes, supervisor ☐
- no, neither ☐

ABOUT YOUR PARTNER'S EDUCATION AND WORK

31. How old was he when he finished full-time education ?

- 16 or under ☐
- 17 ☐
- 18 ☐
- 19 or over ☐

32. What qualifications did your partner obtain at school or college?

- no formal qualifications ☐
- CSE (or equivalent) ☐
- 'O' level (or equivalent) ☐
- 'A' level ☐
- degree ☐
- other (please specify over leaf) ☐

Other qualifications

33. Has he ever worked in paid employment?

- no
- yes *please tell me about this below*

34. What is (was) his current (or last) form of paid employment?

Please write in his job title

35. Is (was) this employment full-time or part-time?

- full-time
- part-time

36. What does (did) your partner actually do?

Please describe his job

37. What firm or organisation does (did) he work for?

Please give the name of his employer or state 'self-employed'

38. Is (was) he a manager or supervisor of any kind?

- yes, manager
- yes, supervisor
- no, neither

INFORMATION ABOUT YOUR BABY'S WEIGHT

What weight was your baby at birth?

pounds ounces *grams*

Please give any additional weights taken of your baby in hospital

pounds ounces *grams* *day* *month* *year* *days old*

Weights taken by your GP, Midwife or Health Visitor during the first 10 days after the birth

pounds ounces *grams* *day* *month* *year* *days old*

Weights since taken at the baby clinic

pounds ounces *grams* *day* *month* *year* *days old*

Appendix 6

Questionnaire Two- Feeding History

QUESTIONNAIRE TWO - FEEDING HISTORY

Date ☐☐ ☐☐☐ ☐☐

Your name ☐

Baby's name ☐ D.O.B. ☐☐ ☐☐☐ ☐☐

1) Are you still breast feeding your baby at all?

no ☐ *please answer (a) below*

yes ☐ *please answer Q below*

1a) How old was your baby when you last breast fed him/her? ☐ weeks

2) Have you had any problems with breastfeeding since my last visit?

- no ☐
- yes ☐ *please go to (a) below*

2a) What problems did you have? (Tick one or more)

- sore or cracked nipples ☐
- baby not latching on to breast ☐
- baby hungry ☐
- baby vomiting ☐
- baby ill ☐
- baby did not like milk ☐
- other[s] (please tick and describe below) ☐

3) So just to check, what sort of milk do you give your baby now?

- breastmilk only ☐
- breastmilk and formula ☐
- formula only ☐
- breastmilk and other milk ☐ *please specify what*
- other milk only ☐ *sort of milk below*

3a) Do you usually give your baby milk evey day?

yes ☐ *(please go to b, c & Q4 below)*

no ☐

3b) How many times do you give milk to your baby during the day?

Breastmilk ☐ Formula/other milk ☐

3c) How many times do you give this formula/other milk to your baby at night?

Breastmilk ☐ Formula/other milk ☐

4) Have you had any problems with formula feeding since my last visit

no ☐ *please go to Q5*

yes ☐ *please go to (a) below*

4a) What problems have you had? (Tick one or more)

baby would not feed from bottle ☐

baby hungry ☐

baby vomiting ☐

baby ill ☐

baby did not like formula ☐

other[s] (please tick and describe below) ☐

5) Has your baby ever had any foods apart from milk such as cereal, rusk or any other kind of solid food?

no	☐	*questionnaire complete*
yes	☐	*please answer all remaining questions*

5a) How old was your baby when he/she first had solids?

☐ weeks old

6) At which meals do you regularly offer your baby solid food at the moment?

Breakfast	☐	*If 3 or more*
Lunch	☐	*go to (a) below*
Evening meal	☐	
Other meals	☐	☐ *please specify*

6a) How old was your baby when he/she first started having three meals of solid food a day?

☐ weeks old

7) Have you ever had any problems in feeding solid food to your baby?

no	☐	
yes	☐	*please answer (a) below*

7a) What sort of problems have you experienced?

- Baby would not take solids ☐
- Baby would only take certain solids ☐
- Baby went off food for a while ☐
- Other problem(s) ☐ *(tick and describe below)*

QUESTIONNAIRE TWO - FEEDING HISTORY (cont'd)

Your name [ ]

Baby's Name [ ] D.O.B. [ ][ ] [ ][ ][ ] [ ][ ]

Date on which the record was completed [ ][ ] [ ][ ][ ] [ ][ ]

8) Please list all the cereal, rusks or solid food that your baby ate yesterday. If this is not possible today, please list all the foods your baby has for any other single day within the next week. Please describe each type of food fully, giving the brand name, or if it's home made, whether the commercial baby food is dried or tinned/jarred and also the time of the meal.

Time of day	Type of food	Write in what brand (or home made)	Please tick to show whether dried	tinned/ jarred

8a) Was yesterday (or the day to which this list refers) a typical day as far as your baby's feeding is concerned?

no ☐ *please answer (b) below*

yes ☐

b) How was your baby's feeding on this day different from usual? (Please describe below).

When complete please return to me as soon as possible using the SAE provided

Appendix 7

Describing the Sucking Patterns of Breastfed Infants

Describing the Sucking Patterns of Breastfed Infants

A description of an infants sucking over a feed has two components: (1) a description of the burst-pause pattern at the beginning of the feed (or at any other point during a feed) and (2) a description of the way the burst-pause pattern changes over the course of the feed.

(1) To describe the burst-pause pattern we assume that:

i) a suck has a *duration*

ii) most short intervals are composed of suck *durations*

iii) bursts of sucks are separated by *pauses*

iv) long intervals are principally made up of *pauses*

The available data consists solely of the intervals from suck to suck. Treating the sucks as point events, there is no means of distinguishing a *duration* and a *pause* as they are defined above. The traditional method of analysing data of this kind assumes that they can be distinguished by their length (e.g. Pollitt, Gilmore and Valcarcel, 1978a), for example, that intervals less than 1.3 s are *durations* and intervals greater than 1.3 s are *pauses*. But the distributions of *durations* and *pauses* in fact overlap so they cannot be correctly distinguished by their length. Analyses which seek to separate the two distributions on the basis of a criterion interval of this kind and then estimate the parameters of the distributions of *durations* and *pauses* separately cannot therefore estimate them correctly.

An approach using a mixture model does not seek to separate the distributions of *durations* and *pauses* using a criterion interval but recognises there are two overlapping distributions and seeks to estimate all their parameters simultaneously.

The approach is parametric i.e. it makes assumptions about the underlying distributions. The first assumption is that the probability density function, $f_1(x)$ for the *durations* of sucks is a normal distribution with mean μ, and variance σ^2. For example in figure A7.1 we have a normal distribution with mean about 0.6 s and standard deviation about 0.08 s. It is clear there is a long tail out to the right which does not fit under this normal distribution. The normal distribution of *durations* is truncated on the y axis in order to show the *pauses* more clearly.

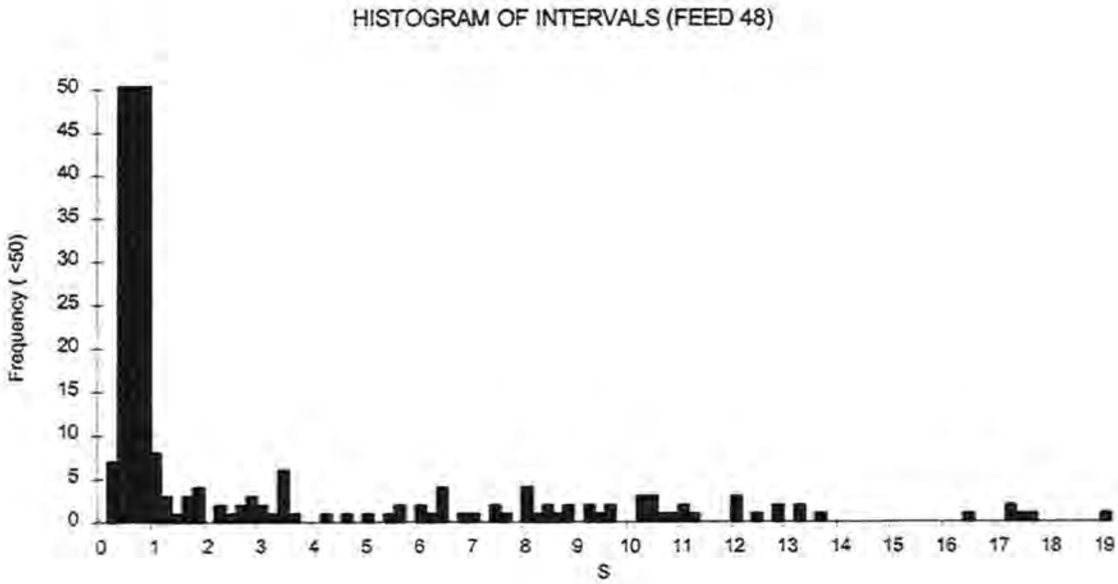
The second assumption is that the probability density function for the *pauses* is an exponential distribution:

$$q(x) = \lambda e^{-\lambda x}$$

Unlike the normal distribution which has two parameters, its mean and standard deviation, the exponential distribution has a single parameter λ. The mean of the exponential distribution is $1/\lambda$ and its variance is $1/\lambda^2$.

Figure A7.1

Histogram of Intervals During One Feed



In addition to estimating μ and σ (the mean and standard deviation of the normal distribution), and $1/\lambda$ (the reciprocal of the mean of the exponential distribution), we also need to estimate the proportion of intervals from each distribution. As each *duration* is a suck duration, the number of *durations* equals the number of sucks; as each *pause* separates a burst of sucking, the total number of *pauses* equals the number of bursts (in long series). So an estimate of the proportion of intervals from each distribution can be transformed to an estimate of the mean number of sucks per burst, which is the number of sucks divided by the number of bursts. Our third assumption is therefore that the probably distribution p(n) for the number of sucks per burst is a geometric distribution:

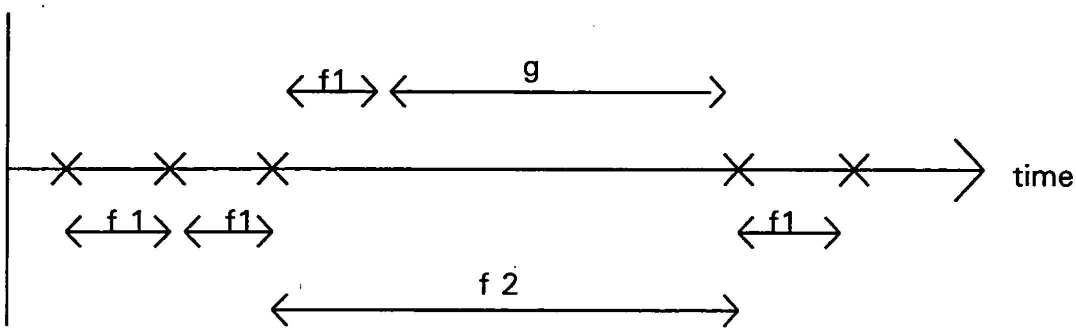
$$p(n) = (1 - \phi)\, \phi^{n-1} : n = 1, 2, ...$$

This has a single parameter ϕ. 1- ϕ is the probability of a *duration* being followed by a *pause,* i.e. of a burst of sucking terminating. $1/(1-\phi)$ is the mean number of sucks per burst.

We must now deal with a slight complexity concerning the *pauses*. Each long interval includes both a *pause* and a suck *duration* as illustrated in figure A7.2 (where the mark X on the time axis is the start of each suck) so the *pauses* referred to in the model consist of a suck duration and a pause between sucks. The probability distribution for long intervals $f_2(x)$ is therefore the sum or 'convolution' of $f_1(x)$ and $g(x)$. The formula for this probability distribution $f_2(x)$ is given in Chetwynd, Diggle, Drewett & Young (1996).

Figure A7.2

Diagram to illustrate the structure of the long intervals.



f1 = suck *duration* (short interval)

g = pause between sucks

f2 = suck duration and pause between sucks

We therefore have a two component mixture model:

$$f(x) = \phi f_1(x) + (1-\phi) f_2(x)$$

where f(x) is the combined density function, $f_1(x)$ is the normal distribution of suck *durations* with mean μ, and standard deviation σ; $f_2(x)$ is the distribution of long intervals with 1-λ the mean length of *pauses;* and ϕ and 1-ϕ are the proportions of intervals from $f_1(x)$ and $f_2(x)$ respectively. In order to keep our terminology consistent with traditional analyses we refer, however, to the following statistics, which in the last two cases are transformations of the parameters we estimate:

mean duration of a suck	μ
standard deviation of this mean duration	σ
mean number of sucks per burst	$\nu = 1/(1-\phi)$
mean pause time	$\zeta = 1/\lambda$

(2) To describe changes over time, we allow the four parameters specifying the mixture distribution to vary over the course of the feed. Exactly how they vary is an empirical question. We began with the simplest possibilities that are logically permissible, and these in fact turned out to be adequate. Mean suck *duration* has to be positive, so its trend in t, where t is the proportion of sucks elapsed over the feed, is specified as:

$$\mu(t) = e^{m_1 + m_2 t}$$

At the start of the feed t = 0, so the value of $\mu(t)$ is e^{m_1}. At the end of the feed t = 1, so the value of $\mu(t)$ is $e^{m_1 + m_2}$. All possible values of $\mu(t)$ are positive since e raised to any power is positive.

Following the same rationale we describe the change in σ as:

$$\sigma(t) = e^{s_1 + s_2 t}$$

and we describe the change in λ as :

$$\lambda(t) = e^{l_1 + l_2 t}$$

The situation with ϕ is slightly different as ϕ is a proportion, so in addition to being positive its upper bound is 1. For ϕ we describe the change over the feed as:

$$\phi(t) = \frac{e^{p_1 + p_2 t}}{1 + e^{p_1 + p_2}}$$

The numerator's lowest possible value is 0, for reasons already given. If the numerator is 0, then $(\phi)t$ is 0. The numerator has no maximum, but if the numerator is large then $(\phi)t$ is a large number divided by the same large number + 1, and so cannot be greater than 1.

Appendix 8

Feed by Feed Parameter Estimates

Feed by feed parameter estimates

	sucks per burst start	sucks per burst end	suck duration start	suck duration end	SD suck duration start	SD suck duration end	pause duration start	pause duration end
[1,]	6.250	2.247	0.890	0.888	0.129	0.177	0.956	4.429
[2,]	2.618	2.475	0.804	0.960	0.067	0.237	0.243	4.159
[3,]	3.906	2.551	0.888	0.994	0.122	0.135	0.257	2.189
[4,]	4.587	2.833	0.845	0.842	0.097	0.119	0.458	3.016
[5,]	3.922	3.717	0.882	0.712	0.201	0.128	1.532	4.931
[6,]	2.793	6.993	0.601	0.363	0.134	0.058	2.808	8.104
[7,]	3.195	5.348	0.974	0.336	0.171	0.117	1.427	7.541
[8,]	2.882	3.125	0.567	0.395	0.210	0.050	1.795	16.672
[9,]	13.889	6.369	0.804	0.832	0.101	0.208	2.321	4.866
[10,]	5.780	4.115	0.625	0.751	0.115	0.141	7.977	4.604
[11,]	6.289	5.814	0.767	0.763	0.079	0.186	0.375	10.452
[12,]	9.615	3.236	0.846	0.483	0.118	0.086	2.211	9.822
[13,]	4.762	3.401	0.780	0.792	0.106	0.132	1.715	5.104
[14,]	4.274	3.279	0.777	0.762	0.110	0.102	3.038	3.354
[15,]	3.378	4.237	0.788	0.752	0.112	0.108	1.705	3.406
[16,]	1.087	4.255	0.823	0.777	0.068	0.099	0.084	4.435
[17,]	11.111	5.128	0.878	0.615	0.151	0.104	0.942	4.924
[18,]	11.364	5.263	0.836	0.608	0.134	0.120	0.911	11.303
[19,]	10.870	13.333	0.817	0.716	0.120	0.113	1.784	5.720
[20,]	17.241	4.132	0.873	0.683	0.110	0.192	2.222	3.557
[21,]	5.988	3.937	0.751	0.485	0.128	0.077	3.323	5.526
[22,]	6.289	2.882	0.850	0.492	0.167	0.066	2.419	4.350
[23,]	12.500	4.184	1.052	0.588	0.148	0.110	5.093	7.362
[24,]	23.810	2.717	0.884	0.587	0.181	0.121	7.243	8.223
[25,]	3.378	3.497	0.702	0.717	0.070	0.128	1.193	1.453
[26,]	6.024	4.292	0.680	0.651	0.067	0.111	0.280	3.420
[27,]	7.353	4.237	0.645	0.541	0.091	0.076	1.403	2.465
[28,]	9.804	3.774	0.653	0.673	0.095	0.123	1.328	1.966
[29,]	23.810	3.559	0.761	0.776	0.082	0.139	0.090	6.781
[30,]	6.329	3.704	0.849	0.541	0.116	0.095	1.455	4.884
[31,]	13.158	4.255	0.935	0.608	0.184	0.071	0.632	6.430
[32,]	27.778	3.861	0.907	0.522	0.172	0.089	0.138	7.634
[33,]	5.747	3.861	0.636	0.719	0.076	0.085	0.332	11.665
[34,]	12.821	5.618	0.770	0.724	0.069	0.094	0.596	6.976
[35,]	18.868	4.878	0.733	0.653	0.098	0.088	0.867	5.878
[36,]	14.706	3.759	0.766	0.663	0.072	0.087	1.871	7.002
[37,]	10.309	4.739	0.770	0.676	0.087	0.151	5.390	8.918
[38,]	12.195	5.587	0.908	0.625	0.124	0.119	1.845	9.703
[39,]	14.493	4.608	0.750	0.822	0.078	0.135	0.592	9.655
[40,]	24.390	5.319	0.792	0.550	0.080	0.091	3.407	7.624
[41,]	12.821	4.651	0.731	0.600	0.077	0.090	1.942	6.446
[42,]	15.873	3.195	0.736	0.625	0.085	0.091	1.457	10.926
[43,]	6.944	6.024	0.697	0.560	0.089	0.092	2.267	4.637
[44,]	6.135	4.902	0.743	0.574	0.092	0.090	3.397	5.473
[45,]	35.714	5.747	0.683	0.482	0.078	0.069	0.964	13.840
[46,]	41.667	8.333	0.617	0.516	0.085	0.066	8.855	6.684
[47,]	18.519	9.091	0.607	0.564	0.075	0.092	6.176	11.893
[48,]	24.390	10.989	0.648	0.536	0.081	0.077	2.158	9.932
[49,]	6.944	3.367	0.638	0.677	0.076	0.131	0.765	3.314
[50,]	4.785	4.464	0.810	0.743	0.148	0.145	0.575	4.866
[51,]	4.902	4.255	0.745	0.695	0.135	0.120	0.649	6.219
[52,]	11.364	5.747	0.971	0.602	0.266	0.076	1.231	12.118
[53,]	7.353	7.143	0.680	0.571	0.079	0.096	0.383	4.535
[54,]	25.641	6.711	0.720	0.542	0.108	0.113	3.878	5.309
[55,]	13.699	16.129	0.669	0.658	0.097	0.102	0.894	21.909
[56,]	38.462	5.525	0.679	0.692	0.069	0.149	7.436	10.078
[57,]	62.500	3.226	0.828	0.766	0.121	0.127	0.970	3.764
[58,]	7.937	3.049	0.789	0.613	0.170	0.114	1.508	6.160
[59,]	15.625	9.259	0.837	0.623	0.131	0.186	2.292	13.506
[60,]	14.706	3.205	0.636	0.670	0.108	0.353	6.613	10.281
[61,]	31.250	5.319	0.778	0.616	0.104	0.115	3.862	3.672
[62,]	142.857	3.215	0.823	0.612	0.151	0.066	4.930	2.680
[63,]	11.111	6.623	0.729	0.557	0.076	0.089	0.217	14.697
[64,]	41.667	4.566	0.808	0.524	0.125	0.066	1.773	3.634

Feed by feed parameter estimates

	sucks per burst start	sucks per burst end	suck duration start	suck duration end	SD suck duration start	SD suck duration end	pause duration start	pause duration end
[65,]	3.472	2.283	0.925	0.733	0.172	0.162	0.539	4.691
[66,]	1.003	5.181	0.695	1.030	0.086	0.197	0.081	3.266
[67,]	11.494	1.969	0.934	0.914	0.154	0.117	0.294	4.544
[68,]	2.747	2.732	0.867	0.957	0.134	0.211	0.248	5.561
[69,]	12.048	7.519	0.719	0.723	0.074	0.096	0.882	13.874
[70,]	12.987	3.175	0.786	0.744	0.089	0.111	0.415	8.925
[71,]	11.494	4.405	0.896	0.627	0.138	0.075	0.840	13.159
[72,]	20.000	3.731	0.855	0.580	0.082	0.112	2.154	16.603
[73,]	30.303	7.353	0.638	0.638	0.082	0.067	0.113	5.840
[74,]	1.004	90.909	0.593	0.758	0.101	0.112	0.007	15.383
[75,]	18.519	5.128	0.595	0.594	0.055	0.064	0.147	4.025
[76,]	58.824	7.634	0.675	0.625	0.094	0.072	0.225	6.542
[77,]	1.189	4.115	0.662	0.741	0.034	0.172	0.042	21.908
[78,]	9.009	2.375	0.852	0.559	0.173	0.128	2.012	6.748
[79,]	4.926	3.984	0.735	0.522	0.095	0.101	1.542	8.381
[80,]	4.132	4.167	0.796	0.575	0.118	0.130	2.252	12.546
[81,]	13.889	4.831	0.813	0.648	0.130	0.201	0.873	15.511
[82,]	20.408	3.257	1.006	0.454	0.248	0.069	1.678	6.834
[83,]	2.915	11.364	0.858	0.723	0.124	0.164	0.518	14.914
[84,]	7.407	4.878	0.863	0.422	0.297	0.044	2.410	13.965
[85,]	7.692	3.185	0.721	0.444	0.143	0.050	3.430	7.057
[86,]	3.521	6.135	0.622	0.623	0.072	0.200	0.791	9.002
[87,]	7.042	1.887	0.744	0.720	0.133	0.174	0.618	9.947
[88,]	11.494	3.584	0.654	0.591	0.117	0.095	3.040	5.824
[89,]	28.571	6.211	0.868	0.690	0.136	0.077	3.312	4.522
[90,]	20.833	4.762	0.766	0.691	0.097	0.092	2.061	2.174
[91,]	1000.000	3.344	0.717	0.750	0.082	0.084	17.072	0.258
[92,]	27.027	7.299	0.767	0.620	0.091	0.111	2.343	5.770
[93,]	6.711	4.464	0.759	0.583	0.102	0.131	2.538	4.854
[94,]	10.417	3.663	0.608	0.617	0.106	0.093	1.274	4.048
[95,]	8.929	4.049	0.743	0.681	0.094	0.196	2.417	3.160
[96,]	10.870	3.774	0.627	0.635	0.079	0.155	0.291	12.457
[97,]	5.917	1.988	0.737	0.906	0.159	0.266	6.364	9.830
[98,]	6.329	2.525	0.807	1.072	0.189	0.213	1.183	14.692
[99,]	43.478	1.321	0.754	0.604	0.141	0.036	16.475	2.039
[100,]	3.322	2.703	1.016	0.738	0.179	0.237	0.272	9.121
[101,]	34.483	3.650	0.805	0.662	0.136	0.083	1.129	6.235
[102,]	5.464	6.024	0.883	0.650	0.154	0.088	0.985	6.141
[103,]	23.810	5.236	0.845	0.619	0.198	0.115	1.873	17.312
[104,]	5.263	6.757	0.800	0.595	0.102	0.095	0.672	13.360
[105,]	5.376	4.425	0.794	0.570	0.139	0.100	2.934	4.222
[106,]	3.546	4.673	0.777	0.499	0.128	0.097	3.036	3.780
[107,]	3.891	5.155	0.703	0.663	0.138	0.166	3.093	5.403
[108,]	3.690	5.236	0.749	0.610	0.128	0.189	1.586	4.695
[109,]	14.706	5.780	0.804	0.550	0.160	0.132	6.232	8.056
[110,]	8.000	5.128	0.858	0.569	0.154	0.084	1.138	8.431
[111,]	10.101	3.279	0.910	0.511	0.175	0.068	0.905	4.778
[112,]	13.889	6.250	0.916	0.697	0.128	0.174	0.736	5.770
[113,]	18.868	17.241	0.686	0.663	0.183	0.075	1.217	18.590
[114,]	13.889	6.250	0.722	0.428	0.150	0.051	2.130	6.317
[115,]	37.037	23.256	0.643	0.680	0.082	0.129	0.044	90.000
[116,]	14.925	9.174	0.755	0.471	0.130	0.105	2.874	3.907
[117,]	10.638	2.786	0.722	0.710	0.082	0.124	2.306	10.167
[118,]	6.329	3.922	0.798	0.588	0.130	0.111	8.726	11.886
[119,]	4.545	6.993	0.714	0.561	0.115	0.078	2.444	11.782
[120,]	7.634	5.464	0.731	0.569	0.096	0.109	3.826	9.235
[121,]	20.833	5.128	0.893	0.603	0.154	0.082	2.645	6.840
[122,]	18.182	4.132	0.788	0.651	0.142	0.106	4.405	2.944
[123,]	26.316	4.219	1.007	0.690	0.166	0.106	1.128	7.792
[124,]	10.989	6.098	0.783	0.522	0.128	0.087	4.442	5.749
[125,]	9.615	5.155	0.527	0.573	0.076	0.088	2.538	5.146
[126,]	7.092	7.692	0.635	0.458	0.122	0.081	2.599	13.255
[127,]	37.037	4.098	0.597	0.744	0.086	0.167	5.345	4.386
[128,]	14.925	5.376	0.619	0.601	0.117	0.085	12.744	3.213

Appendix 9

The Likelihood Ratio Statistic

The Likelihood Ratio Statistic

The likelihood is the probability of the observations, given a value for the parameters in the model. If λ_0 is the likelihood for a model with q parameters and λ_1 is the likelihood for a sub-model with p parameters, where $q > p$ so that λ_1 comes from the model with the greater number of parameters, then

$$D = -2 \log (\lambda_0 / \lambda_1)$$

This is the likelihood *ratio,* and the log of the ratio of likelihoods becomes the *difference* between log-likelihoods. So

$$\begin{aligned} D &= -2 (\lambda_0 / \lambda_1) \\ &= -2 (\log \lambda_0 - \log \lambda_1) \\ &= (-2 \log \lambda_0) - (-2 \log \lambda_1) \end{aligned}$$

Appendix 10

Level 2 (Between Subject) Variance

Level 2 (Between Subject) Variance[1]

The variance of a constant multiplied by a random variable is the square of the constant multiplied by the variance of the random variable (Mosteller, Rourke, and Thomas 1961).

$$\sigma^2_{cx} = c^2\sigma^2_x$$

Here x is a random variable and c is a constant.

The variance of a constant plus a random variable is the variance of the random variable:

$$\sigma^2_{c+x} = \sigma^2_{cx}$$

The variance of two random variables x and y is:

$$\sigma^2_{x+y} = \sigma^2_x + \sigma^2_y + 2\,(\rho\,\sigma_x\,\sigma_y)$$

where ρ is the correlation of x and y and $\rho\,\sigma_x\,\sigma_y$ is the covariance of x and y, also written as cov (x, y).

Extending this, if there are three or more random variables $x_1, x_2, \ldots x_n$, and

$$z = x_1 + x_2 + \ldots + x_n$$

then

[1] This explains how the level 2 (between subject) variance is calculated and was produced with the assistance of Huigi Pan, Institute of Education, London.

$$\sigma^2_z = \Sigma\ \sigma^2_i + 2\,\Sigma\, \mathrm{Cov}\,(x_i,\ x_j)$$

i.e. the variance of the sum of several random variables is the sum of their variances plus twice the sum of the covariances of all their possible pairs.

In the initial growth model as described in chapter 5, the weight of the *j*th infant on the *i*th occasion is

$$y_{cx} = \beta_{0j} + \beta_{1j}\,m + \beta_{2j}\,\mathrm{lnm} + \beta_{3j}\,m^{-1} + e_{ij}$$

where m is age in months. The variance of e_{ij} is the level 1 variance but here we are concerned only with the level 2 variance, i.e. the variance of

$$\beta_{0j} + \beta_{1j}\,m + \beta_{2j}\,\mathrm{lnm} + \beta_{3j}\,m^{-1}$$

where each term is composed of a fixed effect term that is the same for all cases β_0, and a term specific to each infant, for example μ_{0j}, where $\beta_{0j} = \beta_0 + \mu_{0j}$.

Because β_0 is fixed, the expression

$$\sigma^2_{\beta_{0j}} = \sigma^2_{\beta_0 + \mu_{0j}} = \sigma^2_{\mu_{0j} + \beta_0}$$

is an expression of the form:

$$\sigma^2_{x+c}$$

but

$$\sigma^2_{x+c} = \sigma^2_{x}$$

Therefore

$$\sigma^2_{\beta_{0j}} = \sigma^2_{\beta_0 + \mu_{0j}} = \sigma^2_{\mu_{0j} + \beta_0} = \sigma^2_{\mu_{0j}}$$

so it is possible to ignore the fixed effects, $\beta_0 \ldots \beta_3$, and simply consider the random effects $\mu_{0j} \ldots \mu_{3j}$.

The level 2 variance is therefore the variance of

$$z = \mu_{0j} + \mu_{1j}\, m + \mu_{2j} \ln m + \mu_{3j}\, m^{-1}$$

Therefore

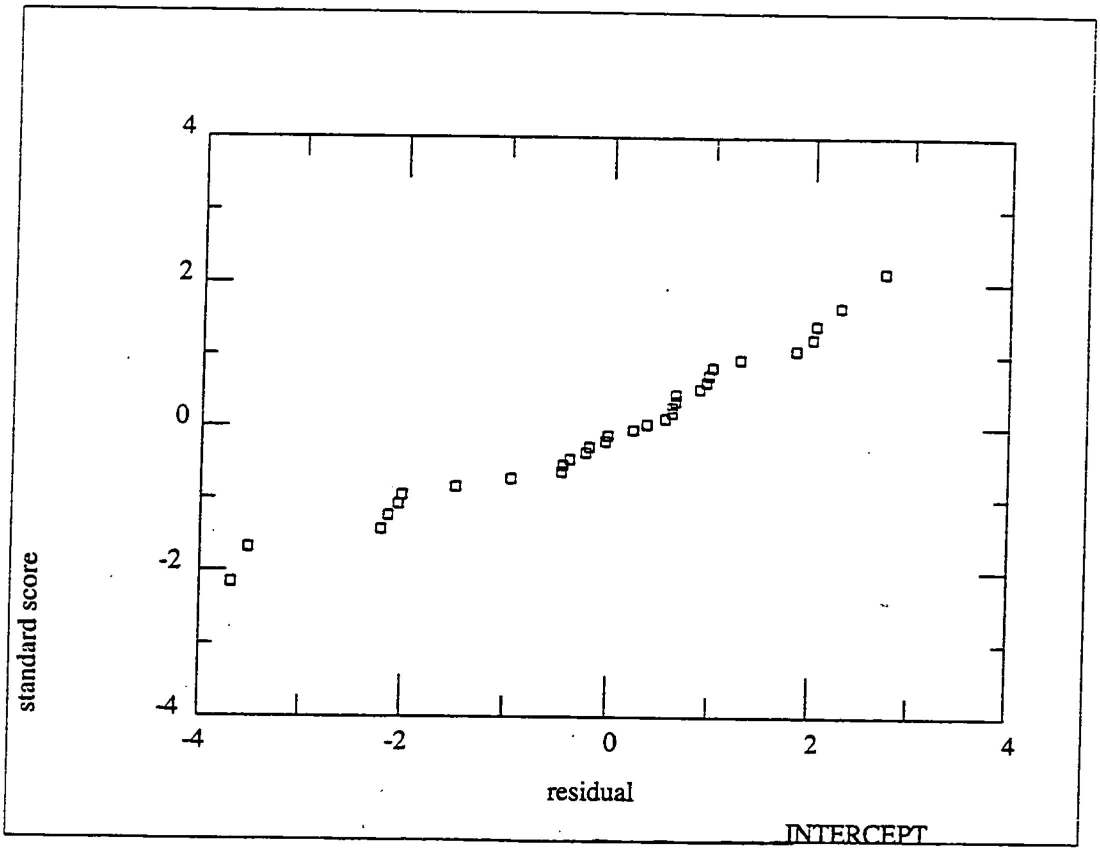
$$\sigma^2_{x} = \sigma^2_{\mu_{0j}} + m^2 \sigma^2_{\mu_{1j}} + (\ln m)^2 \sigma^2_{\mu_{2j}} + (m^{-1})^2 \sigma^2_{\mu_{3j}}$$

is the sum of the level 2 variances, each multiplied by the square of the associated fixed effects plus twice the covariance of all the possible pairs.

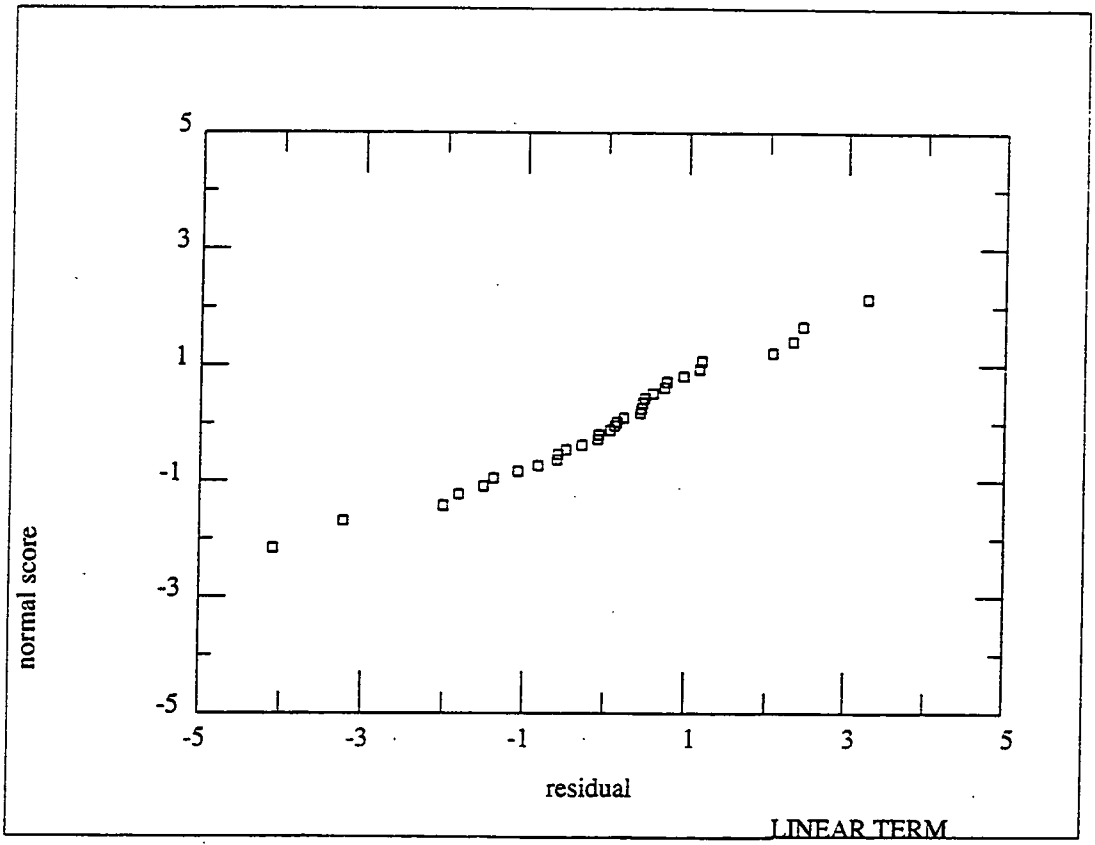
Appendix 11

Level 2 Normal Plot of Standardised Residuals

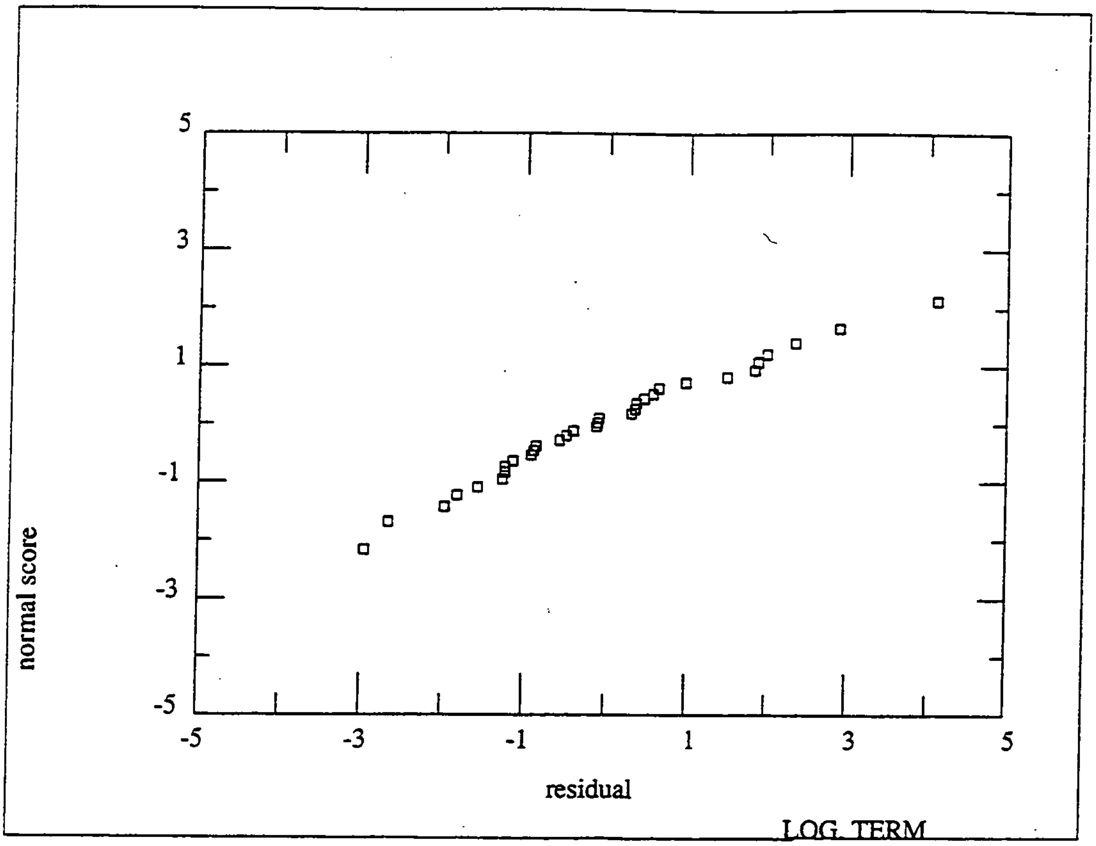
Level 2. Normal Plot of Standardised Residuals - Intercept



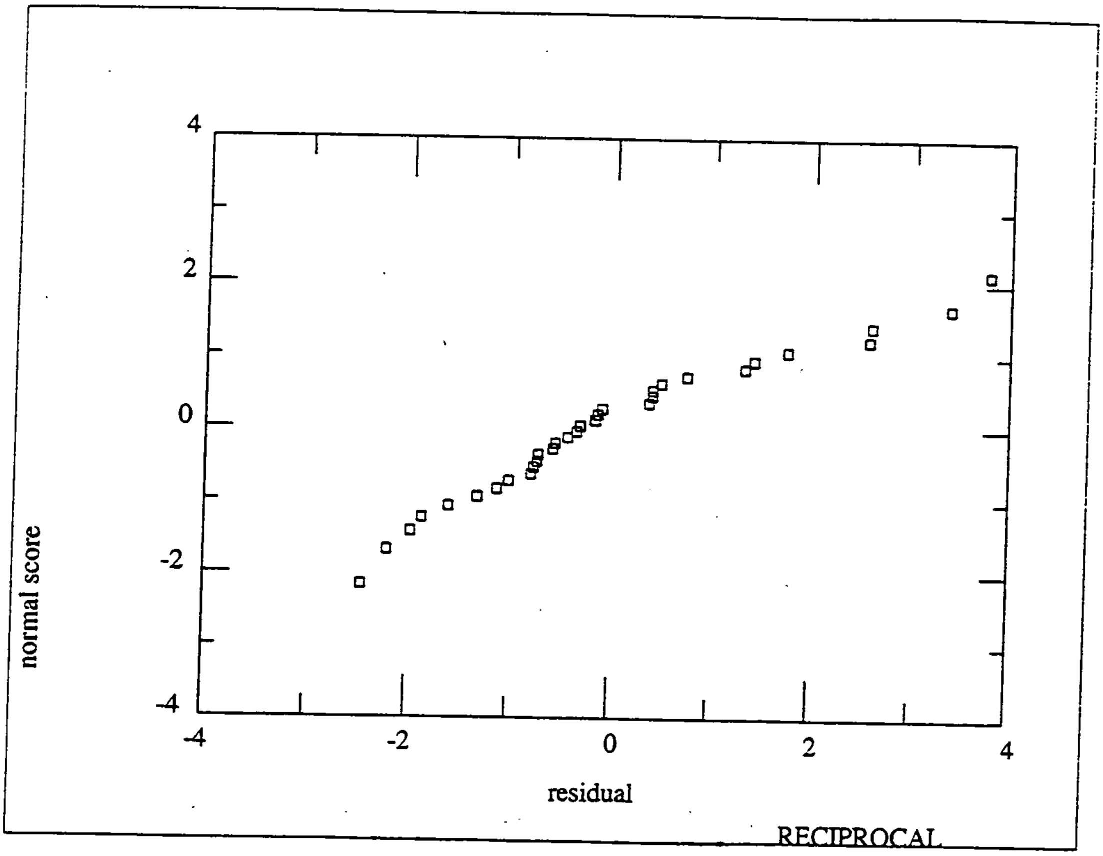
Level 2. Normal Plot of Standardised Residuals - Linear Term



Level 2. Normal Plot of Standardised Residuals - Log Term



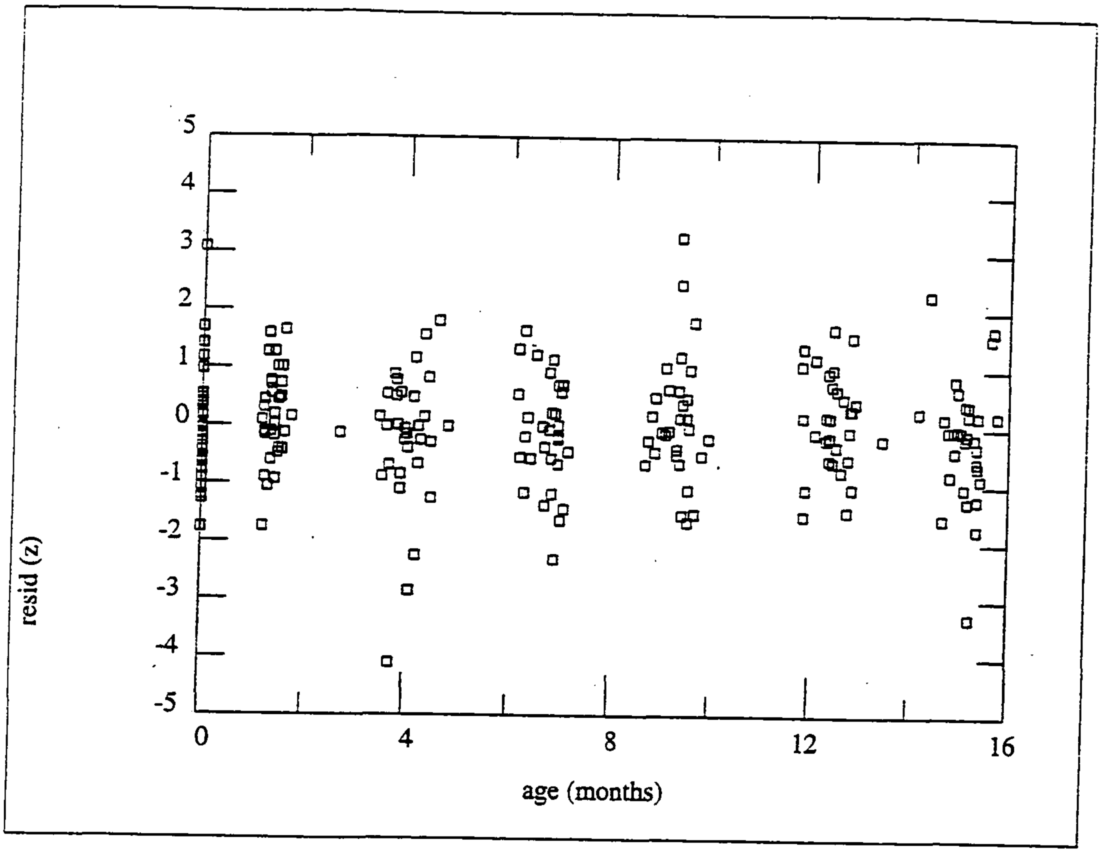
Level 2. Normal Plot of Standardised Residuals - Reciprocal Term



Appendix 12

Level 1 Plot of Standardised Residuals Against Age

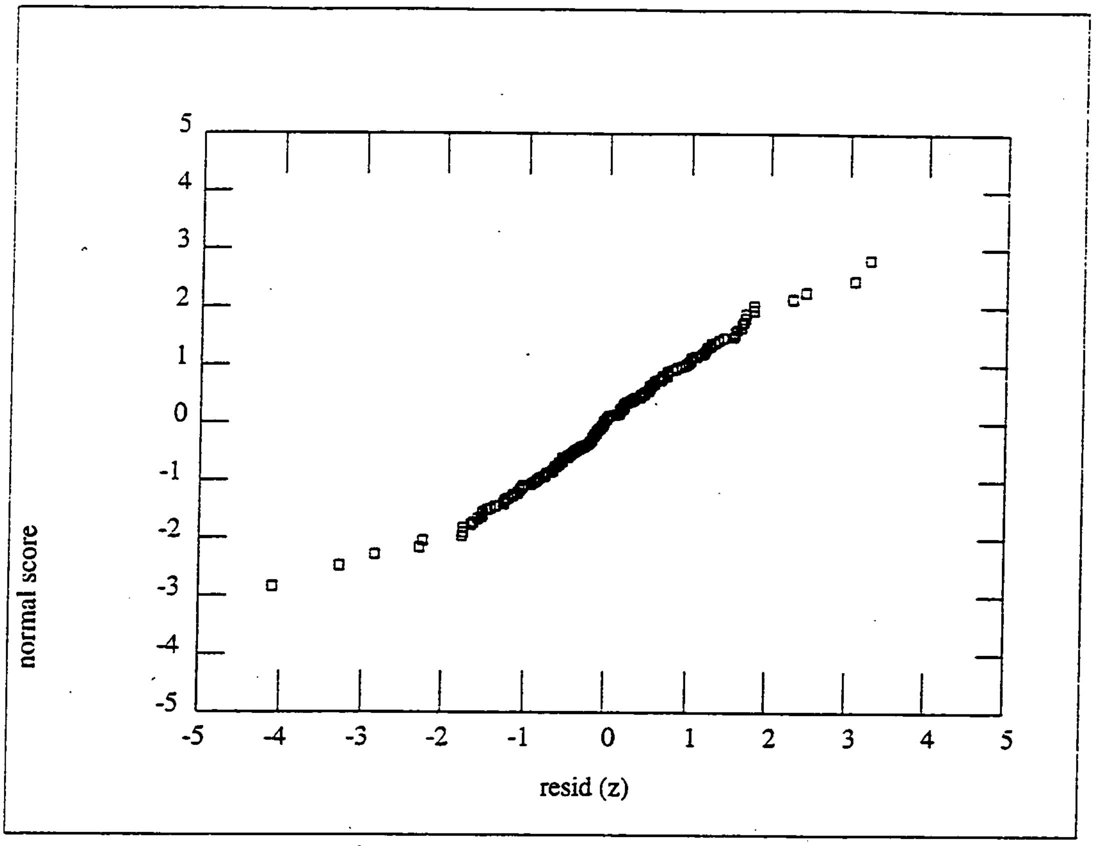
Level 1. Plot of Standardised Residuals Against Age



Appendix 13

Level 1 Normal Plot of Standardised Residuals

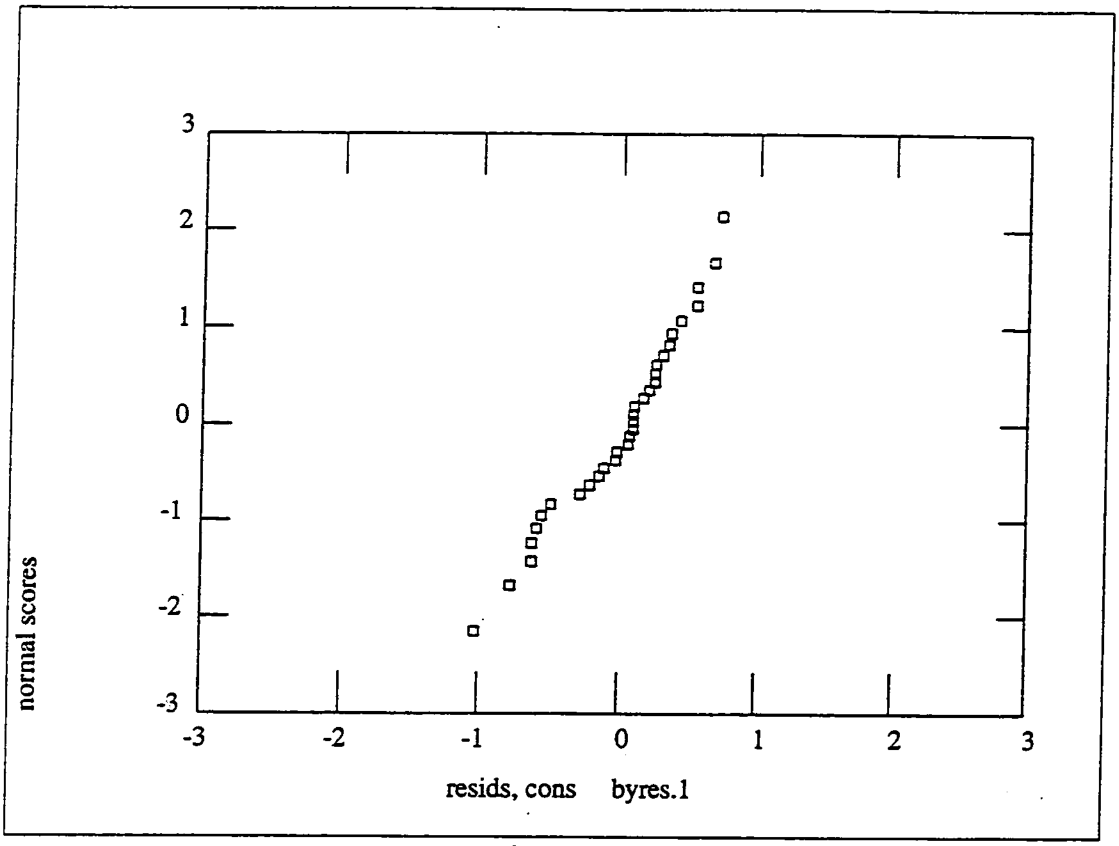
Level 1. Normal Plot of Standardised Residuals



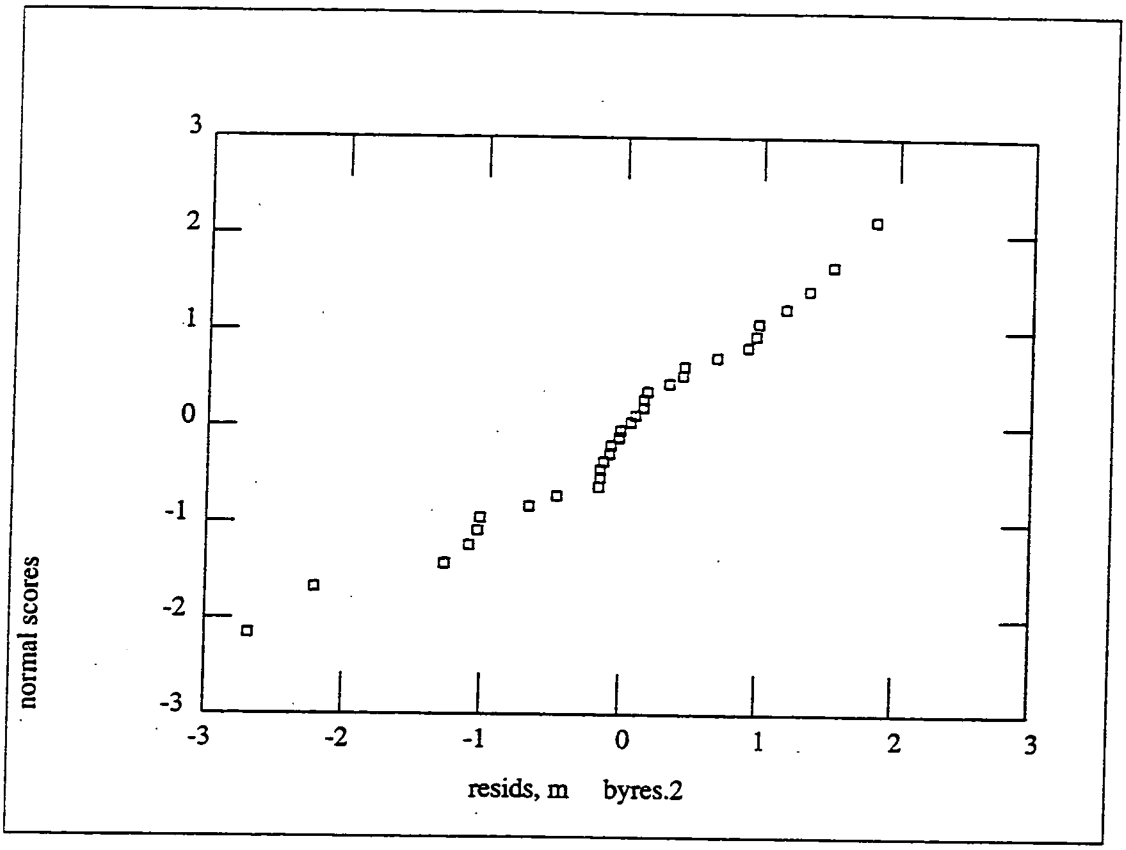
Appendix 14

Final Model. Level 2 Normal Plot of Standardised Residuals

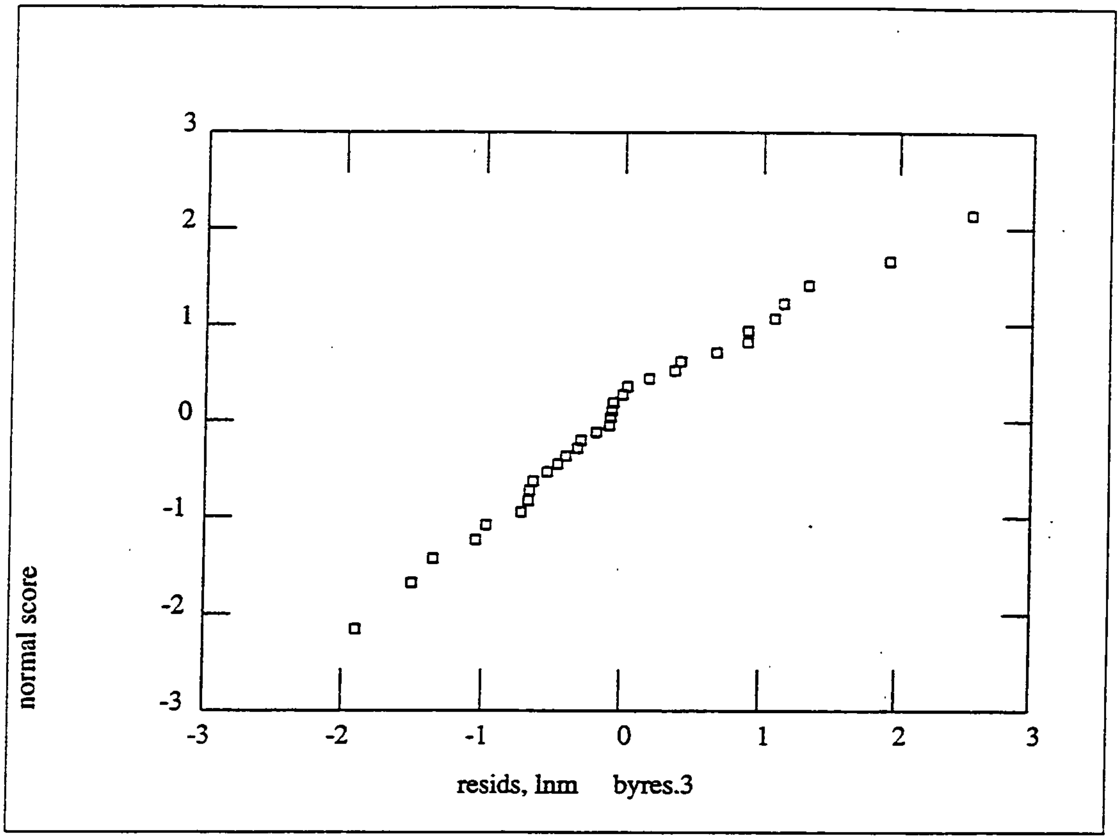
Final Model
Level 2. Normal Plot of Standardised Residuals - Intercept



Final Model
Level 2. Normal Plot of Standardised Residuals - Linear Term

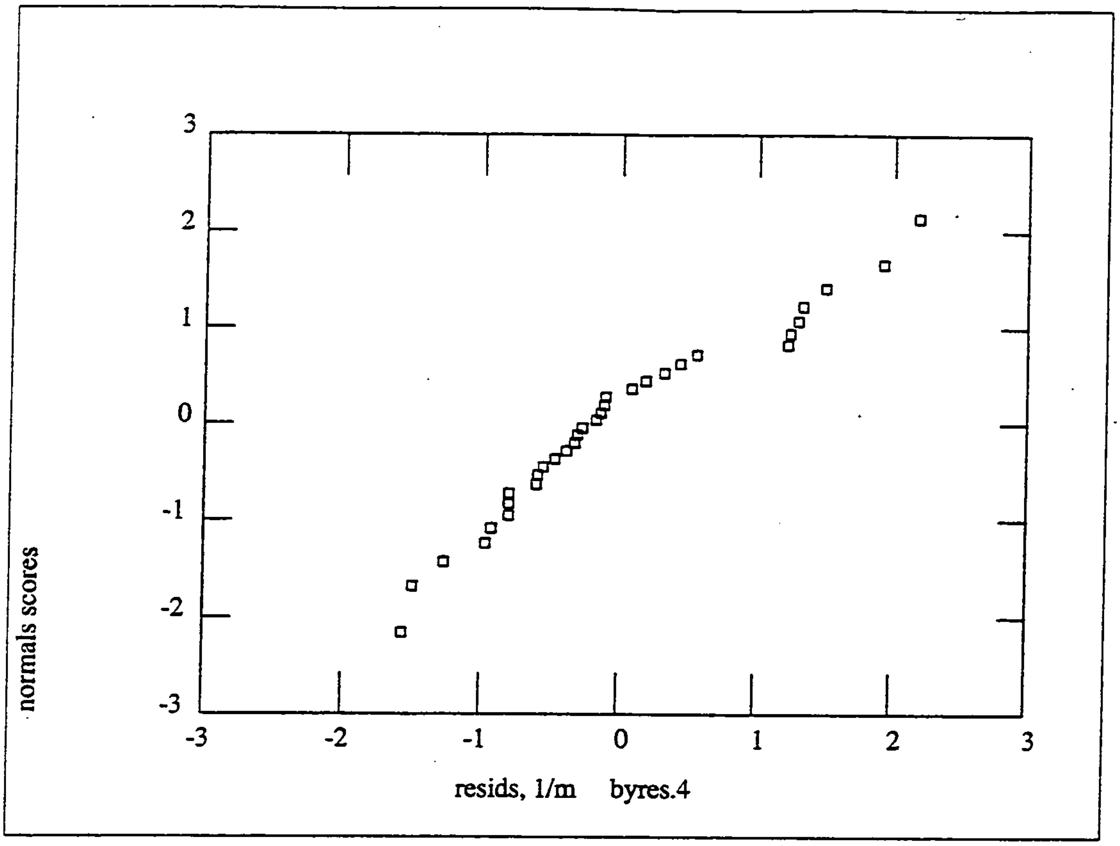


Final Model
Level 2. Normal Plot of Standardised Residuals - Log Term



Final Model

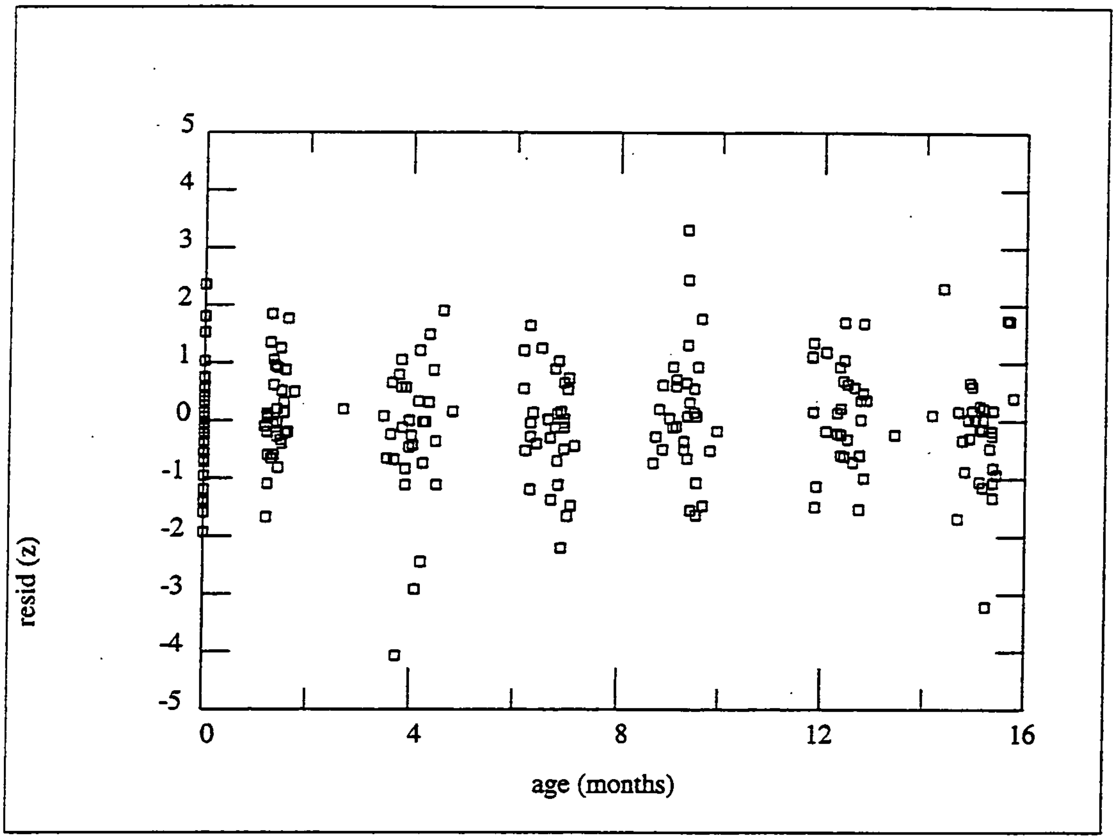
Level 2. Normal Plot of Standardised Residuals - Reciprocal Term



Appendix 15

Final Model. Level 1 Plot of Standardised Residuals Against Age

Final Model
Level 1. Plot of Standardised Residuals Against Age



Appendix 16

Final Model. Level 1 Plot of Standardised Residuals

Final Model
Level 1. Normal Plot of Standardised Residuals