A behavioural study of infant feeding

Ann Bowen-Jones

How to cite:

Bowen-Jones, Ann (1980) A behavioural study of infant feeding. Doctoral thesis, Durham University.

A BEHAVIOURAL STUDY OF INFANT FEEDING

by

ANN BOWEN-JONES

A thesis submitted for the degree of Doctor of Philosophy
in the
University of Durham

Department of Psychology
Durham

May, 1980

ACKNOWLEDGEMENTS

First and foremost, I would like to express my thanks to my supervisor, Dr. R. F. Drewett, for kindling my initial interest in this subject and for his enthusiasm, guidance and encouragement. My grateful thanks also go to Professors F. V. Smith and M. J. Morgan for making the research facilities at Durham available to me.

I am deeply indebted to Cathy Thompson for her patience and generosity in giving me the benefit of her computing expertise. My thanks must also go to the Technical Staff of the Psychology Department, in particular to Malcolm Rolling for photographic and general assistance and to Arthur Perry and Steve Teasdale for the design and construction of apparatus. I would like to thank Gwenneth Kell for her typing of my thesis, and Angela Trew and Dr. Keith Kendrick for their support and their practical help when two hands were not enough.

I am very grateful to all the women and babies who gave so much of their time and from whom I learned a great deal, and to Dr. Alastair Malcolm and the staff of his general practice for their interest and help.

I would like to acknowledge the financial support of the Social Science Research Council.

Last but in no sense least, I wish to thank all my family and friends who have supported me so gallantly.

ABSTRACT

Bowen-Jones, A.: "A behavioural study of infant feeding"

The main part of this thesis sets out to study the sequential organisation of sucking during normal breast feeding. Data on breast feeding are scarce when compared with the large body of work on sucking during bottle feeding.

One of the initial outcomes is that on the first breast, as compared with the second, sucking is slower overall. The widely-quoted dichotomy between nutritive and non-nutritive modes of sucking is not upheld. Rather, the organisation of sucking exhibits complete gradation between tnese two rhythms, and pausing is always a feature of sucking on the breast.

Sucking patterns were also seen to change progressively through the feed, and attempts are made to account for these changes using several different approaches.

Sucking patterns, in particular sucking rate, during breast feeding appear to be determined largely by the rate of milk flow rather than by the baby's hunger, fatigue or behavioural state, although the concurrent changes in milk composition cannot be ruled out since changes in milk flow and composition on the breast cannot be dissociated. However, the probability of the baby sucking at any one time is less strongly correlated with milk flow rate. An attempt is made to place the findings in their evolutionary and social context.

TABLE OF CONTENTS

CHAPTER 1

THE MAMMARY GLANDS AND LACTATION

1.1. Introduction

Lactation is unique to, and defines, the mammalian class. It is the means of providing food and water for the young until they are able to fend for themselves. Mammary glands have evolved, probably from apocrine sweat glands (Salazar, Tobon and Josimovich, 1975), to secrete milk and make it available to the young.

The milk is secreted continuously through the day. It then has to be stored so as not to leak out but in a way that allows it to be mobilised from the secretory lobules when appropriate. In gross anatomy, wide variation is seen in almost every feature of the mammary gland in meeting these requirements for different mammalian species. The glands vary in their number, their situation, their size and in the channels through which the milk is made available to the young. A few examples will illustrate the diversity seen, and then the human mammary gland will be described in detail.

In echidna, a member of the most "primitive" sub-class of mammals, the Prototheria, the young hatches out of its egg in a pouch in the abdominal wall of the mother (Cowie and Tindal, 1971). There are two mammary glands in the pouch, one on either side of the abdomen. They have no actual teats but the milk-secreting lobules of each gland open to the exterior at the two areolae, where the milk is actively sucked by the offspring from nipple-like protruberances (Griffiths, 1968).

In the marsupials (sub-class Metatheria), the mammary glands, of which there may be two to twenty-five, have nipples and are usually located in the pouch (Cowie and Tindal, 1971). In the Kangaroo, the minute new-born young crawls to its mother's pouch where it becomes permanently attached to one of the four nipples. Often, two generations of young are suckled simultaneously, the "young on foot" returning to suck its original teat which may by now be up to 7.5cm long and dangling out of the pouch. This mammary gland will be at quite a different stage of development from that nourishing the other, very young, offspring, and the composition of the milk produced by the two glands is also quite different.

The third and largest sub-class is that of the Eutheria, or placental mammals. They are adapted to a wide range of habitats and the mammary glands show corresponding diversity. For example, the two glands of the whale are long, narrow and flat, lying either side of the ventral mid-line with their nipples recessed on either side of the genital slit (Slijper, 1962). This streamlined arrangement is suited to an aquatic environment. Primates have one or more pairs of mammary glands on the ventral surface and usually not only the resting gland but also the lactating gland looks flat.

Just as there is a wide range in the structure of mammary glands, so there is a wide range of feeding patterns; from the continuous feeding, or, at least, continuous presence on the teat, of Metatherian young, to hourly feeding in the pig, right through to the one day a week of feeding received by the northern fur seal pup (Harrison, 1969). The composition of the milk varies with feeding patterns; infrequent feeders receive high-calorie, fat and protein rich milk, whereas frequent feeders receive low fat, low protein milk (Blurton Jones, 1972).

1.2: The human mammary gland and milk synthesis

The female breast is a roughly hemispherical organ, variable in shape and size, extending from the second rib down to the sixth costal cartilage and surmounted by a nipple. The nipple is surrounded by the tubercled areolar area, which can be regarded as an extension of the nipple; it has a very similar epidermal structure and is functionally a "continuation of the organ of sucking" (Cooper, 1840).

The anatomy of the breast has been described beautifully and in detail by this author. Internally, the breast consists of glandular and fatty tissue, the proportions of which vary from individual to individual and with the stage of the reproductive cycle. Embedded in the fat is the glandular tissue which is divided by fibrous tissue septa into 15 - 20 inter-ramifying but unconnected lobes which each consist of several lobules. Each lobule is well-supplied with blood and lymph vessels and with nerves, and is subdivided into thousands of alveoli, which secrete the milk. Small ducts lead from the alveoli and merge into the main lactiferous ducts which widen into distensible lactiferous sinuses underneath the areola. These sinuses open to the exterior via 6 - 15 milk ducts in the nipple (see Figure 1.1).

In the "resting" breast the proportion of secretory tissue is low. One of the first signs of pregnancy is a feeling of fullness or tightness in the breasts and an increase in their size, due primarily to the proliferation of ducts, lobules and then alveoli (Cowie and Tindal, 1971). By mid-pregnancy this growth slows down and differentiation of alveolar tissue in preparation for milk secretion takes place. Mammary blood flow is almost doubled and from mid-term onwards, colostrum begins to be secreted in small quantities and can be expelled from the nipples (Vorherr, 1974).

After parturition, the initiation of lactation, evidenced by the flow of colostrum, is triggered by a dramatic fall in the level of inhibitory circulating steroids (McNeilly, 1977). Lactation occurs even if delivery is premature, in fact it has been recorded after only four months of pregnancy (Newton, 1961). Milk secretion begins whether or not the breasts are

Figure 1.1: Ducts and glandules of the human breast; a photograph of Plate VI from Cooper (1840)

Coloured waxes were injected through the galactophores into the duct system. The ducts were then displayed by maceration and dissection of the breast.

The original captions are:

(1) Lactiferous tubes or ducts injected with red wax, showing their radiated direction, and, in some places, their interramification.

(2) Mammary ducts injected with red, yellow, black, green and brown, and seen less intermixed than the former.

(3) Ducts injected more minutely with yellow, red, green, blue and black. This preparation shows two additional circumstances:- First, the glandules from which the ducts begin are seen filled with wax. Secondly, at the lower part of the preparation the separate ducts are seen passing above and beneath are single.

(4) This preparation exhibits the anterior folds of the breast; some of the ducts are injected, and the glandules of the breast upon the surface of the folds are filled with wax. This is only a part, but the whole of the breast when well injected and dissected, has a similar appearance.

sucked, however, its continuation beyond a few days with the production of normal amounts of milk depends upon adequate sucking stimulation

Prolactin is the key hormone in the production of milk, although other hormones, for example growth hormone and insulin, may be involved (McNeilly, 1965) Prolactin is produced by the anterior pituitary (adenohypophysis), and, in the absence of progesterone, acts directly upon the alveolar cell membrane to initiate and stimulate the synthesis and release of milk proteins, lactose and lipids Prolactin levels in the blood of women increase steadily through pregnancy until the last month and begin to fall a few days after delivery The decline is more rapid in mothers who do not breast feed (Bonnar et al, 1975) The mammary epithelium is prevented from responding to the high prolactin levels during pregnancy by the inhibitory effects of fetoplacental oestrogen (Bruce and Ramirez, 1970, Brun del Re et al, 1973) and, more especially, progesterone, blood levels of which also increase towards term (Bonnar et al, 1975) As already mentioned, levels of these steroids decline precipitously following parturition, initiating milk production

Prolactin is released in response to mechanical stimulation of the nipple and areola (Hwang, Guyda and Friesen, 1971, Bonnar et al, 1975), which leads to refilling of the breasts The amount of prolactin released is directly proportional to the intensity and duration of the stimulation (Tyson, 1977), and the quantity of milk secreted shows a similar, but delayed, response to the amount of sucking stimulation (Egli, Egli and Newton, 1961) An illustration of the relationship between sucking and prolactin response comes from the successful breast feeding of twins, the prolactin released when both infants are fed simultaneously is double that when one is fed (Tyson, 1977)

Anaesthesia of the nipple prevents the release of prolactin (Tyson, 1977), showing the stimulus to be a neural one. It is interesting, therefore, to note that there is a dramatic increase in nipple sensitivity at parturition (Robinson and Short, 1977); this might enhance the prolactin response to sucking. Prolactin is not released when, for example, the mother plays with the baby before feeding, so its release is unlikely to be conditionable (Noel, Suh and Frantz, 1974).

Sucking or similar stimulation of the nipple is necessary for full lactation, the initiation of which is generally felt as the sudden "coming in" of the milk at 2 - 5 days postpartum (Vorherr, 1974). The sooner after birth the baby is put to the breast, and the more often feeding takes place, the more quickly the milk "comes in" and the less time it takes for him to regain his birth-weight (Archavski, 1952). The effectiveness of the prolactin reflex is illustrated by the fact that lactation can be initiated by repeated mechanical stimulation of the nipple alone in, for example, middle-aged grandmothers (Slome, 1956) and post-menopausal women (Newton, 1961).

Given adequate mechanical stimulation of the nipple and the regular removal of milk, lactation can continue almost indefinitely, provided maternal nutrition is satisfactory. Newton (1961) cites women lactating continuously for four or more years, and wet-nurses often nursed one baby after another for many years. It is easier to continue lactation if feeding is on demand (McNeilly, 1977).

Lactation is dependent upon adequate removal of milk, but the breasts can accommodate increased quantities of milk for up to 48 hours before milk production declines (Vorherr, 1974), although this degree of engorgement is very painful for the mother. Involution of the secretory tissues follows, primarily in response to local mechanical factors arising from the pressure of milk, rather than to hormonal changes, and lactation is thereby suppressed

(Newton, 1961; Mayer and Klein, 1961).

1.3: The milk ejection reflex

In every mammal which has been studied, milk is ejected as a response to suckling. The only satisfactory explanation for this phenomenon is that the sucking stimuli cause nervous excitation of the neurosecretory fibres of the neurohypophysis, and release of oxytocin from their vesicles. The oxytocin then circulates in the blood and causes the myoepithelial cells of the mammary gland to contract, ejecting the milk and making it available to the baby. This process is known as the draught, let-down, or milk ejection, and despite the diversity of mammary gland structure and of feeding patterns seen within the class, it seems to be found in all mammals. In those such as the goat and the sheep, it is not essential for milk removal, partly because these animals have large cisterns and sinuses in their mammary glands containing milk which is immediately accessible (by "passive" withdrawal). But the adequate functioning of the milk ejection reflex is essential for suckling in woman (Newton and Newton, 1967), as in the pig and the rat.

The knowledge that the milk of a lactating animal is not always readily available but that it generally becomes available precipitately upon suckling or milking or in the presence of another suitable stimulus goes back into antiquity (Amoroso and Jewell, 1963). Early farmers made very good use of stimuli such as the presence of the calf in order to obtain milk for themselves. Practical knowledge of the effects of the let-down in women is also very old (Folley, 1969). Astley Cooper (1840) talks about the "draught" furnishing an abundant stream of milk by a "vis a tergo", i.e. a propulsive force operating from behind, once the small amount in the milk sinuses was drained, and of this milk "spirting in the infant's eyes" if he did not catch the nipple immediately.

The first stage of the milk ejection reflex consists of afferent neural inputs from the mammary gland which trigger the release of the polypeptide hormone oxytocin from the posterior pituitary. The nipple, or teat, is very sensitive to tactile stimuli and its sensitivity increases during pregnancy (Robinson and Short, 1977). It is richly supplied with nerve endings, especially at its base (where maximal stimulation can be expected from the infant's gums during sucking); in fact it is one of the most highly innervated tissues of the body (Lancet, 1949; Cowie and Tindal, 1971). Receptors in the nipple and areola transform stimuli into nerve impulses which trigger the release of oxytocin. The stimuli which have this effect are touch, pressure, and extremes of temperature, of which the most effective single factor seems to be touch (Sala et al, 1974), touch and pressure together having maximal effect. In addition, thoughts of the baby or of feeding, conditioned responses to events associated with feeding, and cervical dilation, may cause milk ejection (Isbister, 1954; Sica-Blanco, unpublished data quoted by Caldeyro-Barcia, 1969).

The oxytocin then circulates in the blood and when it reaches the myoepithelial cells of the alveoli and ducts it stimulates them to contract; the milk is forced out of the alveoli and into the sinuses, and may even jet out of the nipple. The secretory alveoli are surrounded by a network of stellate myoepithelial cells, and spindle-shaped myoepithelial cells lie along the finer ducts, becoming denser as the ducts increase in size (Pitelka and Hamamoto, 1977). Their existence was known to 19th century German histologists (Linzell, 1952) and their contractile function correctly postulated. However, this work was generally forgotten so that when Ely and Petersen put forward their theory of the neuroendocrine milk ejection reflex in 1941, the expulsive force was thought to be provided by smooth muscle. The full extent of the myoepithelial network was demonstrated by Richardson (1949, 1951). Soon after, Linzell (1952) stained cells from distended mammary glands of several species and these from glands previously emptied by the injection of oxytocin, thereby showing the way in which they contract.

The myofibrils within the myoepithelial cells contract in response to oxytocin from the capillary bed, with which they are in close association. In doing so, the long tapering branched cells become short and fat, increasing the pressure within the elastic alveoli, and the fine ducts become wider and shorter to allow for rapid passage of milk. Thus the bulk of the stored milk is squeezed into the larger ducts and sinuses and made accessible to the baby. Myoepithelial cells also contract in the same way as a direct response to local mechanical stimulation (the "tap reflex": Cross, 1954).

1.4: Inhibition of milk ejection by stress

Astley Cooper, the surgeon and anatomist, was also no mean psychologist. "Lactation is one of those functions which are subject to great changes from mental impressions... and proceeds best in a tranquil state of mind" (Astley Cooper, op cit, 1840). He then lists "a fretful temper, fits of anger, grief, anxiety of mind, fear and terror" as factors which will decrease or halt the flow of milk. Newton and Newton (1948) showed that stresses such as fear, discomfort or embarassment reduce the amount of milk available to the baby at that feed.

With the elucidation of the hormonal basis of lactation, these observations have been explained in terms of the susceptibility of the milk ejection reflex to disruption by a wide range of stressful factors, such that when it is blocked, the milk, although it may be plentiful in the gland, is not available to the young.

Stress could inhibit the milk ejection reflex in a number of different ways, as follows:

A. Central; neural inhibition of oxytocin release

B. Peripheral; reduction of the response of the gland to circulating oxytocin, by:

(i) constriction of blood vessels by adrenalin

(ii) sympathetically mediated increased resistance of mammary ducts and/or sphincters to milk flow

(iii) direct inhibition by adrenalin of the action of oxytocin on myoepithelial cells.

As regards the relative importance of the central and peripheral mechanisms, it seems that the central is the more important (Bisset, 1974). Cross (1955), working with rabbits, concluded that the main factor in the blocking of milk ejection is the inhibition of oxytocin release from the neurohypophysis. He concluded that the evidence available at that time went against the existence of B (iii) (above). However, evidence for the direct inhibition of the action of oxytocin has since accumulated. Vorherr (1971) has shown that α-receptors are present in the mammary blood vessels and β-receptors in the myoepithelial cells: upon contact with adrenalin, α-receptors cause constriction of the blood vessels (B (i)), and β-receptors, relaxation of the myoepithelium (B (iii)). It seems that in the latter case there is direct competition between oxytocin and adrenalin for the receptor sites on the myoepithelial cells; the strength of the milk ejection depends upon their relative proportions. The resistance of mammary ducts may also play a minor role - Grosvenor et al (1972) have shown that in rats some diffuse motor control of ductal and vascular tone is exerted by the sympathetic nervous system, and that this is sensitive to both central and peripheral factors. It is worth remembering that conditioned inhibition of oxytocin release has never been directly demonstrated in humans.

It has been said (for example, Newton, 1972) that the inhibition of milk ejection by stress makes good survival sense since it would be unwise to nurse the young, and therefore to be immobilised and vulnerable, in tense or dangerous situations. However, not milk ejecting is one thing; not nursing is another. There is no evidence that nursing is inhibited in stressful situations.

1.5: Structure of the breast as related to function

Nursing is facilitated by a happy concinnity of adaptations in the breast and in the baby; for instance, the bumpy surface of the areola and nipple is complemented by sucking pads on the baby's lips.

The nipple is extremely important. Without it, the infant could not obtain the milk secreted by the gland. Another vital role is in helping to retain milk between feeds. The milk ducts decrease in diameter towards the tip of the nipple (Cooper, 1840); but this alone would not suffice to retain the milk. It was once thought likely that a mechanism existed in the nipple to act as a sphincter (Harris and Pickles, 1953). Subsequently it was found that the smooth muscle surrounding the larger milk ducts can reduce their calibre and therefore impede the passage of milk (Vorherr, 1974; Cross, 1977). Sympathetic nervous activity can also have this effect. These factors are, however, overcome when the pressure of milk from within the gland is great enough to cause it to stream from the orifices of the nipple (Bisset, 1974).

The protractility and compressibility of the flexible tissues of the nipple and areola are apparently more important than nipple shape for successful breast feeding (Gunther, 1955); the baby grasps the areola with its lips and gums and draws out the nipple between the palate and the gums to resemble "a cherry on the end of a wide soft stalk" (Lancet, 1949). The teat thus formed fills the length of the mouth and stimulates the baby to suck (Gunther, 1955, 1958). Protractility of the nipple increases as a result of the physiological changes of pregnancy (Hytten and Baird, 1958). The nipple increases in diameter (Hytten and Baird, 1958) and in length (from $\frac{1}{2}$" - $\frac{3}{4}$" up to 1"), and its usual cone-shape becomes reversed, i.e. it is now broadest at its extremity (Cooper, 1840). As this author pointed out, this shape renders the adhesion of the child's mouth "much more firm and complete."

The nipple elongates during sucking. This is due both to the passive stretching effect of the pressure in the child's mouth and to the contraction of the complex network of smooth muscle fibres around the base of the nipple and beneath the areola, in response to touching the nipple or areolar area,which makes the flaccid nipple stand out firmly, (Lancet,1949; Cowie and Tindal, 1971). This enhances its effectiveness in stimulating the baby's rooting reflex. Reflex erection of the nipple occurs in most mammals, in response to the infant's lips on the nipple, the pulling of the nipple into the mouth, and the mechanical stimulation it receives during sucking. Ardran, Kemp and Lind (1958b), in a cineradiographic study of breast feeding, mention that the teat formed from the areola and nipple is cylindrical, as wide or wider than the resting nipple and about three times as long, when the jaw is lowered. As well as improving the hold the baby has on the nipple, the elongated teat helps him expel the milk efficiently since the milk sinuses in the nipple and areola are also elongated and expanded in the process of nipple erection. Under the areola are the larger milk ducts and reservoirs, and at the beginning of the feed their small contents may possibly encourage the child to continue sucking until the bulk of the milk becomes available through the milk ejection reflex.

One of the most interesting features of the female human breast is its relatively large size and rounded form. Contributing to this is the arched form of the ribs. In most primates the lactating breast is almost flat, whereas in woman even the non-lactating breast is round. This is due primarily to adipose rather than to glandular tissue; though the increase in breast size during pregnancy and lactation is due to a proliferation of glandular tissue and to increased vascularity.

The nipples are projected forwards and outwards, with a slight turn upwards. Their outward orientation and their displacement from the chest wall enables the child to rest upon the mother's lap and arm in the most convenient (sideways) position for suckling. (Providing he is in a suitable position, the rooting reflex (Peiper, 1961) will aid him in finding the nipple). In this position, with the infant held close to, but not right up to, the mother, mother and child can look into each other's faces, as Abercrombie (1971) points out. Eye-to-eye contact can then easily occur; in fact it is virtually unavoidable. Eye contact is one of the most important elements in the development of affection and bonding between mother and child (Klaus, Kennel, Plumb and Zuehlke, 1970). Therefore, during feeding, interaction and communication between the two are facilitated. Indeed this was first pointed out by Cooper in 1840, who observed that the baby, while sucking under the mother's eye, thereby "almost irresistibly solicits her tender and regular attention."

This is one explanation of the different shape of the breast in human beings and other primates. Another is that rounded breasts evolved to mimic the strong sexual signal of the buttocks when in an upright stance (Morris, 1969). It is difficult to make progress on this issue without knowing the form of the ancestral breast; for another possibility is that the round form is primitive, with the flat form an adaptation to carrying prehensile young slung below the body in quadrupedal walking. The young could hardly hang below a nipple already hanging close to the ground.

CHAPTER 2

INFANT SUCKING

2.1 The mechanics of sucking

Sucking is not a purely reflex action. It may occur spontaneously while awake or asleep (Wolff, 1967) and can be evoked and modified by a variety of stimuli, for example by stroking the perioral area or the lips, or by introducing a suitably-shaped object into the mouth. It can be elicited from the 24th week of foetal life by stimulating the mouth region (Humphrey, 1964). Sucking is coordinated directly with swallowing in the uterus, and after birth successful feeding necessitates precise integration with the other components of feeding - the rooting reflex, taking the nipple into the mouth, and swallowing - and with breathing (Peiper, 1963). The synchronisation of sucking, swallowing and breathing can be influenced by the fluid ingested; some fluids, for example, breast milk, promote better coordination than others (Johnson and Salisbury, 1975, 1977).

The term "sucking" can be misleading since although one sense of the word is "to draw liquid into the mouth by contracting the muscles of the lips, cheeks and tongue so as to produce a partial vacuum" (Shorter Oxford English Dictionary, 1933), another is "to apply the lips to, for example, a teat or breast for the purpose of extracting milk; to draw milk from the above with the mouth", which does not imply the use of negative pressure. In actual fact the sucking of the baby has both positive pressure (expression) and negative pressure (suction) components.

The flow of milk or other fluid into the baby's mouth is governed by the magnitude and the duration of the positive and negative pressure applied to the nipple or teat, the size of the hole or duct through which the fluid must pass, the viscosity of the fluid, and any extrinsic forces which facilitate its entry to the mouth, for example the milk ejection reflex in breast feeding (see Chapter 1) and gravity in both breast and bottle feeding. Before the importance of milk ejection was generally recognised it was often thought that infants obtained their nourishment from the breast by suction alone, and so especially rigid feeding nipples were produced to prevent collapse during suction (Ardran, Kemp and Lind, 1958a). An alternative and popular theory, also proved incorrect, was that the milk was obtained by compressing the lacteal sinuses between the jaws (Waller, 1938).

Various authors have put forward different views as to whether positive or negative pressure is central in obtaining milk. For example, in 1958 Colley and Creamer followed the changes in pressure within an artificial nipple and in the mouth and upper alimentary tract during feeding, concluding that suction pressure generated in the mouth is the more important factor. In contrast, Ardran, Kemp and Lind, in their cineradiographic studies of breast and bottle feeding in infants aged from a few days to six months (1958a,b), interpreted their findings as showing the pre-eminence of the expression component of sucking produced by compressing the teat between the tongue and the hard palate for obtaining milk. Subsequently they combined this technique with the recording of pressure changes in the mouth, which supported the conclusions of the previous two papers (Ardran and Kemp, 1959).

It seems that the relative balance of positive and negative pressure during sucking can be varied by the baby in response to the needs of a particular situation (Sameroff, 1968), and with hindsight the search for the "primary mechanisms" seems rather a red herring. As Kron and Litt (1971) point out, the source of the disparate results of such investigations are to be found in the differing methods and the different apparatus used. In fact, they are an illustration of the considerable adaptability of sucking.

A composite picture of what occurs during sucking on the breast or on an artificial teat with similar physical characteristics can be built up from the descriptions of Gwynne-Evans (1951), Colley and Creamer (1958), Ardran, Kemp and Lind (1958a,b, 1959), and Tulley and Campbell (1965).

During breast feeding, a teat is first formed by sucking into the mouth the nipple, areola and underlying tissues of the breast. The nipple forms the mobile bulb of the teat and the neck arises from the stretching of the areola and underlying tissues. The teat is up to three times as long as the nipple in repose, and shortens to its original proportions as soon as the baby's hold on it is released (Ardran, Kemp and Lind, 1958b). Its protractility and flexibility are important to the success of breast feeding (Gunther, 1955), and increase automatically during pregnancy (Hytten, 1958). This accords with Ardran, Kemp and Lind's emphasis on the compressibility of the teat which facilitates the expression of the milk.

The infant's lips form an airtight seal around the teat which, when the jaw is lowered, extends to the back of the mouth and is held between the hard palate and the tongue. The tongue is grooved longitudinally and positioned well forward in the mouth. The neck of the teat is compressed against the upper gum pad by the upward-curving anterior margin of the tongue. This bulging of the front part of the tongue is supported by the jaw coming up, and as the tongue is raised against the lower surface of the teat from before backwards its central furrow is progressively obliterated in this direction.

This "stripping" or milking" of the teat by the tongue causes it to narrow and it shortens as the tongue moves backwards, the positive pressure squeezing the milk into the mouth. Milk also enters the mouth as a result of the negative pressure created by the simultaneous lowering of the back of the tongue behind the teat. The jaw and tongue are then lowered and the tongue again becomes grooved longitudinally, creating further negative pressure, and as a result milk is drawn in to refill the teat which expands to fill the enlarged mouth cavity. The tongue then again comes forward and up, followed by the jaw moving up as the rhythmic cycle continues. Colley and Creamer's interpretation varies in that they say the tongue moves backward in order to produce negative pressure, like a piston withdrawn in an airtight syringe, and not simply to strip the teat.

On the breast, the balance of positive and negative pressures is likely to change with availability of milk, e.g. Ardran and Kemp (1959) state that "after some minutes of feeding (on the breast) the pressure (in the mouth) did not fall so low as it did initially and peaks of positive pressure appeared more frequently." With rigid bottles, where teats cannot be occluded by the tongue, the depression of the back of the tongue behind the teat creates suction which, alone or with the aid of gravity, can provide the child with adequate milk (Ardran, Kemp and Lind, 1958a; Ardran and Kemp, 1959).

2.2. Classification of sucking

There are several possible ways of characterising sucking behaviour, which must not be confused. Distinctions can be based upon:

(i) The motivation for sucking. This can be hunger or thirst, or the baby can suck for comfort and reassurance. Sucking can also be used to provide or maintain stimulation under appropriate experimental conditions. For example, thirteen month old infants will suck to bring a picture back into focus (Kalnins and Bruner, 1973). This is an indication of the control over his sucking which the infant develops.

(ii) Whether or not the infant is obtaining fluid.

(iii) The rhythm, patterning, amplitude or temporal organization of sucking. (The term "organization" of sucking as used in this thesis refers to this aspect, rather than to the coordination of the individual movements which constitute a suck). Sucks usually occur in groups, termed sucking bursts, separated by pauses. Both the relative duration of bursts and pauses and the distribution of sucks within the bursts, i.e. the within-burst sucking rate, can be used to characterise sucking.

2.3. Measurement and stability of sucking

Sucking on a bottle can be measured either digitally (Levin and Kaye, 1964) or analogically, using apparatus based on that developed by Kron, Stein and Goddard (1963) and by Sameroff (1965), in which the positive and negative pressure changes exerted on a modified artificial nipple are recorded simultaneously by means of fine polyethylene tubes connected via pressure transducers to a polygraph. Fixed amounts of nutrient can be given contingent upon the production of positive or negative pressure above a certain threshold. The response can occur for each suck or at a set ratio, or can be related to the burst/pause pattern of sucking. A more recent development is the recording of sucks by the direct measurement of the flow of milk through the feeding bottle, by means of an electromagnetic flowmeter transducer located between the reservoir and the nipple (Johnson and Salisbury, 1975).

Although sucking during breast feeding is most easily recorded by observation of the movements of the baby's jaw (e.g. Kaye, 1972, 1977), measurement of the concurrent pressure changes in the mouth can also be used as with bottle feeding (Ardran and Kemp, 1959). Luther, Arballo, Sala and Cordero Funes (1974) fixed polyethylene catheters to the mother's nipple such that they lay within the baby's mouth during sucking. The tubes were connected to pressure transducers and thence to a polygraph, and both positive and negative pressure changes were recorded.

Many measures have been used to characterise the sucking records, such as number of bursts or sucks per unit time, burst length, inter-burst interval or pause length, and, at a finer level, inter-suck interval (ISI) or its reciprocal, the within-burst sucking rate, amplitude of sucks, and the expression/suction ratio. In much of the early literature, rate per unit time was the primary measure used with no allowance made for pauses (e.g.

Kron, Stein and Goddard, 1963).

Although the normal infant already has the ability to suck at birth, the reflex may need initial "priming" with an appropriate stimulus before it attains its full vigour (Gunther, 1955). Once established, the orderliness and regularity of its organization are remarkable. The stability exhibited during repeated tests on the same infants is striking (Balint, 1948; Kaye, 1968). For example, quite high positive correlations are found between an infant's responses to different nipples and nipple-shaped objects (Dubignon and Campbell, 1968a). Kron, Ipsen and Goddard (1968) looked at various measures of sucking with milk delivery and found consistent individual differences between infants over the first eighteen feeds of life. In addition, all parameters (sucks per minute, average peak pressure per suck per minute, milk consumed per minute) increased over this period and the infants also differed consistently in their rates of increases. The authors conclude that sucking pressure is the best discriminating measure, on the grounds that rate is unreliable because it is used to regulate intake.

In contrast, Lipsitt, Reilly, Butcher and Greenwood (1976) found less stability with 15% sucrose solution; within-burst sucking rate alone had significant test-retest coefficient from Day 1 to Day 2. When no fluid was given, the total number of sucks, the number of pauses, the number of responses per burst and the mean within-burst ISI showed high correlations over this period. This corresponds with the findings of Sameroff (1967, 1971) of individual stability in the number of sucks, the frequency and average length of bursts, and the average length of pauses under similar circumstances. Pollitt, Gilmore and Valcarcel (1978) found mean amplitude of sucking and the amount of time during nutritive sucking with milk formula to be stable over a 4-week period.

Interest in these stable individual sucking parameters centres around the fact that in the search for reliable ways of characterising early human behaviour, with a view to identifying possible correlates with and predictors of the course of future psychological development, sucking stands out as one of a baby's most highly organized activities. It is one of the most, if not the most, highly developed and well-coordinated motor responses of the young infant, present far in advance of e.g. hand-mouth coordination. This early competence means that it forms one of the most important points of contact, or channels of communication and exploration, between the infant and the outside world. This, together with its ease of recording and its malleability, has resulted in the response being used as a way of studying the behaviour, the perceptual abilities and the social capabilities of the young infant.

The highly ordered, consistent rhythm of sucking in the human infant provides a clear example of temporal regulation and arrangement of units of motor behaviour. This in turn has potential value in the elucidation of the relationship between cerebral activity and behaviour, since there is much evidence that the pattern of sucking is a CNS-regulated phenomenon. For example Wolff (1973) found precise rate concordance between the sucking and the tail movements of the infant goat, indicating a common central "pacemaker". Human infants sometimes open and shut their eyes in time to their sucks at the beginning of a feed (Wolff, 1973), and both motor patterns are affected in identical ways by rate-modulating peripheral stimuli, suggesting a common central oscillatory mechanism. In addition, infants with quite gross abnormalities of the oral cavity e.g. hare lip, show no differences in the patterning of their sucking movements (Wolff, 1967).

Since sucking is dependent on the integrity of the CNS, one would expect a variety of disturbances in infants with major malformations of the brain or those with metabolic disorders, and this is indeed the case (Wolff, 1968b). For example, full-term infants with an Rh incompatibility and transient hyperbilirubinemia, tested in the first ten days, sucked at lower mean rates with more interburst variance than did normal infants, and the degree of abnormality was greater the higher the serum bilirubin level. Infants with major abnormalities of the higher centres, e.g. anencephalics, had reduced sucking rates but a normal pattern of sucking. Similar results were seen with three microencephalics aged between three and twelve months. This suggests that sucking is primarily organized in the older parts of the brain. In contrast, children who had no neurological abnormalities but who had sustained damage to the CNS of a less dramatic nature showed altered sucking patterns. Newborns with a history of perinatal distress, although appearing neurologically undamaged, showed greater variability in a variety of sucking parameters (Dreier and Wolff, 1972). The absolute differences in the measures of sucking behaviour are not always large even though significant, and there is a certain amount of overlap with normal values so that they cannot be used as clinical tests of the neurological status of individual infants. Nevertheless, it is interesting that they often reveal that the brain has still not fully recovered from its earlier insult even where no other signs of abnormality are detected. Whether or not they have any predictive value for later development is not yet known.

2.4. Sucking and obstetric medication

Another influence on infant sucking behaviour which is increasingly pertinent is the medication which may be given to the mother before or during labour. Many drugs cross the placenta; their effects upon the baby depend upon the type and dose of drug and the timing of the administration. For example, pre-medication of the mother with high doses of barbiturate, which at one time was widely used, leads to a lack of responsiveness and hence depressed sucking in the infant during the first few days after birth which could hinder their adaptation to breast feeding (Brazelton, 1961). Kron, Stein and Goddard (1966) carried out a more detailed study, which excluded the confounding factor of the drug on the mother's behaviour. Infants whose mothers had received barbiturate sedation but no other medication during labour had significantly slower overall sucking rates, pressures, and consumption of milk formula when compared with a control group.

2.5. Nature of the sucking object

The sucking rhythms can be modified by moment-to-moment peripheral feedback. This can be thought of as a transient adaptation to differing conditions which continues as long as these conditions are maintained. Under many circumstances a considerable degree of plasticity, or ability to adapt, is seen in response to intra- and extra-oral stimuli. No learning is involved as the responses are modified virtually immediately; sucking seems to have built in to it a prior adaptability.

Sucking can be elicited by placing a nipple-like object, for example, a human finger, in the infant's mouth; the amount of sucking is influenced by the physical characteristics of the object - contour, compressibility, size, etc. For example, Lipsitt and Kaye (1965) showed that rubber nipples elicit twice as much sucking as do quarter-inch diameter rubber tubes. The above factors are important for successful breast feeding (Gunther, 1955, see Chapter 1) and when considering the design of artificial feeding nipples. It has been suggested (Peiper, 1963) that artificial nipples are more effective in eliciting sucking than are human nipples, in other words they are "super-normal" elicitors of the response in the ethological sense of specific stimuli releasing innate patterns of behaviour (Tinbergen, 1951). Bearing in mind the observation of Ardran, Kemp and Lind (1958a) that the rigid feeding nipples in use at that time did not allow the infant to utilize the positive pressure component of sucking to obtain milk, it is clear that this is not always the case, although the distinction must be kept between the ability of the teat to stimulate sucking and the extent to which it allows efficient removal of milk.

When no-fluid sucking using soft and hard tubes were compared (Dubignon and Campbell, 1968a), significantly more sucks per minute were obtained with soft tubes. They also found that tubes of large diameter (11/16") elicited less sucks per minute than those of a small diameter (½" and quarter-inch), which had similar counts. Even the counts for the "best" tube are considerably reduced when compared with those obtained with a rubber nipple (37.1 per minute compared to 79.7 per minute). Similar effects were found during nutritive sucking where the infants received milk formula (Christensen, Dubignon and Campbell, 1976). This is important because it shows that the above effects are not over-ruled by the powerful stimulus of fluid in the mouth.

Crook (in press) suggests that the organization of no-fluid or non-nutritive sucking, once elicited, is relatively invariant but that its amplitude or vigour may be considerably reduced, the apparently slower counts and altered rhythms of sucking seen with sub-optimal stimuli resulting from the use of a pressure threshold that is too high.

2.6. Nutritive and non-nutritive sucking

Another major source of intra-oral variables which provide peripheral feedback is the fluid the baby may receive during sucking, and the effects of its qualitative and quantitative properties have been widely studied. A predominant theme running through the literature is that of two dichotamous modes of sucking, the nutritive and the non-nutritive, which are distinguished by their differing temporal organization (Halverston, 1932; Balint, 1948; Colley and Creamer, (1958; Dubignon and Campbell, 1968b, 1969; Wolff, 1967, 1968a). The implication is that these are two distinct behaviours. Nutritive sucking occurs in response to fluid and non-nutritive sucking occurs when none is available, for example during pacifier sucking. The non-nutritive mode is also seen in the spontaneous mouthing of sleepy or sleeping infants (Wolff, 1966, 1968a). This is interesting in that it suggests that the pacifier merely functions to elicit sucking but does not influence its "pre-set" organization.

Wolff in particular has extensively studied the occurrence and organization of both modes of sucking. The bottle feeding apparatus he used was based on that of Sameroff (1965) and the sucks were recorded by polygraph. Nutritive sucking is described as a near-continuous steam of sucks with mean inter-suck intervals varying from 1.0 seconds at 4 days to approximately 0.7 seconds at 3 months. Non-nutritive sucking is described as a regular alternation of bursts and pauses, the mean inter-suck intervals within the bursts ranging from 0.48 seconds at 4 days to 0.41 seconds at 3 months (Wolff, 1968a,b).

Wolff's criterion for defining a pause in sucking is that the polygraph writer should remain in the baseline position for one second or longer. This makes it impossible to make an exact comparison between his data and data analysed according to the more common criterion of a pause, which is that the interval between equivalent points on two sucks should be greater than a certain length. The use of the baseline criterion could result in a variable cut-off point (in terms of inter-suck intervals) between within-burst intervals and pauses according to how fast the pressure falls to baseline and subsequently rises again. It is unfortunate, too, that Wolff does not give any indication of how much milk his infants received with each suck.

Towards the end of a bottle feed, the infant is said to shift from nutritive to non-nutritive sucking and back again, i.e. "the slow and the fast rates of sucking are represented as discontinuous quantities"(Wolff, 1972, 1973). Nutritive sucking breaks up into segments of variable length towards the end of a feed (Wolff, 1968a). Hence when nutrient flow is switched on in a nipple designed to record sucking, the pattern of sucking changes almost immediately from the non-nutrititive mode to that typical of nutrititive sucking (Wolff, 1968a; Dubignon and Campbell, 1968, 1969).

Human infants are said to be the only ones who respond to differing milk flows in this way. Wolff (1968,1973) examined the sucking patterns of a wide variety of infant mammals when milk was flowing through modified teats and when the milk supply was cut off. Infants other than humans who continued to suck following this interruption continued to suck with the continuous sucking of the nutritive mode, with no appreciable change in the sucking rate. The work of Brown and Pieper (1973) with human, chimpanzee and orangutang infants confirms the continuous nature of non-nutritive sucking in the primates closely related to humans. Wolff concludes that although most mammals suck nutritively and non-nutritively, only in human babies does the organization of sucking differ in the two conditions. It is in non-nutritive rhythms that humans differ; nutritive sucking across species is similar in organization although its rate varies from one to four sucks per second. Wolff goes on to say that this reflects the occurrence of a qualitative shift in the temporal organization of sucking during human evolution, with the implication that two separate central oscillatory centres control the rhythms of the two modes of sucking.

A rather different picture is found in Kaye (1972), who discusses the burst/pause pattern which Wolff maintained was characteristic of non-nutritive but not of nutritive sucking. As a result of a variety of observations on breast and bottle fed babies he states (without supplying the data) that the burst/pause pattern occurs with both nutritive and non-nutritive sucking and that the patterning is a simple, unlearned response to the rate of milk flow. With a rapid flow of milk, sucking may continue for several minutes without a pause. Pauses occur as a result of the depletion of milk or its absence, and their length varies according to rate of milk flow. Above an unspecified threshold they disappear. In a subsequent paper, Kaye (1977) goes on to suggest that the equation of pausing with non-nutritive sucking alone is a misconception brought about by, for one thing, a comparison merely of fast fluid flow with no flow at all. His work in this paper is based upon data from breast and bottle feeding together and no attempt is made to separate the two.

Luther et al (1974) also mention a wide range of sucking rates of between 53 and 122 (mean 75 ± 2) sucks/minute during the breast feeding of 66 children. Unfortunately it is not clear whether these are average values, one per nursing period, or the rates which occur during individual bursts of sucking. In any case, they do not distinguish between the stages of the nursing period when milk is easily obtained and when it is more scanty (before milk ejection and towards the end). They do, however, describe sucking subsequent to the milk ejection as an alternation of sucking and relaxing periods of approximately similar duration, which in pattern does not correspond to Wolff's nutritive mode, as might perhaps be expected, but rather supports Kaye's (1977) observation that all sucking is fundamentally organized in a burst/pause pattern.

Both burst/pause patterns and sucking rates were described by Crook (1976) for conditions in which 0.01 or 0.03 ml of 5% sucrose solution were given for each criterion suck. The lower rate of milk flow elicited significantly more pausing and a significantly faster within-burst sucking rate when compared with the higher flow. Crook's findings with respect to the within-burst sucking rate were replicated by Burke (1977) in his study of sucking and swallowing using 0.01 and 0.04 ml of sucrose solution.

These studies suggest that the pattern of sucking is influenced by the quantity of fluid the baby receives with each suck when these quantities are small, so that the characteristics of nutritive sucking may approach those of non-nutritive sucking when the flow rate is very low. However, the circumstances of testing are very different from natural breast feeding, to which the baby's sucking behaviour is adapted, and the fluid used differs from breast milk in many respects. There is clearly a need to look at the baby's sucking from a more naturalistic perspective.

2.7. Pauses during sucking

Pausing is a distinctive feature of human sucking. It has only been demonstrated in one other species, the rat (Drewett, Statham and Wakerley, 1974).

Several explanations of why pauses occur have been put forward, although as Crook (in press) cautions, it cannot be assumed that the determinants of pausing are the same on the breast as on the bottle.

Pausing during bottle feeding does not appear to be caused by momentary fatigue, since pause durations do not correlate with the length of the preceding bursts (Crook, in press). Possible effects of fatigue over longer periods of feeding inevitably become entangled with any effects of satiety on pausing. Satiety does seem to have an effect; this is suggested by Wolff's (1973) finding that pauses increase in length and frequency during a bottle feed with no change in milk flow or composition. This would have two effects:

(1) It could be used by the baby as a means of regulating milk intake;

(2) Since the mother is likely to notice an increase in pausing more than she would notice, for example, changes in sucking rate, it could serve as a means of signalling satiety to the mother.

Sucking may be organized such that a certain milk flow rate triggers a particular proportion of sucking and pausing. For example, during non-nutritive sucking as commonly defined, more pausing is seen than when milk is flowing. As Hillman and Bruner (1972) suggest, the more liquid enters the baby's mouth, the more likely sucking is to continue, once begun. Pauses could occur as a result of the violation of the baby's expectation of a steady milk flow, as a result of which he stops to scan the situation. Alternatively, as Campbell points out in a discussion of Brown's (1973) paper, infants could initiate a burst of sucking in order to investigate the object in the mouth, and, when they discover that no milk is available, "switch off" the sucking. Soon after, they "switch on" again to investigate, and so on in an "on/off" pattern. When the baby discovers fluid in the mouth, there is then no need to "switch off".

Pauses could also allow the refilling of the milk sinuses and ducts under the areola during breast feeding. However, Ardran, Kemp and Lind (1958) state that the pauses are longer than would be needed for this purpose, and Crook (in press) states that the length of a pause does not correlate with the length of the following burst (neither author supplies the relevant data). Another function of pausing might be to protect the mother's nipple from damage during feeding when milk is not flowing. Sustained negative pressure, unrelieved by swallowing, can cause lesions of the tissue of nipple and areola (Gunther, 1945). However, Gunther also says that infants can maintain considerable negative pressure during a pause.

It has also been suggested (Bruner, 1968; Kaye, 1972, 1977) that an important function of pauses is to provide an opportunity for social interaction and dialogue between mother and child, and that the turn-taking developed during feeding is a "prototype" for similar interaction in later development. And mothers do look at and talk to their infants more during pauses than during sucking (Bernal Dunn and Richards, 1977)

2.8. Intermittent fluid delivery

The introduction of a few drops of liquid into an infant's mouth will elicit sucking which may persist long after its introduction (Peiper, 1963; Crook, 1978). In a study of the organization of sucking in response to differing fluid contingencies (Dubignon and Campbell, 1968b), the mean within-burst rate of sucking decreased from 1.7 to 1.3 sucks per minute and the bursts increased in length when 0.5 ml of 5% dextrose solution was given at every 10th suck. Thus the introduction of fluid at even this low rate of delivery has an immediate and pronounced effect, shifting the non-nutritive pattern towards that more typical of nutritive sucking.

A similar increase in the length of sucking bursts, accompanied by a decrease in pause length, was described by Hillman and Bruner (1972) with increased reinforcement in infants receiving milk formula on fixed interval (up to 2 seconds) and fixed ratio (FR1, FR2, FR3, FR4) schedules.

This suggests that receiving a particular volume of fluid in response to a suck triggers the characteristic response (in term of the rate of sucking within the burst and in burst length) regardless of whether the same volume or less is received with subsequent sucks. Monitoring the fluid and "setting" the appropriate response may therefore only take place at the beginning of each burst of sucking, or be periodic.

2.9. Characteristics of the ingested fluid

Over and above the effect of having fluid in the mouth, the characteristics of the fluid can influence the infant's sucking. The property which has received most attention is taste; others, such as viscosity (which may alter concomitantly with taste, as in sugar solutions), have not been closely examined for an effect on sucking. The temperature of the fluid has been found to have no major effect over the range 20° - 40°C. (Hytten, 1951), although finer effects on the structure of sucking rhythms may yet be found.

Work on taste has centred on the four basic elements of taste in humans; sweet, sour bitter and salty, and on milk itself, whose flavour is predominantly the result of its fatty acids and its lactose content, together with any flavours originating in the mother's diet which may appear in her milk (Galef and Sherry, 1973).

Newborn infants ingest more of a concentrated sugar solution than of a weaker one, suggesting that sweeter tastes are innately preferred (Maller and Desor, 1973). It is suggested that pure water is aversive to human infants and that they maximally inhibit its intake, so that no further diminution is seen with salty, bitter or sour solutions (Desor, Maller and Andrews, 1975), though they can detect these tastes, as shown by the expressions of dissatisfaction they provoke (Peterson and Rainey, 1910).

A more sensitive indicator of the discriminatory ability and the preferences of infants than their intake is the technique developed by Crook (1978). Small quantities of the test fluid are given during pauses in non-nutritive sucking. Almost invariably a burst of sucking rapidly ensues, the length of which is related to the taste of the fluid; the more preferred the taste, the longer the burst. Decreased burst length with salt solution, relative to that in response to plain water, is a demonstration of the infant's aversion to salt. This technique is an extension of the finding that sweeter fluids result in longer bursts of slower sucking (Lipsitt, 1977). Its findings accord with the fact that the response to a sugar solution is an increase in the number of sucks per minute as compared with the number obtained with pure water (Kobre and Lipsitt, 1972).

This increase in sucking has been examined in more detail by Lipsitt, Reilly, Butcher and Greenwood (1976), who found that the within-burst sucking rate was slower with 15% sucrose solution than in the condition with no fluid. The associated increase in responses/unit time resulted from a combination of longer bursts and a reduction in the number of pauses.

Crook (1977) included the pure water condition, which is necessary in order to distinguish the effects of sweetness from those of fluid per se, by supplying his infants with sucrose solutions of 0, 5, 10 and 15%. As the concentration of sucrose increased, the number of bursts decreased and their length increased; both parameters peaked with the 10% solution. The data suggest that 10% sucrose is the preferred concentration. These results are in keeping with, and extend, the findings of Crook and Lipsitt (1976) concerning changes in the organization of newborns' sucking with sweet solutions. The concurrent increases in heart-rate (Crook and Lipsitt, 1976; Lipsitt, Reilly, Butcher and Greenwood, 1976; Lipsitt, 1977) from no fluid to plain water and with increasing sweetness have led to the suggestion that the changes constitute a hedonic response, the infants' sucking being slowed to enable savouring of the sweeter, more pleasant, fluids. However, whereas preferences indicated by e.g. total amount of sucking and intake of fluid peak at 10% sucrose, the mean ISI continues to increase through to 15% (Crook, 1977).

Newborns consume greater quantities of milk than of water (Maller and Desor, 1973). In a study comparing sucking with 5% corn syrup and milk formula, Kron et al (1967) report that infants fed cow's milk sucked at a significantly higher overall rate than those fed corn syrup. Dubignon and Campbell (1969) documented the changes in the rhythm and within-burst rate of sucking when 5% dextrose solution was replaced by milk formula. Both the mean ISI and the proportion of time spent sucking increased.

Most studies of sucking rhythms have used cow's milk; the effect of different milks has only recently been looked at. Johnson and Salisbury (1975) examined the effect of expressed breast milk and cow's milk on sucking and breathing, using an electromagnetic flowmeter. While the total number of sucks did not differ, their frequency distributions did. There are more very short intervals (below 0.5 seconds) and more long intervals (above 1.5 seconds),i.e. pauses, with breast milk than with cow's milk. There was also much more individual variation in the sucking patterns, varying from the situation where the two records for an infant were indistinguishable to that where the infant sucked continuously with cow's milk and in a pattern of bursts and pauses with breast milk. (This may also be a reflection on the considerable amount of variation in the composition of breast milk, both between different women and in the same woman at different stages of the day).

All these many lines of evidence show that taste exerts a powerful influence upon sucking rhythms, affecting both the overall amount of the response and its detailed structure.

If an infant's sucking is changed by changes in the composition of the fluid ingested, changes in rhythm might be expected as a result of changes in the composition of breast milk during a feed. The "hind milk" has half as much protein again and up to four times the amount of fat of the "fore milk" (Hytton, 1954).

Hall (1975) has suggested that the changes in taste and/or viscosity resulting from the rise in the lipid content of breast milk as the breast is emptied act as cues enabling the baby to obtain the appropriate balance of energy and fluid. This, she suggests, is achieved through the baby deciding when to come off the breast, rather than necessarily by changing his sucking. Hall does not discuss whether or not the behaviour might be learnt, by, for example, a mechanism such as that of conditioned satiation, which has been demonstrated in man by Booth, Lee and McAleavey (1976). Presumably the cues on the second breast would have a stronger effect than the same ones towards the end of feeding on the first breast, in parallel with the way in which the palatability of a food changes during the course of a meal in adults as satiety is approached.

Chan, Pollit and Leibel (1979) found no support for Hall's hypothesis when the lipid density of formula milk was abruptly increased during a bottle feed. However, the vegetable lipids they used would not provide the infants with the same cues as breast milk lipids, and their subjects were bottle fed infants who had presumably never before encountered a rise in the lipid density of the milk during a feed.

It is not yet known whether infants can distinguish between milk of differing fat levels. If they can (as seems fairly likely given the high concentration of flavour components in the lipid fraction), it would be interesting to see whether differing fat levels do influence the organization of sucking. So far, it is only sweetness which has been shown to exert such an effect, and lactose levels remain much the same throughout a breast feed.

2.10. Factors arising within the baby

When considering the course of a feed, any effects of a hunger/satiation and fatigue on sucking must also be taken into account. The time elapsed since the last feed influences whether or not the infant is willing to feed in the first place. It seems that once the nipple has been accepted and feeding begun, the actual degree of hunger has little effect on the rate of sucking. Dubignon and Campbell (1969) studied sucking throughout a bottle feed (i.e. nutritive sucking). During the last quarter of a feed, there was a significant decrease in the number of suction and expression responses as compared with the first three quarters, which all had broadly similar counts. Thus satiety was marked not by a decrease in the rate of sucking within bursts, in which no significant differences were found, but by the infants spending less time actually sucking. The sucking mechanism also appeared to change, as there was an increase in the expression/suction ratio, due to a pronounced drop in the frequency of the suction component. The authors liken it to a chewing or mouthing of the nipple.

Several studies on the effect of satiety on non-nutritive sucking have also been reported. Levin and Kaye (1964) examined overall sucking rates under non-nutritive conditions at intervals of between 10 and 90 minutes after feeding, and obtained a significant correlation with time since feeding. On the other hand, Wolff (1972) found no influence of gastric loading with milk on the organization of non-nutritive sucking on a blind nipple but does not give the measure of overall sucking rate which would allow comparison between the two findings.

Any effects of milk and the consequent decrease in hunger upon the organization of sucking must be dissociated from their effects on the infant's behavioural state and the ensuing effect of this change in state upon sucking. However, this may be difficult.

The particular mode of functioning of the nervous system, manifesting itself as a particular state (for example, regular sleep, quiet wakefulness) has been shown to be a predictor of infant behaviour (Prechtl et al, 1973), including the response to stimuli. For example, sucking cannot always be elicited by a nipple; hence it may often be important to know the state of an infant being studied. However, Bell and Haaf (1971) found virtually no correlation between the state of the infant and his reaction to a test of motor response, to removal of a teat, and measures of non-nutritive sucking. They therefore caution that it may often not be necessary to make complex assessments of state.

In order to study the possible effects of hunger on state and on non-nutritive sucking, Wolff (1972) worked with young infants recovering from surgery to remedy tracheo-oesophageal fistulas. This enabled him to compare normal feeds, direct gastronomy feeds with no opportunity for the infant to suck, and feeds in which the infant sucked for milk which was continuously aspirated from the stomach via a gastronomy tube. Loading the stomach with milk, especially when this is accompanied by sucking, affects the infant's state such that he is more likely to fall asleep, whereas oro-pharyngeal stimulation alone does not have this effect. Wolff's results confirm the view that the organization of non-nutritive sucking, tested after feeding, is not altered by any of the types of feed, although the likelihood of sucking is reduced.

As to the effects of fatigue, studies on a pacifier over periods of 10-15 minutes (Levin and Kaye, 1964) show that work decrements are small with a complete recovery of initial sucking rates after one minute of rest. Infants are capable of sustaining remarkably long periods of sucking without apparent fatigue, in contrast to adults who very quickly tire within 1-2 minutes when they attempt to do likewise (Wolff, 1968a,b). It appears then that fatigue has no major influence on sucking patterns during bottle feeding.

2.11. Conclusion

The research conducted to date on behavioural aspects of infant feeding is curiously divided. On the one hand, there is a wealth of "common knowledge" and traditional practice relating to breast feeding and its management. This is not always firmly grounded on empirical data. On the other hand, laboratory studies provide a large body of such data, at least on sucking and how it is influenced; but most of these data have been collected on bottle feeding infants, and studies of this kind quite ignore the need to understand the behaviour of the baby in relation to the mother's lactation. It is therefore very difficult to relate these bodies of work one to the other. One would like to see them more closely integrated.

The emphasis of the behaviourist tradition in studying sucking has been to modify and manipulate sucking without prior study of the range and organisation of the behaviour in its natural setting. There is a need for observational studies describing the organisation of sucking during natural breast feeding, and for studies of the way the sucking patterns respond to changes in milk flow as a result of milk ejections or the emptying of the breast. Such studies might be more relevant in the investigation of breast feeding difficulties than isolated study of the baby's sucking.

In this thesis results of work of this kind are presented.

CHAPTER 3

THE ORGANISATION OF SUCKING DURING BREAST FEEDING

3.1. Introduction

Some of the factors which influence the organisation of infant sucking have been described in Chapter 2. A recurring theme is that of the two different sucking patterns, nutritive and non-nutritive, shown by human infants. These two modes of sucking are distinguished firstly by their different temporal organisation - non-nutritive sucking occurs in a burst-pause pattern, nutritive sucking in a more continuous stream of sucks; and secondly by the different rates of sucking within episodes of continuous sucking, non-nutritive has a mean inter-suck interval of 0.41 - 0.48 seconds and nutritive sucking of 0.7 - 1.0 seconds (Wolff, 1968a,b).

When the child is sucking on the breast, very little milk is available to him before milk ejection, and since this resembles Wolff's non-nutritive condition during bottle feeding one would expect to see the corresponding pattern of fast sucking interspersed by pauses. As the milk begins to flow, one would expect this to change to the nutritive pattern of sucking, and later on as the breast empties one might expect a return to the non-nutritive pattern. In this chapter, therefore, sucking patterns during breast feeding are examined to see whether sucking on the breast corresponds with what would be expected on the basis of this earlier work on bottles. This possibility is of interest for two reasons:

(1) The data on nutritive and non-nutritive sucking related to bottle feeding and we need to know whether comparable results are found during breast feeding, to which it is naturally adapted.

(2) If it is possible to pick up a clear and obvious change in the sucking rate around the point of milk ejection as the milk suddenly begins to flow, this could provide a non-intrusive way of detecting the occurrence of a milk

ejection, in contrast to more disruptive methods such as cannulation of the nipple (Cobo et al, 1967; Luther et al, 1974).

This could be of use in studying difficulties associated with breast feeding; the sucking rate of the baby might indicate whether or not milk was available and therefore whether the milk ejection was being blocked, for example by stress or anxiety (Newton and Newton, 1948).

3.2. Subjects

The subjects were eight lactating, breast feeding mothers and their babies. Most of the mothers were approached during ante-natal National Childbirth Trust classes and if they expressed interest in taking part in the research they were contacted again three to four weeks after the birth of their child. The other women were contacted informally. No criteria for inclusion other than the good health of mother and child were used. The eight infants were studied for a total of 41 breast feeding sessions (details in Table 3.1).

TABLE 3.1

Subjects		Parity of mother	Age of baby in days at time of session(s)	No. of sessions
Ms F. and Alexandra	(AF)	1	28- 56	3
Ms G. and Angela	(AG)	1	91-121	4
Ms L. and Andrea	(AL)	1	29	1
Ms R. and Emily	(ER)	1	23-120	12
Ms R. and Sian	(SR)	2	35- 70	4
Ms S. and Jamie	(JS)	1	32-116	9
Ms Y. and James	(JY)	1	25- 98	6
Ms Z. and Joanna	(JZ)	2	45- 64	2

3.3. Method

A room was set aside as a nursery to be used purely for work on infant feeding. For reasons of hygiene, only those directly involved with this work were allowed into the room. The room resembled a sitting-room, with easy chairs, one of which was particularly suitable for sitting in to breast feed. The room was quiet and the window was high enough to prevent passers-by seeing in. The arrangement of the room during recording sessions is illustrated in diagrammatic form in Figure 3.1.

On a pre-arranged day, the mother was contacted early in the morning to establish the time of her baby's next feed, as far as it was possible to predict it. The couple were then fetched so as to arrive at the nursery fifteen minutes before this time, allowing time for settling in. The mothers were asked to breast feed their infants as they would at home, for the same length of time, with such interruptions as they wished. The baby was not put to the breast until he (or she: but I will use "he") showed clear signs of hunger such as rooting behaviour, agitation or crying. This was left entirely to the discretion of the mother. The emphasis throughout was on minimal disruption to the feed, the aim being that it should resemble, in timing, comfort and privacy, a feed at home, and thus disturb the infant's behaviour as little as possible. Every effort was made to put the mother at her ease and the sessions were not hurried in any way.

A Hitatchi videotape recorder, model SV-612K, and a Shibaden CCTV camera, model HV-165, were used, together with a television screen in the nursery for monitoring the picture during recording. The video recorder was housed in an adjacent room in case its fairly loud running noise disturbed the baby or the mother. The baby's face was viewed from the side, so as to have the line of the camera at right-angles to the direction the child was facing. This gave a clear view of the movements of the jaw, cheeks and throat during feeding. Because of the need for a close-up view of the infant's sucking movements, the picture generally included the mother's breast but nothing more, as a result of which her behaviour and that of the baby, other than sucking, were not generally visible.

3.4. Transfer of sucking record from videotape to computer

The video recordings were first timed with a stop-watch to give a precise record of each time the baby went on and came off the breast. This

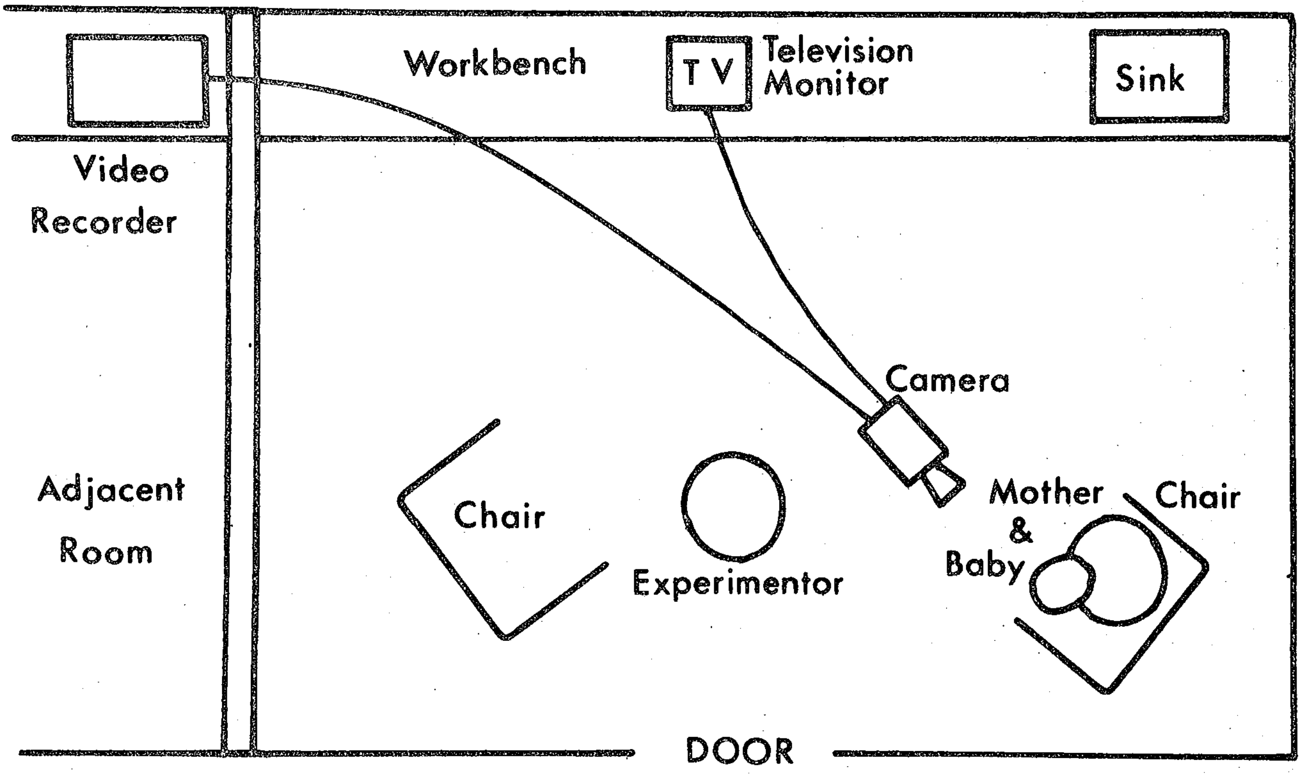


Figure 3.1. Arrangement of nursery during recording sessions

greatly facilitated the subsequent keying-in of the sucks.

To increase the manageability of the large amount of data the sucks were stored on computer disc. Manual key-pressing signals were used to indicate sucks, and these were stored as the sequential inter-suck intervals of a feed. Thus as the video recording was viewed the key was pressed each time a suck occurred. (It should be borne in mind that inter-suck intervals include the duration of the sucks themselves, which are difficult to delineate, as well as the actual intervals between them, and therefore are essentially intervals between successive equivalent points in the sucking cycle, and not, literally, between sucks).

Sucks were generally very obvious and clear from the rhythmic movements of the jaw and cheeks. (Occasionally if the jaw was obscured from time to time, despite the mother's attempts to make it more visible, the concurrent movements of the breast proved very helpful in following the sucks). A suck was recorded at a point immediately following the completion of the "up-stroke", i.e. when the infant's lower jaw had come up to meet the upper. This was chosen because it is a very clear point in the sucking cycle. Sucks were recorded a slight interval after this point in order not to anticipate a suck before it had occurred, which is a danger when recording such a series of rhythmical movements where successive intervals can in fact vary considerably in any burst of sucking.

Reaction times between observing a suck and pressing the key will inevitably vary and are likely to be between 150 and 200 milliseconds (Teichner and Krebs, 1972). This constitutes a non-systematic error, the effect of which on the accurate representation of the rate of sucking over a period of time will be minimal. As a measure of the reliability of the keying-in, the sucks from one section of tape approximately one minute long were transcribed three times, with the following results:

	No. of sucks	Mean of intersuck intervals (within bursts)
1	98	70.1 centiseconds
2	100	70.3 "
3	99	69.1 "

The moment of going on the breast was defined as the moment the infant took the nipple firmly and fully into his mouth (not merely touching it with his lips or tongue) and the baby was recorded as having come off the breast when he released the nipple from his mouth, and breast and mouth were no longer in contact.

In addition to the key for recording the sucks, a second key was available which acted as an event recorder. When the inter-suck intervals were listed on the computer print-out, an "X" was printed beside the intervals during which the "event" was recorded. This was used to record subjective reports of milk ejection, recorded on the sound channel of the video tape.

Each separate block of data was keyed-in with the beginning of the record being the point at which the first suck occurred; the end of a block was signalled either manually when the baby came off the breast, or by an automatic cut-off at 5 minutes, which was the maximum period for which I could focus on the monitor screen with the necessary degree of attention without considerable eye-strain. Thus where the baby was on the breast continuously for 5 minutes or more, the first five minutes only of this period on the breast were recorded. A representative sample of sucking during the feed was obtained, since the infants generally came off several times during a feed (see Figure 3.4).

The blocks or episodes of sucking stored on disc were labelled 1A, 1B, 2A, 2B etc., 1 and 2 referring to the first and second breast and A, B, etc. to the serial order of the episodes on each side. The following information was recorded with each episode:

Name and age of baby;

Left or right breast;

1st or 2nd side;

Serial order of episode on each breast - A, B, C, etc.

3.5. Results

Figure 3.2 shows the distribution of the length of the feeds and Figure 3.3 the periods of time actually spent on the nipple.

The raw data on sucking stored in the computer are the successive inter-suck intervals in centiseconds for each episode, 1A, 1B, etc. of each breast feed. These inter-suck intervals were grouped together in 10-second categories (bins), for all feeding episodes pooled.

The distribution of these inter-suck intervals can be seen in Figure 3.4 as a histogram of the number of intervals in each bin. The same data presented as a histogram of the survivor scores are plotted in Figure 3.5. Beginning with the total number of scores, those in each successive bin are subtracted in turn. The survivor data are plotted on a logarithmic scale in Figure 3.6. This is the log survivor function, a transformation of the frequency histogram in which the intervals are cumulated to the left and the frequency values are logged (Machlis, 1977). Plotted as log survivor functions, negative exponential curves appear as straight lines, and the probability of an inter-suck interval occurring in the category adjacent to any particular category is proportional to the slope of the line (Cox and Lewis, 1966; Machlis, 1977).

The two straight lines of Figure 3.6 represent two smooth distributions of inter-suck intervals. This indicates two negative exponential decays in the distribution of intervals, approximately from 0.4 to 1.1 seconds and from 1.5 seconds upwards. Once an inter-suck interval of the former distribution (of shorter intervals) has occurred, the probability is high that it will be followed by other short inter-suck intervals in rapid succession; in other words sucks occur in bursts.

The point of intersection of these two distributions can thus serve

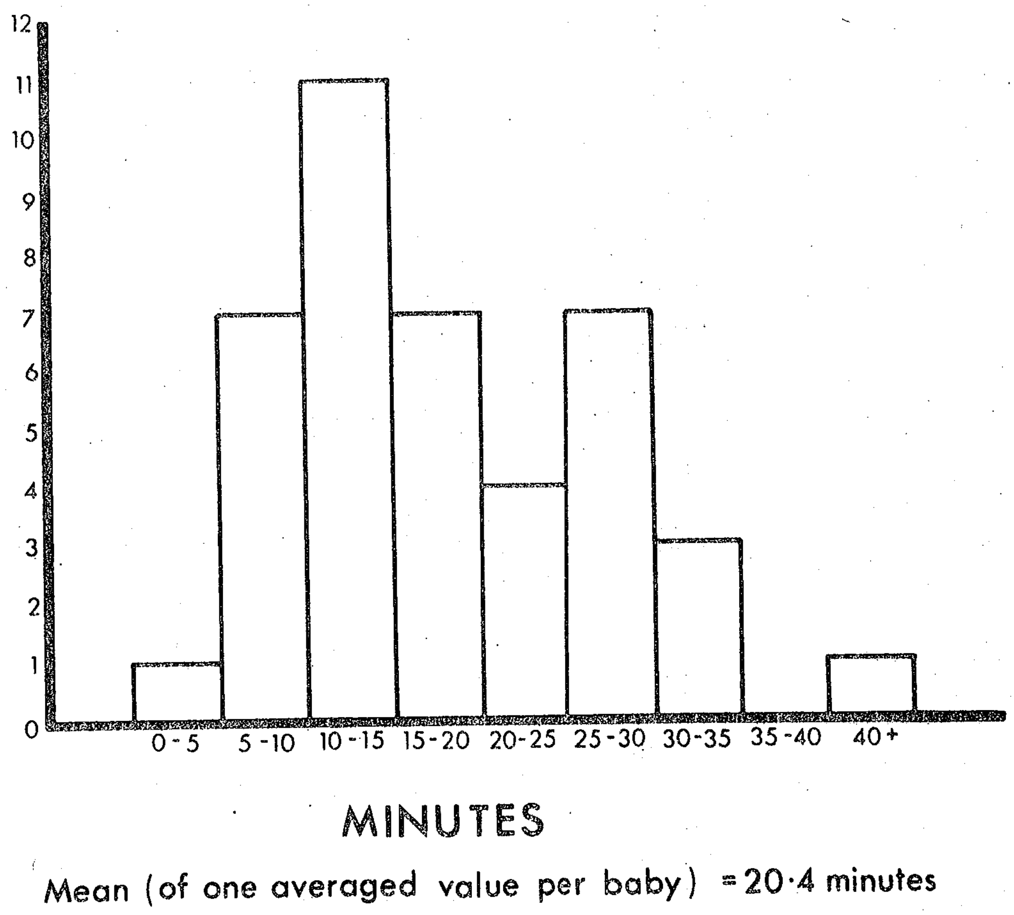


Figure 3.2. Distribution of length of breast feeds

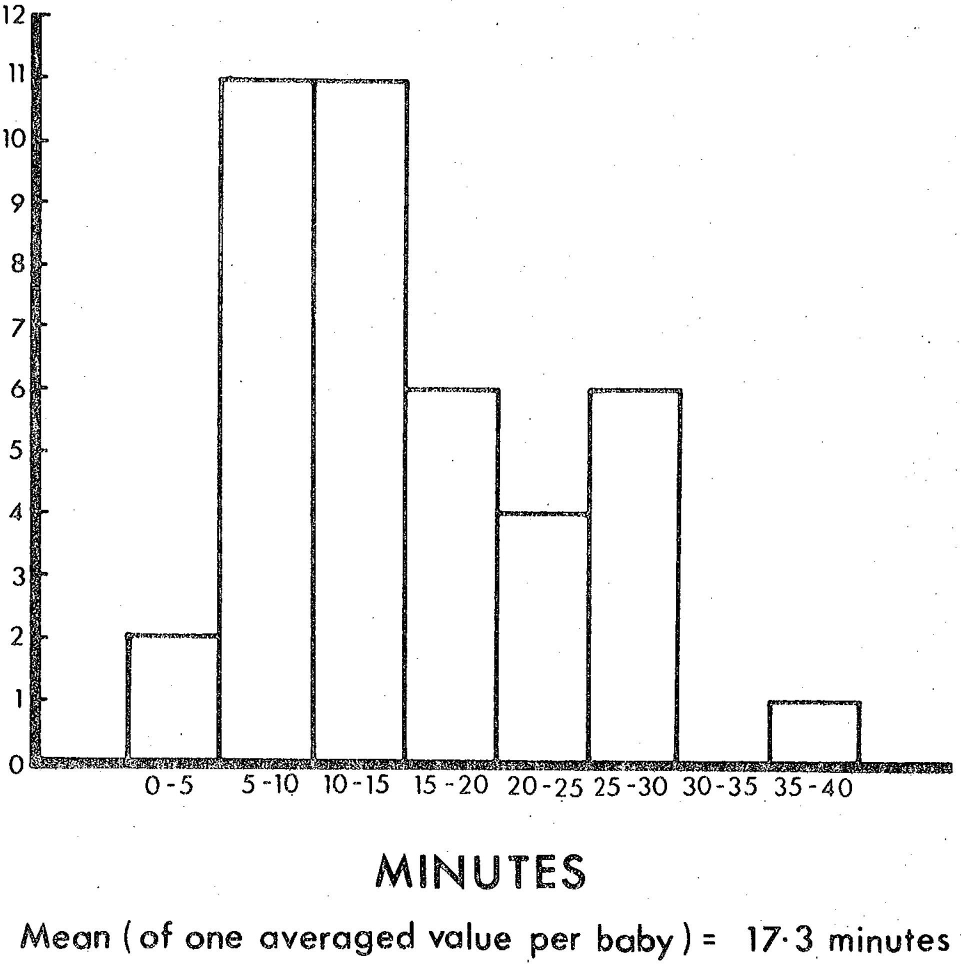


Figure 3.3. Distribution of time spent on nipple

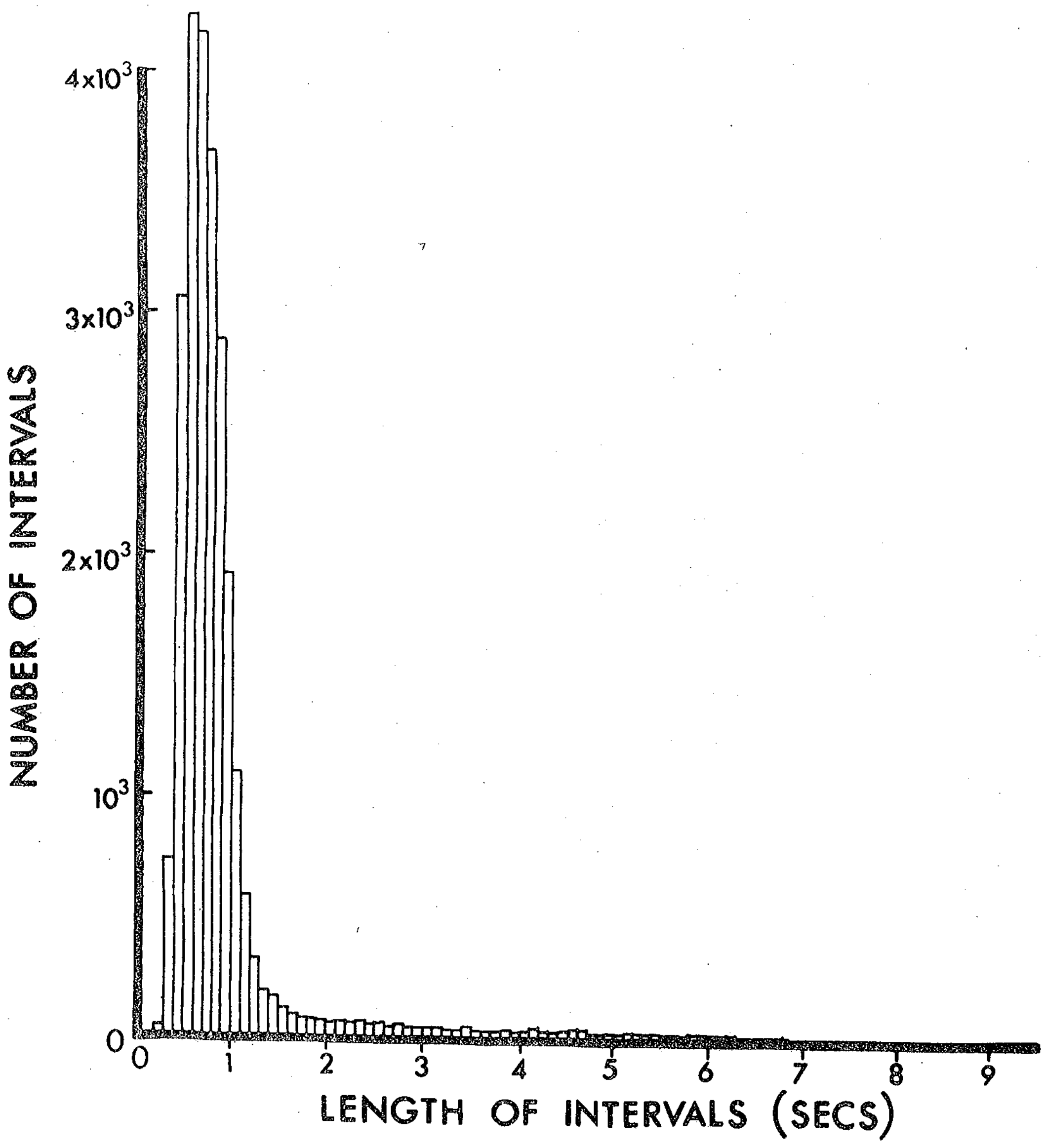


Figure 3.4. Histogram of inter-suck intervals

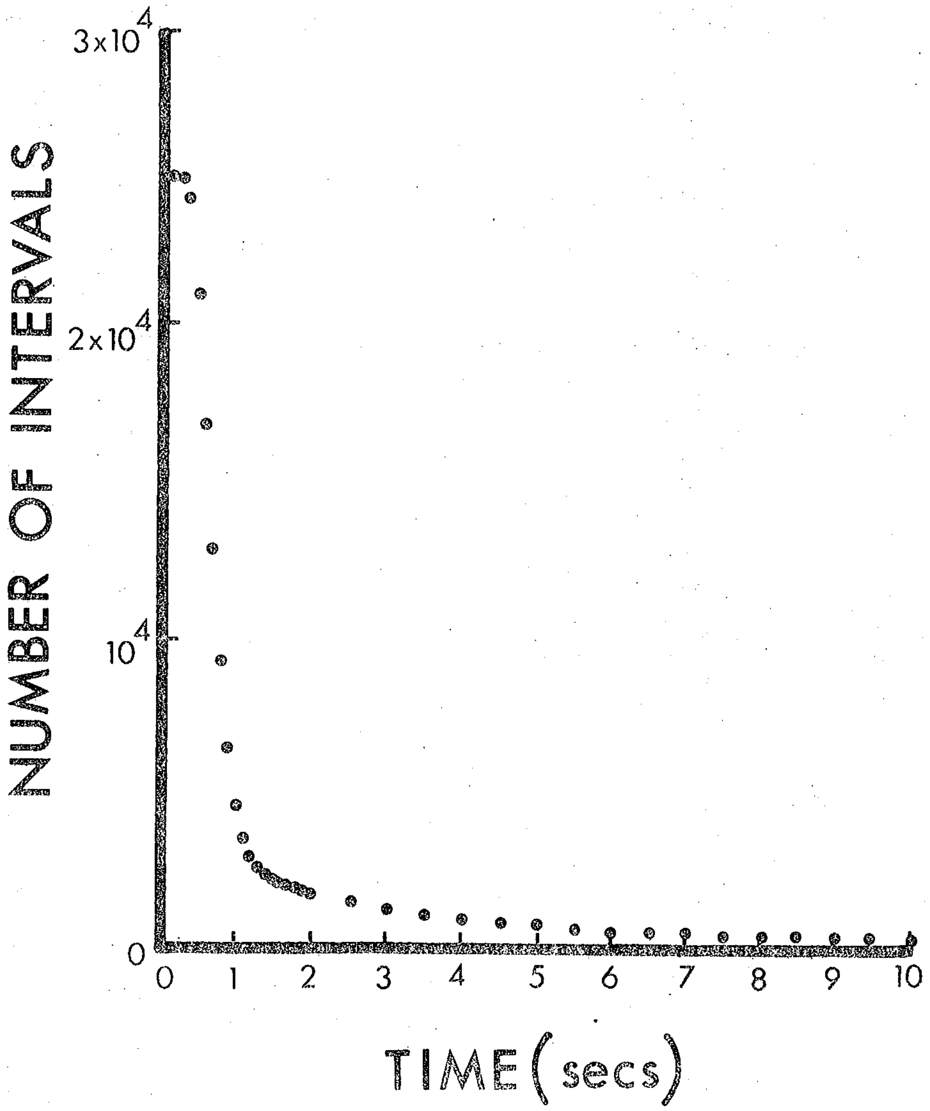


Figure 3.5. Survivor function of inter-suck intervals

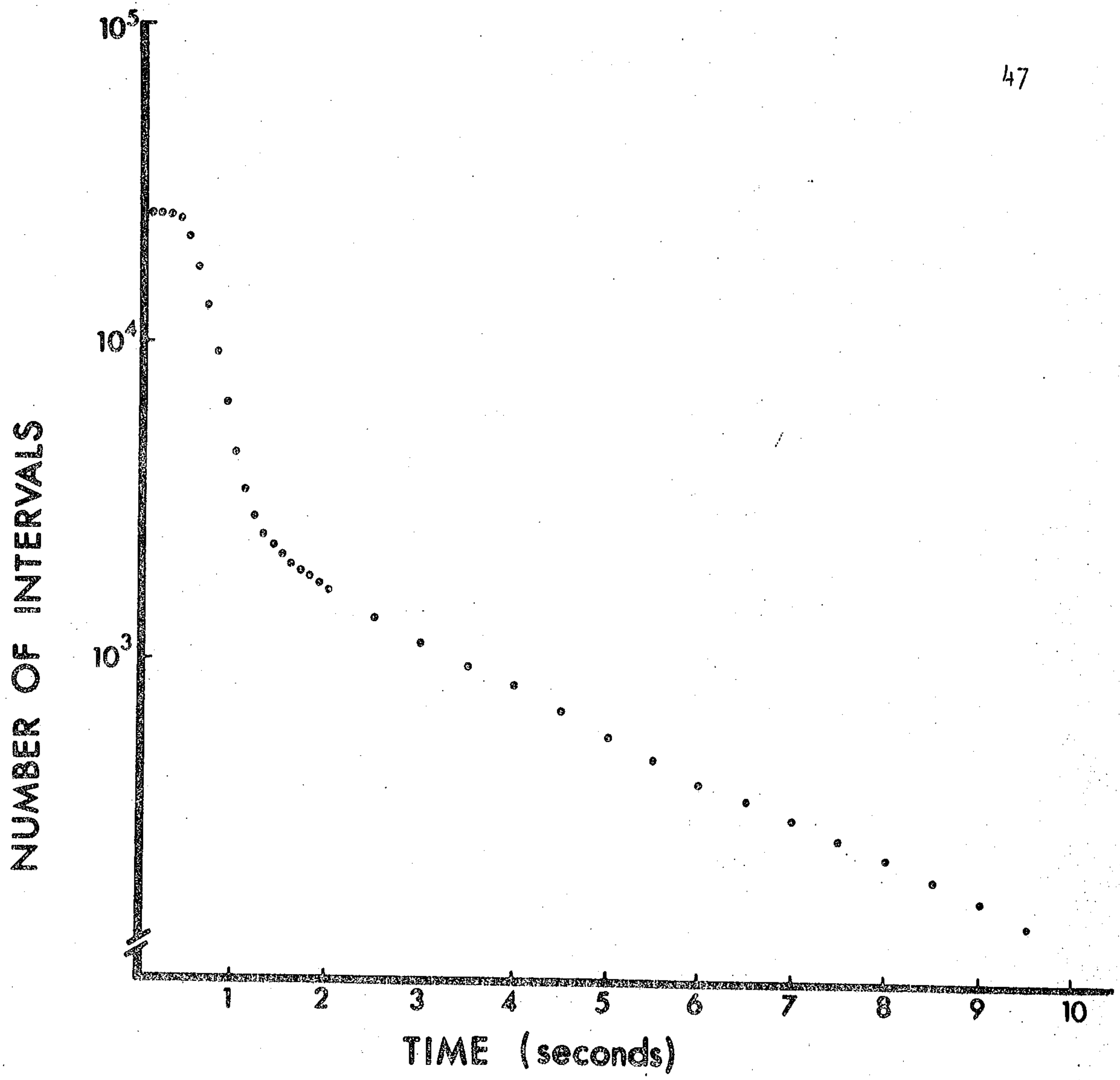


Figure 3.6. Log survivor function of inter-suck intervals

to mark the division between the short within-burst inter-suck intervals and the longer pauses between bursts of sucking.

The method of least squares was used to find the best straight lines for the two distributions, as follows:

Axes	Distribution 1 (within-burst sucking)	Distribution 2 (pauses)
1. x = length of ISI's, y = no. of ISI's		
gradient	-0.014	-0.001
intercept	5.05	3.43
correlation	0.998	-0.999
2. x = no. of ISI's, y = length of ISI's		
gradient	-72.30	-741.79
intercept	365.57	2565.04
correlation	- 0.998	- 0.999

The two sets of values for the gradient (m) and the intercept (c) obtained from the y on x and the x on y were substituted into the equations

$$y_1 = m_1 x_1 + c_1$$

$$y_2 = m_2 x_2 + c_2$$

The two distributions cross at the point (x, y) where both equations are satisfied, and by solving the two equations simultaneously a value for the intercept (x, y) is obtained, for x on y and y on x.

1. 130.4 centiseconds
2. 128.8 centiseconds

Mean = 129.6 centiseconds

Values 1 and 2 are very close, which, together with the high values of the correlations (above), indicates two distinct and well-separated distributions.

The mean figure for the intercept is rounded up to 130 centiseconds, or 1.3 seconds, as the technique of transcribing the sucks does not warrant a greater degree of precision. It is interesting that the overlap between the two distributions is in fact so small when it is considered that the effect of the non-systematic error due to random variation in reaction time between observing a suck and keying it in to the computer would be to blur the transition point rather than to introduce a bias towards either long or short sucks.

For the rest of this thesis the following terminology is used. Intervals between sucks which last longer than 1.3 seconds are called "pauses"; intervals between sucks of 1.3 seconds or less are called "inter-suck intervals" (ISI's). Inter-suck intervals provide a measure of "within-burst sucking rate" (or simply "sucking rate"). "Bursts" consist of one or more sucks. Two or more adjacent sucks are classified as one burst when the intervals between them are all less than 1.3 seconds (i.e. are "inter-suck intervals"). The sum of the pauses as a percentage of the total time on the breast is called the "percentage pausing time".

The cut-off point of 1.3 seconds between the distributions of inter-suck intervals (continuous sucking within bursts) and of the pauses between the bursts was used in all subsequent analyses.

Figure 3.7 shows log survivor functions for the first and second breast separately. These functions are normalised, i.e. the number of ISI's in each bin is expressed as a percentage of the total. They are shown in this form to allow comparison between the two sides.

Figure 3.8 shows the distribution of intervals of each length on sides 1 and 2. Both types of representation are needed in order to give a clear picture of the distribution of the intervals between sucks.

The total number of intervals on each side is similar (12,474 for side 1 and 12,665 for side 2). From Figure 3.8 it is clear that there is a greater number of long intervals on side 2 than on side 1. Figure 3.8 shows that the modal interval on side 1 is 0.6 seconds whereas on side 2 it is 0.5 seconds. The wider curve for side 1 indicates a greater variability of intervals than occurs in the more peaked distribution of side 2.

Table 3.2 gives the percentage pausing time for each baby on sides 1 and 2;

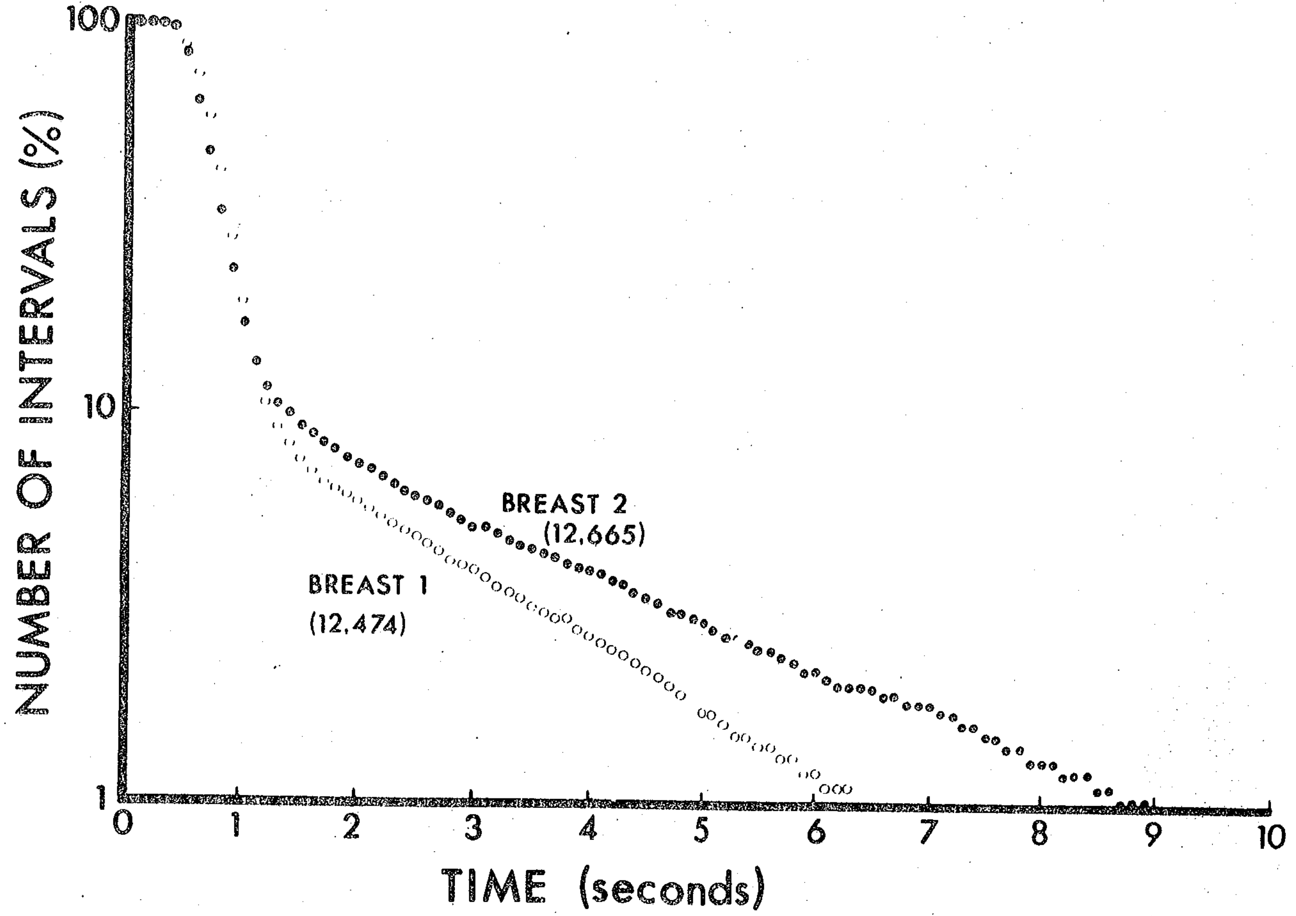


Figure 3.7. Normalised log survivor functions of inter-suck intervals from Breast 1 and Breast 2

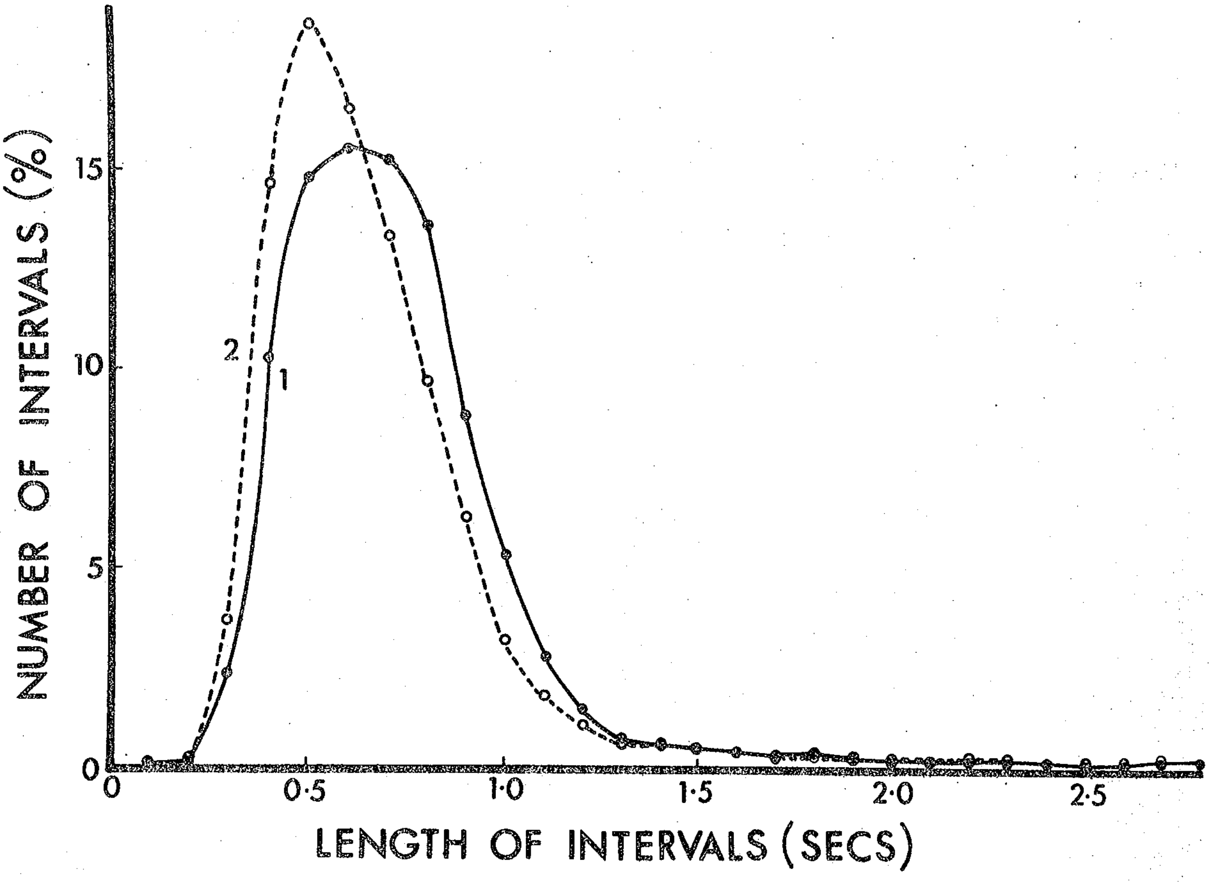


Figure 3.8. Percentage of intervals of particular lengths. Breasts 1 and 2 separately

the single value per baby represents the pooled data from all that baby's feeds, and the scores on the two sides were evaluated using a t-test. The differences do not reach significance with this test.

TABLE 3.2

PERCENTAGE PAUSING TIME

Subject	Side 1	Side 2
AF	29%	42%
AG	12%	23%
AL	18%	30%
ER	27%	40%
SR	32%	55%
JS	40%	38%
JY	26%	38%
JZ	20%	15%
Mean	25.5%	35.1%
S.E.	3.1	4.4

t-test;
t = 1.182, N.S.

3.6 Discussion

The sucking records presented here do not uphold the concept of two dichotamous sucking rates, nutritive slow sucking and non-nutritive fast sucking punctuated by pauses. The only discontinuity in the overall log survivor function of Figure 3.6 occurs well outside the range of that postulated to divide nutritive from non-nutritive sucking, in that there appear to be two separate distributions, that of intra-burst (short) and of inter-burst (long) intervals (referred to in this text as ISI's and pauses, respectively). The distributions are quite distinct, with the transition between them occurring at 1.3 seconds.

Within the distribution of intervals below 1.3 seconds, ISI's are graded between 0.5 and 1.1 seconds. This range covers the sucking rates of both nutritive and non-nutritive sucking as described by, for example, Wolff (1968a,b) for bottle feeding infants. If the nutritive and non-nutritive sucking rates were discontinuous, such bimodal distribution would be reflected in the log survivor function.

H. Kaye(1964, quoted by the same author, 1968) excludes ISI's greater than 1.5 seconds from bursts of sucking but does not give the rationale behind his choice; neither do Sameroff (1971) or Wolff (1973), who use a criterion of 1.0 seconds. K. Kaye (1977) defines the cut-off point as 2.0 seconds on the basis that since the distribution of sucks he finds in breast and bottle feeding is bimodal and almost no intervals of 2.0 seconds are seen, this is likely to be the transition point.

The cut-off between ISI's and pauses occurs at 1.3 seconds, as determined from the survivor function.

Tht distribution of ISI's differ between the two sides (Figures 3.7, 3.8); the mode on side 1 occurs at a higher ISI than that of side 2, i.e. sucking is slower overall, and on side 1 there is a greater variability about the mode.

Why is the baby's sucking different on the second breast? Fatigue has been shown to have little influence on sucking patterns in bottle feeding (see Chapter 2). Nevertheless, it is feasible that, despite the facilitating milk ejection mechanism, sucking on the breast could prove to be cumulatively more tiring for the baby than bottle feeding since the baby must actively maintain the shape of the teat (formed from nipple and areola) in order to feed. Thus fatigue could possibly be a factor in changing sucking patterns.

The baby's hunger is likely to be reduced by the time he is put to nurse on the second breast because he will have already consumed a good portion of the feed. It seems reasonable that a baby should suck for less of the time whilst approaching satiation (as has been demonstrated by Wolff (1973) with bottle fed infants), and this is consistent with the increase in percentage pausing time observed on the second side. Perhaps the baby takes a little milk and then stops without yet being ready to come off the breast. The role of satiation is also supported by Wolff's finding that pauses increase in length and frequency during the course of a bottle feed, despite a presumably constant rate of flow and unchanging milk composition.

The factors associated with the milk which might explain the different sucking patterns on the two breasts are its availability and its composition. Milk intake is the resultant of its availability and of the baby's hunger and vigour in sucking. Availability influences its rate of flow; evidence that this can exert an influence on sucking patterns at low rates of flow during bottle feeding was discussed in Chapter 2. Milk availability might well be lower on the second breast since this is usually the one that was given first, and therefore the more thoroughly drained, in the previous feed.

3.7. Further analysis. Within-burst sucking rates and the milk ejection reflex.

Milk ejection usually occurs within one minute of the baby going onto the breast, unless it has already occurred as a result of stimuli associated with preparing to feed. Latencies of between 10 and 30 seconds are quoted by Isbister (1954) and are said to be constant for an individual at a particular stage, and to lengthen as the lactation progresses. Caldeyro-Barcia (1969) notes that the first contractions of the mammary glands are usually seen within 60 seconds of the onset of sucking; and Sala, Luther, Arballo and Cordero Funes (1974), in their study of intra-mammary pressure during nursing, state that sucking evoked reflex milk-ejection within 45-70 seconds. Thus the baby may have a period during which he is obtaining little or no milk and during this time his sucking might be expected to show the typical no-fluid pattern. And a shift in the pattern of sucking towards the nutritive mode may occur when the milk becomes precepitately available as the circulating oxytocin stimulates the myoepithelial networks to contract and expel their contents. If so, this would give a guide to whether or not the MER has occurred. Isbister (1954) cites the observation of the baby's sucking movements as one method of detecting milk ejection. Giving no data, she describes the baby as sucking or nibbling the nipple, often in a restless, hungry fashion, for periods of from a few seconds to one minute after taking the nipple, then becoming still and sucking in a regular rhythmic mode for a few minutes, presumably when the milk becomes available.

In order to see whether any such changes can be detected objectively in the baby's sucking rate, the ISI's were analysed for each successive 30-second period the baby was on the breast. A 30-second period was chosen as being long enough to give a good estimate of sucking rate and short enough not to obscure any changes.

In all cases in which the baby stayed on the breast for at least one minute before coming off (29 out of the 41), the mean ISI for the first and second 30-second periods were compared, see Table 3.3. One subject, AG, was not represented because she did not suck at all during the first 30 seconds on the nipple so it was not possible to get a measure of rate.

For each subject, the mean ISI is longer for the second than for the first 30 seconds, i.e. the sucking rate decreases during the first minutes of feeding. A correlated t-test was carried out on the data. The highly significant decrease found in within-burst sucking rate during the first minute of breast feeding is most probably associated with the sudden onset of the flow of milk as a result of milk ejection, although proof would require measurements of intramammary pressure. It therefore appears that the rate of sucking changes in the predicted way.

Assuming that they are associated with milk ejection, the differences

TABLE 3.3

Subject	No. of feeds pooled	Within-burst 30-second ISI, mean of all feeds per subject.	
		1st 30-seconds	2nd 30-seconds
AF	2	0.72	0.88
AL	1	0.77	0.98
ER	5	0.85	0.92
SR	4	0.69	0.82
JS	9	0.59	0.68
JY	6	0.76	0.95
JZ	2	0.67	0.76

df = 6, t = 6.611, $p < 0.001$, 2-tailed.

in mean ISI are almost certainly underestimates of the change in sucking rates due to milk ejection since there are two factors which would effectively decrease the differences:

(i) In some cases the milk may have been let down before the baby went on to the breast, so there would be no difference between the two 30-second periods.

(ii) In other cases the milk may have come in very soon or very near the end of the first 60 seconds of the feed, giving similar sucking rates for both periods.

If the precise time at which the let-down occurred was known, for example through monitoring the changes in intra-mammary pressure (Friedman, 1960; Luther, Arballo, Sala and Cordero Funes, 1974), one would expect to see an even greater difference in the mean ISI's before and after this point. The mothers in this experiment were requested to report any milk ejections they felt, as they felt them, in order to relate these times to the sucking of the baby. The criterion used was that of a tingling, sometimes painful, sensation in either breast. Subjective methods of detecting milk ejection have been used by, for example, Isbister (1954), and shown to be correlated with an increase in intra-mammary pressure (Luther, 1974). However, a clear experience as described above was very much the exception among this group of women, and when they were reported, the timing was uncertain due to delay or to the diffuse nature of the sensation. This may be due to the preponderance in this sample of primipara, who often do not feel such tingling sensations until they have been breast feeding for many weeks (Isbister, 1954).

CHAPTER 4

A MORE ACCURATE MEASUREMENT OF INTER-SUCK INTERVALS

4.1. Introduction

Video recording was used in the previous chapter to measure the rate of infant sucking over a period of time comparable to the length of a sucking burst. In order to get a more accurate and precise record of inter-suck intervals throughout the range seen, and to determine whether indeed there is a smooth, continuous distribution between the short and the longer ISI's (approximately 0.5 - 1.0 seconds), the baby's sucking rate was recorded on film. On film, the interval between two events can be measured exactly by counting the number of frames between them. This can be converted into the actual time elapsed. The technique is limited only by the certainty with which the events in question can be identified and by the accuracy with which the running speed of the camera is known.

To be certain of including ISI's of both the nutritive and the non-nutritive rates (see Chapter 3), filming was carried out mainly during the first minutes of a feed. During this time a wide range of ISI's is generally seen, as demonstrated by the substantially slower sucking rate of the second half-minute as compared with the first half-minute of a breast feed, shown in Chapter 3.

4.2. Method and analysis

Mothers were recruited as before and brought to the nursery with their babies just before the expected time of a feed. Details of the subjects are given in Table 4.1.

The baby was put to the breast when he showed signs of hunger, and the mother was asked to proceed just as she would at home. Filming was in black and white at 24 frames/second and began in most cases as soon as the baby

TABLE 4.1

Subjects	Parity of mother	Age of baby in days at each session	No. of sessions
Ms C. and Ann	1	59	1
Ms C. and Rachel	1	42	1
Ms J. and Catherine	1	85	2
Ms L. and Christopher	2	42	1
Ms S. and Michael	2	74	1
Ms T. and Heather	2	50	1
Ms T. and Katherine	1	76	1

Unfortunately the identifying section of three films was lost in development. The two other subjects who were filmed are:

Ms W. and Emma	1	25	1
Ms R. and Paul	1	under 3 months but exact age not known	1

The third unidentifiable session is accounted for by another session from one of the other subjects.

went on to the first breast. Two cameras were used on different occasions; both were Canon Scoopic 16 mm models. During all but two sessions, one reel only was used giving three minutes of recorded sucking from each feed. In order to conserve film, filming was stopped whenever the baby came off the breast and continued once he was back on. Eleven sessions were filmed (nine infants).

To check on the running speed of the two cameras and hence the accuracy of the timing of the data, each camera was used to film the face of a digital quartz crystal clock for 30 seconds. The clock was an OMB electronic counter timer, model 745, accurate to 1 in 10^6. From the film, the number of frames spanning 20.00 seconds was counted by hand. This figure was divided by 20 to give the running speed of the camera in frames per second.

One camera ran at exactly 24.00 frames per second; the other at 24.15 frames per second. This deviation, amounting to a constant error of 0.62%, is negligible for the purposes of this experiment, and both cameras were taken as running at 24 frames per second. (It is for this reason that time is given in units based on 1/6 sec).

Each film was analysed frame-by-frame,using a Motion Analysis projector, Specto model MKIII. As the film was run through the projector, each frame moved the counter along by one position; this was reversed when the film was rewound making it possible to keep a continuous record of one's position along the film. Two people were required for the analysis, one to operate the projector and to note the counter reading as the other person indicated the sucks. An equivalent point in each sucking cycle was identified as accurately as possible; this was the top point of the movement of the lower jaw, when it had just begun to travel down again.

The resulting data were summarised in the form of the number of ISI's of each frame length per session, and the data were then pooled. The total number of ISI's recorded was 1,556.

4.3. Results and discussion

A histogram shows the distribution of ISI's (Figure 4.1A). The ISI's are pooled in bins of 1/6 second.

If the baby's sucking were divided into the two rates, nutritive and non-nutritive, the distribution of ISI's below one second in length in figure 4.1A would be bimodal. This is clearly not the case. The experiment therefore upholds the conclusion of Chapter 3 (based on video recordings) that sucking on the breast is not divided into nutritive and non-nutritive modes. Furthermore, the distribution of ISI's is graded on either side of the mode, illustrating the continuity of the distribution of the ISI's. In Figure 4.1A, the modal ISI is 0.66 - 0.83 seconds in length.

Most of the records were obtained during the first few minutes of a feed, beginning as soon as the baby went on to the breast. For comparison, therefore, the corresponding pooled data obtained from the video recordings of all episodes 1A in Chapter 3 are presented in Figure 4.1B in the same form, a histogram in bins of 1/6 second. The 1A episodes cover approximately the same

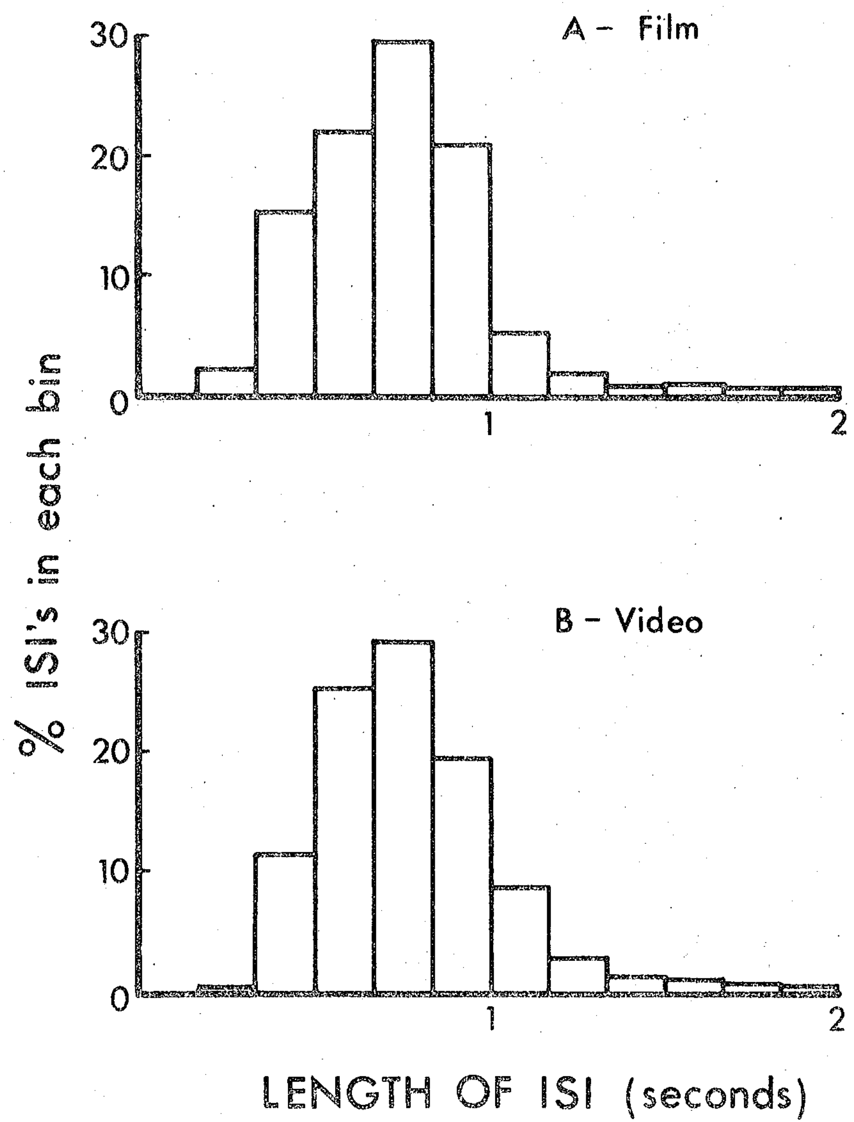


Figure 4.1 Distribution of inter-suck intervals

stage of the feed as was filmed.

The two histograms are very similar and the modal ISI in Figure 4.1B is again 0.66 - 0.83 seconds, which is the same as that of the film data of Figure 4.1A. This validates video recording as an accurate technique for the measurement of ISI's since the modal sucking rate is the same when measured more reliably, hence no systematic error occurs with video. There is no suggestion of a bimodal sucking rate with either technique.

TABLE 5.1

Subjects	Parity of mother	Age of baby in days at each session
Ms B. and Emma	2	44, 49
Ms C. and Alice	1	35, 50, 56, 63
Ms C. and Michael	1	72
Ms D. and Hannah	2	33
Ms F. and Anne-Marie	1	39
Ms F. and Lorna	1	55
Ms K. and Barbara	1	34

health of both mother and baby.

5.3. Procedure

Mother and baby were fetched so as to arrive at the nursery approximately 15 minutes before the estimated time of the baby's next feed, giving an opportunity to settle in and to discuss the procedure for the feed.

Just before being put to the breast, the baby was weighed on a Mettler E20 top loading balance, modified for the purpose by having a child's car safety seat with its straps removed fixed to it at a suitable angle (see Figure 5.1). The balance, which is designed to withstand tough working conditions and is not harmed by the movements of a restless baby, weighs up to 20kg and the tare extends to 5kg so that the scale can be adjusted to zero with the seat in place. Weighing was done to the nearest 10g, or to 5g if the baby remained exceptionally still, which is sufficiently accurate for the purpose of monitoring milk intake during a feed. The child remained in the same clothes throughout the feed so that any increases in weight could be attributed entirely to milk ingested. Losses due to the evaporation of sweat and the loss of water vapour from the lungs during the feed are insignificant relative to the gains involved.

When the baby began to show signs of hunger the video equipment (described in Chapter 3) was switched on, the camera focused on the child's face, and breast feeding began. The choice of which breast to put the child to first was left to the mother.

Figure 5.1. Mettler E20 balance modified for weighing babies

A stop-clock was switched on when the baby first took the nipple fully into his mouth, as opposed to simply mouthing or licking it. Sucking usually followed immediately. After three minutes, whatever the proportion of that time actually spent on the nipple (provided that the infant was held throughout in a position which allowed feeding), the baby was lifted from his mother's arms and weighed. If he was sucking at the time, the mother would often wait until the end of a sucking burst and then gently extricate her nipple from his mouth. Removal of the baby occasionally elicited some protest, especially in the early part of the feed, although the infants were generally tolerant of being taken off the breast. After weighing, the baby was returned to his mother to resume the feed, and a baby who had cried on being taken from the breast would always settle down again very quickly.

The same procedure was followed throughout the feed, which was thus divided into 3-minute periods timed in each case from the acceptance of the nipple.

The point at which the baby was transferred to the other breast was left to the mother's judgement. Weighing was done at this point too, but because of the flexibility of feeding it often happened that the mother arranged the changeover to coincide with the end of a 3-minute episode. In many cases, the baby had his nappies changed between sides, which necessitated re-weighing before going back on the breast. The duration of the feed was left to the mother and the baby. The 3-minute episodes are referred to as 1A, 1B etc.(for the first side) and 2A, 2B etc. (for the second side).

5.4. Transfer of data onto computer

The video recording of each session was first played in order to obtain a complete record of when the baby was on the breast, i.e., of both the duration and the exact timing of the 3-minute periods and the intervals between them, and of the amount of time actually spent on the breast within these periods.

While watching each session a second time, the sucks were keyed in to the computer as described in Chapter 3, giving a record of the ISI's in centiseconds; the times at which the baby went on and came off the breast within each 3-minute period were also inserted by the use of a second key. A complete computer record of a feed consisted of the above data for each 3-minute episode, together with the following information:

Name and age of baby
Date of session
Left or right breast
1st or 2nd side
Serial order of episode on each breast - A, B, C, etc.
Interval from preceding episode
Milk intake during the 3 minutes

The ISI's were stored in 10-centisecond bins. The cut-off point of 1.3 seconds, established in Chapter 3, was used to differentiate between the ISI's of bursts and those of pauses; only ISI's below this value were included in the subsequent calculation of sucking rates.

5.5. Results

5.5.1. Sucking patterns

The data were analysed by comparing the sucking pattern analysed as specified in section 5.4, during the first, second and third 3-minute periods of sucking on the first breast, i.e. episodes 1A, 1B, 1C (there were not enough episodes from side 2 to allow a similar analysis through this side); and from episode 1A to episode 2A, using one averaged value per subject in each case. 1A and 2A are episodes fairly far apart in the feed which allow a comparison of sucking patterns with similar milk flow rates but presumably differing extents of satiety in the baby. This comparison is carried out in order to examine any effect of hunger on sucking patterns.

The measures examined were:

Mean ISI;

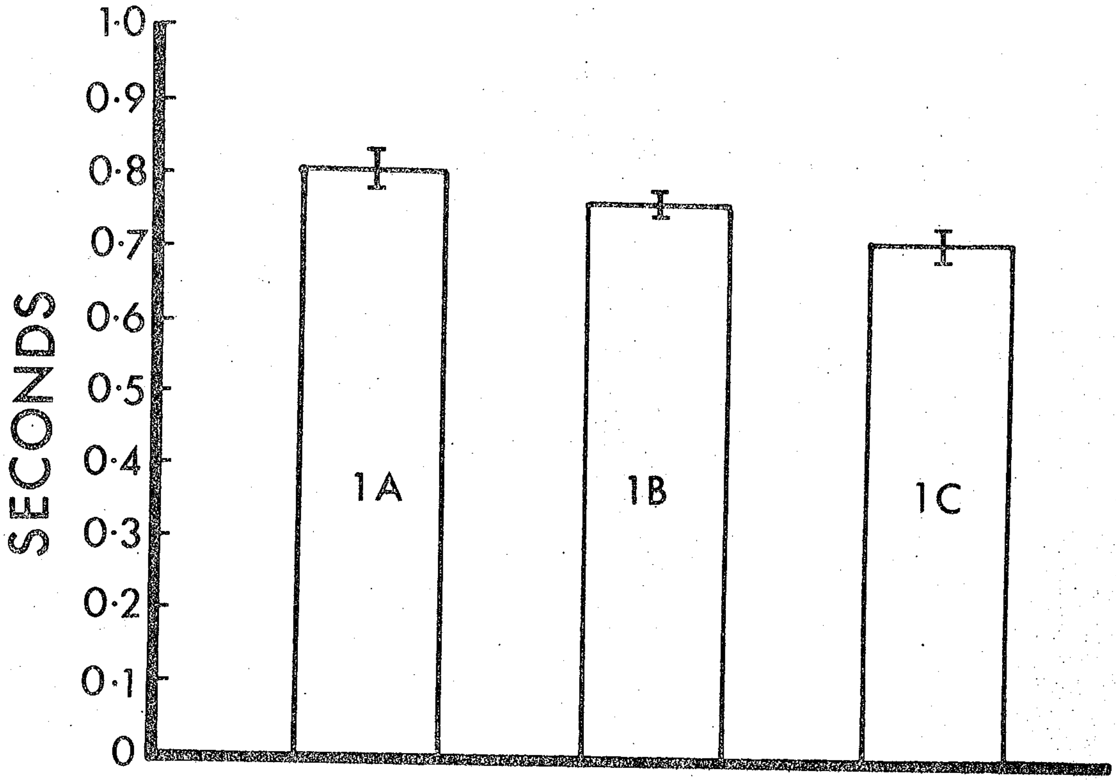
Mean pause length;
Mean burst length;
Mean number of sucks/burst;
Mean % pausing time

(as defined in section 3.5).

In two subjects out of the seven, the feed on side 1 did not include an episode 1C and so they were excluded from the first part of each analysis, i.e. comparison of 1A, 1B and 1C. Analysis of variance was carried out on these measures as they varied from 1A to 1C and a t-test for correlated samples was used to compare episodes 1A and 2A. The data are given in Figures 5.2 - 5.11.

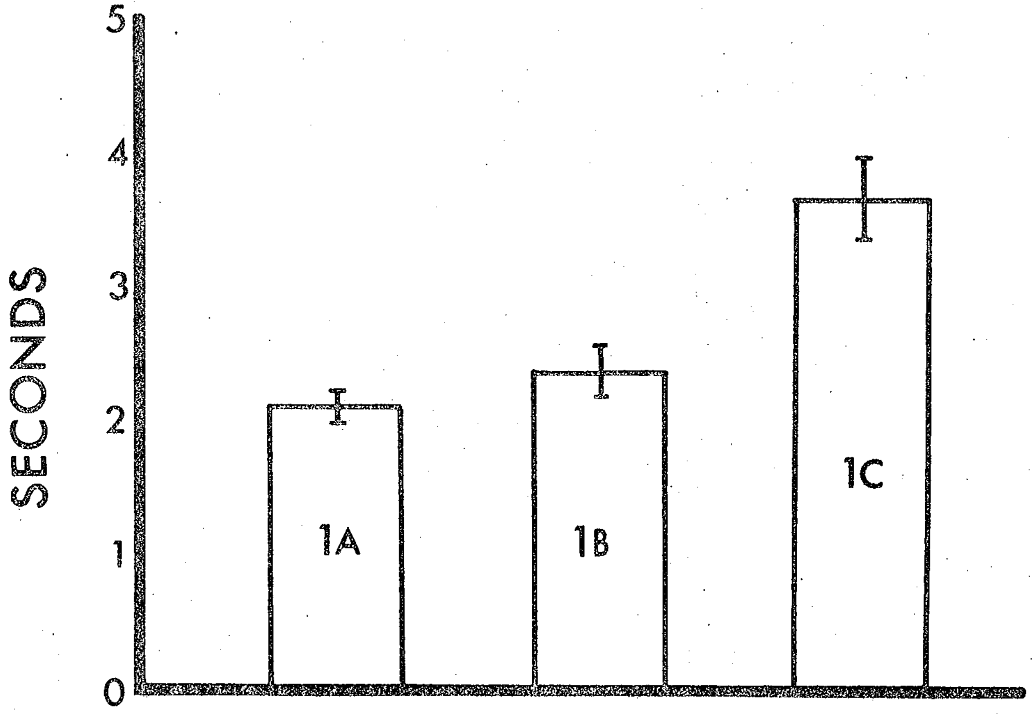
FIGURES 5.2 - 5.6

COMPARISON OF THE THREE CONSECUTIVE 3-MINUTE EPISODES ON BREAST 1 (1A, 1B, 1C)



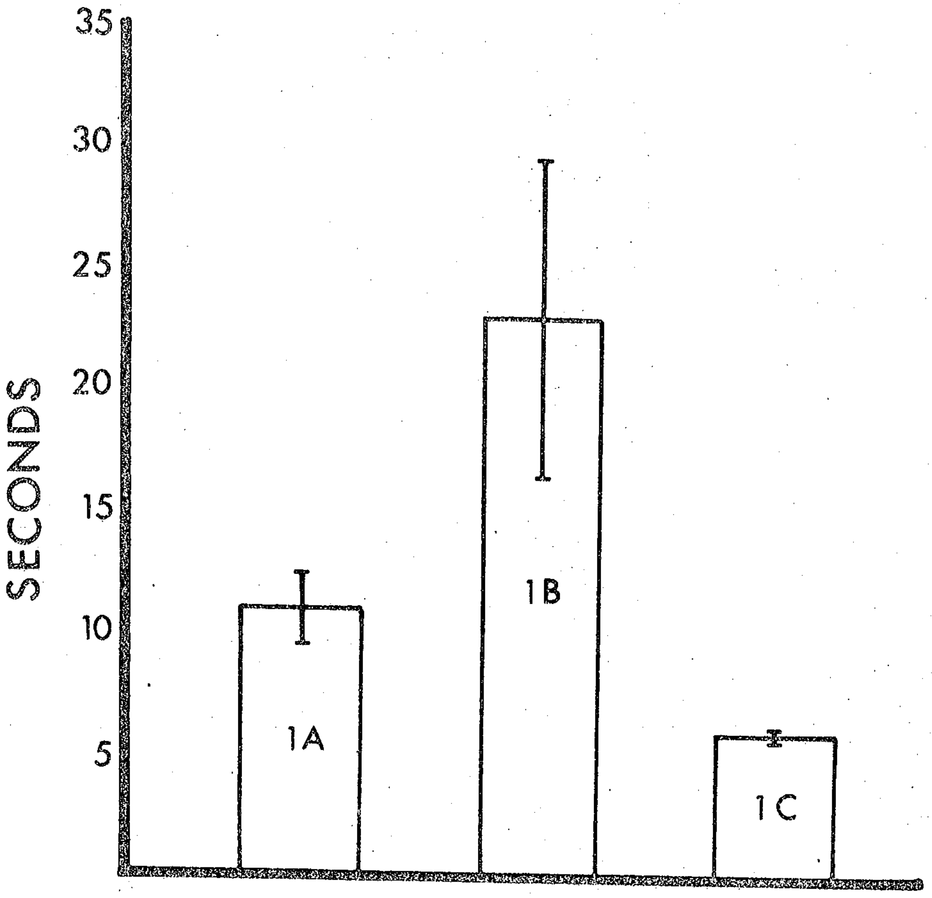
ANOVAR F = 12 , df = 2,8, p= <0·005

Figure 5.2. Mean ISI + S.E.'s



ANOVAR, df = 2, 8, F = 6·31 $p < 0.05$

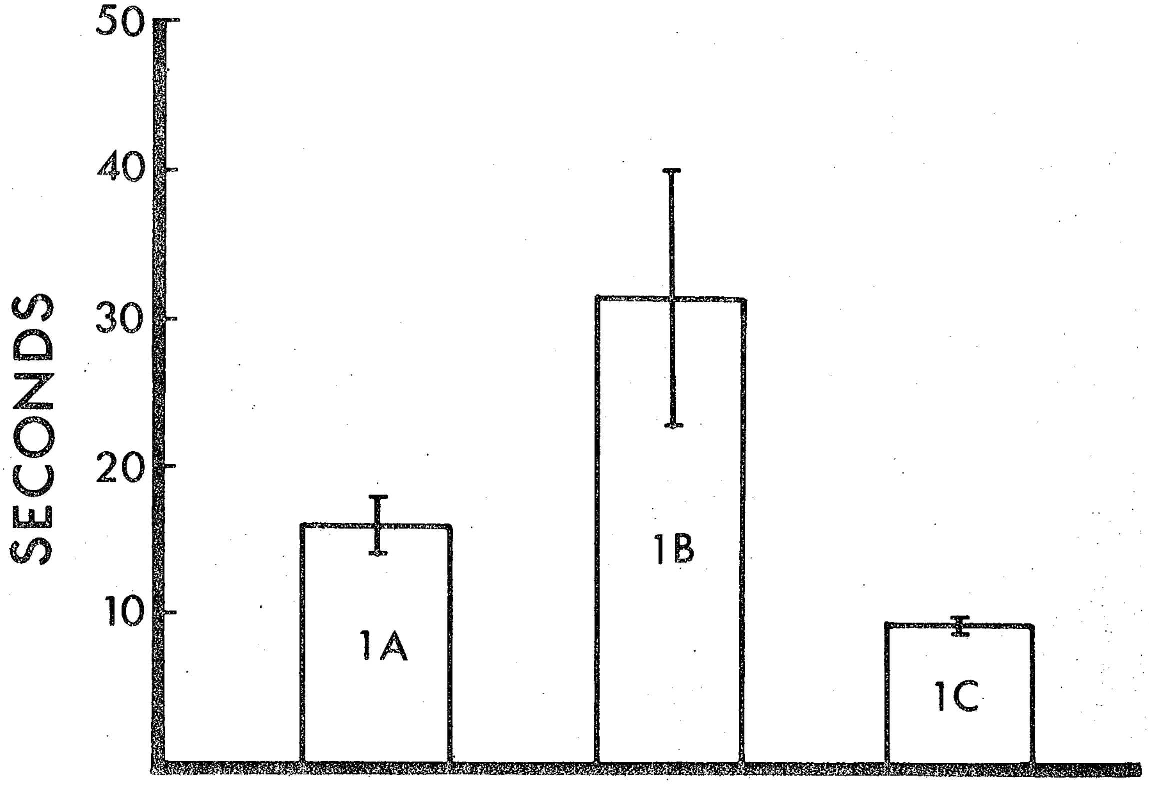
Figure 5.3. Mean pause length + S.E.'s



ANOVAR, df = 2.8, F = 1·00, N.S.

Figure 5.4. Mean burst length + S.E.'s

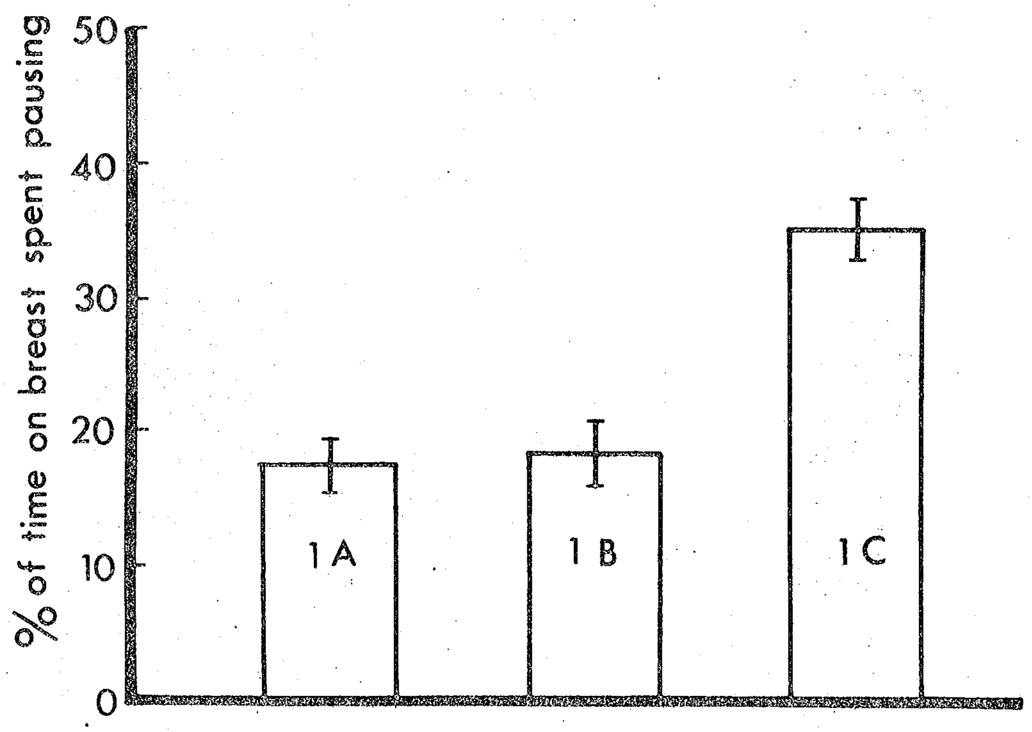
The differences were still not significant after logarithmic or square root transformation of the data (to deal with the unequal variance).



ANOVAR, df =2, 8, F =0·99 N.S.

N.S. also after logarithmic or square root transformation

Figure 5.5. Mean no. sucks/burst, + S.E.'s



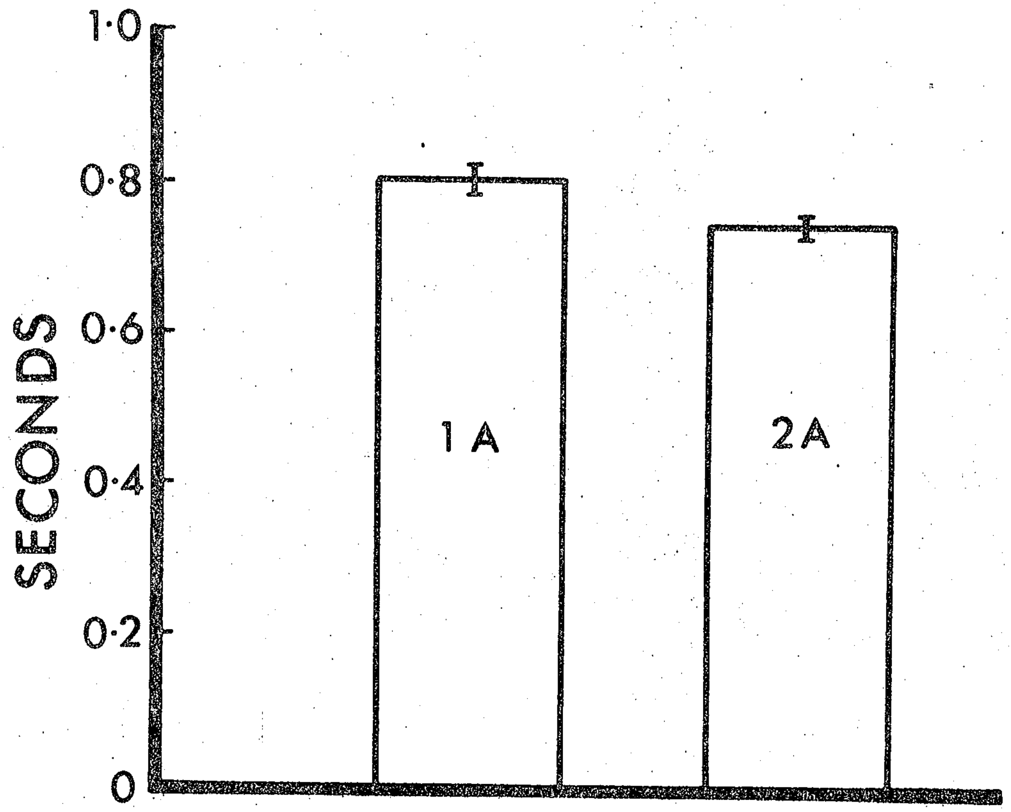
Anovar, df - 2·8, F = 6·30, $p < 0{\cdot}05$

Figure 5.6. Mean % pausing time + S.E.'s

FIGURES 5.7 - 5.11

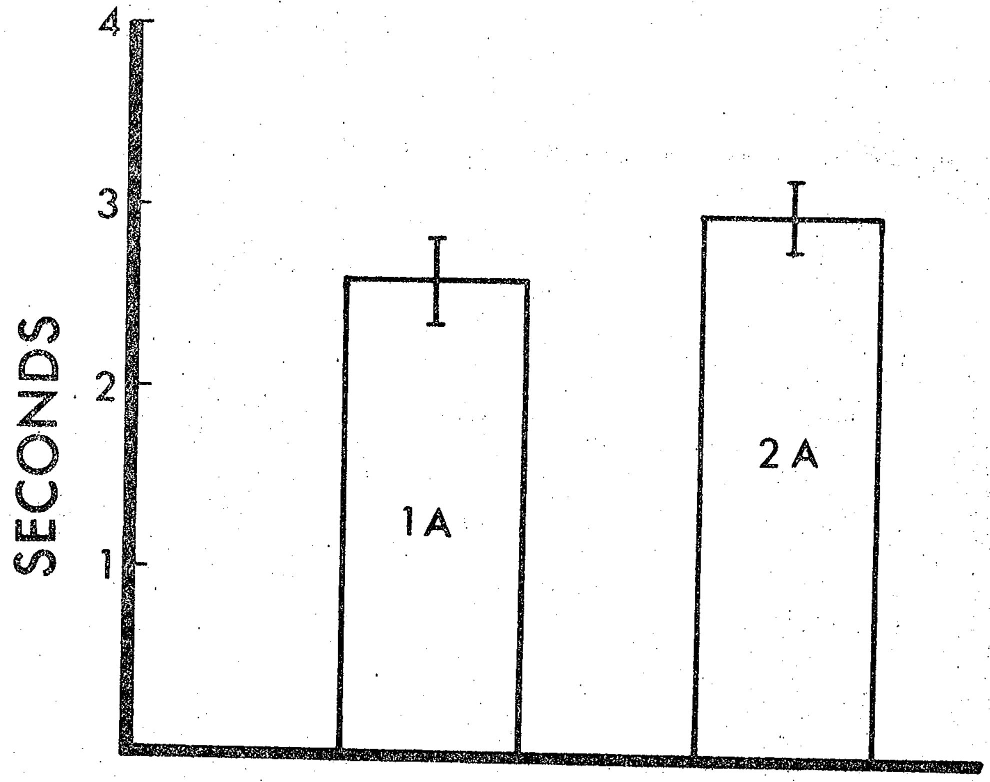
COMPARISON OF BREAST 1 and BREAST 2

FIRST 3 MINUTES ON EACH (1A and 2A)



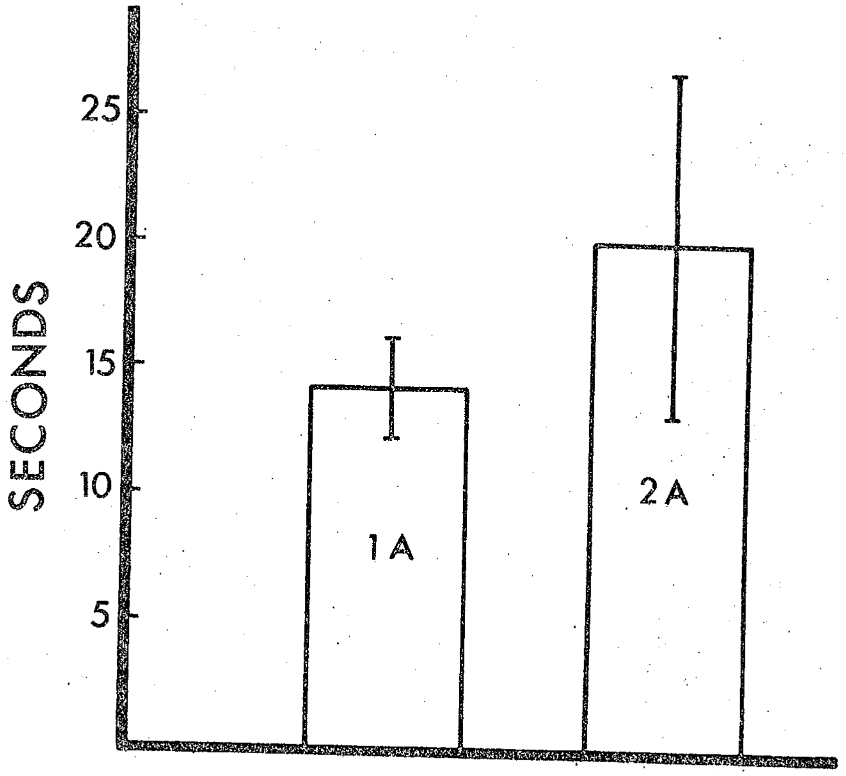
df = 6, t = 1·9625, N.S.

Figure 5.7. Mean ISI + S.E.'s



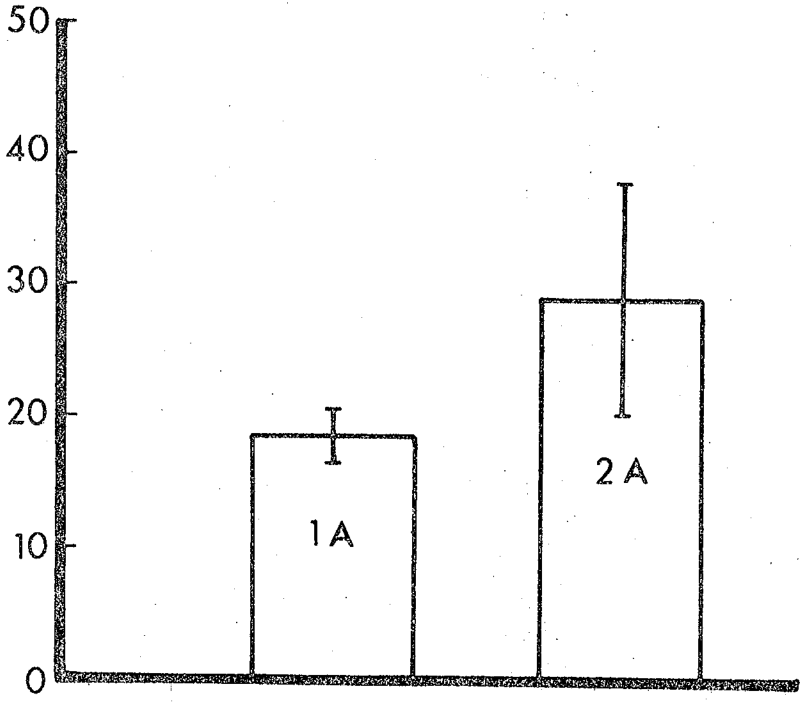
t= −0·7131, df = 6, N.S.

Figure 5.8. Mean pause length, + S.E.'s



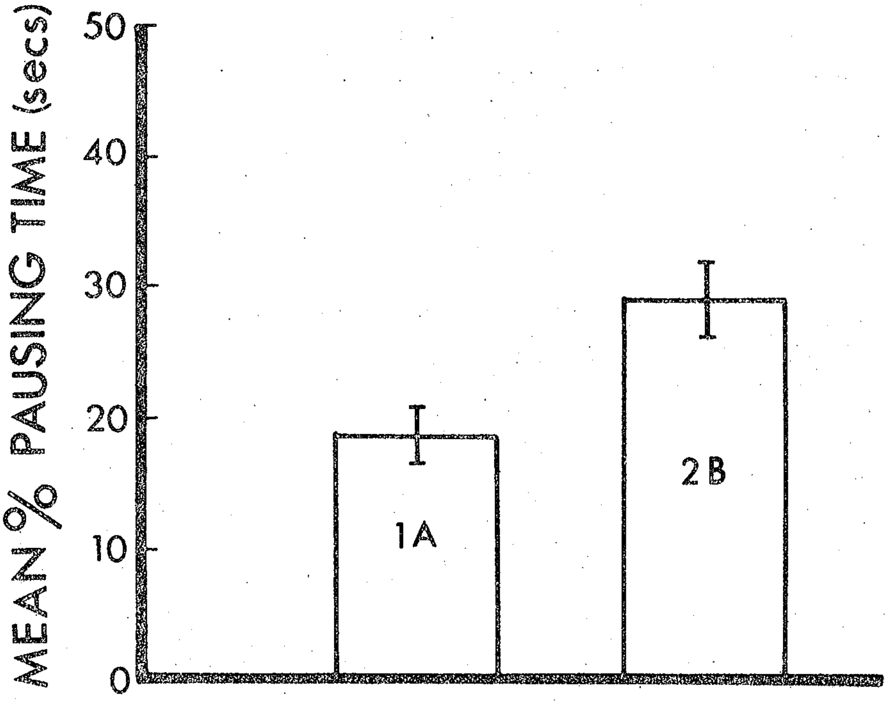
t = −0·454, df = 6, N.S.

Figure 5.9. Mean burst length ± S.E.'s



t = −0·529, df = 6, N.S.

Figure 5.10. Mean no. sucks/burst + S.E.'s



t = -1·7751, df = 6, N.S.

Figure 5.11. Mean % pausing time + S.E.'s

We can now summarise the results, as follows:

(1) Mean ISI decreases from the beginning to the end of the first half-feed. Over the same period, mean pause length and % pausing time increase.

(2) There is no significant difference between sucking for the first three minutes on breast 1 and on breast 2 (i.e., between episodes 1A and 2A), on any measure.

In order to allow comparison with other experiments, the data of the first half-feed were also analysed using the criteria used by, for example, Lipsitt (1976) and Kaye (1977), see Table 5.3. In this analysis, a burst is recorded when two or more ISI's of 2.0 seconds or less occur together, i.e. when three or more sucks are separated by 2.0 seconds or less.

Although the changes through side 1 are less pronounced with these criteria, the changes are similar in that mean ISI decreases and percentage pausing time increases whilst mean burst length and the mean number of sucks per burst do not significantly change. Mean pause length does not increase using these criteria, whereas it does so with those used before. Clearly the main differences, in ISI and % pausing time, are robust and survive a certain element of analytic arbitrariness.

TABLE 5.3

SUCKING PATTERNS DURING THE FIRST HALF-FEED, ANALYSED WITH COMMONLY-USED CRITERIA WHERE A BURST = 2 OR MORE ISI's OF 2.0 SEC. +

				Analysis of variance df 2,8	
	1A	1B	1C	F	p
Mean ISI	0.86	0.81	0.78	9.18	0.01
Mean pause length	3.35	3.16	4.96	2.52	N.S.
Mean burst length	47.09	66.72	13.49	0.82	N.S.
Mean no. ints/burst	55.0	87.5	18.53	0.83	N.S.
Mean % pausing time	9.17	12.26	29.65	7.75	0.02

5.5.2. Milk intake during breast feeding

In this experiment milk intake through a breast feed was monitored by weighing the baby at intervals. This was done in order to examine the relationship between the amount of milk taken in with each suck and the sucking pattern; but the data obtained on milk intake are themselves interesting since they provide information on how much milk is taken by the baby at various stages of the feed on both breasts. Such data may be clinically useful in the management of lactation, for instance, in deciding how long the baby should be fed. Other studies are based upon the amount of milk obtained by extraction with a breast-pump from one breast as the baby feeds from the other (Hytten, 1954; Hall, 1975); on cross-sectional test-weighing data, for example Lucas, Lucas and Baum (1979);or else the method is not given, for example Smith and Merritt (1922).

Intake is determined by the milk available and the baby's readiness to ingest it, so procedures which extract all the milk in the gland do not necessarily reflect the volume of milk the baby would actually ingest at any one feed.

Figures 5.12 and 5.13 show, respectively, the mean amount of milk ingested during each 3-minute interval and the mean intake of milk per minute of time actually spent on the breast, as the feed progressed. Figure 5.14 shows the pattern of milk intake during the feed (a mean value of the percentage of the feed taken in each episode was calculated for each baby, and the mean of these calculated). Figures 5.15 and 5.16 show how the milk intake is distributed between the two half-feeds, in terms of grams per half-feed and grams per minute on the breast, respectively.

All the mothers rountinely alternated which breast they gave to their babies first so that the first breast given at a particular feed is that which was given last in the previous feed. This alternation prevents the uncomfortable build-up of milk in one breast which could lead to engorgement

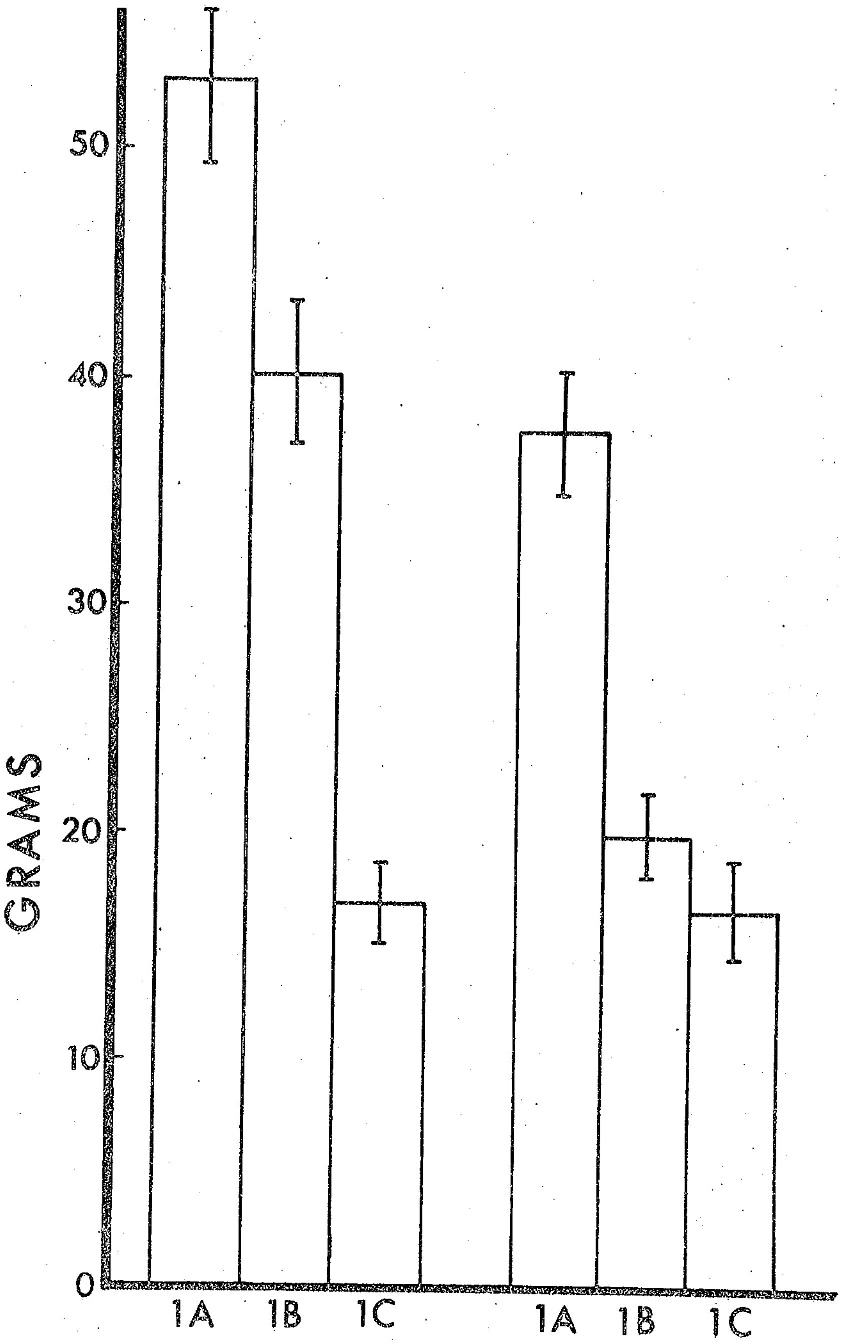


Figure 5.12. Mean milk intake per 3-minute episode + S.E.'s

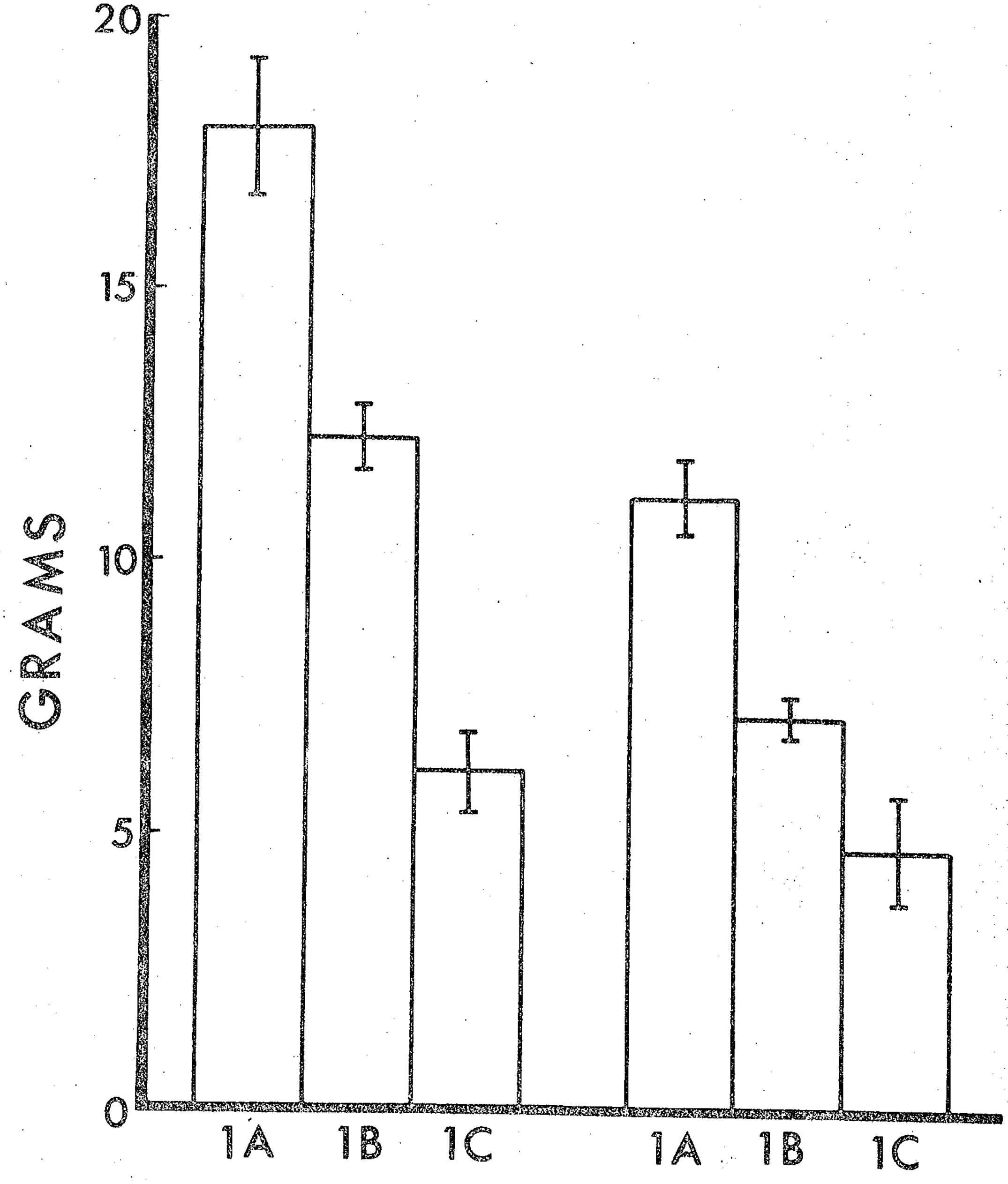


Figure 5.13. Mean milk intake in grams per minute on the breast, + S.E.'s

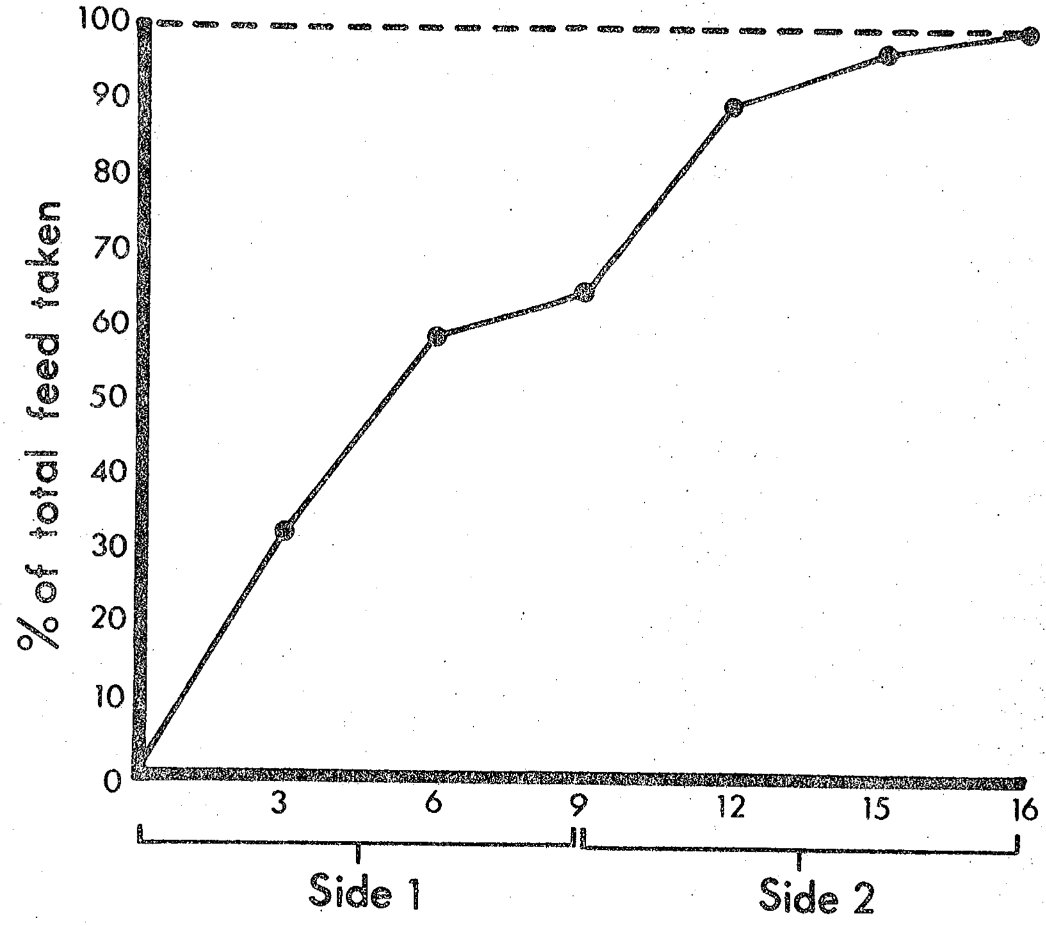
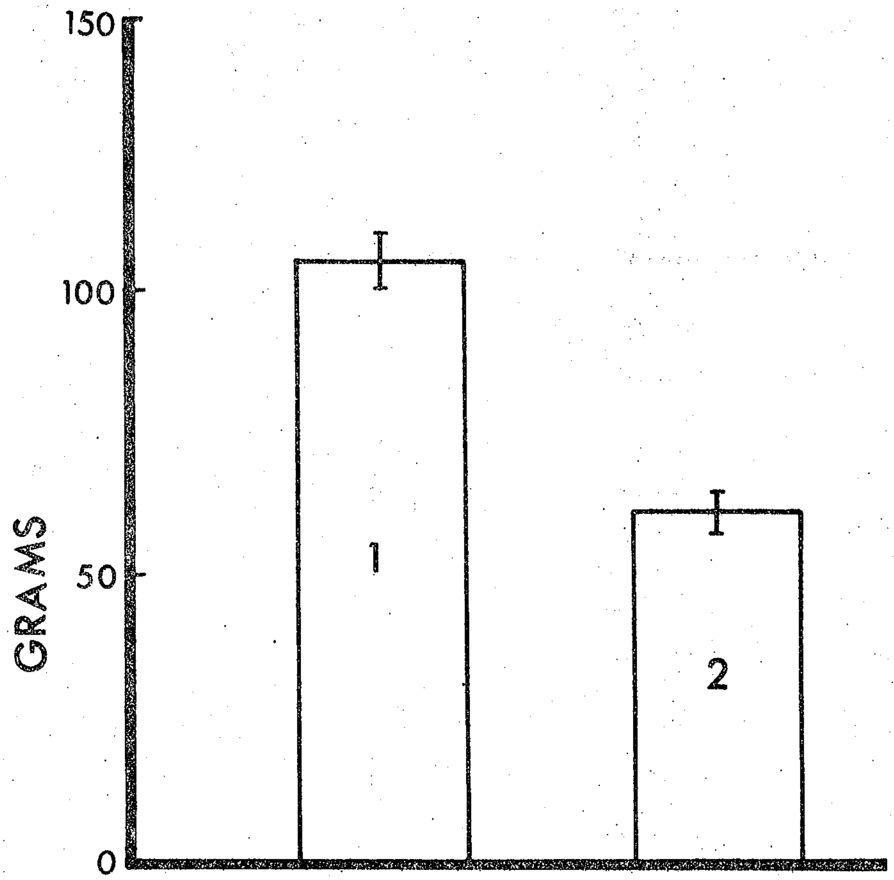
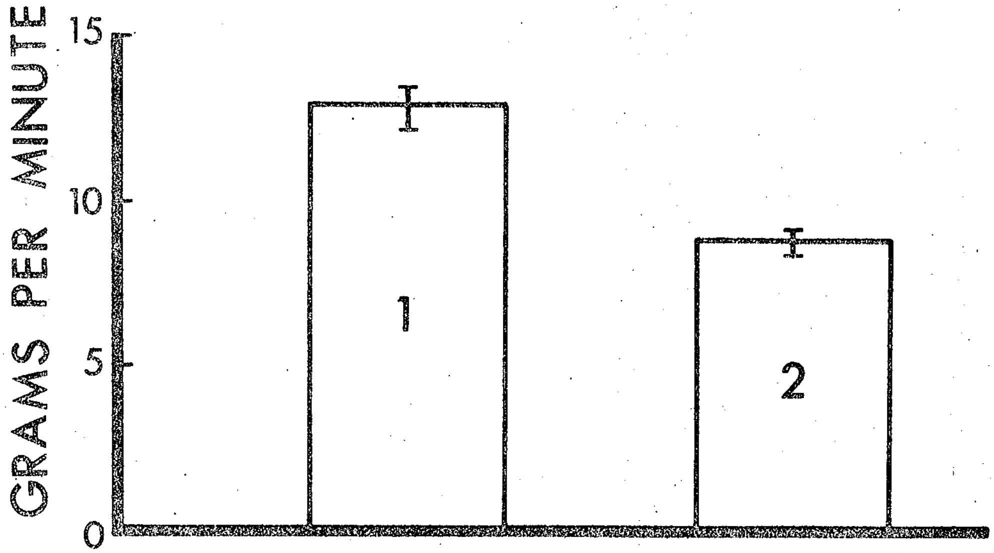


Figure 5.14. Pattern of milk intake throughout the feed



SUBJECT		
EB	143	55
AC	80	46
MC	130	75
HD	80	30
AF	110	80
LF	100	70
BK	90	70

Figure 5.15. Milk intake + S.E.'s. Side 1/side 2



SUBJECT		
EB	16·1	6·8
AC	11·5	10·5
MC	17·6	9·4
HD	14·5	9·6
AF	9·5	11·3
LF	9·7	5·8
BK	11·5	7·9

Figure 5.16. Rate of milk intake + S.E.'s side 1/side 2

and infection, and also stops one breast eventually becoming larger than the other.

Mean milk intake on breast 1 is 72% greater than that on breast 2, amounting to 63% of the total intake. The rate of milk intake is correspondingly greater. Intake per 3-minute episode declines through side 1 and through side 2; intake in the first episode of side 2 is higher than that of the last on side 1. Using intake per minute on the breast as a measure, these trends are equally pronounced - intake declines steeply through side 1, rises again as the baby goes onto the second side, but only to just over 60% of the value attained in episode 1A, and then falls off gradually.

In episode 1A (three minutes), the baby obtains approximately 51% of his intake on the first side, and approximately 90% in episodes 1A and 1B together, which make up the first six minutes of the feed. This accords with Smith and Merritt's figure of 40-60% of the milk being taken during the first four minutes of the feed when the baby is fed on one breast only during a feed (Smith and Merritt, 1922). Lucas, Lucas and Baum (1979) found that 6-day old infants had consumed over 45% of the milk intake on the first breast in two minutes and 90% after four minutes on that breast.

It may appear from this that very short feeds on each side are adequate; however, as Hall (1975) has pointed out, much of the fat and hence the energy (and also the fat-soluble vitamins) is in the hind milk. Hall quotes a baby as obtaining only 13% of the total milk volume between the 11th and 16th minutes of a feed on one side, but this milk supplied nearly a quarter of the total lipid and one sixth of the total protein and energy.

5.5.3. Milk intake per suck

The milk intake per 3-minute feeding episode was divided by the number of sucks in that episode to give values for the intake in grams per suck. These are of course mean values and there may be considerable variation within an episode. However, 3 minutes is a short enough period over which to pick up differences through the course of a feed. The values of mean milk intake/suck for each episode are given in Table 5.4 and the overall value per episode in Figure 5.17. Individual values range from zero to 0.48g; most fall between 0.1 and 0.3g. The majority of the highest values occurred during the first episode on the first side. Intake/suck declines through the first and through the second half-feeds. It is lower on breast 2 than on breast 1 ($t = 2.63$, $df = 6$, $p < 0.05$). Mean intake/suck in 2A is not significantly lower than in 1A.

TABLE 5.4

MILK INTAKE/SUCK

	1A	1B	1C	2A	2B	2C
EB	0.39 0.48	0.21 0.25	0.21 0.07	0.13 0.12	0.22	
AC	0.23 0.31 0.38 0.16	0.09 0.23 0.30 0.19	 0.09 0.11 0.06	0.10 0.21 0.14 0.31	0.15	
MC	0.41	0.27	0.19	0.22	0.10	0.17
HD	0.31	0.14		0.17		
AF	0.14	0.18	0.05	0.23	0.09	
LF	0.25	0.11	0.06	0.13	0.13	0.00
BK	0.17	0.31		0.20	0.23	0.12

5.5.4. Correlation between sucking measures and milk intake per suck

The five sucking measures used (mean ISI, mean pause length, mean burst length, mean no. sucks/burst and mean % pausing time) were correlated with the corresponding values of milk intake/suck using the Spearman rank-order correlation test. Figures 5.18 - 5.22 show each measure plotted against intake/suck, with the correlation coefficients.

Mean ISI is positively correlated with intake/suck, and mean pause length and mean % pausing time are negatively correlated with this measure.

Since the correlation between mean ISI and flow rate was much the

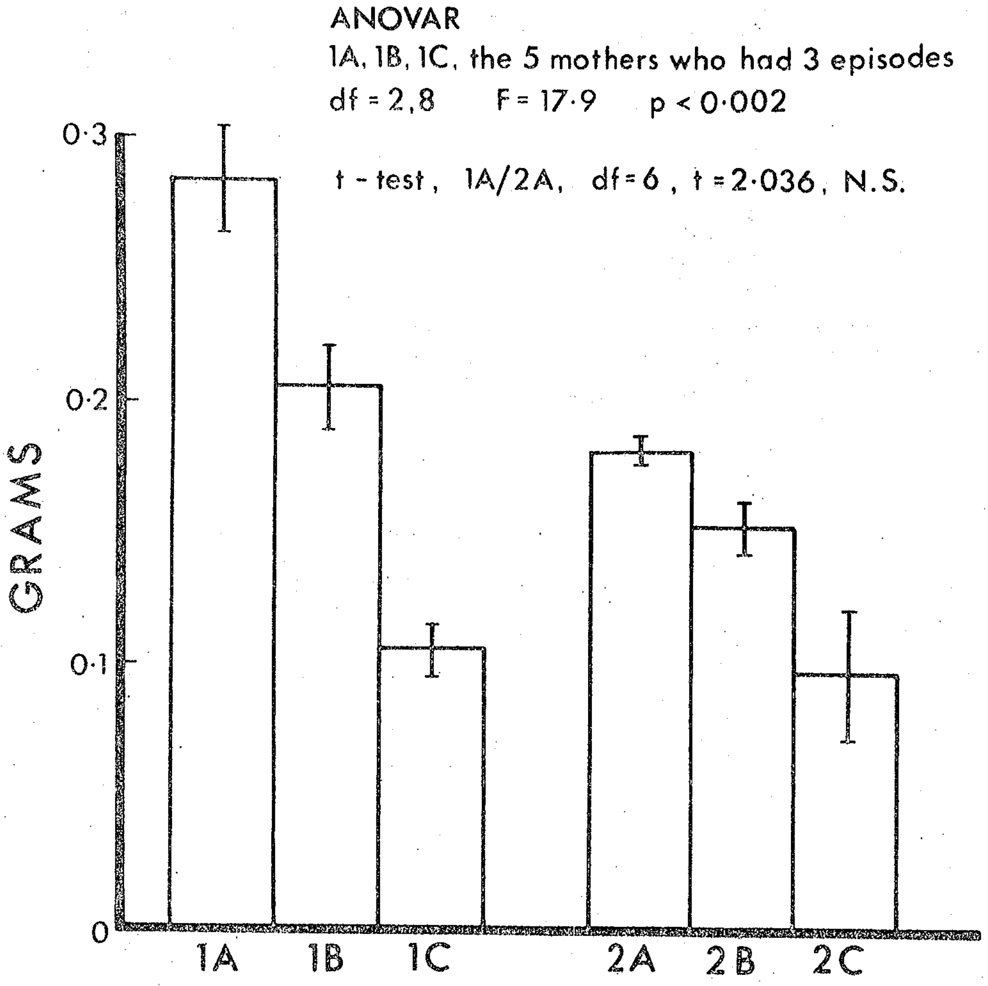


Figure 5.17. Overall mean + S.E.'s intake/suck

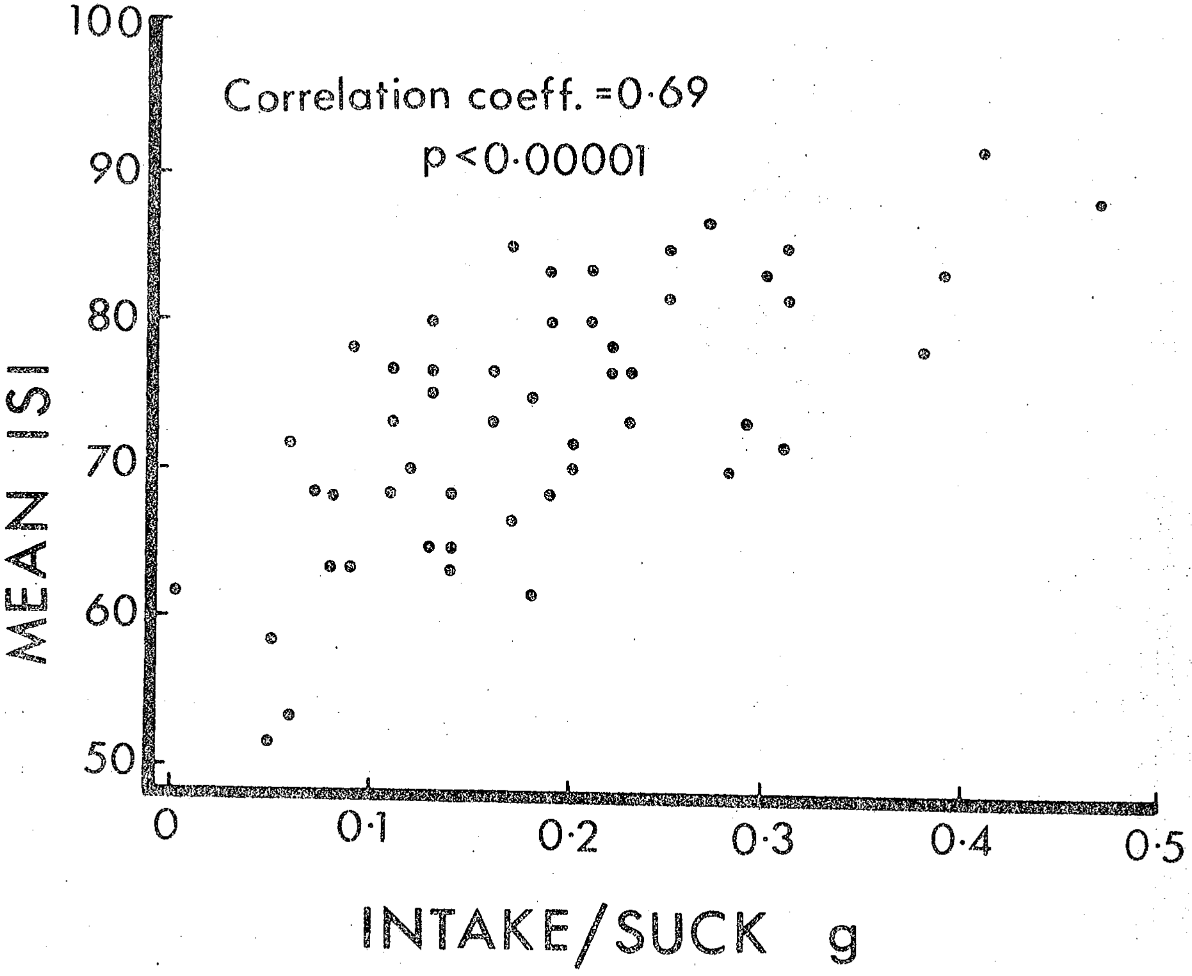


Figure 5.18. Mean ISI vs intake/suck

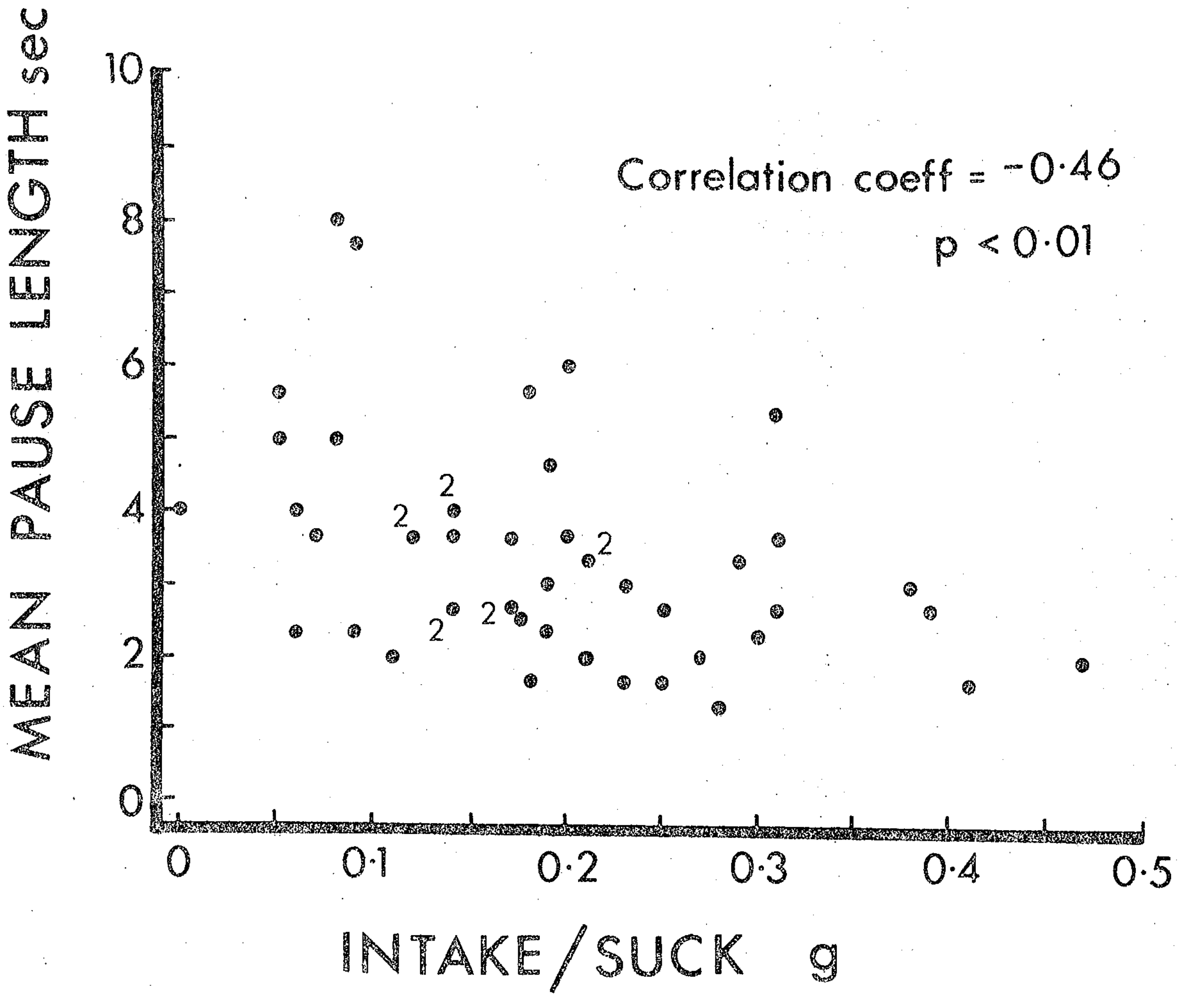


Figure 5.19. Mean pause length vs intake/suck

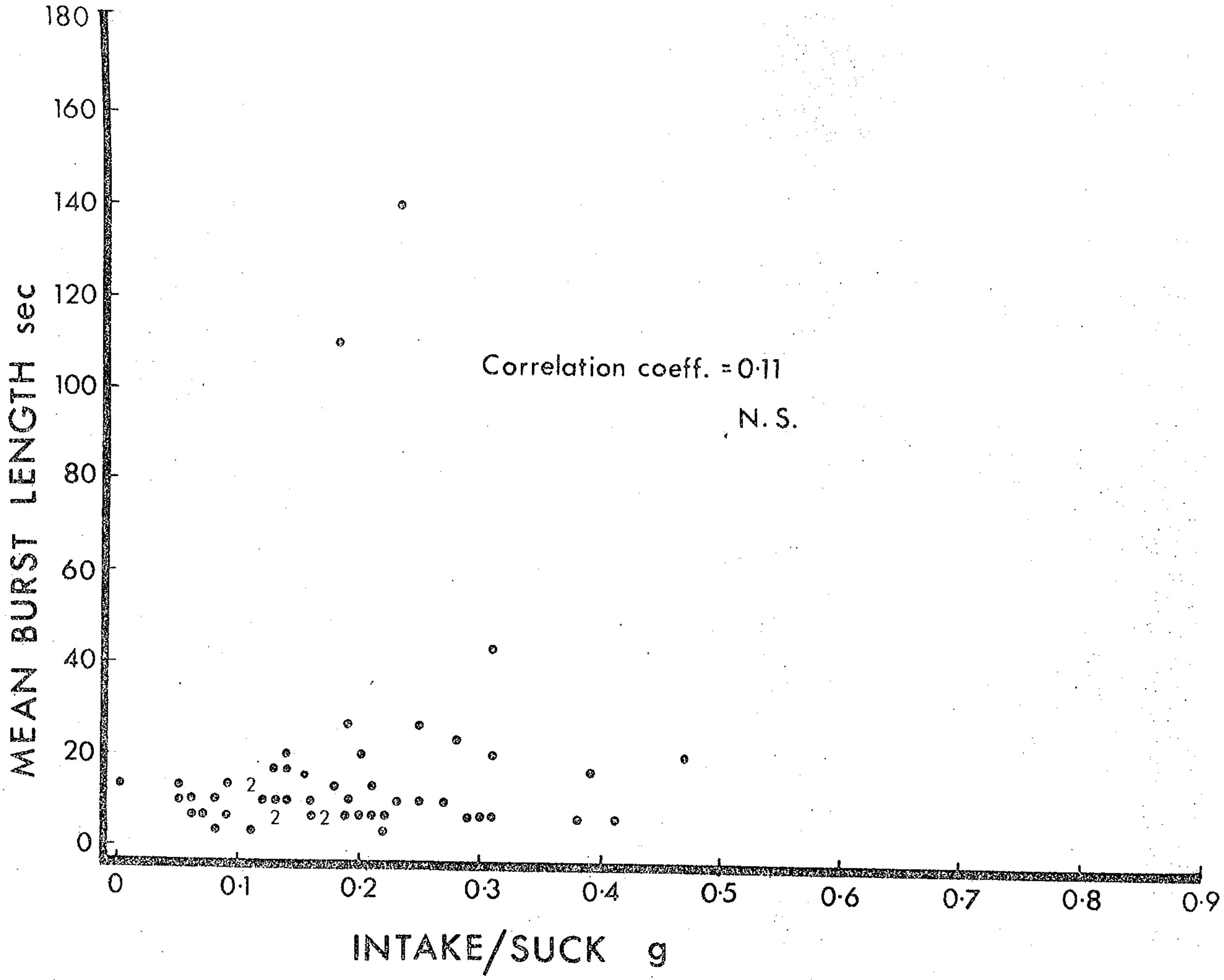


Figure 5.20. Mean burst length vs intake/suck

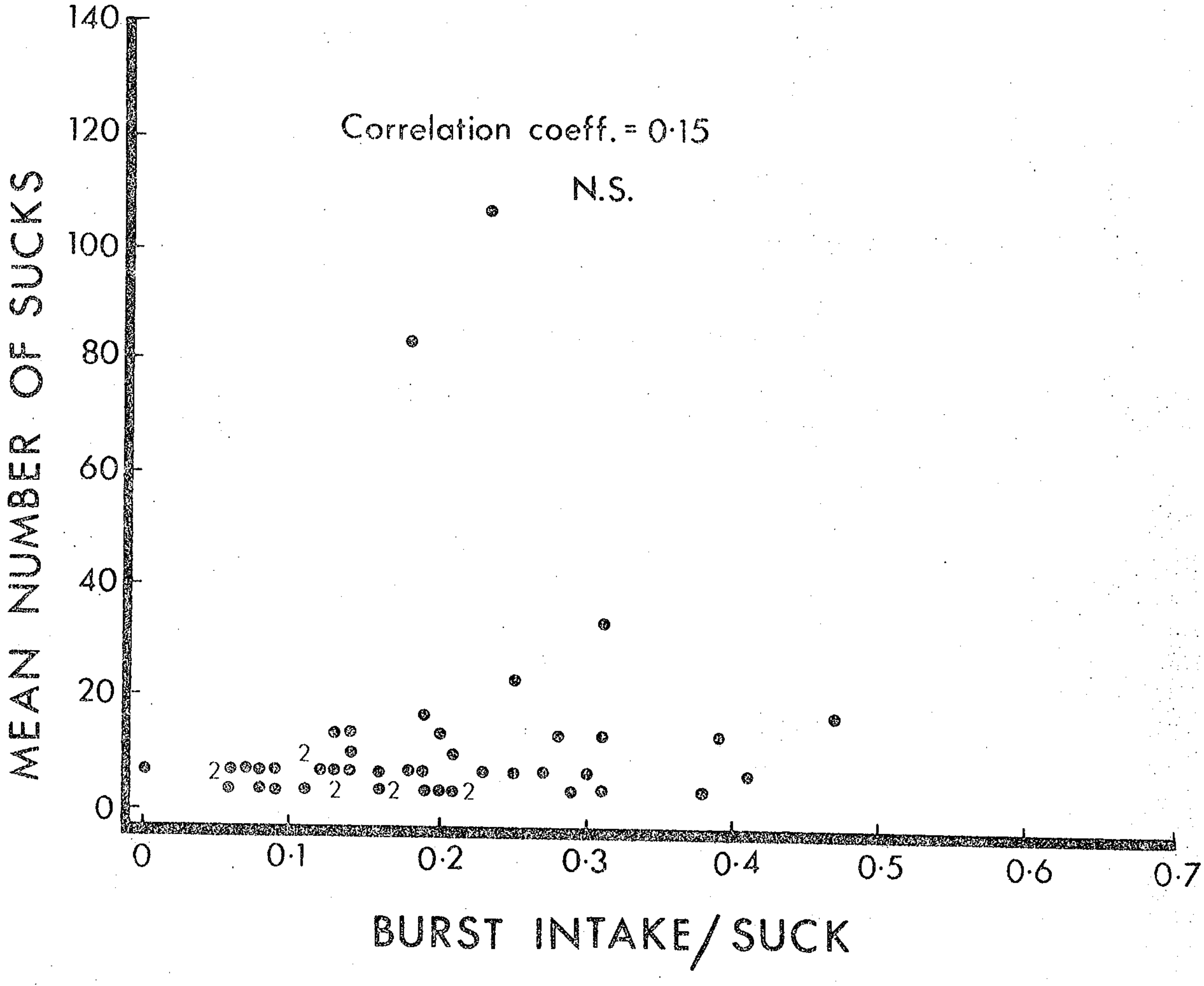


Figure 5.21. Mean number of sucks/burst vs intake/suck

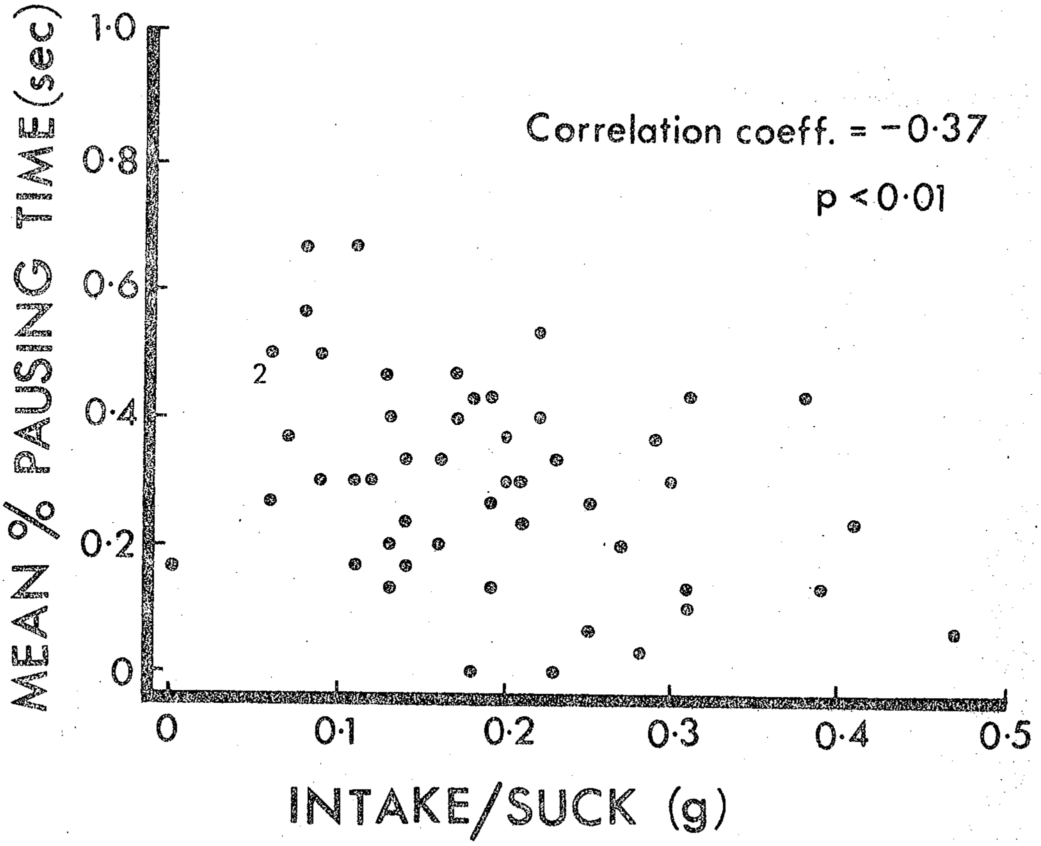


Figure 5.22. Mean % pausing time vs intake/suck

strongest, the relationship between these two measures was further analysed for each baby individually. Values of mean ISI are plotted against the corresponding milk intakes/suck for each baby in Figures 5.23 - 5.29. The gradients (m values) and the F values are given. The F value and its level of significance give an indication of how closely the points approximate to the regression line of mean ISI on intake/suck.

The graphs from the individual infants show even more clearly than the pooled graph the relationship between sucking rates and milk intake/suck; the pooled data lose some of their individual clarity since there are differences in the gradients of the regressions (which are given with each graph). These differences indicate variation among infants in the particular ISI corresponding to a particular value of intake/suck; although the pattern is the same in each case and individual responses are consistent.

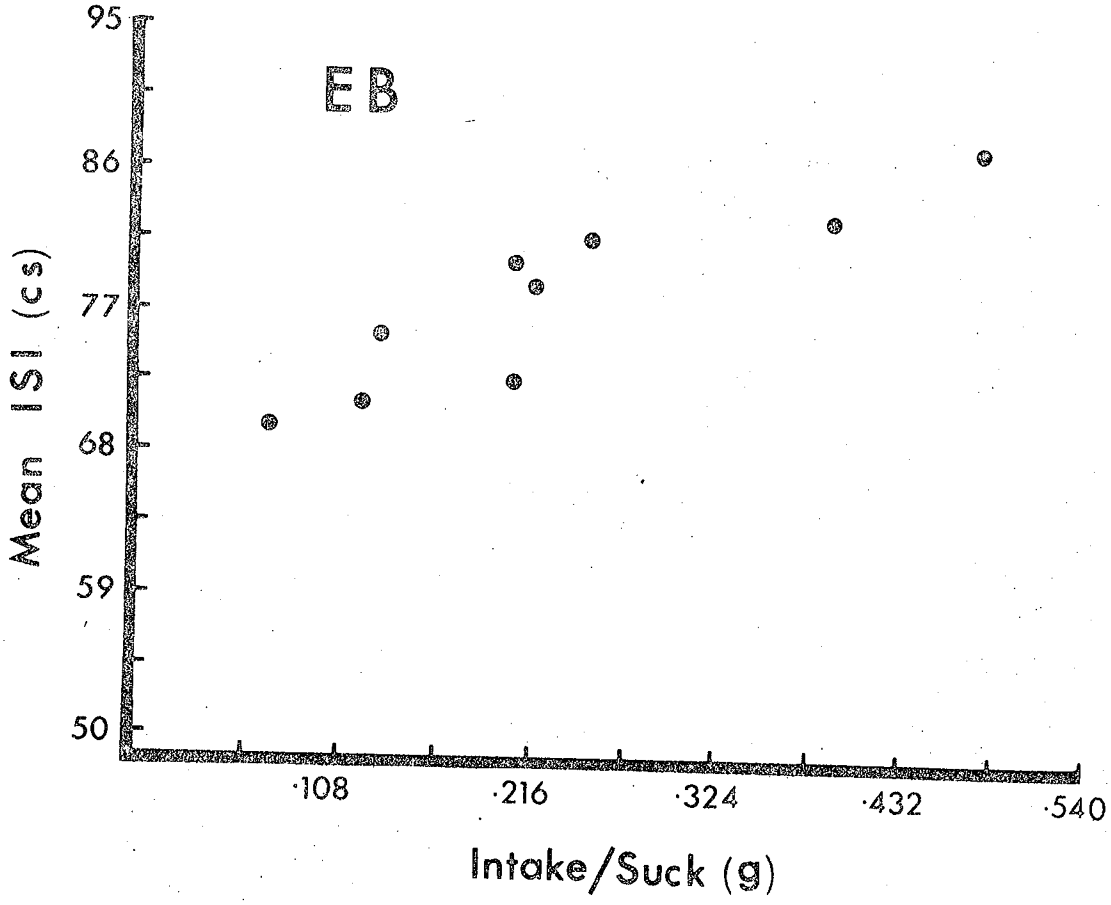
5.6. Discussion

The work presented in this chapter shows in some detail how the sucking of a baby changes during a breast feed. Mean (within-burst) ISI shows a very significant decrease through the first half-feed, and pause length and % pausing time a significant increase. This accords with the direction of the change towards more time spent pausing on side 2 as compared with side 1, i.e. with the progression of the feed, which was noted in Chapter 3. The findings of Chapter 3 are extended in that a graded pattern of changes in several sucking parameters on the first breast is shown. There is the indication of mean ISI varying inversely with pause length, i.e. periods of slower sucking are interspersed with shorter pauses. This suggests that the two covary as part of an overall change in sucking pattern, although this need not imply that both are necessarily determined by the same factors.

It has been said that the baby spends less time sucking as a feed progresses, on the breast (Peiper, 1961; Luther et al, 1974; Kaye, 1977) and on the bottle (Dubignon and Campbell, 1969; Crook, 1977). However, no data

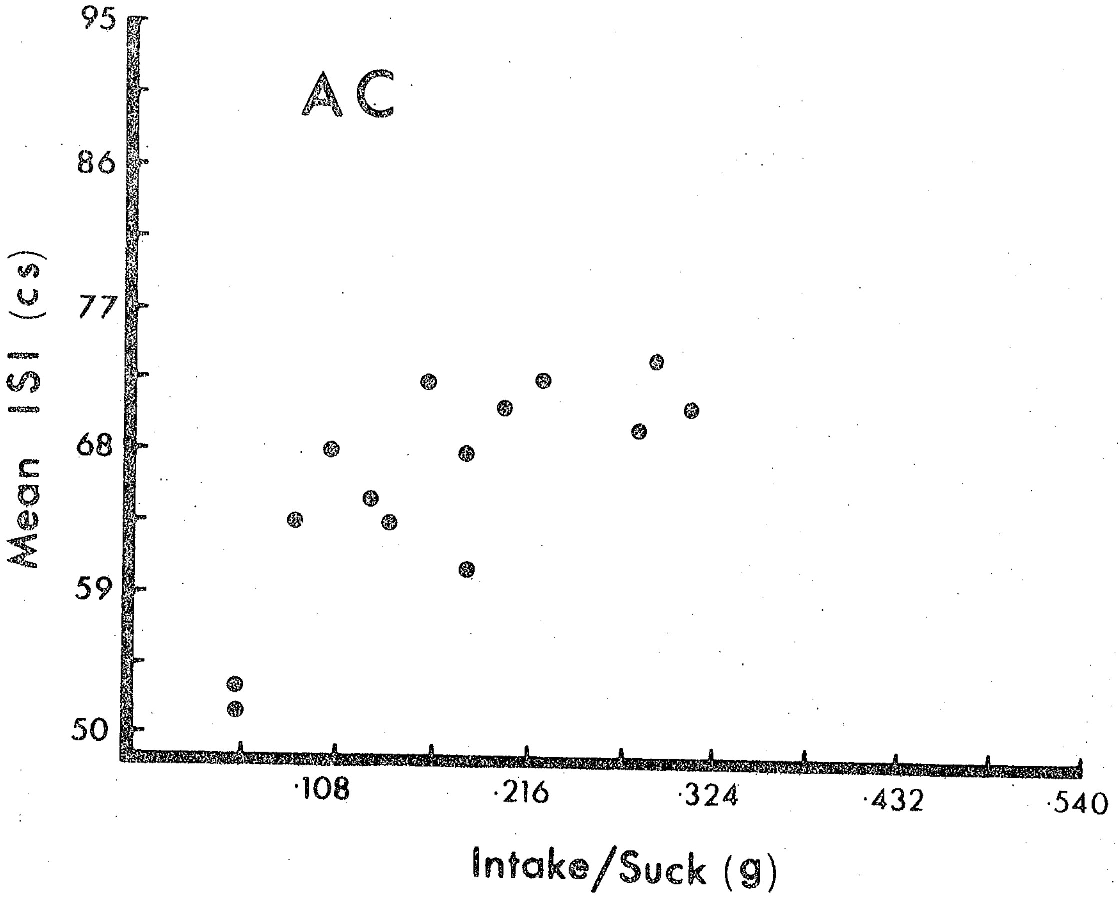
FIGURES 5.23 - 5.29

MEAN ISI vs MILK INTAKE/SUCK FOR EACH BABY INDIVIDUALLY



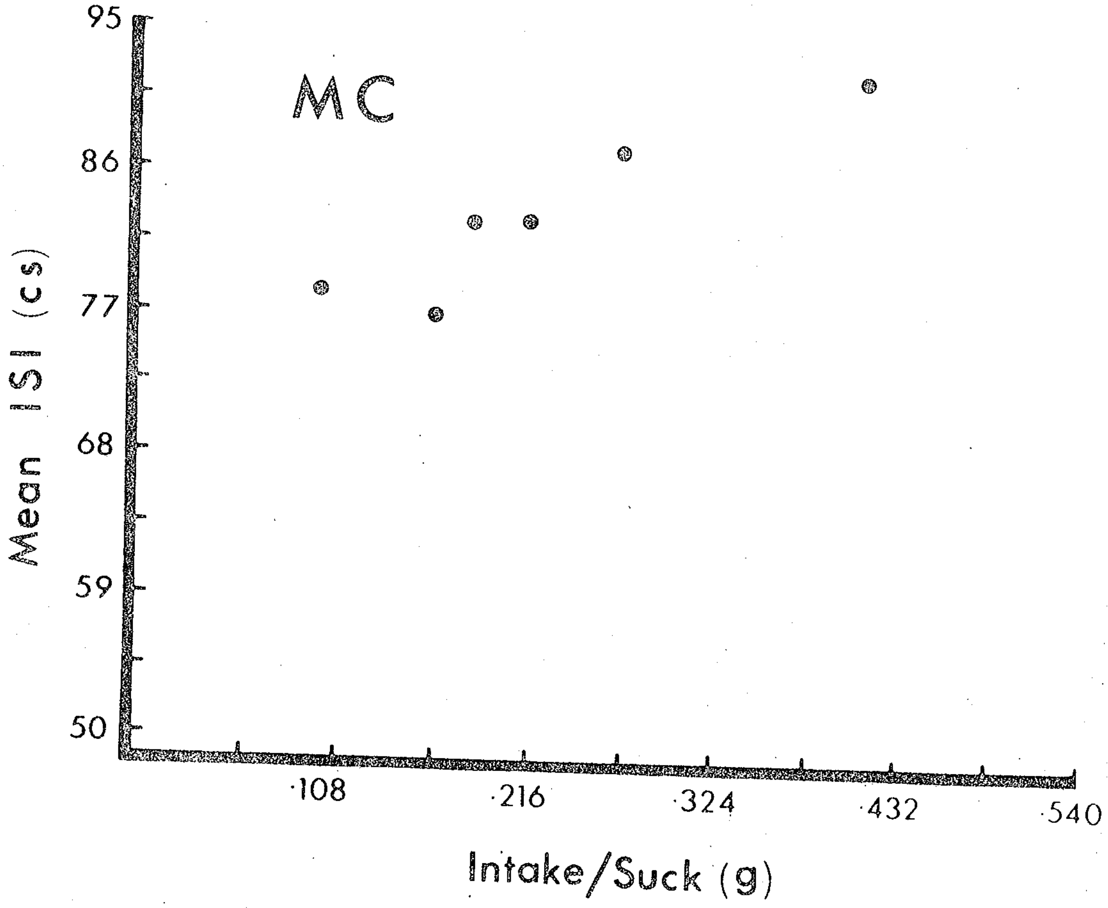
F value = 33.54; $p < 0.001$; gradient (m) = 43.90

Figure 5.23



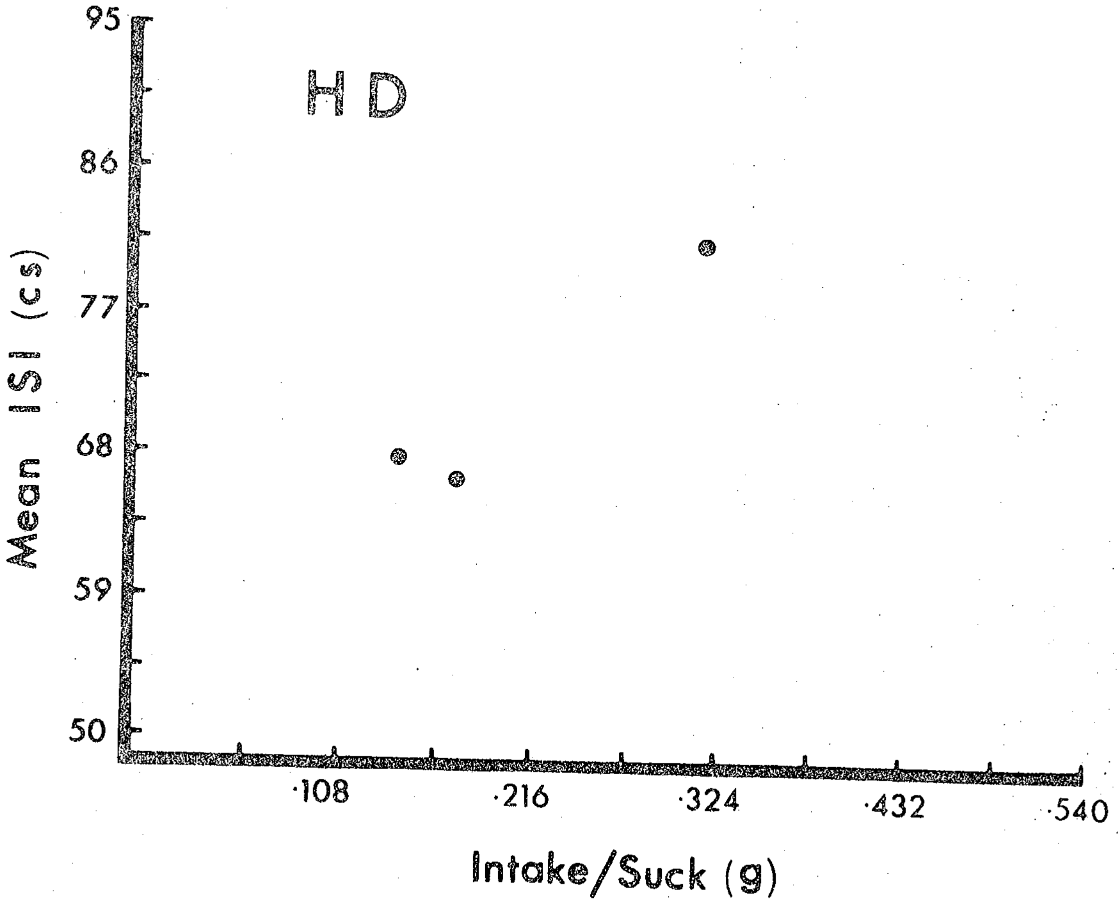
F value = 28.74; $p < 0.0001$; gradient (m)=68.08

Figure 5.24



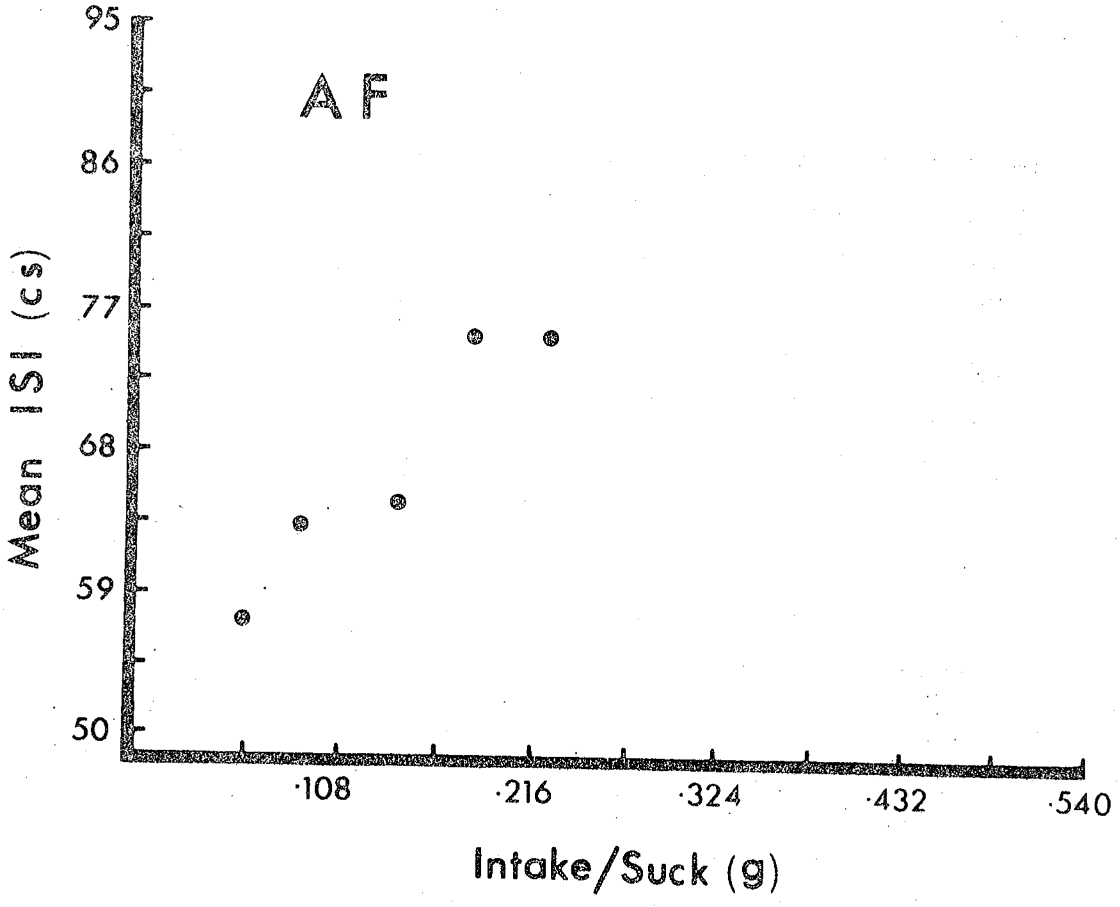
F value = 25.23; $p < 0.01$; gradient (m) = 48.76

Figure 5.25



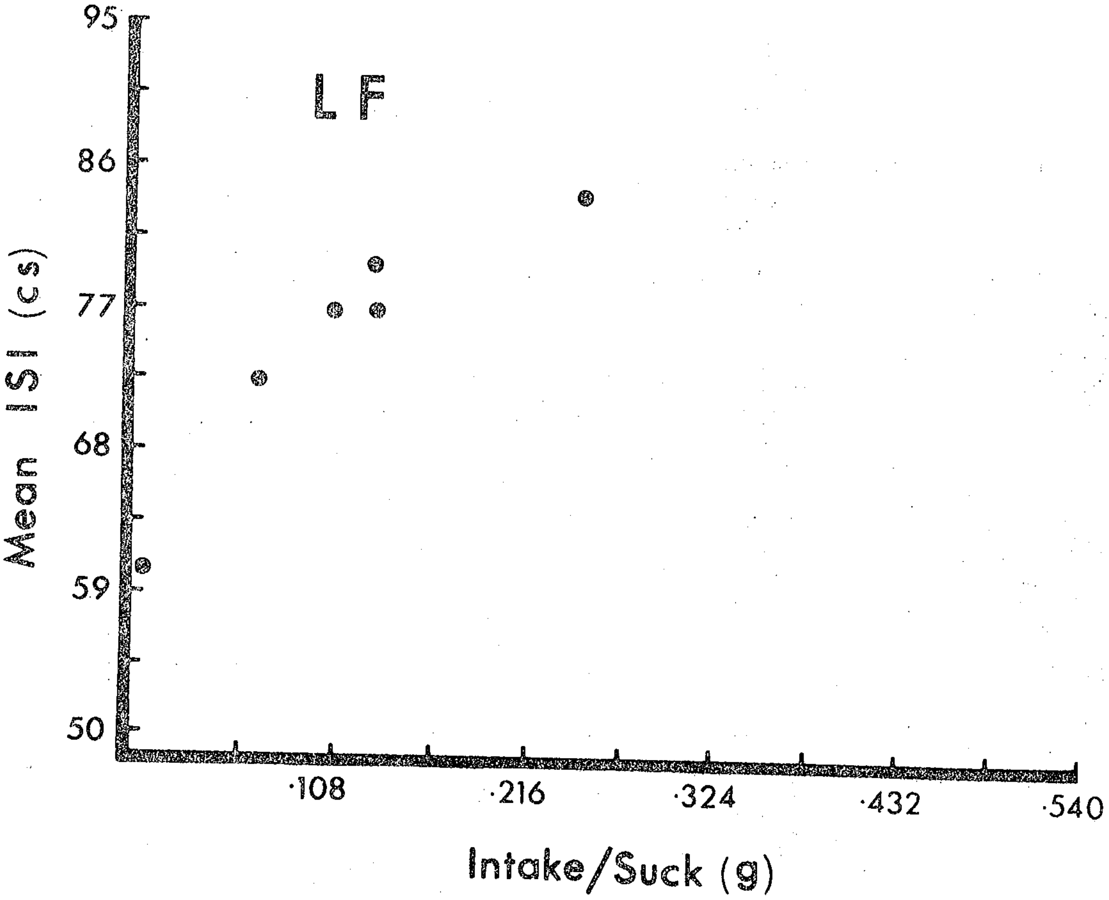
F value = 19.67; N.S.; gradient (m) = 91.29

Figure 5.26



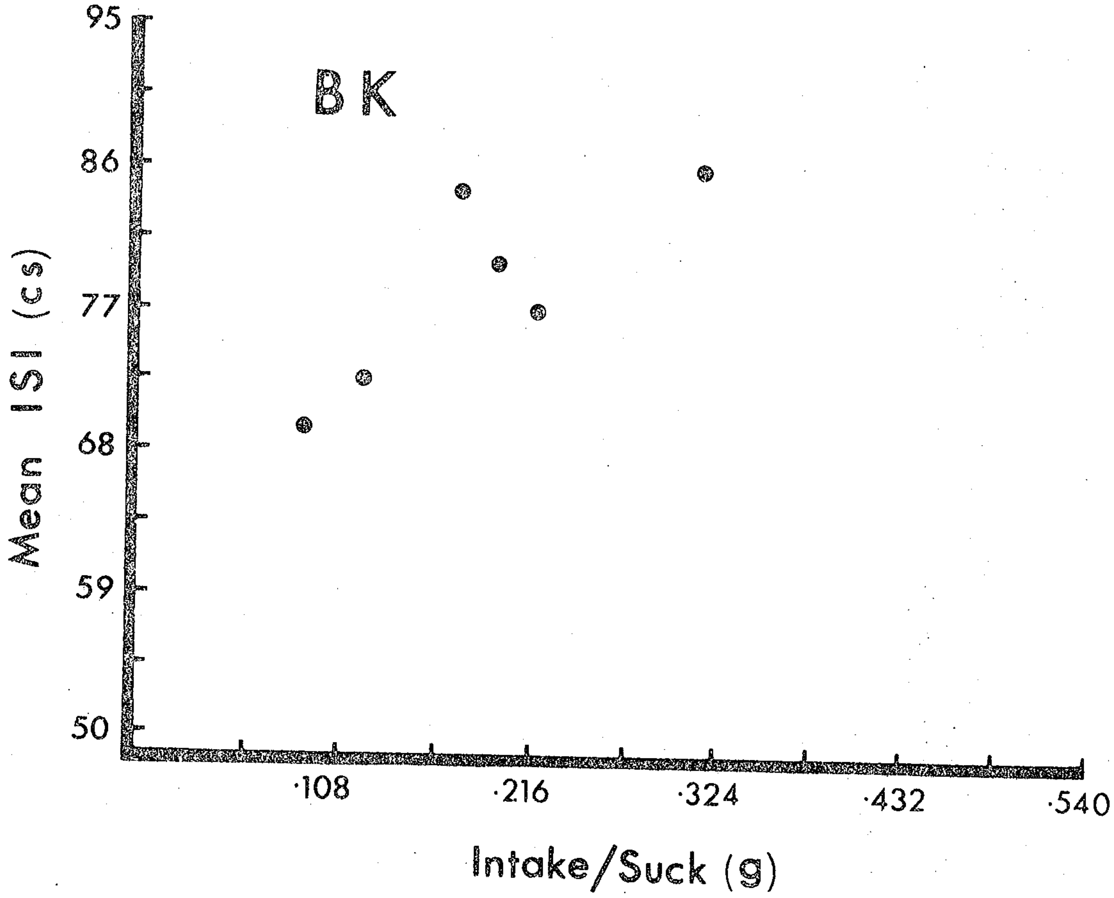
F value = 39.82; $p < 0.01$; gradient (m) = 106.20

Figure 5.27



F value = 30.17; $p < 0.01$; gradient (m) = 91.14

Figure 5.28



F value = 7.34; N.S.; gradient (m) = 66.13

Figure 5.29

has previously been presented to support this observation for natural breast feeding.

At the beginning of the second half-feed, sucking reverts to a pattern similar to that seen at the beginning of feeding on the first breast, as shown by the lack of a significant difference between the sucking patterns of episodes 1A and 2A. Both episodes have high milk flow rates but are separated by the ingestion of an average of 31.5% of the total milk taken (see Figure 5.14). This finding provides no support for any effect of satiety on sucking; but of course it is possible that this amount of milk does not satiate the baby much.

The weight of milk ingested per suck changes through the feed in parallel with milk intake per unit time on the breast. It decreases through both the first and the second half-feeds and is less, overall, on side 2 than on side 1.

The study reveals a strong positive correlation between mean milk intake/suck and mean ISI; and weaker, negative correlations with mean pause length and percentage pausing time. This does not support Kaye's statement that there is typically no increase on breast or bottle in pause duration over the course of a feed (Kaye,1977). Milk flow rate is correlated with a general shift in sucking pattern. High flow rates are associated with sucking patterns similar to Wolff's nutritive mode with slow continuous sucking (although with a proportion of pauses); and very low rates with sucking patterns resembling the non-nutritive mode with its faster sucking rates and more frequent pausing.

Further, what emerges is that the whole organization of sucking (and not simply the sucking rate, as demonstrated in Chapter 3) shows gradations between the nutritive and non-nutritive modes described by Wolff and others. Wolff's work was carried out on infants feeding from bottles under two conditions: with and without milk. The more varied conditions of breast feeding reveal that this may be an underestimation of the repertoire of infant sucking, which is here seen to vary widely in rate and proportion of time spent pausing.

In order to establish the direction of causality in these relationships, there is a need for experiments in which one factor is a true independent variable. The next three experiments meet this requirement in various ways. In other words, the hypothesis that milk flow rate affects sucking behaviour is tested in a predictive way. It must not be forgotten that other, closely-related, factors also change through the course of a feed. These factors have been discussed in Chapter 3; the same points are relevant here in attempting to account for the more detailed changes in sucking pattern as were relevant in Chapter 3 in relation to the differences in sucking between sides 1 and 2. However, a full discussion of the relative contributions of the various factors is deferred until the discussion section of Chapter 7.

CHAPTER 6

CHANGES IN SUCKING PATTERNS AS MILK PRODUCTION IS RESTORED DURING RELACTATION

6.1. Introduction

The previous experiment demonstrated a correlation between the amount of milk ingested per suck and the pattern of sucking. Correlations do not in themselves indicate the direction of causality, but the evidence from bottle feeding studies suggests that it is milk flow which determines sucking patterns.

A chance to test this came adventitiously with a mother whose lactation was completely suppressed pharmacologically, and who then sought to re-establish the lactation by putting the baby to the breast. Sucking patterns and milk yield were studied throughout the relactation.

The subject was a 24- year old woman who had successfully established breast feeding following the induced birth of her first child. However, when the baby was nearly three weeks old, the mother suffered severe puerperal psychosis and was compulsorily admitted to a psychiatric ward. She was treated with largactil (chlorpromazine), to which she became allergic, and then with melleril (thioridazine).

The mother kept the baby with her but was given bromocriptine (2-bromo-α-ergocriptine: 5mgs. b.d. for two weeks followed by 2.5 mgs.b.d. for a further two weeks) to suppress lactation. This drug is one of the most effective agents available for suppressing both puerperal and established lactation (Brun del Re et al, 1973; Walker et al, 1975). Lack of sucking stimulation is an important factor in the suppression of lactation (see Chapter 1), but if bromocriptine is concurrently administered, it additionally inhibits the production or release of prolactin and therefore further reduces plasma prolactin levels (Walker et al, 1975).

Nineteen days later, the mother was discharged from hospital as she

TABLES 6.1 - 6.4

DETAILS OF THE SIX FEEDS
DURING THE PERIOD OF RELACTATION

TABLE 6.1

MILK INTAKE DURING LACTATION

Day	Age of baby	Weight of baby at beginning of each	Episode	Weight gain,g	Mean intake/ suck
6	68 days	5.280 kg	1A	0	0
			2A	0	0
11	73 days	5.350 kg	1A	0	0
			2A	0	0
18	80 days	5.610 kg	1A	20	0.05
			2A	20	0.05
27	89 days	5.790 kg	1A	30	0.08
			2A	22	0.07
34	96 days	5.840 kg	1A	45	0.11
			2A	40	0.11
39	101 days	5.870 kg	1A	30	0.08
			2A	42	0.12

TABLE 6.2

SUCKING MEASURES DURING RELACTATION

Feed Day	Episode	Mean ISI (seconds)	Mean pause length (seconds)	Mean burst length (seconds)	Mean no. sucks/ burst	% pausing time
6	1A	0.56	4.57	4.73	9.4	48.4
	2A	0.49	4.26	2.82	6.7	57.0
11	1A	0.55	12.15	6.38	12.5	64.5
	2A	0.51	7.23	4.53	9.9	60.7
18	1A	0.52	7.71	6.76	14.0	52.2
	2A	0.52	7.75	5.70	12.0	56.8
27	1A	0.54	5.44	11.56	22.2	31.2
	2A	0.55	6.88	5.66	11.2	51.2
34	1A	0.61	3.73	7.16	12.8	33.4
	2A	0.59	4.97	11.50	20.6	28.8
39	1A	0.58	3.85	9.00	16.6	28.1
	2A	0.60	3.44	14.09	24.4	18.4

TABLE 6.3

FAT LEVELS OF THE MILK DURING RELACTATION

Feed		Creamatocrit	Fat, g/100ml Replicates	Mean value
Day 27	1	6.7	4.2	4.3
		6.9	4.3	
	2	15.2	10.0	10.1
		15.4	10.1	
	1	6.4	4.0	4.2
		6.8	4.3	
	2	10.6	6.9	6.9
		10.7	6.9	
	3	11.2	7.3	7.3
		11.3	7.3	
Day 34	1	4.7	2.8	2.8
		4.5	2.7	
	2	12.6	8.2	8.4
		13.1	8.6	
	1	6.0	3.7	3.8
		6.2	3.8	
	2	14.6	9.6	9.6
		14.6	9.6	
Day 39	1	5.2	3.2	3.1
		5.0	3.0	
	2	14.1	9.3	9.3
		14.1	9.3	
	1	10.0	6.4	6.3
		9.7	6.2	
	2	11.8	7.7	7.3
		10.7	6.9	

1 = before feeding
2 = after feeding

Dotted line indiates end of sampling on first breast
Samples taken before baby put on breast and after end of feeding, on each side.

Day 27: Extra sample taken towards end of feed because at the time this was thought to be the end of the feed. Baby then protested and was returned to breast.

TABLE 6.4

CORRELATION BETWEEN MILK YIELD AND SUCKING PARAMETERS 1A + 2A DURING RELACTATION

Sucking parameter	*r*	*p*
Mean ISI	0.813	N.S.
Mean pause length	-0.679	N.S.
Mean burst length	0.928	$p < 0.05$
Mean no. sucks/burst	0.884	$p < 0.05$
% pausing time	-0.823	$p < 0.05$

had improved considerably. As she was anxious to re-establish breast feeding, twenty-four days later she began to put the baby to the breast for periods of up to 30 minutes before each bottle feed. It was by now six weeks since the baby had last fed on the breast.

6.2. Method

Mother and baby came to the nursery six times during the relactation period. If the day on which the baby resumed sucking on the breast is designated Day 1, the observations were on Days 6, 11, 18, 27, 34 and 39. All the visits except the first, which was at 10 a.m., took place in the early afternoon, when a feed was due. (It was important to test-weigh during a comparable feed each time since the amount of milk the baby obtains varies according to the amount taken at the previous feed and the time elapsed since that feed). The baby was weighed before being put to the breast and at 5-6 minute intervals until she was transferred to the bottle to complete her feed. The sucking was recorded on videotape. The sucks were subsequently stored on computer disc as described in Chapter 3.

During the last three sessions, 1-2 ml samples of breast milk were manually expressed from each breast by the mother immediately before and after nursing. These samples were analysed for percentage fat by the "creamatocrit" method (Lucas et al, 1978). This is a simple micromethod for the estimation of fat in milk and involves centrifuging the milk held in a capillary tube in a haematocrit centrifuge. The length of the cream layer is read from the capillary tube and expressed as a percentage of the total length of the milk column i.e. the "creamatocrit". Lipid concentration, expressed in g/100ml, is calculated with reference to a standard curve.

6.3. Results

The baby's weight at the beginning of each session, the milk yields and the flow rates during each feed are shown in Table 6.1. For each sucking episode on the breast mean ISI, mean pause length, mean burst length, mean number of sucks/burst and % pausing time were calculated, and these data are presented in Table 6.2. The creamatocrit values for the percentage of fat in the milk are given in Table 6.3.

Figure 6.1 shows the progression during relactation of the milk yield from each breast with its percentage fat, and sucking parameters from the combined episodes 1A and 2A of each feed (which are the periods when the baby obtains most of the milk (Smith and Merritt, 1922) - an average of 80% during the last four feeds, in which the baby received milk).

Milk yield increases steadily and seems to have reached a plateau by the session on Day 34. By this time the baby was again entirely breast fed and, as can be seen from Table 6.1, was gaining weight. The percentages of fat before and after feeding on each side show the expected increases as the breast is progressively emptied (Table 6.3). The values are at or above the higher end of the normal range (Hytten, 1954; Macy and Kelly, 1961).

Each sucking measure for 1A and 2A together was correlated with milk yield using the Spearman rank-order correlation test, see Table 6.4. This table shows that mean burst length, no. sucks/burst and % pausing time change significantly with increasing milk yield. In conjunction with Figure 6.1 it can be seen that mean ISI also changes as predicted, although this just fails to reach significance.

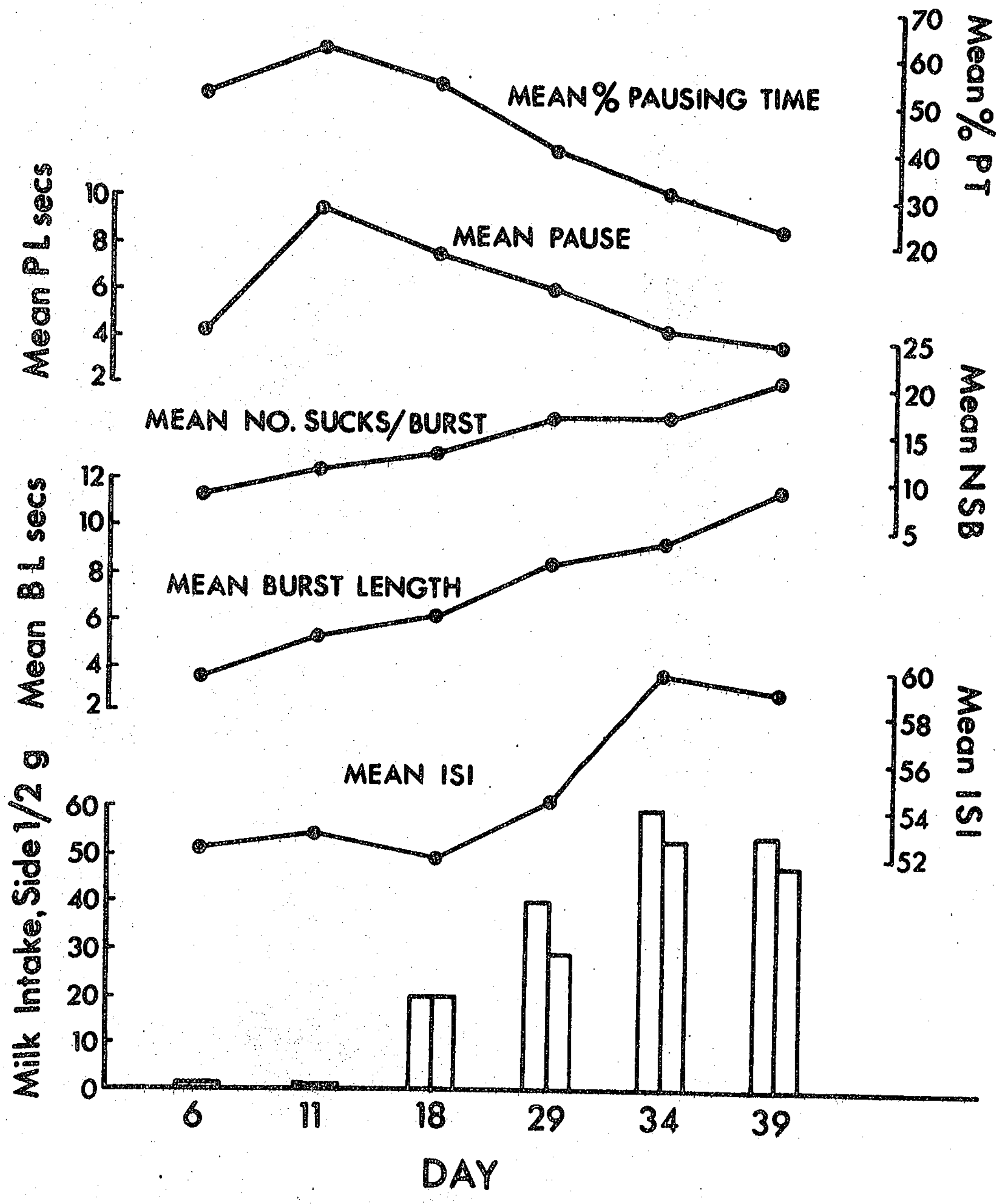


Figure 6.1. Changes in milk intake and sucking measures with relactation

6.4. Discussion

This case demonstrates, firstly, that it is possible to re-establish breast feeding shortly after a course of bromocriptine, a proven suppressor of lactation. This has not previously been recorded. The baby was first put back to the breast six weeks after the change to bottle feeding and the beginning of bromocriptine treatment. It therefore seems that no substantial effect of the drug persists over this length of time to prevent milk synthesis. However, although the baby's milk intake during each feed seemed to have reached a plateau by the fifth session, it is probable that lactation was still not fully restored at the time of the last session. (The study ended at this point because the family moved abroad). This is suggested by the values of milk intake/suck, which do not rise above 0.12g, compared with a maximum of 0.48g recorded in the previous experiment (in a 61-day old baby). Bearing in mind a possibly reduced intake/suck as a result of the longer periods of feeding between weighings in this experiment, this suggests that the rate of flow of milk may perhaps not have been restored to quite the levels one would find in a normal lactation. The baby was, however, gaining weight satisfactorily; at the time of the last session her weight before feeding (allowing 250g for her clothes and nappy) was just above the 50th centile on the growth standards of Tanner, Whitehouse and Tahaish (1966). Presumably therefore, with sufficient periods of nursing and enough feeds in a day, she was obtaining adequate nourishment.

It is not possible to make an exact comparison of yield with the average values for uninterrupted lactations at similar times post-partum (approximately 14 weeks) because the correct basis for comparison is per 24 hours rather than per feed. Nor is it possible to compare these yields with those recorded in the previous chapter since most of them took place in the morning and the baby's milk intake is known to vary through the day. Most is taken early in the morning (Hytten, 1954), which reflects its accumulation during the night when the baby takes less milk. The actual rate of secretion is effectively constant over the 24 hours (Gunther and Stanier, 1949).

There is a high proportion of lipid in the milk of this mother, especially in the hind milk of both the first and second breasts. This may be related to the relatively low volume of milk taken during these (afternoon) feeds.

As the relactation progressed and milk yield increased, the sucking changed. All measures except mean pause length and mean ISI are significantly correlated with milk yield (Table 6.4). Figure 6.1 illustrates these changes through the relactation. The changes are entirely consistent with the results of the previous experiment and are in the direction which would be expected if milk availability and/or composition determine sucking rate.

The data from this study can be usefully incorporated into Figure 5.18 to provide additional points at the lower end of the distribution. This has been done in Figure 6.2. It can be seen that the distribution forms a true continuum throughout the range of milk intakes/suck, with no thresholds or doscontinuities.

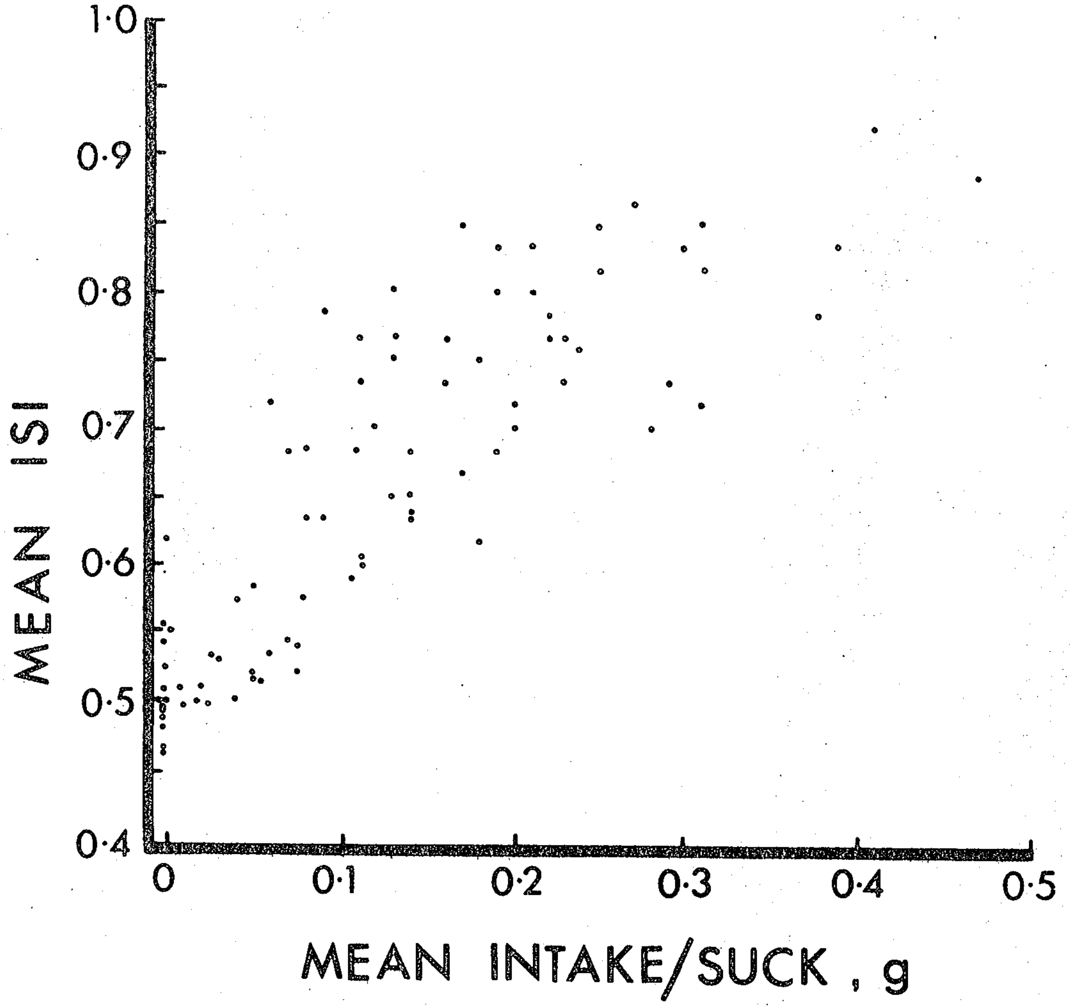


Figure 6.2. Cumulative plot of mean inter-suck interval and mean milk intake/suck

CHAPTER 7

A FURTHER STUDY OF THE EFFECT OF MILK AVAILABILITY ON SUCKING PATTERNS

7.1. Introduction

In the last chapter sucking patterns were shown to change as milk availability increased during relactation. No other case of relactation was encountered. So in the experiment reported in this chapter the same object was achieved by comparing the baby's sucking on full and empty breasts during established lactation.

7.2. Subjects and procedure

As before, a group of mothers was contacted through National Childbirth Trust classes or through a G.P.'s well-baby clinic (details in Table 7.1).

The feed was carried out as follows:

At the first feed:

(1) The baby emptied (or nearly emptied) one breast,

(2) The baby was either fed on the second breast, or returned to the first breast.

At the second feed:

As for the first feed, but with the other option followed for (2).

The order was counterbalanced across the eight mothers, as detailed in Table 7.2. The important feature of this design is that the baby is equally hungry before being tested on the full and the empty breast.

The eight mothers and their infants were assigned, two to each of the four groups in Table 7.2. The mothers were asked in advance to arrange feeding such that they would want to nurse first on the appropriate side at that visit.

TABLE 7.1

Subjects	Parity of mother	Age of baby in days at times of sessions
Ms F. and Lorna	1	83, 84
Ms M. and Stephanie	2	82, 89
Ms R. and David	2	67, 73
Ms R. and Steven	2	110,116
Ms S. and Catherine	1	56, 60
Ms S. and Mathew	2	58, 71
Ms W. and Mark	1	64, 71
Ms W. and Rebecca	2	41, 59

TABLE 7.2

	Feed	1st part	2nd part
(1)	1st	L	back on to L
	2nd	L	R
(2)	1st	L	R
	2nd	L	back on to L
(3)	1st	R	back on to R
	2nd	R	L
(4)	1st	R	L
	2nd	R	back on to R

L = left side
R = right side

Mother and baby were brought to the nursery on two days, at similar times of the day, when a feed was nearly due, and the visits were as near together as possible (see Table 7.1) to keep as constant as possible the many factors which can influence breast feeding. The baby was weighed to the nearest 10g on a modified top-loading balance immediately before going on the breast and again at approximately 3 minute intervals throughout the feed. The baby's sucking was recorded on videotape.

The mother was asked to identify the point at which she was about to change the baby over to the other breast. The criteria were those of mother and baby and no attempt was made to influence the decision.

One feed was as normal, the mother transferring the baby from one breast to the other in the usual way, after weighing. At the changeover point in the other feed, she was asked to postpone putting the baby to the other breast and instead to put him back on to the first breast, after weighing, for a further three minutes. Only then, after a further weighing, was he put to the second breast and from then on the experimental feed did not differ from the control.

7.3. Results

The results were analysed in a similar way to those of the previous experiment. For each 3-minute period the sucking was transferred from videotape to computer and stored on disc together with relevant details of each period. The 3-minute feeding episode when the baby was put back on to the emptied breast was designated 1F (for Final); on the full breast it is called 2A as usual.

The mean of the values of milk intake/suck was calculated for all 1F and all 2A periods, as was the mean of the mean values of ISI, pause length, burst length, mean number of sucks/burst and % pausing time for these two periods.

For each baby, the values of mean milk intake/suck were plotted against the corresponding mean ISI's for episodes 1F and 2A (Figure 7.1). This illustrates that the pattern for each baby is the same and that it accords with the results reported in Chapters 5 and 6; low intakes of milk/suck are always associated with short ISI's i.e. fast sucking rates, and high intakes with slower sucking rates. Complete emptying of the first breast was not essential, and intakes/suck vary from 0 - 0.11g for episode 1F; for episode 2A, they vary from 0.09 to 0.35g.

A related-measures t-test was carried out on all the sucking measures between episodes 1F and 2A from the two feeds of each baby, and the results are presented with the corresponding histograms, in Figures 7.2 - 7.7.

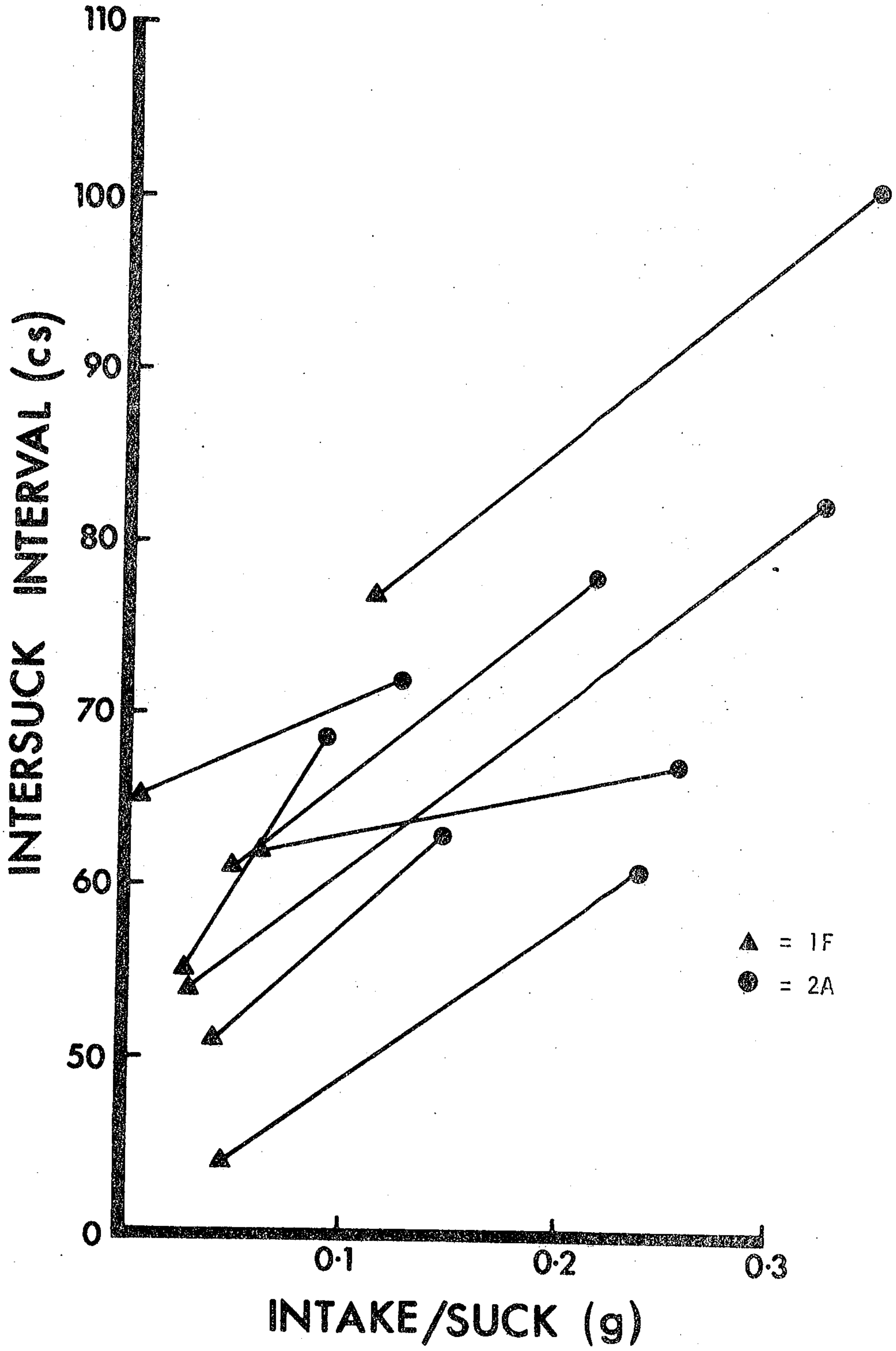


Figure 7.1. Mean milk intake/suck vs mean inter-suck interval for episodes 1F and 2A

FIGURES 7.2 - 7.7

SUCKING ON FULL AND EMPTY BREASTS WITH THE BABY IN A COMPARABLE STATE OF HUNGER

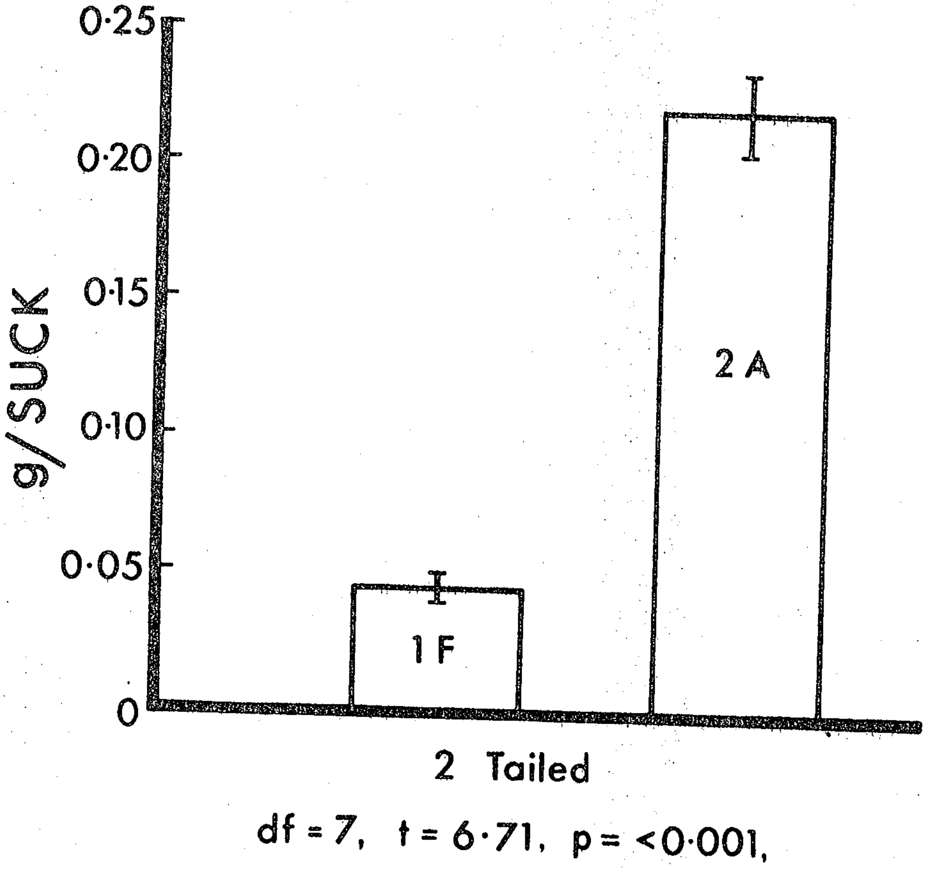


Figure 7.2. Mean intake

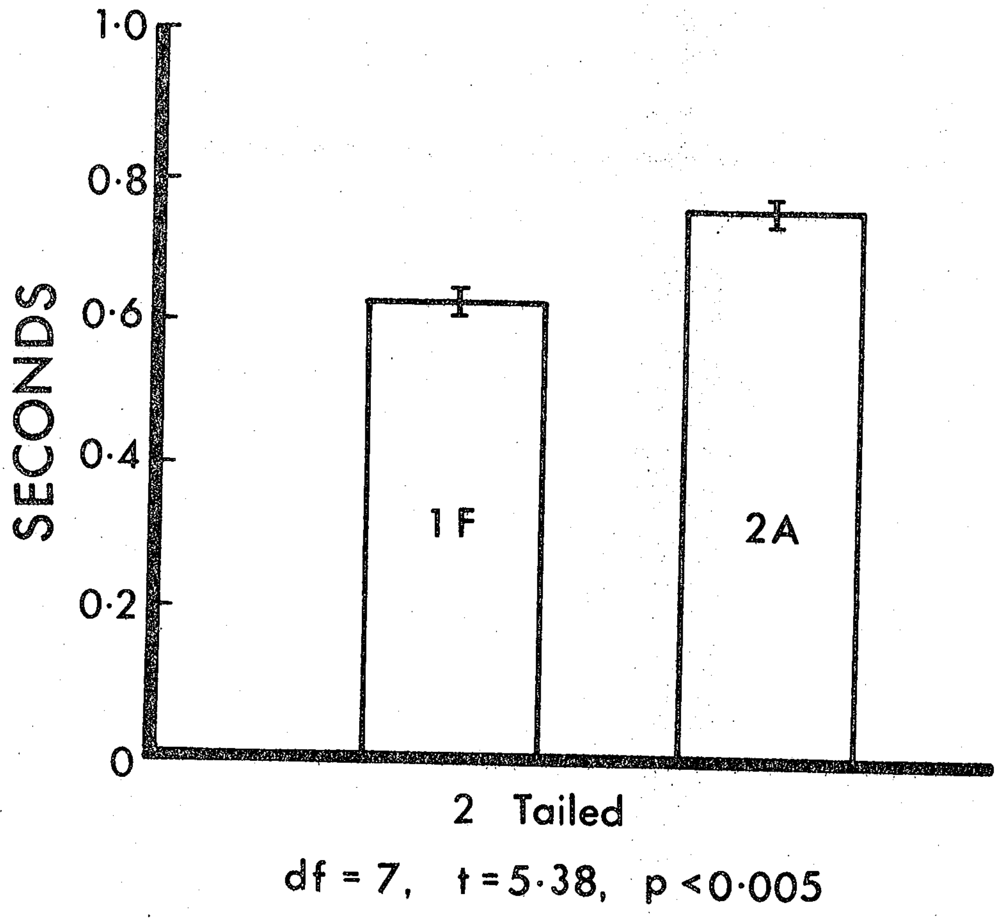


Figure 7.3. Mean ISI

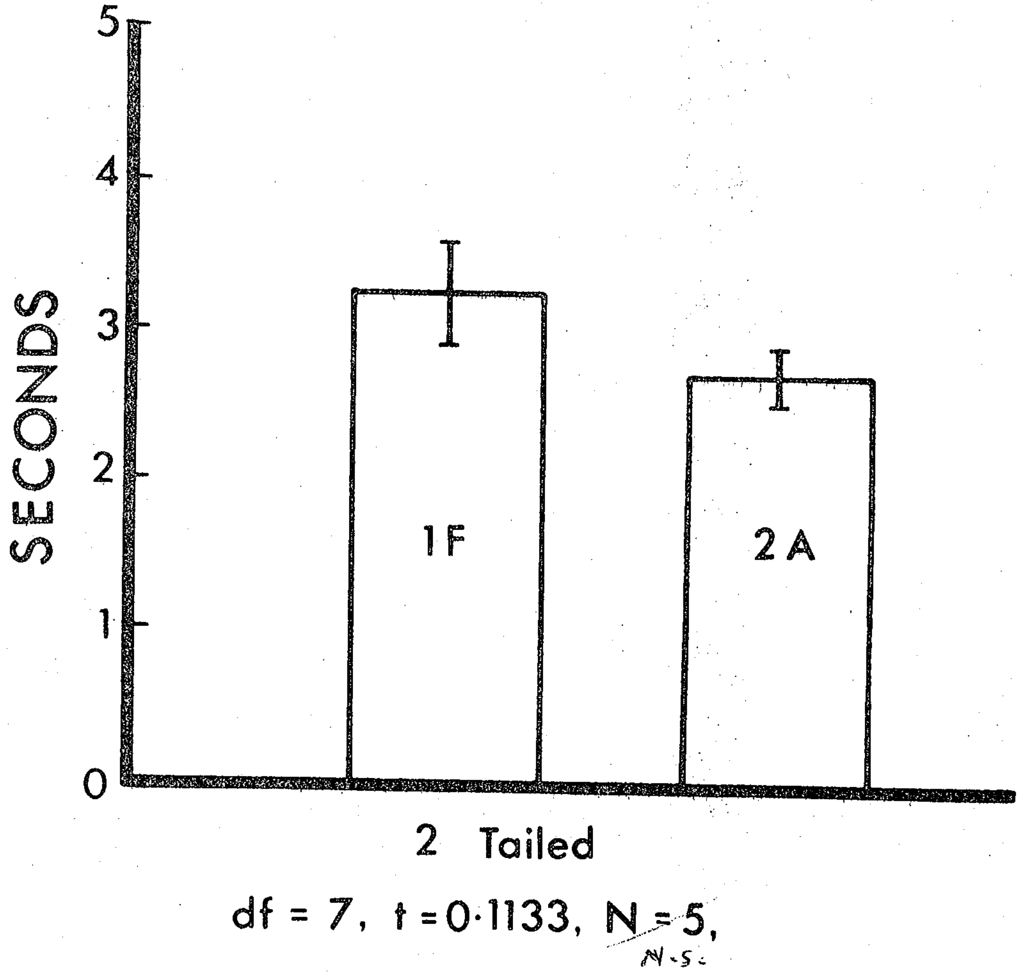


Figure 7.4. Mean pause length

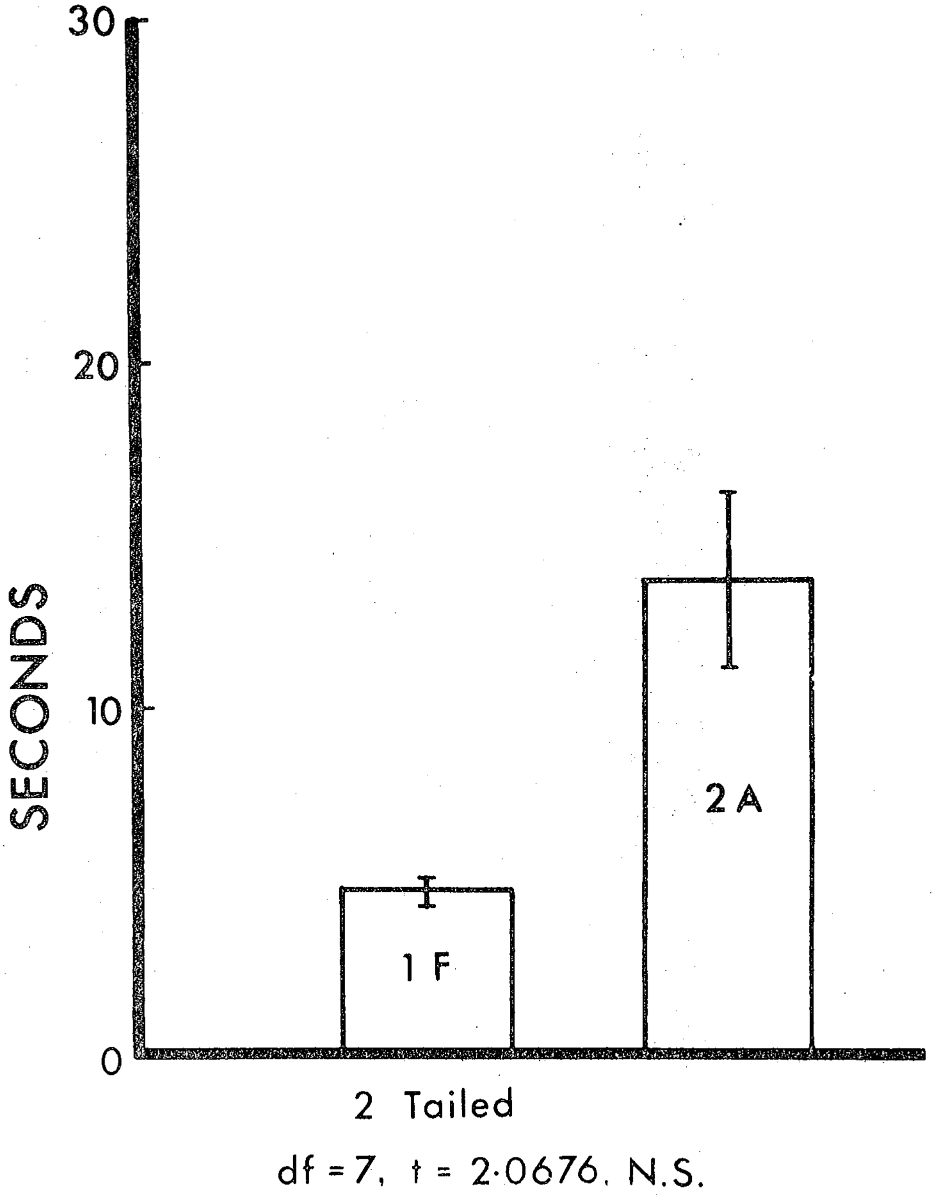


Figure 7.5. Mean burst length

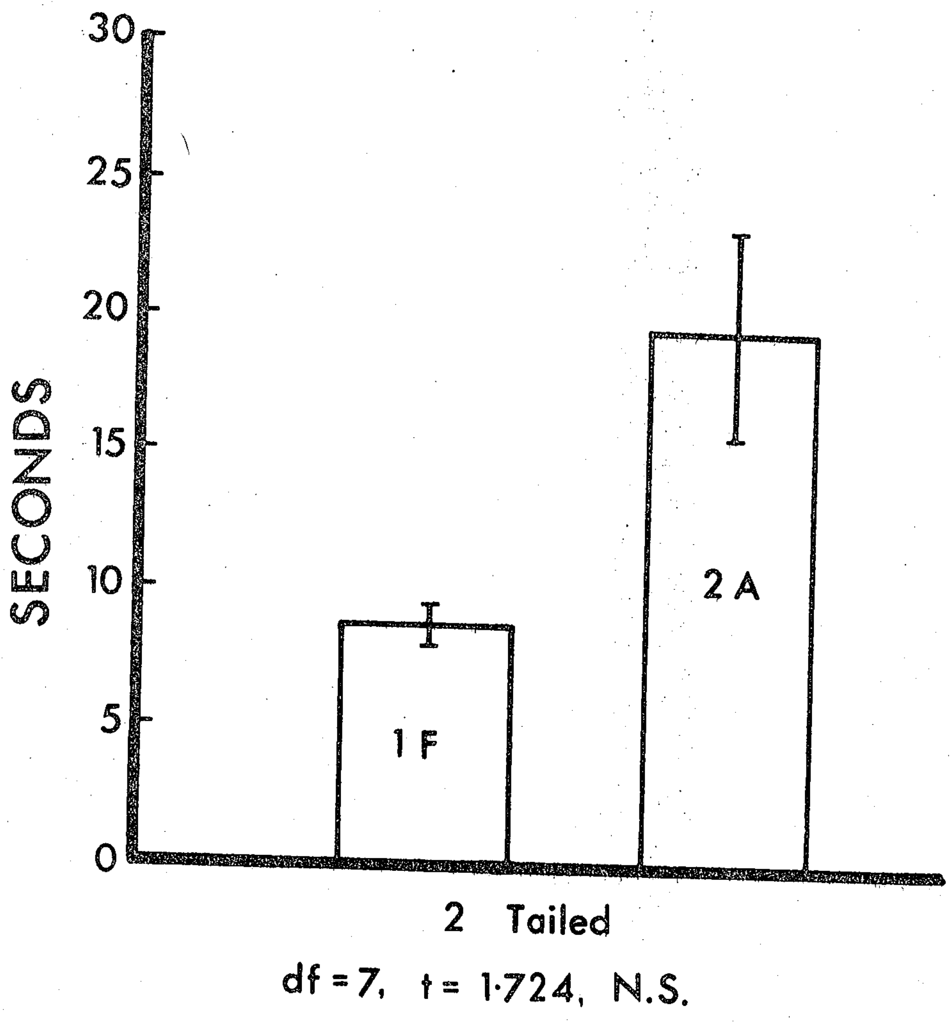


Figure 7.6. Mean no. sucks/burst

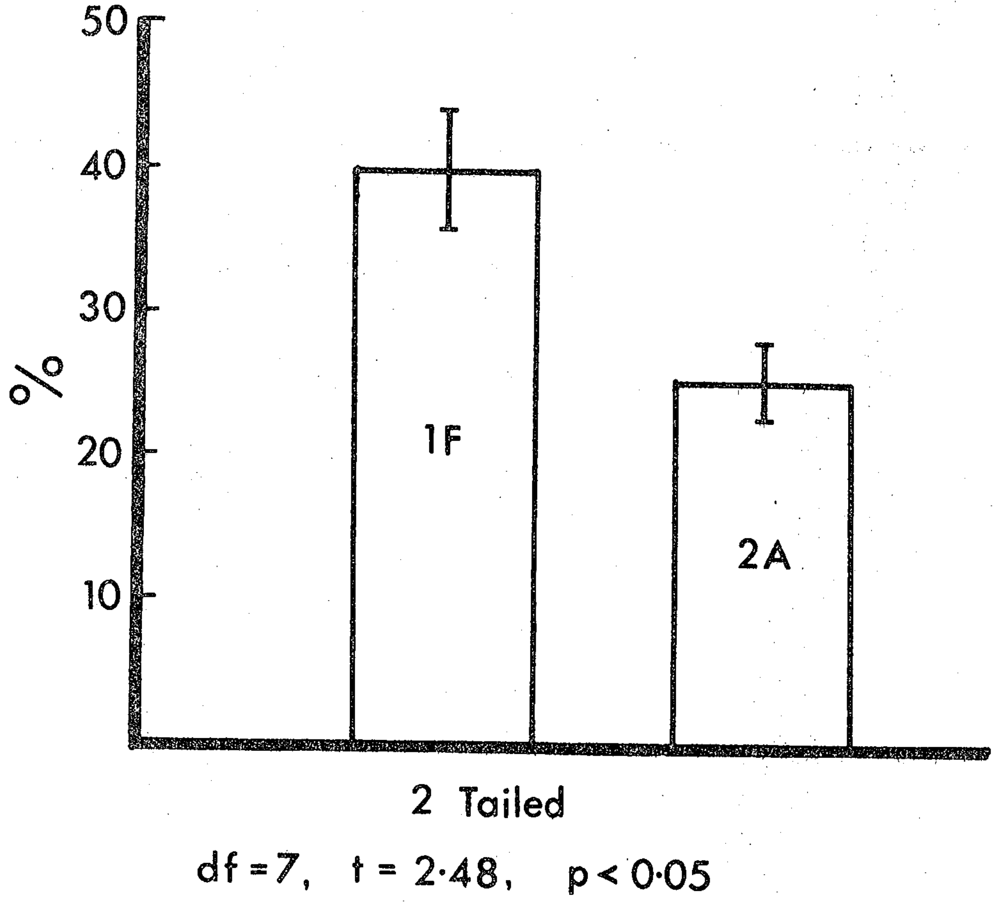


Figure 7.7. % pausing time

Milk intake/suck is significantly different between the two episodes. Of the sucking parameters, mean ISI and mean % pausing time are significantly different but the other measures are not, although they change in the direction which might be expected on the basis of the work of the previous chapters. The variance is very great, which probably accounts for the lack of significance in measures other than mean ISI and mean% pausing time.

7.4. Discussion

The results of this experiment demonstrate that when the availability and hence the flow rate of the milk presented to a breast feeding baby varies, mean ISI and mean % pausing time differ even though the baby is satiated (and fatigued) to a comparable degree. Mean pause length, which was shown in Chapter 5 to correlate with flow rate, does not significantly change, which may indicate that this parameter depends more upon the state of the baby than on the rate at which he is receiving milk.

Thus milk availability has a consistent and predictable effect upon sucking which is independent of the hunger state and fatigue of the baby. The changes are consistent with the results of the previous experiments. Combining the findings, therefore, we see that ISI is increased, % pausing time is decreased, and mean burst length and no. sucks/burst are increased with higher milk flow. So sucking varies with the availability of the milk even when the baby's state is constant. The sucking parameters probably differ in the extent to which they are influenced by the two types of factor, as was noted in Chapter 5 and in this chapter,where by far the most reliable and consistent correlations with milk flow is shown by mean ISI.

This greater correlation of milk flow rate with sucking rate than with other aspects of the organization of sucking, which may collectively be termed the probability of the baby sucking at any one time, is interesting in that it echoes Crook's study where within-burst sucking rate was determined exclusively by another property of the fluid the baby received, namely its sweetness (Crook, 1977). The other parameters of sucking, such as burst length, were found by him to be more influenced by factors relating to the progression of the feed, i.e. state changes, satiation and fatigue. This too was the conclusion reached by Dubignon and Campbell (1969), and by Hillman and Bruner (1972), again with bottle fed babies.

This seems logical since intra-oral variables are among the most potent in influencing sucking rate (see Chapter 2). Given this, one should perhaps look first to intra-oral variables in an attempt to account for the changes in sucking rate during breast feeding. Parameters relating to the probability of sucking during a breast feed show a somewhat weaker correlation or no correlation with milk flow. This again illustrates the fact that sucking rate and the burst/pause pattern do not necessarily always covary during breast feeding, which Hillman and Bruner (1972) demonstrated for bottle feeding (see section 2.7).

We can now recapitulate the findings of the experimental work so far: and attempt to build up a composite picture, before going on to discuss possible explanations for the findings.

(1) Virtually continuous nutritive sucking is very rarely seen during breast feeding. For example, out of the total number of 228 episodes observed during the breast feeds of Chapter 3 (each episode being up to 5 minutes in length, with several to a feed), only 3 had a % sucking time of 100%. This may partly be due to the nature of the milk. Johnson and Salisbury (1975) noted more pauses with breast milk than with bottle milk when it was given to the infants through the same apparatus.

In addition, the data do not provide any evidence for the critical threshold of milk flow postulated by Kaye (1972), above which he suggests the burst/pause pattern disappears. They support his later contention that all sucking is fundamentally organised in a burst/pause pattern (Kaye, 1977).

(2) No discontinuities between sucking rates, of the kind which might be expected from the nutritive/non-nutritive distinction, were found, even at the fine level of analysis possible with film. These two now appear rather as the extremes of a continuum. It follows that there may be just one central oscillatory mechanism which sets the pace of sucking, responsive to external cues which vary the rate.

(3) Sucking patterns change with changes in milk availability and composition. The changes seen through the course of the first half-feed are an increase in sucking rate combined with a decreased probability that the infant is sucking at any one time. There is a definite, predictable gradation in the parameters, suggesting the influence of a factor or factors which must also change in this orderly way. These gradations are an intriguing feature of sucking in human infants and are another illustration of its considerable plasticity.

(4) Milk intake/suck decreases from the beginning to the end of the feed. This measure correlates highly with sucking rate, and to a lesser extent with pause length and % pausing time. Variation in milk intake/suck is associated with predictable and consistent changes in ISI and % pausing time during the natural course of a feed; when the baby's hunger state is controlled the same correlation is found. This suggests that milk flow rate determines sucking rate in a very precise way, and, to a lesser extent, determines the probability of sucking.

This is the obvious explanation. On the breast, however, milk flow is confounded with milk composition. In most circumstances in which flow is high, the fat content is lower. Any effect of this change of milk composition has not yet been examined, though Chan, Pollitt and Leibel (1979, discussed in Chapter 2) did not find differences in intake in response to artificial milks of differing lipid levels.

Given the lack of data on the possible effects of milk with different lipid contents on sucking patterns, it is impossible to assess the extent of any such effect.

In any case, there would appear to be a number of pieces of evidence which suggest that flow rate is the stronger contender for the major influence on sucking behaviour. Previous, well-known, effects on sucking patterns during bottle feeding are based on milk volume. For example, the nutritive/non-nutritive distinction is itself based upon differing flow rates, i.e. zero/brisk flow of milk.

Although there may be considerable differences between breast and bottle feeding, the work of Crook (1976) and Burke (1977) on bottle fed infants demonstrates a similar effect of increased fluid volume/suck on sucking rate and on mean pause time, albeit the volumes used are very small and the fluid is sucrose solution not milk. In addition, there is the interesting finding of Hillman and Bruner (1972) that as delivery of a fixed amount of milk was made less frequent, sucking bursts became shorter and pauses longer. (During breast feeding, milk flow may become intermittent towards the end of feeding on each side).

It therefore seems likely that milk flow rate is the predominant influence on sucking patterns (especially on within-burst sucking rate) during breast feeding.

During bottle feeding, monitoring of fluid volume appears not to occur at each suck since a given quantity of fluid delivered with every 3rd, 5th or 10th suck produces a similar rate to that resulting from delivery of that quantity of fluid with every suck (Hillman and Bruner, 1972). In other words, sucking rate is periodically "triggered" for the next few sucks. It is not known whether a similar effect operates during breast feeding.

If milk flow does influence sucking rate during breast feeding, explanations of how this occurs must be sought. An explanation has been proposed with reference to bottle feeding, and requires examination in order to see whether it can shed light upon the changes seen during breast feeding.

Sucking and swallowing are necessarily closely linked, and there have been several suggestions that swallowing exerts an influence upon infant sucking rates (Peiper, 1963, p.445-7; Dubignon and Campbell, 1969; Wolff, 1972, 1973). Burke (1977) has made a detailed examination of swallowing rate in relation to sucking rate. His infants received fixed quantities of 5% sucrose solution per criterion suck and swallowing was detected with a piezo-electric crystal wafer positioned over the thyroid cartilage.

The ratios of sucks to swallows were as follows:

vol./suck, ml	0	0.01	0.02	0.04
sucks/swallow	10.8	2. 7	2.6	1.9

When the ISI's were divided into those associated with, that is, immediately following, a swallow and those not associated with a swallow, the former were found on average to be approximately 0.20 seconds longer than the latter.

Burke interprets his results as showing that the number of swallows accompanying sucking is a major determinant of the lengthening of ISI with increased flow rate that he and Crook (1976) have demonstrated with bottle feeding. Burke maintains that changes from non-nutritive sucking rate to the slower rates seen when liquid is introduced can be accounted for by increased swallowing combined with an increase in the amplitude of sucking (i.e. of anterior tongue pressure) resulting from the introduction of fluid. The latter finding is attributed to Nowlis (1973) and Nowlis and Kessen (1976). However, these authors demonstrate only an increase in the amplitude of anterior tongue pressure as a result of increasing the concentration of the sugar solution given, and do not present equivalent measures for no-fluid sucking. In addition, Burke's suggestion assumes that an increased amplitude of anterior tongue pressure directly increases ISI, but this need not necessarily be the case since the speed of the response could likewise increase, neutralising any tendency to increased ISI.

There are several dissimilarities between Burke's work and that presented here. His work is entirely on bottle feeding, using sucrose solution. Comparable studies of swallowing during breast feeding have not been published. It cannot be assumed that what applies to one automatically applies also to the other. The quantities of fluid received by Burke's infants are all at one extreme of the range seen during breast feeding. Since quantity is critical its role needs detailed examination.

Burke gave his infants quantities of fluid varying from 0.01 to 0.04 ml/suck, whereas during breast feeding infants have been observed to receive from 0 to 0.48g/suck (Chapter 5). It is possible that influences which predominate at low flow rates are usurped by others at much higher flows. For example, the changes in ISI's <u>not</u> associated with swallowing noted by Burke are in the same direction as the changes in overall ISI, which he attributes solely to an increase in swallowing. Although the former changes are small and do not reach significance at low flow rates, it is possible that this lesser effect continues to operate as flow rates increase to the higher levels commonly seen during breast feeding, and that it may even become the major influence on sucking rate whilst the effect of the number of swallows reaches a ceiling. This contention is supported by the fact that the minimum number of sucks per swallow observed by Burke is 1.9, and in a linear extrapolation of the line drawn from the above data in graphical form the maximum ratio of 1 suck/swallow in a burst of sucking is reached even before 0.1 ml/suck. This does not account for the continued increase in ISI seen far beyond this point during breast feeding.

There appears to be a difference between breast and bottle feeding when the amount of fluid obtained with each suck approaches zero, as in Burke's experiments. For example, Burke notes a considerable difference in the mean ISI with no fluid and 0.02 ml/suck, 0.68 and 0.81 sec respectively.

On the other hand, with breast feeding there is no such large difference, or jump, at this point; a more gradual decline in mean ISI is apparent throughout the range of flow rates and the line cuts the axis where one might at first sight expect, as can be seen from the cumulative graph of milk intake/ suck against mean ISI, Figure 6.2.

These are interesting differences betweeen breast and bottle feeding which cast serious doubt upon the possibility of explaining the results reported here along the lines proposed by Burke.

Another explanation of how fluid volume could affect sucking rate is that the more milk there is in the teat formed from the nipple and areola, the longer it takes for the tongue to "strip" or "milk" the teat as it moves backwards in the mouth during a suck. This explanation is attractive in that it removes the need to postulate a precise volume-monitoring mechanism in, for example, the back of the oral cavity. It would not necessarily apply to bottle feeding, nor would it necessarily be innate. The baby could learn to maximise milk intake in this way, as he can learn to modify his sucking rate so as to hear more of a novel sound stimulus (Eimas, 1975), or to bring a motion picture into focus (Kalnins and Bruner, 1973). This instrumental use of sucking is impressive and implies a level of higher CNS involvement. It must be remembered that sucking is one of the most competent and well-developed activities of the young infant and one of his earliest points of contact with the outside world.

One should be careful always to view any aspect of an infant's behaviour in the context of his overall development and his interactions with other people, bearing in mind the social basis for cognitive development, language acquisition, etc., and assuming that most physical or behavioural features which arise in the course of evolution do not do so without having adaptive value. The importance of not isolating a particular behaviour from its social context and implications applies especially to such a central feature of the infant's behavioural repertoire as sucking, this being one of the activities ,if not the activity, at which the young infant is most competent.

A convenient way of looking at the situation is to see no-fluid or non-nutritive sucking as the "ground-state" or basic organization of sucking in human infants, since progressive changes in intra-oral variables modify it to produce a range of "nutritive" rhythms. This pattern of sucking, therefore, whilst very stable in its (centrally determined) organization, becomes malleable and flexible once fluid is present, and a whole variety of sucking rates, arrangements of bursts and pauses, and degress of positive and negative pressure exerted can then be elicited. This is in apparent contrast to other mammals, where sucking patterns in response to fluid and no-fluid conditions cannot be distinguished (see Chapter 2). This single pattern (which resembles human sucking when fluid is flowing fairly briskly) is their basic or "ground-state" pattern. It can be said that for other species, the no-fluid pattern is <u>not</u> modified by the introduction of fluid. The original question in the literature, of why human infants should have two distinct sucking patterns whereas other mammals appear to have only one, has now become that of why human sucking has so many sucking patterns i.e. why their sucking behaviour is so malleable.

Looking at it from another angle, humans share a common sucking pattern with other species at moderate to high milk flows. When the milk supply is cut off, either the infants: (a) continue with the same sucking pattern; (b) show a completely disrupted sucking pattern; or (c) come off the teat. Only human infants continue to suck with a modified, but stable,pattern. Graded sucking patterns therefore appear as an adaptation to low or very low milk flows. This could have evolved to enable the baby to suck for lengthy periods without receiving milk, which could suggest another (non-nutritional) function of sucking, possibly that of social interaction as expounded by Kaye (1977).

The nature of a typical feed implicit in this thesis is, it must be remembered, a typical feed in the contemporary West, which naturally has its own particular customs. Blurton Jones (1972) provides a variety of lines of evidence which tend to suggest that this is typical neither from a geographical nor a historical viewpoint, but rather that more characteristic of our species is the pattern whereby mothers customarily carry their infants or keep them close by for much of the time. The babies are fed frequently, perhaps more than once an hour, during daytime. Under these circumstances, which probably prevailed during the period of the evolution of the sucking behaviour under consideration and which must therefore by considered in any attempt to explain them,the milk in the breasts would rarely build up to the quantities common today and the infants would therefore suck mostly with fairly low rates of milk flow or even without receiving milk. This again points to the organisation of human sucking having evolved as an adaptation to sucking whilst receiving little milk.

Blurton Jones also suggests that the uniqueness of human no-fluid sucking results from the supposed difficulty of retaining the relatively short human nipple in the mouth, possibly related to the unusual shape of the human breast (see Chapter 2). In this case, one would imagine that a much simpler solution would have been for human mothers to evolve longer nipples, comparable to certain other primates.

However, there is a possible connection here with the explanation of differing sucking rates which relates to the "milking" of the teat during breast feeding. The "milking" mechanism could lead to variable inter-suck intervals in humans but not in other infants as a result of the necessity of actively maintaining the shape of the teat, created from the nipple and areola in humans. In this case, variable sucking rates would be seen as a side-effect or a by-product of another development, and there would be no need to ask "why did they evolve?"

CHAPTER 8

SUCKING IN RESPONSE TO DIFFERING MILK FLOW RATES DURING BOTTLE FEEDING

8.1. Introduction

In the previous experiments changes in sucking rates associated with differing rates of milk flow during breast feeding were described. Sucking parameters are correlated with milk flow rate and are significantly different with differing milk flow rates at comparable stages in the feed. They change in the predicted direction as milk yield increases during relactation. The correlations between milk flow and sucking patterns are strong, and it seems likely that the milk determines the sucking rather than the other way round.

The experiment reported in this chapter was carried out in order to see whether milk flow indeed determines sucking during bottle feeding, and whether the associations referred to above occur over a broad range of flow rates comparable to those commonly seen during breast feeding. Indications that sucking is determined by flow rate at low rates of flow (0.01 - 0.04 ml/suck) come from Kaye (1972), Crook (1976) and Burke (1977).

Bottle feeding with suitably modified apparatus gives the experimenter the advantage of precise control over the quantity of milk the baby receives with each suck. It also ensures that the baby receives milk of a constant composition throughout the feed. This is important since a major confounding factor in the study of the effect of changing milk flow rate during breast feeding is the inevitable concurrent change in milk composition.

8.2. Apparatus

Methods of directly recording sucking while the infant receives fluid through a teat have been described in Chapter 2. The method used in this experiment is based on that developed by Kron, Stein and Goddard (1963) and Sameroff (1965). As the baby sucks on the modified teat, the positive (expression) pressure caused by the squeezing of the nipple and the negative (suction) pressure are transmitted by fine polyethylene tubes to pressure transducers. The resulting signals are used to trigger fluid delivery into the baby's mouth and can be charted by a polygraph or, as in this case, recorded on an FM direct tape-recorder. The apparatus is represented in diagrammatic form in Figure 8.1.

The teats used were Boots rubber teats. The existing hole was enlarged and another one made, and through these were passed the milk delivery tube and the negative pressure tube, both made of rubber, internal diameter 1mm, cut flush with the surface of the tip of the teat. A new teat and tubes were used for each session, sterilized by immersion in Milton's solution for the preceding 24 hours. A third tube, made of polyethylene, internal diameter 1.5mm, was attached to the sealing disc of the collar of the feeding bottle and positive pressure applied to the nipple was transmitted through it.

The positive and the negative tubes were connected to pressure transducers (National Semiconductor fluid-filled transducer, model LX1601GF, pressure range -5 to +5 lb/sq in, for which it gives a range of output of 10 volts) which converted changes in pressure as a result of the baby's sucking into simplified analog electrical signals. Only the negative signal was used to activate a Schmidt trigger, which caused a peristaltic metering pump (Watson-Marlow, MHRE/200) to operate for 0.50 seconds; the speed of revolution of its rotor determines the amount of fluid the baby receives. The pump was triggered each time a signal was received so the baby received a fixed quantity of liquid each time he sucked. A digital signal of length 265msec was transmitted by the Schmidt trigger to a channel of the 4-channel FM tape recorder (Ampex SP300), so the sucking record comprises all those sucks as a result of which the baby received fluid.

The milk used was SMA Gold Cap ready-prepared formula in 100g bottles; composition per 100ml: fat, 3.6g; protein, 1.5g; lactose, 7.2g; energy content

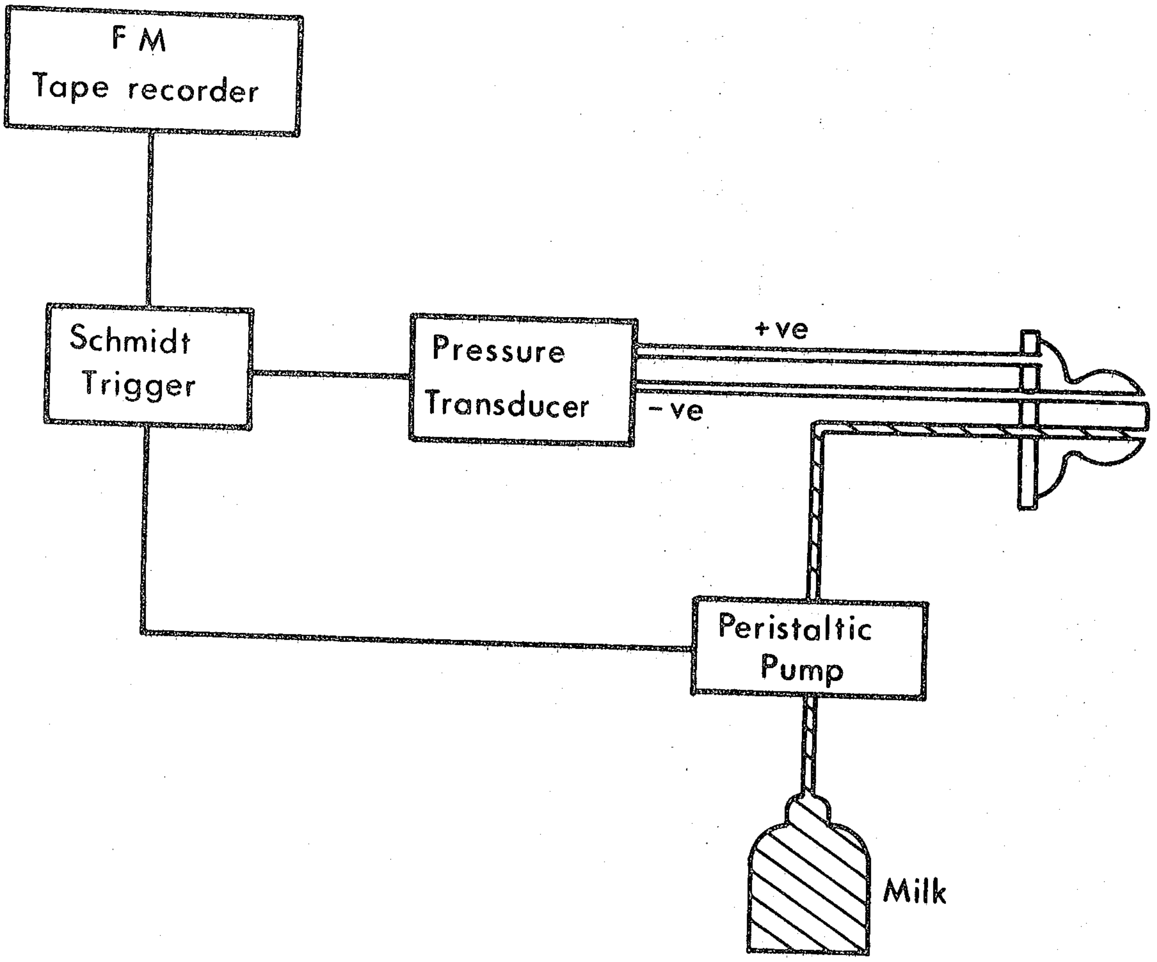


Figure 8.1. Bottle feeding apparatus

65 K cals/100ml. Immediately before the feed, the lid of the milk bottle was replaced by a sterilized lid from another similar bottle through which a rubber ring had been inserted. A glass tube passed through the ring to connect the milk supply to the tubing of the peristaltic pump. This silicone rubber tubing had especially thick elastic walls, internal diameter 1.6mm, external diameter 4.8mm, to withstand the pressure of the pump. The milk was driven by the revolving rotor of the pump, reaching the feeding bottle via fine rubber tubing which passed through the heater in the bottle and opened out at the tip of the teat.

The heater was a thick aluminium sheath surrounding a heating element connected to a Variac transformer. The voltage was adjusted such that the temperature of the milk reaching the baby was as close as possible to blood heat (36°C), the approximate temperature at which milk is normally given to infants. There might be some variation in the temperature of the milk reaching the baby's mouth as the rate of milk flow is changed, but Hytten (1951) and Elder (1970) have shown that even quite large variations in milk temperature, for example between 20° and 40°C, have no significant effect on sucking behaviour.

8.3. Subjects

Mothers and their bottle fed infants were contacted through a G.P.'s well-baby clinic. Provided the mothers were amenable, the babies were then chosen on the basis that they were healthy and already being fed on SMA Gold Cap formula, since the G.P. advised against changing the baby's milk unnecessarily. Another advantage of giving the same milk, albeit unavoidably prepared in a different way, is to minimize the baby's need to adjust to a new taste, which could temporarily disrupt his sucking behaviour. Six babies were selected on this basis.

8.4. Procedure

Mother and baby were brought to the nursery soon before the time of an expected feed, and the procedure was explained to the mother. Each baby sucked for 2½ minutes at each of the three flow rates, and they were assigned to one of six groups in which the order of the flow rates was varied systematically to give all possible orders. Details of babies and treatments are given in Table 8.1.

The three flow rates given were 0.08, 0.16 and 0.24 ml/suck. These quantities were chosen on the basis of data reported in Chapter 5. They are within the normal range of values obtained during feeding on the breast, where significant differences in sucking measures are associated with them. Although the intake of milk per suck during breast feeding was estimated by its weight and is here measured by volume, this is not likely to lead to discrepancies (see Section 5.1).

TABLE 8.1

Subjects	Parity of mother	Age of baby in days at time of session	Trials (order of flow rates) 1	2	3
Ms D. and Louise	1	99	0.08	0.16	0.24
Ms T. and Jonathan	2	138	0.08	0.24	0.16
Ms C. and Anthony	2	66	0.16	0.08	0.24
Ms F. and Catherine	2	61	0.16	0.24	0.08
Ms W. and Suzanne	1	55	0.24	0.08	0.16
Ms C. and Alastair	1	51	0.24	0.16	0.08

The bulk of the equipment was hidden behind a screen, through which passed connecting tubes to the bottle. The modified bottle was in every case acceptable to the mother; its weight is similar to that of a full bottle of milk formula.

The infants were fed as soon as they appeared hungry to the mother. Immediately the bottle was put in the baby's mouth the trigger level was zeroed before the trials began.

The baby's going on and off the bottle was signalled verbally using another channel of the FM tape recorder. This was also used for recording details of the trial about to take place for subsequent identification of the blocks of signals on the tape. After the experimental period the infants either completed their feed with milk from the apparatus or fed from a ready-prepared bottle the mother had brought with her.

8.5. Analysis and results

The data were first transferred from the FM tape recorder to computer disc by means of a programme which received as its input the signals from the FM tape and stored and printed out the ISI's in centiseconds. As the tape was played, the verbal record of the times at which the baby went on and off the bottle were used to press a key to indicate these events.

A log survivor plot was drawn up from the collective data (Figure 8.2). The survivor function is broadly similar in shape to that obtained from babies feeding on the breast. There are two distributions represented by straight lines, one extending from approximately 0.5 to 1.1 seconds, the other made up of longer intervals. The point of intersection between the two distributions was determined in the manner described in Chapter 3, using the method of least squares. The two distributions cross at point (x, y) therefore by simultaneously solving the two equations $y_1 = m_1 x_1 + c_1$ and $y_2 = m_2 x_2 + c_2$ both for x on y and y on x, two values for this point are obtained:

(1) 141 centiseconds

(2) 137 centiseconds

Mean = 139 centiseconds = 1.4 seconds

The distributions of inter-suck intervals and of pauses shown by infants feeding on this apparatus show a similar pattern to that seen on the breast, however the cut-off point between them is displaced by 0.1 seconds.

Figures 8.3 - 8.7 give, for the three flow rates, the mean values of ISI, pause length, burst length, no. sucks/burst and % pausing time, calculated using the appropriate cut-off point of 1.4 seconds.

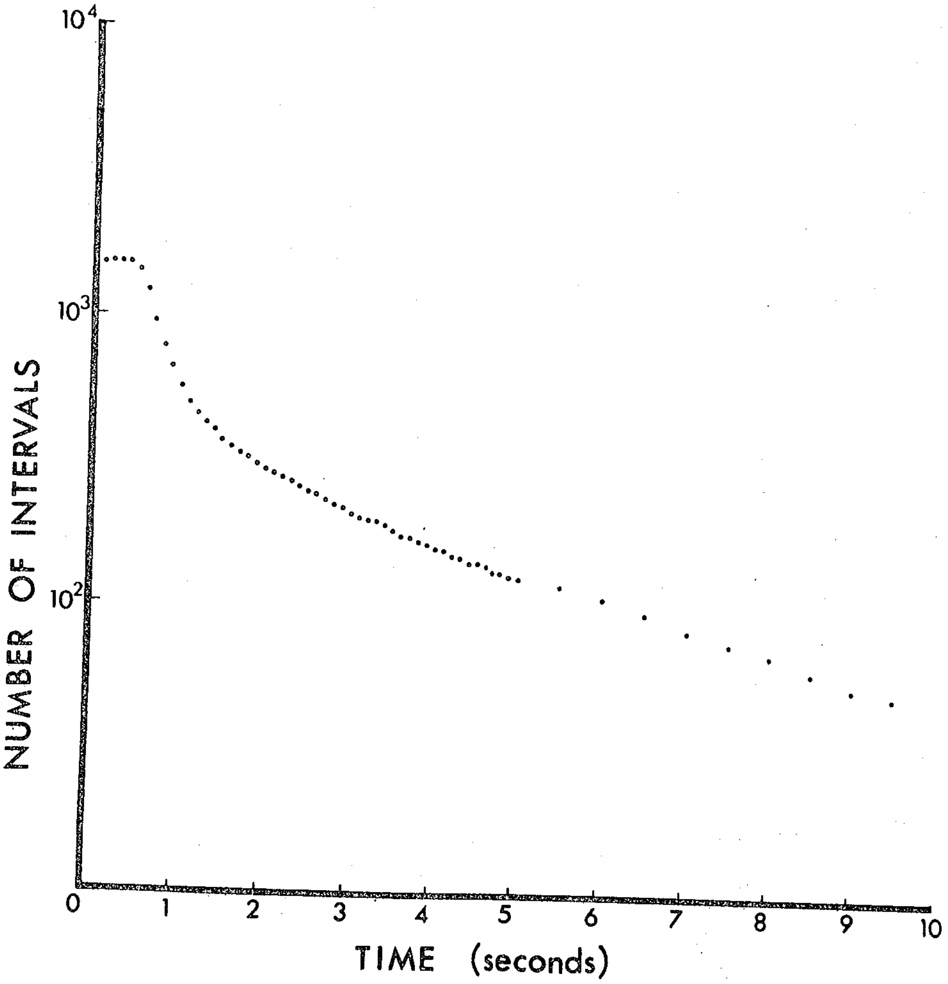


Figure 8.2. Aggregate survivor plot for all bottle data

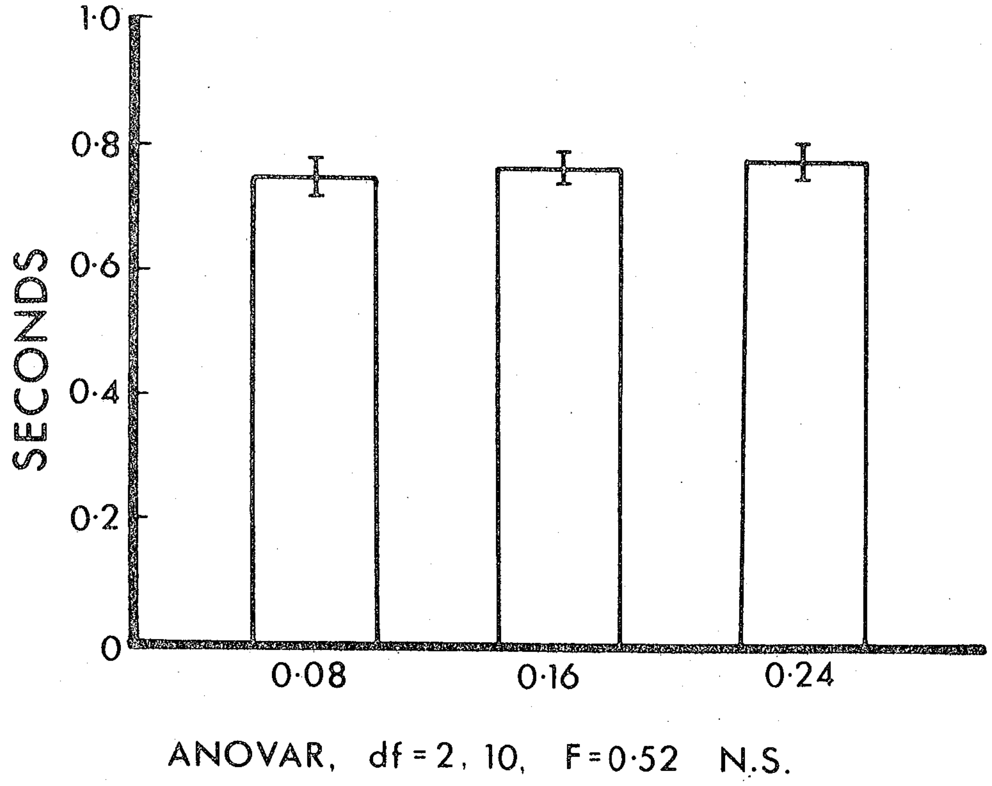


Figure 8.3. Mean ISI with increasing intake/suck

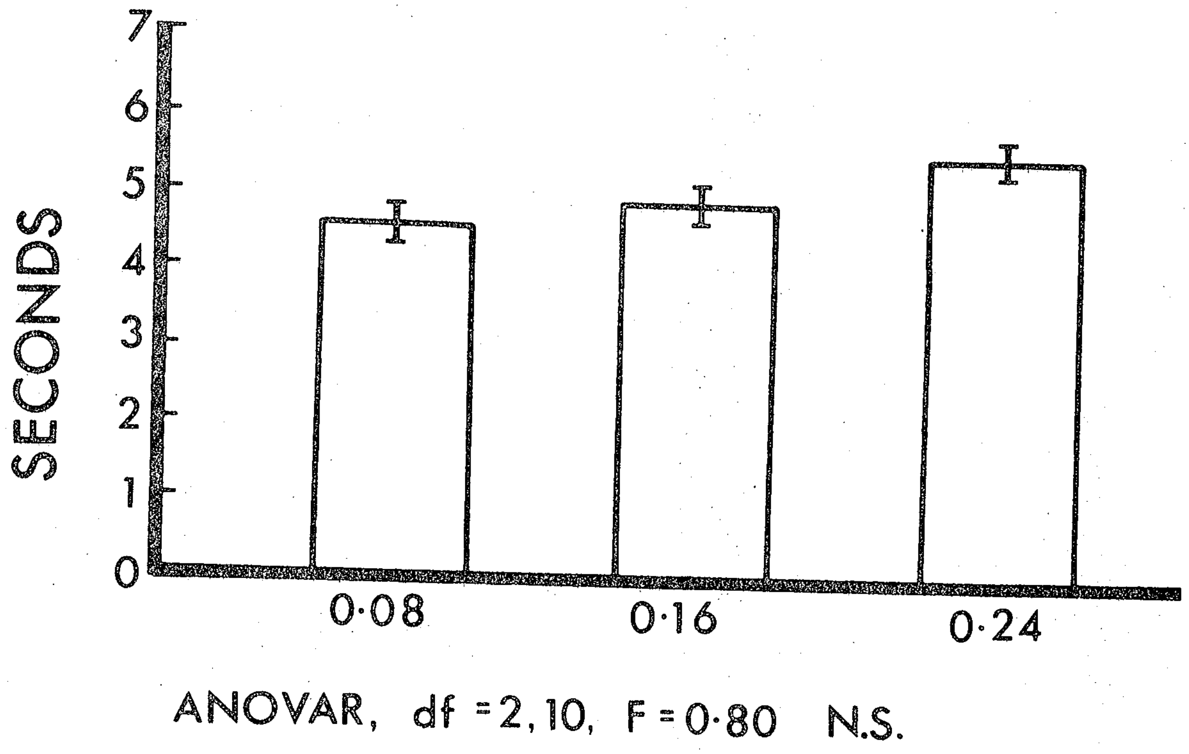


Figure 8.4. Mean pause length with increasing intake/suck

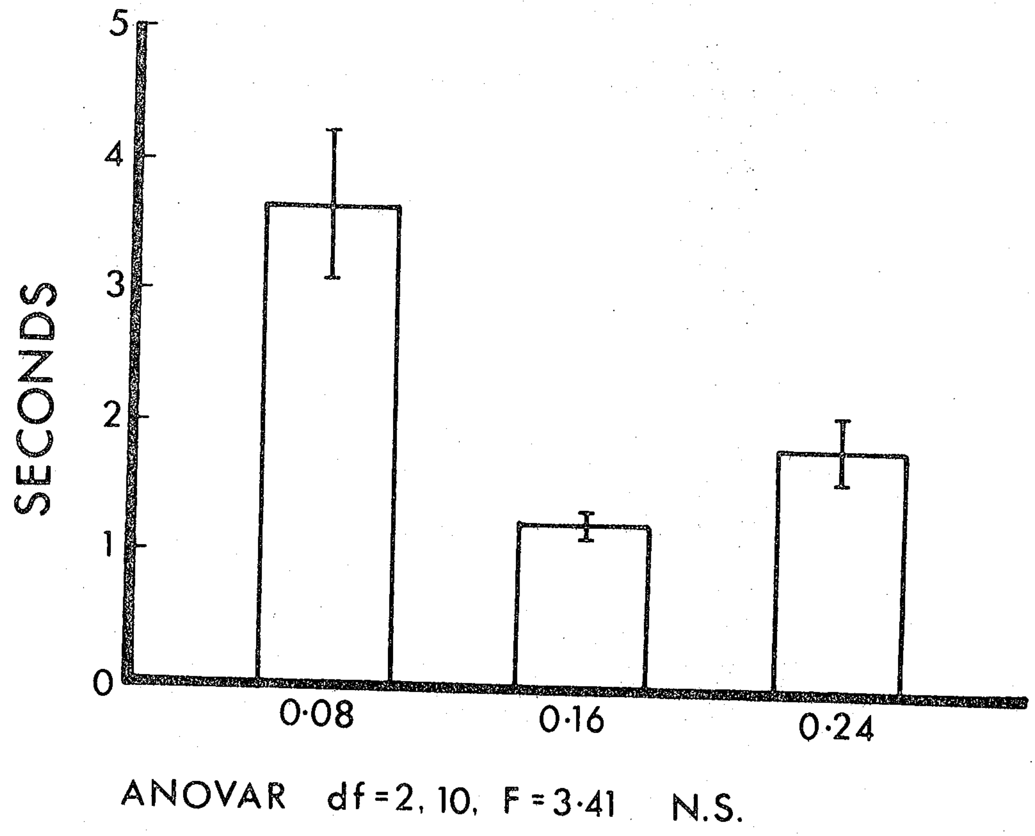
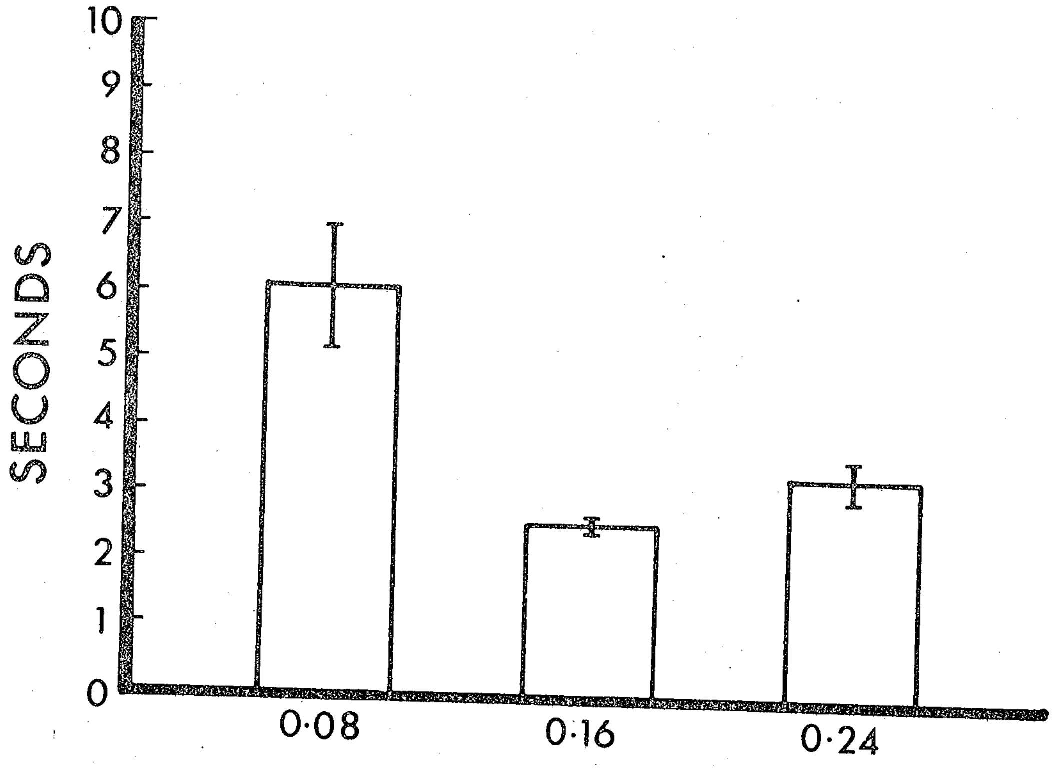


Figure 8.5. Mean burst length with increasing intake/suck



ANOVAR df = 2, 10, F = 3·27 N.S.

Figure 8.6. Mean no. sucks/burst with increasing intake/suck

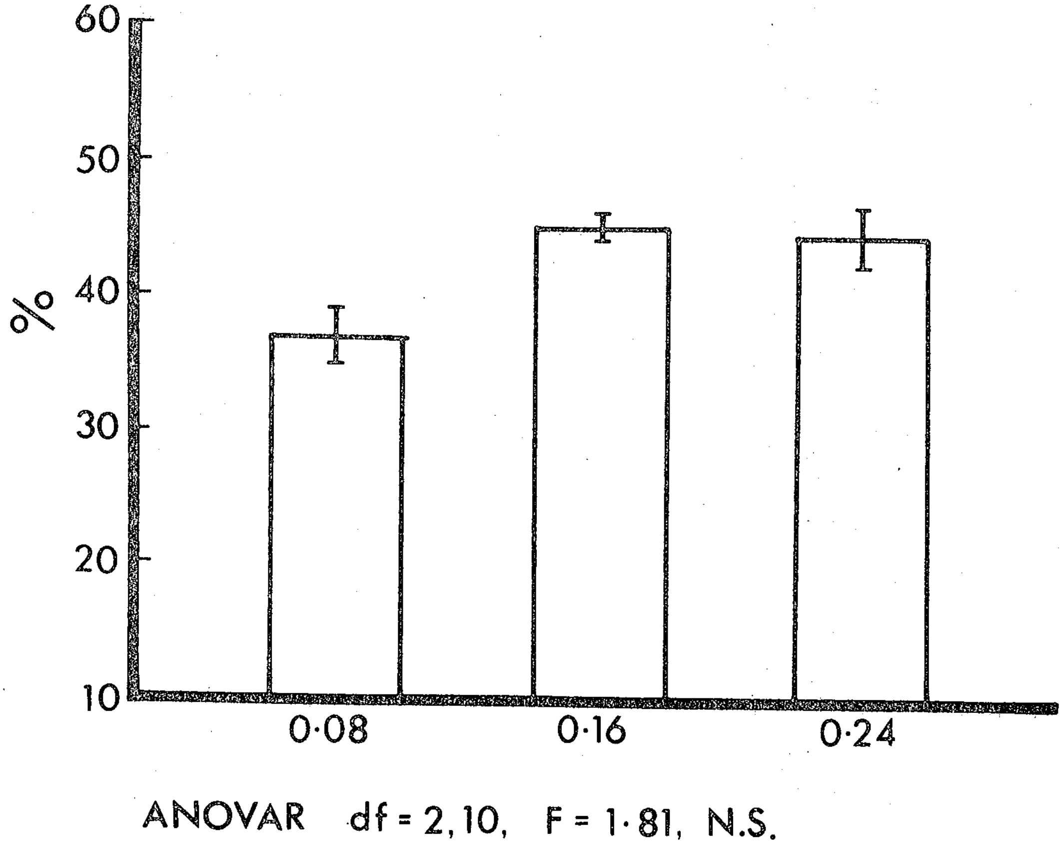


Figure 8.7. % pausing time with intake/suck

The sucking patterns were compared with analysis of variance. No significant differences were found between the three flow rates in any case (see figures).

8.6. Discussion

There are no significant differences in mean ISI, pause length, burst length, no. sucks/ burst or % pausing time between the three conditions in this experiment. The correlation found during breast feeding between sucking measures and the rate of milk intake was not therefore found in bottle feeding. Possible explanations for this are:

(1) The inference from the data gathered so far, mainly from breast feeding, may be wrong, and milk flow rate not in fact the main determinant of sucking pattern. With reference to the discussion in Chapter 7 of the factors which could influence sucking pattern, the other most likely agent is milk composition. Since the composition of milk received by the baby in this experiment was the same throughout each session one would not expect sucking patterns to change either if milk composition determines sucking.

(2) The method by which flow rate changes sucking patterns may not be stimulated properly in this bottle feeding experiment. This might be the case if, for example, the mechanism of such an effect involves the "stripping" or "milking" of the teat from the base to the tip by the tongue, an action which takes longer, the more milk is held in the teat (see section 7.4).

It is very difficult to say which of these explanations is the more probable. I am inclined towards the second, but clearly proper investigation of this point is needed.

CHAPTER 9

SUMMARY AND CONCLUSIONS

A picture emerges as a result of the experimental work presented in this thesis of sucking patterns during natural breast feeding and of the way in which they change through the course of a feed.

During sucking, intervals between sucks fall into two distinct distributions, of short within-burst inter-suck intervals and longer pauses between bouts of sucking. This is the first clear demonstration of two populations of inter-suck intervals, and the cut-off point (at 1.3 seconds) provides an objective statistical criterion for distinguishing between them.

During breast feeding, sucking varies considerably in rate and in the proportion of time spent pausing. Pausing is always a feature of sucking on the breast. The division of sucking into two modes, the nutritive (slow sucking with little pausing) and the non-nutritive (fast sucking with frequent pausing) is not upheld; these are, rather, the extremes of a continuum. It is likely that much of the earlier work looked simply at the two extremes, i.e. at the no-fluid condition and at relatively fast fluid flows.

On the first breast the baby's sucking rate first shows a pronounced decrease, perhaps as milk availability attains its maximum as a result of milk ejection. Subsequently, as availability declines, the sucking rate increases and the baby spends more time pausing. On the second breast, as compared with the first, more time is spent pausing and the mean sucking rate is faster (i.e. mean ISI decreases). Various possible explanations for these gradations in sucking parameters during a feed are examined.

Milk intake/suck decreases through the feed. It is correlated with sucking rate, and as the milk taken with each suck decreases, so also does the probability that the infant will be sucking at that time.

The possibility was investigated of assessing the occurrence of milk ejection during breast feeding in a non-intrusive way by observing the baby's sucking rate as milk became available.

Although a highly significant decrease in mean ISI was found between the first and the second 30-second periods of a breast feed which is most probably a result of the sudden flow of milk due to milk ejection, the change in ISI is not sufficiently sharply defined to pin-point the precise moment of milk ejection. For this, a device such as that of Friedman (1966), which records intra-mammary pressure via a water-filled adaptor held over the nipple by a suction cup, remains essential. However, the estimation of sucking rate over periods of half to one minute would appear to provide a good inciation of whether or not milk ejection has occurred. This may be more so for older than for younger infants, since in the older ones there is presumably a far greater contrast between milk flow before and after milk ejection as the volumes of milk involved are greater.

Sucking patterns in response to differing flow rates comparable to those commonly seen during breast feeding were examined using modified bottle feeding equipment. No consistent pattern emerged with the three flow rates used. This is the first study of sucking on a bottle with recorded high flow rates. It is difficult to reconcile the results with data obtained from breast feeding without suggesting that the mechanisms operating in breast and bottle feeding are different in some respects and cannot properly be compared. For example, if on the breast mean ISI varies as a result of the greater time taken by the tongue to "strip" the teat when it is full of milk, there is no reason why this should also occur during bottle feeding.

On the other hand, there is a real possiblity that composition, not milk flow rate, determines sucking patterns. The bottle feeding experiment needs to be repeated with larger numbers of infants and then with milks with varying proportions of fat. It must however be recalled that Chan, Pollitt and Leibel (1979), in studies of this kind involving much smaller quantities of fluid, found no such effect in bottle fed babies (see Section 2.9 for comments on this study).

The work of this thesis has used a non-intrusive and objective method of studying infant sucking on the breast to develop sensitive and reliable measures of characterising sucking behaviour in order to provide descriptive data on normal breast feeding. Reliable, naturalistic studies of this kind are badly needed in order to put into context and proper focus the large body of work on infant sucking which relates largely to bottle feeding. The baby's sucking behaviour must be related to the mother's lactation because in many ways breast and bottle feeding are not comparable activities. For example, rubber teats and human nipples are very different and the changes in the nipple during nursing cannot be simulated; neither can the mechanism of milk ejection. The texture, composition and taste of breast milk varies through a feed and other stimuli, for example tactile stimuli, are more varied in breast feeding. This thesis goes some of the way towards clarifying the relationship between the bodies of knowledge on breast and bottle feeding, but much further work is needed.

Regrettably it was not possible single-handed to include simultaneous observations of the mother's behaviour, although it is acknowledged that it may have an influence on the baby's sucking pattern. Specifically, it could influence the proportion of time spent sucking and pausing since mothers often respond to a pause in sucking (Kay, 1977). The primary objective here was to describe the infant's sucking during breast feeding. Future studies would do well to incorporate observations of the mother's behaviour.

Again, given this overall aim of the study, it was not possible either to chart any developmental changes in sucking, especially since at times there was a serious shortage of subjects. There was no sub-grouping or screening of infants according to age any more precisely than that the lactation was established and that the infants were receiving all or most of their food in this way. The infants were mainly 1-3 months old (serving incidentally perhaps to redeem the balance in the literature, which refers mainly to newborns). A developmental study along the lines given below would be a priority for future work.

There are already some indications as to the type of changes which might be found. Wright, Fawcett and Crow (1980), in a developmental study of the differences in the feeding behaviour of breast and bottle-fed infants, give data showing an increase in within-burst sucking rate from 1 week to 1 month to 2 months of age, both at the beginning and at the end of a breast feed. The biggest differences are seen between 1 week and 1 month, with little difference between 1 and 2 months, suggesting that the rate increases during the first few weeks but thereafter (during the period studied in this thesis) stabilises.

In a paper by Drewett and Woolridge (1979) the modal ISI for a complete feed in 5-8 day old babies is 0.7 - 0.8 seconds, in contrast to my corresponding figure of 0.5 - 0.6 seconds. However, exact comparison is not possible because the milk flow rates are not described and the feeds are much shorter than those in the present study. The shorter mean ISI in this thesis might well therefore reflect a longer period of (faster) sucking seen with low flow rates. It is of interest that these authors give a cut-off point of 1.3 seconds between intervals representing within-burst sucking and pausing, which is the same as that found in this study. This, therefore, may not depend upon the age of the baby.

These two papers are in accord with Wolff's findings with bottle feeding infants (1968, a,b). He describes sucking rate increasing with age, from a mean ISI of 1.0 seconds at 4 days to 0.7 seconds at 3 months for his nutritive condition, and from 0.48 to 0.41 seconds over the same period for his non-nutritive condition.

It would seem therefore that a broad trend showing sucking rates increasing with age, particularly during the first few weeks, has emerged since the work of this thesis was done. The developmental shifts in these particular measures are not great, and could reflect in part differences in milk flow rates during the course of a lactation and the known changes in the composition of breast milk. Detailing their minute changes is therefore felt to be perhaps of secondary importance.

However, it would be of interest to study infants' complete sucking patterns from the earliest feeds using the techniques described in this thesis. This would include the period of establishing lactation (4-8 weeks (Isbister,1954)). Feeds could be recorded on, for example, days 1,2,3,4, 5,6,7,14,21,28; and thereafter at monthly intervals throughout the lactation.

Other factors which could also be recorded include:

Other behaviour of the baby
Milk intake
Intra-mammary duct pressure
Subjective reports of milk ejection
The behaviour of the mother
Blood oxytocin and prolactin levels

In other words, a thorough study of the patterning of milk flow and its associated physiological changes in the mother.

Blood prolactin levels in women decline steadily after parturition (Bonnar et al, 1975) with superimposed transient increases during nursing. It would be most interesting to try to relate the baby's behaviour to the release of prolactin during breast feeding. Certain patterns of sucking might, for example, be found to be particularly potent stimulators of prolactin release. It would be interesting also to see whether it is the strong sucking in the early part of the feed which maximally stimulates prolactin secretion or whether the factor which is really significant in tailoring milk production to the baby's needs is the amount of sucking done by a still-hungry baby even when there is little or no milk left in the breast. A satiated baby shows a decrease in oral behaviours after a breast feed (Wright, 1977) and this presumably includes less "non-nutritive" sucking. The role of sucking in promoting oxytocin release can also be filled by mouthing or licking the breast, leaning on it, etc., but this does not appear to be the case for prolactin release.

As discussed in Section 1.2, the amount of prolactin released is proportional to the intensity and duration of sucking, but the quantities involved must change as lactation progresses since in the early days high levels of prolactin are associated with small volumes of milk whereas later on the opposite is true. A particularly interesting way to study this relationship would be to examine prolactin levels during tandem nursing, i.e., when a child is still being nursed throughout and beyond his mother's next pregnancy. The mother's "baseline" prolactin levels and the prolactin released in response to sucking by the two children of different ages could be studied. The volumes of milk produced in response to a fairly constant sucking stimulus superimposed on an increasing "baseline" level during pregnancy would lend an interesting perspective to the relationship between the sucking stimulus, the amounts of prolactin released, the sensitivity of alveolar tissue and the amount of milk produced. One could also study first and subsequent (or better still, the same woman in successive lactations) to see whether the prolactin response is different. It is generally the case that the milk "comes in" more quickly in second and later lactations (Isbister, 1954), but whether this is due entirely to more responsive alveolar tissue (it having already been "primed") or whether the prolactin response is somehow different is not known.

It would be of interest to extend the studies to other cases of relactation and to cases of nulliparous women putting adoptive babies to the breast (adoptive lactation). It is not certain how prolactin levels build up from a low "baseline" in response to sucking. It was regrettably not possible to measure prolactin levels during the relactation studied in Chapter 6 although this would have provided valuable supplementary data.

Oxytocin levels during human lactation also require considerable further study in order to elucidate the extent of their role. Most of the work to date on the milk ejection reflex is on other mammals, or, if on humans, has not combined direct radioimmunological assay of oxytocin levels in the blood of lactating women with the measurement of milk expulsion by such means as the recording of intra-mammary pressure (Friedman, 1960; Cobo et al, 1967) or the woman's own subjective sensations of let down and the observation of milk flow from the nipple (Isbister, 1954). The lack of such data is in no small way related to the difficulty of direct oxytocin measurement and the very low blood levels involved, and to the transient nature of its release.

There appears to be evidence for the quantal release of oxytocin, or at least for the pulsatile release of variable amounts during suckling in women, as suggested by Cowie and Tindal (1971). For example, the most faithful reproductions of the pressure changes in the mammary gland during nursing are produced by the intermittent injection of small amounts of oxytocin (Cobo et al, 1967; Caldeyro-Barcia, 1969, quoting Sica-Blanca et al, 1960). This probable transient, pulsatile release, i.e. several milk ejections per feed, necessitates that attempts to monitor oxytocin release during breast feeding involve very rapid and continuous serial sampling.

It is not known whether milk ejection regularly occurs only in response to the baby actually being on the breast and sucking or licking it, or earlier. There are plenty of reports from women of milk ejection and consequent release of milk occurring in response to factors such as thinking of the feed or hearing their baby cry. (Caldeyro-Barcia (1969) quotes data from Sico-Blanco which shows the cry of a newborn triggering an increase in the intra-mammary pressure of the mother, beginning 1½ minutes later). The conditioning of milk release is of course a well-known phenomenon in dairying, and it would be very interesting to establish whether it occurs in humans and, if so, how usual it is. It may even be that the ease with which let-down is conditioned is an important factor in successful breast feeding (in which case, breast feeding management should provide opportunity for it to occur). Conditioning of milk ejection would probably also help in preventing sore nipples, often caused by sucking, particularly with sustained negative pressure, before milk ejection. It would be useful to study the pattern of oxytocin release from the earliest days of lactation.

Once one had built up a reasonably clear picture of the pattern of oxytocin release during normal lactation, it would then be of considerable benefit to study its release, or the lack of it, with breast feeding difficulties. This could perhaps be combined with observations of the sucking, and might indicate how often breast feeding failure due to the milk supply "drying up" is due to the inadequate stimulation of the milk ejection reflex or its inhibition by anxiety (Newton and Newton, 1967). Many women experience difficulty in establishing lactation despite a desire to do so; in fact it is not difficult to imagine that an over-anxious mother keen to "succeed" could bring about a tense situation in which milk ejection is blocked.

To return to the findings of this thesis, milk flow rate is found to be a reliable and consistent predictor of sucking pattern (especially of sucking rate). This correlation does not of course indicate which is influencing which. There is much evidence from specially contrived situations that infants can intentionally vary sucking parameters. For example, Kalnins and Bruner's study (1973) where infants suck to bring a picture back into focus; and the work of Eimas (1975) where infants modified their sucking rate to hear more of particular adult phonetic sounds.

This ability of the infant to modify sucking patterns is impressive, and leads us to ask why he should be able to do this, and what the parallel could be in feeding. Or, if there is no parallel, what this ability could be a side-effect of. For example, as previously discussed, particular sucking patterns when the baby is properly "fixed" on the breast could be especially effective in causing the release of prolactin and oxytocin, or could be used by the baby to regulate his intake. It seems that breast-fed babies already have more opportunity to regulate their intake than do bottle fed infants, shown in a study by Wright, Fawcett and Crow (1980), of the infant's capacity to express satiety behaviourally. In Chapter 7, pause length was seen to have more relation to the baby's satiety and fatigue than with the milk flow rate. It therefore seems that pause length is used in a regulatory way (i.e. is a reflection of satiety).

However, there is no conclusive evidence that sucking pattern is used by the baby to control intake, and bearing in mind the large literature on the influence of fluid in the mouth on sucking, it is more reasonable to suppose that it is milk flow rate which determines sucking pattern (particularly sucking rate) rather than the other way around. However, the two are not entirely mutually exclusive explanations and the same explanation need not be true for all sucking parameters in all situations. The idea put forward by Kaye (1977) that pauses serve as an opportunity for turn-taking and dialogue is attractive and plausible, although there is no firm evidence that the infant does so deliberately.

If it is then the quantity of the fluid in the mouth which appears to control sucking, the correlated changes in milk texture and composition during breast feeding cannot be ruled out as the agent of these changes. Although, as it is argued in Section 7.4, milk flow rate is the more likely contender. Unfortunately neither the availability nor the composition of the milk received during breast feeding can be varied while the other is kept constant. The question of their individual effects should therefore be approached through a study of the effects of expressed breast milk fed to the baby through bottle feeding apparatus. The milk could be centrifuged to produce milks with particular proportions of lipid. Such procedures would however have the grave disadvantage of changing the system of milk delivery and thereby also probably changing the baby's response. This experiment would also be a test of Hall's hypothesis (1975) that the rise in the lipid content of breast milk acts as a cue which enables the baby to obtain the appropriate balance of calories and fluid.

Priority should be given to studying the infant's ability to detect changes in the lipid content of fluid. Much is known about the choice of sweetness, sourness, etc., but very little of the effects of other tastes and flavours which have relevance for breast feeding. Possibly Crook's (1978) method using small quantities of fluid could be used, since there are problems in obtaining large quantities of breast milk. In addition, the same methods could be used to study the sucking patterns of infants receiving, for example, sterilized cow's milk humanised to various degrees, and fluids containing various constituents of human milk, singly and in combination. The actual effects of different fluids per se and of their constituent elements could then be teased apart.

It would be interesting to examine breast feeding newborns, who receive probably quite small amounts of colostrum, which has less lipid than mature milk.

There is need for work of the kind presented here on other nursing mammals, particularly other primates, who exhibited "nutritive" sucking rates very similar to those of human babies on Wolff's bottle feeding apparatus (Wolff, 1968). This would provide a basis for sounder comparisons between the human and other species so that it would be possible to evaluate the extent to which human sucking is truly unique. All the work done on other species has used bottle feeding apparatus, and there are no naturalistic studies of sucking patterns during nursing on the mother. The question asked in the past has been why humans should have two modes of sucking, nutritive and non-nutritive, as opposed to one "all-purpose" mode, but it now seems that what may require explanation is rather why humans should have evolved such a remarkably sensitive and consistent graded response to differing milk flow rates.

The proper data does not yet exist on which to base any statement that human sucking is more responsive than that of other mammals to external or peripheral factors. It may be that other species show considerable plasticity of response when conditions are suitable for its expression, for example when nursing on the mother.

However, if one is to search for an explanation of the plasticity of human sucking, one possible value of it could follow from considerations of the developing capabilities of the child. REM sleep in the foetus is thought to approach 100% of all sleep, in the newborn it occupies half the total sleep and at three months it falls to one third. Subsequently it continues to fall at a more gradual rate into adulthood. One suggestion as to why this should be so (Roffwarg, Muzio and Dement, 1966), is that REM sleep, with its large increase in neuronal activity in the brain, provides stimulation from within, which may be essential for the normal growth and development of the brain when there is little or no environmental stimulation. This also provides "practice" for the brain so that when external stimulation increases, it will be able to deal with it. In other words, the immature CNS is "anticipating" and "preparing for" its future active role long before such capabilities are actually required.

Trevarthen (1977) describes how the organs of growing, immature organisms usually have intrinsic organisation in excess of their essential functions at that time, this prefunctional development of parts helping to "drive" development. Coordination of facial muscles by neural pathways is very good from the first days of life, in fact it is far more advanced than that of other muscles, such as those of the hands. Speech requires exceedingly refined coordination of the muscles of the tongue, lips and throat as well as of chest and vocal chords. The human face has been called the most expressive organ in creation, having a huge range of expression; an ability which requires a very high level of coordination of the facial muscles.

Could there be a parallel with the suggested advantage of REM sleep to the immature brain in the value of sucking for subsequent speech and facial expression? Where the organisation of a system, - muscles, neural pathways, etc. - is set up in advance of the organism's capacity to utilize it (in this case, for speech), it is plausible that varied, responsive sucking might be providing stimulation to maintain the very large masses of neural tissue devoted to the facial area which are not yet directly involved in their full range of motor and sensory reactions. This explanation would provide a sound reason for differences in the sucking of human infants compared with that of all other mammals.

Certainly, there is evidence which suggests the importance of oral feeding experience for motor development in general. Dowling and DeMonterice (1974) observed five children with unrepaired oesophageal atresia from birth for periods of from 8 months to 9 years. The three who were fed only via gastronomy tubes and whose oral experience was very deficient from birth had severe motor retardation and were generally much less responsive to their surroundings. In sharp contrast, the two who received a wide range of oral experience including sham feeds of milk and baby foods (which drained through an oesophagostomy) were normal in every respect.

The view of human sucking is now one of sucking basically organised in one mode (the "non-nutritive"), with progressive increases in flow rate, taste, etc. modifying it to produce a range of "nutritive" rhythms. To accommodate the considerable plasticity demonstrated, the concept of dual CNS oscillatory centres controlling two modes of sucking ("nutritive" and "non-nutritive", Wolff, 1968, 1973), has given way to the concept of one oscillator which sets the pace of sucking. This oscillator is very responsive to feedback from both internal and external cues which vary the rate and overall pattern of sucking.

Another aspect of sucking which merits further study is the intensity of sucking and the ratio of positive and negative pressures exerted by the baby. This could be studied during breast feeding using a tube taped to the nipple, as did Ardran and Kemp (1959), who found that "after some minutes of feeding the pressure (in the mouth) did not fall so low as it did initially and peaks of positive pressure appeared more frequently." This echoes findings with bottle feeding apparatus (Dubignon and Campbell, 1969; see Section 2.10).

A systematic study of the positive and negative pressure components of sucking throughout a feed combined with other techniques as suggested earlier in this chapter might well show that different ratios are differentially effective in eliciting oxytocin and prolactin release. It would be interesting to see whether the ratio is the same at the beginning of a feed, before milk ejection, and at the end, when the baby is again ingesting little or not fluid. One can speculate that different sucking patterns may actually be associated with different ratios, for example, slower rates of sucking could reflect greater suction pressure; and the manipulation of positive/negative ratios could afford the baby control over the rate of milk ingestion.

There are certain clinical implications following from the work in this thesis. For example, the case study in Chapter 6 clearly demonstrates the possibility of relactating after a course of bromocriptine to suppress lactation.

If the inhibition of the milk ejection reflex is an important cause of problems in breast feeding, a non-intrusive method of assessing milk flow would be of considerable value. Although it cannot be an absolute guide as the extremes of rhythmic, slow sucking with few pauses and fast sucking with more frequent pausing do overlap, observation of sucking patterns can provide useful corroborative support to the mother's and the attendants' observations of "proper" sucking. It can perhaps provide a quick guide as to what to look out for.

One practical use for these methods that has already been proved is in the design of nipple shields, which are used to improve eversion of poorly-formed nipples and to protect sore or cracked ones. Woolridge, Baum and Drewett (1980) have shown that a thin, latex nipple shield designed so that normal sucking patterns are minimally disrupted is more acceptable to the baby and interferes less with milk transfer than the conventional thick, rubber "Mexican hat". Related to this is the development of a new system, which will enable the measurement of milk flow during breast feeding to be combined with periodic sampling of the milk, in which one of the components is a modified thin nipple shield. This promising new technique should cast much light upon the detailed inter-relationships between milk flow rate, milk composition and sucking patterns. It may even allow an input of breast milk lipid to enrich the milk entering the baby's mouth, thereby providing the only satisfactory evaluation of the "Hall hypothesis" (see above).

It is to be hoped that the clinical value of sucking patterns as an index of the effects of perinatal factors such as medication transferred from the mother's circulation and perhaps also as a predictor of certain aspects of subsequent development can be developed. This is an area as yet barely touched upon, and a more precise description of normal sucking patterns and improved techniques of analysis such as presented here might contribute towards this aim.

APPENDIX

CHAPTER 5

Mean ISI through the first half-feed (seconds)

	1A	1B	1C
EB	0.86	0.81	0.71
AC	0.77	0.70	0.62
MC	0.92	0.87	0.83
AF	0.65	0.75	0.58
LF	0.84	0.77	0.72

Mean pause length through the first half-feed (seconds)

	1A	1B	1C
EB	2.25	2.94	3.58
AC	2.67	3.60	5.29
MC	1.51	2.04	2.25
AF	2.55	1.52	5.11
LF	1.57	1.86	2.28

Mean burst length through the first half-feed (seconds)

	1A	1B	1C
EB	15.00	8.06	4.63
AC	5.69	9.40	5.85
MC	5.35	6.83	6.62
AF	12.11	81.81	4.84
LF	22.01	8.70	6.33

Mean no. sucks/burst through the first half-feed

	1A	1B	1C
EB	18.6	11.0	7.6
AC	8.4	14.4	10.2
MC	6.8	8.8	8.9
AF	19.5	110.0	11.1
LF	27.1	12.3	9.8

% pausing time through the first half-feed

	1A	1B	1C
EB	12.2	25.9	35.2
AC	31.0	27.2	45.1
MC	22.3	21.3	25.5
AF	15.4	1.2	45.2
LF	6.0	16.7	25.7

APPENDIX

CHAPTER 5

Mean ISI (seconds)

	1A	2A
EB	0.86	0.73
AC	0.76	0.67
MC	0.92	0.84
HD	0.82	0.67
AF	0.65	0.76
LF	0.84	0.79
BK	0.85	0.80

Mean pause length (seconds)

	1A	2A
EB	2.25	3.96
AC	2.36	4.60
MC	1.51	2.03
HD	5.34	3.54
AF	2.55	1.50
LF	1.57	2.18
BK	2.60	3.05

Mean burst length (seconds)

	1A	2A
EB	15.02	5.74
AC	7.95	9.71
MC	5.35	4.24
HD	33.45	4.03
AF	12.11	106.69
LF	22.01	13.75
BK	3.77	3.65

Mean no. sucks/burst

	1A	2A
EB	18.6	8.9
AC	11.9	15.2
MC	6.8	6.1
HD	41.8	7.0
AF	19.5	141.0
LF	27.1	18.3
BK	5.4	5.6

% pausing time

	1A	2A
EB	11.1	35.5
AC	23.8	32.8
MC	22.3	30.7
HD	11.3	45.8
AF	15.4	0.7
LF	6.0	12.9
BK	40.2	44.9

APPENDIX

CHAPTER 6

Mean intake/suck (g)

	1F	2A
LF	0.00	0.13
SM	0.03	0.33
DR	0.11	0.35
SR	0.04	0.24
CS	0.04	0.15
MS	0.03	0.09
MW	0.05	0.22
RW	0.06	0.26

Mean ISI (seconds)

	1F	2A
LF	0.69	0.73
SM	0.59	0.82
DR	0.79	0.96
SR	0.48	0.65
CS	0.58	0.68
MS	0.60	0.73
MW	0.66	0.78
RW	0.65	0.69

Mean pause length (seconds)

	1F	2A
LF	2.38	1.44
SM	3.74	4.49
DR	2.81	2.93
SR	0.0	3.21
CS	7.13	2.24
MS	3.66	2.68
MW	3.10	2.68
RW	3.08	1.89

Mean burst length (seconds)

	1F	2A
LF	2.39	6.29
SM	1.46	2.49
DR	1.75	1.81
SR	2.93	5.91
CS	1.62	2.17
MS	1.93	2.37
MW	2.49	2.27
RW	2.36	2.45

Mean no. sucks/burst

	1F	2A
LF	3.03	7.42
SM	2.14	2.93
DR	2.21	2.10
SR	4.35	7.38
CS	2.37	2.81
MS	2.68	2.97
MW	3.22	2.76
RW	3.08	3.11

% pausing time

	1F	2A
LF	29.2	3.4
SM	63.0	39.2
DR	44.9	45.1
SR	0	5.9
CS	72.1	26.8
MS	47.8	31.4
MW	32.2	33.4
RW	33.9	18.0

APPENDIX

CHAPTER 8

Mean ISI (seconds)

	0.08	0.16	0.24 (ml/suck)
MC	0.64	0.58	0.68
JT	1.03	0.99	1.02
LD	0.69	0.75	0.63
SW	0.74	0.83	0.80
BC	0.78	0.76	0.86
CF	0.63	0.74	0.69

Mean pause length (seconds)

	0.08	0.16	0.24 (ml/suck)
MC	5.27	6.37	7.19
JT	3.71	3.08	5.13
LD	3.42	5.35	6.24
SW	3.44	6.33	4.77
BC	4.91	4.40	4.04
CF	6.94	3.50	5.68

Mean burst length (seconds)

	0.08	0.16	0.24 (ml/suck)
MC	2.50	0.98	0.66
JT	2.89	0.78	1.58
LD	8.32	1.19	1.33
SW	4.47	1.13	3.54
BC	3.51	1.40	2.93
CF	0.28	1.96	0.92

Mean no sucks/burst

	0.08	0.16	0.24 (ml/suck)
MC	4.5	2.3	2.0
JT	3.8	1.8	2.5
LD	14.0	3.0	3.0
SW	6.7	2.4	5.1
BC	6.5	2.9	5.2
CF	1.3	3.4	2.0

% pausing time

	0.08	0.16	0.24 (ml/suck)
MC	65.3	80.6	89.5
JT	53.2	63.3	74.3
LD	26.8	76.0	80.5
SW	41.3	80.1	42.3
BC	52.6	60.6	43.2
CF	84.2	61.6	83.8

REFERENCES

Abercrombie, M.L.J., Face to face - proximity and distance. J. Psychosomatic Res., 1971, vol. 15, p.395-404.

Amoroso, E.C., and Jewell, P.A. The exploitation of the milk-ejection reflex by primitive peoples. Occasional Papers of the Royal Anthropological Institute, 1963, vol. 18, 126-137.

Archavski, I.A. The Physiological basis of breast feeding of newly born children immediately after birth with a view to the prevention of physiological loss of weight. Vopr. Pediactric, 1952, 20, 45-53.

Ardran, G.M., and Kemp, F.H. A correlation between suckling pressures and the movements of the tongue. Acta Paediatrica, 1959, (May) 48, 261-272.

Ardran, G.M., Kemp, F.H. and Lind, J. A cineradiographic study of bottle feeding. Br. J. Radiol., 1958a, 31, 11-22.

Ardran, G.M., Kemp, F.H. and Lind, J. A cineradiographic study of breast feeding. Br. J. Radiol., 1958b, 31, 156-162.

Bacon, C.J. and Wylie, J.J. Mothers' attitudes to infant feeding at Newcastle General Hospital in Summer, 1975. British Medical Journal, 7th Feb., 1976, 1, 308-309.

Balint, M. Individual differences of behaviour in early infancy, and an objective method for recording them. J. of Genetic Psychology, 1948, 73, 57-79, 81-117.

Bell, R.Q. and Haaf, R.A. Irrelevance of newborn waking states to some motor and appetitive responses. Child Development, 1971, 42, 69-77.

Bernal Dunn, J. and Richards, M.P.M. Observations on the developing relationship between mother and baby in the neonatal period. Chapter 17 in "Studies in mother-infant interaction" Ed. H.R. Schaffer, Academic Press, 1977, 427-455.

Bisset, G.W. Milk ejection. Handbook of Physiol. Section 7, Endocrinology, Vol. IV, part 1. American Physiol. Soc., 1974, 493-520.

Blurton Jones, N. Comparative aspects of mother-child contact. Chapter 12 in Ethological studies of child behaviour. Ed. N. Blurton Jones, Cambridge University Press, 1972.

Bonnar, J., Franklin, M., Nott, P.N. and McNeilly, A.S. Effect of breast feeding on pituitary-ovarian function after childbirth. British Medical Journal, 1975, 4,82-84.

Booth, D.A., Lee, M. and McAleavey, C. Acquired sensory control of satiation in man. B.J. Psychol., 1976, 67, 2, 137-147.

Brazelton, T.B. Effect of maternal medication on the neonate and his behaviour. J. Pediatrics, 1961, vol. 58, no. 4, 513-518.

Brown, J.V. and Peiper, W.A. Non-nutritive sucking in great ape and human newborns. American J. of Physical Anthropology, 1973, 38, 549-554.

Brown, J.V. Non-nutritive sucking in great ape and human newborns: some phylogenetic and ontogenetic characteristics. in J. Bosma (Ed) Fourth symposium on oral sensation and perception, 1973, Springfield, Illinois, pub. Charles C. Thomas.

Bruce, J.O. and Ramirez, V.D. Site of action of the inhibitory effect of oestrogen upon lactation. Neuroendocrinology, 1970, 6, 19-29.

Brun del Re, R., del Poso, E., de Grandi, P., Friesen, H., Hinselmann, M. and Wyss, H. Prolactin inhibition and suppression of peurperal lactation by a Br-ergocryptine (CB 154). Obstetrics and Gynecology, 1973, 41, 884-890.

Bruner, J.S. "Feeding and looking" Chapter in Processes of cognitive growth: Infancy. Vol. 3, 1968 Heinz Werner Lecture Series, Worcester, Mass. Clark University Press, with Barre Publishers.

Burke, P.M. Swallowing and the organization of sucking in the human newborn. Child Development, 1977, 48, 523-531.

Cannon, W.B. Bodily changes in pain, hunger, fear and rage. (An account of recent researches into the function of emotional excitement). 1929. D. Appleton & Co.

Carlsson, B., Ahlstedt, S. et al. E. coli antibody in milk from healthy Swedish mothers and mothers from a very low s-e gp. of a developing country. Acta Paed. Scand. 1976, 65, 417-423.

Chan, S., Pollitt, E. and Leibel, R. Effects of nutrient cues on formula intake in 5-week-old infants. Infant Behaviour and Development, 1979, 2, 201-208.

Christensen, S., Dubignon, J. and Campbell, D. Variations in intra-oral stimulation and nutritive sucking. Child Development, 1976, 47, 539-542.

Cobo, E., DeBernal, M.D., Gaitan, E. and Quintero, C.A. Neurohypophyseal hormone release in the human; II: Experimental Study during lactation. American Journal of Obstetric Gynaecology, 1967, 97, 519-29.

Colley, J.R.T. and Creamer, B. Sucking and swallowing in infants. British Medical Journal, August, 1958, 422-3.

Caldeyro-Barcia, R. Milk ejection in women. in: Lactogenesis: the initiation of milk secretion at parturition. Ed. M. Reynolds and S.J. Folley. Philadelphia: Univ. of Pennsylvania Press, 1969, 229-243.

Cooper, Sir Astley, P. On the anatomy of the breast, 1840. London, Longmans, Orme, Green, Brown and Longman.

Cowie, A.T. and Tindal, J.S. The Physiology of Lactation. Edward Arnold Lt., 1971.

Cox, D.R. and Lewis, P.A.W. The statistical analysis of series of events. 1966, London, Methuen, 1-16, 59-61.

Crook, C.K. Neonatal sucking: effects of quantity of the response-contingent fluid upon sucking rhythm and heart rate. *J. Exp. Child Psychol*., 1976, *21*, 539-548.

Crook, C.K. and Lipsitt, L.P. Neonatal Nutritive Sucking: effects of taste stimulation upon sucking rhythm and heart rate. *Child Development*, 1976, *47*, 518-522.

Crook, C.K. Taste and the temporal organization of neonatal sucking. Chapter 11 in *Taste and development, the genesis of sweet preference*, 1977, 146-160. Ed. J.M. Weiffenbach. US DHEW.

Crook, C.K. Taste perception in the newborn infant. *Infant behaviour and development*, 1978, *1*, 52-69.

Crook, C.K. The organization and control of infant sucking, in H.W. Reese and L.P. Lipsitt (Eds.) *Advances in child development and behaviour*, *13*, NY Academic Press (in press).

Cross, B.A. Milk ejection resulting from mechanical stimulation of mammary myoepithelium in the rabbit. *Nature*, 1954, *173*, 450.

Cross, B.A. Neurohormonal mechanisms in emotional inhibition of milk ejection. *J. Endocrin*., 1955, *12*, 29-37.

Cross, B.A. Comparative Physiology of milk removal. *Symp. Zool. Soc. Lond. '77* *41*, 193-210. Comparative aspects of lactation. ed. Malcolm Peaker, Academic Press.

Desor, J.A., Maller, O. and Andrews, K. Ingestive Responses of Human Newborn to Salty, Sour and Bitter Stimuli. *J. Comparative and Physiological Psychol*. 1975, 89, *8*, 966-970.

Dreier, T. and Wolff, P.H. Sucking, state, and perinatal distress in newborns. *Biology of the Neonate*, 1972, *21*, 16-24.

Drewett, R.F., Statham, C., and Wakerley, J.B. A quantitative analysis of the feeding behaviour of suckling rats. *Animal Behaviour*, *22*, 1974, 907-913.

Dubignon, J. and Campbell, D. Intraoral stimulation and sucking in the new born. *J. Expt. Child Psychol*, 1968a, *6*, 154-166.

Dubignon, J. and Campbell, D. Sucking in the newborn under 3 conditions: non-nutritive, nutritive and a feed. *J. Expt. Child Psychology*, 1968b, *6*, 335-350.

Dubignon, J. and Campbell, D. Sucking in the newborn during a feed. *J. Expt. Child Psychology*, 1969, *7*, 282-298.

Egli, G.E., Egli, N.S. and Newton, M. The influence of the number of breast feedings on milk production. *Pediatrics*, 1961, *27*, 314-317.

Eimas, P.D. Speech perception in early infancy, 1975. Chapter 6, 193-231, in *Infant perception: from sensation to cognition*, *11*. *Perception of space, speech and sound*. Ed. L.B. Cohen and P. Salapatek. Academic Press, NY.

Elder, M.S. The effects of temperature and position on the sucking pressure of newborn infants. Child Development, 1970, 41, 95-102.

Ely, F. and Petersen, W.E. Factors involved in the ejection of milk. J. of Dairy Science, 1941, 211-223.

Eysenck, H.J. Manual of the Maudsley Personality Inventory, 1959 University of London Press, London.

Fasman, G.D. (ed.) Handbook of Biochemical and Molecular Biology, 1976, Physical and Chemical Data, volume 1. CRC Press.

Folley, S.J. The milk-ejection reflex: a neuroendocrine theme in biology, myth and art. J. Endocrinology, 44, 1969.

Friedman, E.A. Direct measurement of milk-ejection pressure in unanaesthetized lactating humans. Am. J. of Obstetrics and Gynaecology, 1960, 80, 119-123.

Galef, B.G. and Sherry, D.F. Mother's milk: a medium for transmission of cues reflecting the flavour of mother's diet. J. Comp. and Physiol. Psychol. 1973, 83, No. 3, 374-8.

Griffiths, M. Echidnas. International series of monographs in pure and applied biology, Zoology Division. Ed. Kerkut, G.A. Vol. 38 Oxford, Pergamon Press.

Grosvenor, C.E., et al. Central and peripheral neural influences on the oxytocin-induced pressure response of the mammary gland of the unanaesthetised lactating rat. Journal of Endocrinology, 1972, 55, 299-309.

Gunther, M. Sore Nipples, Causes and Prevention. Lancet, 1945, Nov. 10, 590-593.

Gunther, M. Instinct and the nursing couple. Lancet, 1955, March 19, 575-578.

Gunther, M. In discussion on the breast in pregnancy and lactation. Proc. Royal Soc. Medicine, 1958, 51, 306-8.

Gunther, M. and Stanier, J.E. Diurnal variation in the fat content of breast milk. Lancet, 1949, Aug. 6, 235-237.

Gwynne-Evans, E. The organisation of the oro-facial muscles in relation to breathing and feeding. Brit. Dental J., 1951, 91, 6, 135-142.

Hall, Barbara, Changing composition of human milk and early development of an appetite control: A hypothesis. Lancet, 1975, April 5, 779-781.

Halverston, H.M. Journal of Genetic Psychology, 47, 1932.

Harris, G.W., Pickles, V.R. Reflex stimulation of the neurohypophysis (Posterior Pituitary Gland) and the nature of posterior pituitary hormone(s). Nature, 1953, 172, 1049.

Harrison, R.J. Reproduction and reproductive organs. In: *The Biology of Marine Mammals*., 1969, ed. H.T. Andersen, p. 335, Academic Press.

Hillman, D. and Bruner, J.S. Infant sucking in response to variations in schedules of feeding reinforcement. *J. Exp. Child Psychology*, 1972, *13*, 240-247.

Humphrey, T. Some correlations between the appearance of human foetal reflexes and the development of the nervous system. in: *Progress in brain research*, 1964, *4*, 93-135. ed. D.P. Purpura and J.P. Schade, Elsevier.

Huntingford, P.J. Intranasal use of synthetic oxytocin in management of breast feeding. *British Medical Journal*, March 11, 1961, 1, 709-11.

Hwang, P., Guyda, H. and Friesen, H.G. A radioimmunoassay for human prolactin. *Proceedings of the National Academy of Science of the U.S.A.*, 1971, 68, 1902.

Hytten, F.E. Observations on the vitality of the newborn., *Archives of Disease in Childhood*, 1951, 26, 477-486.

Hytten, F.E. Clinical and Chemical studies in human lactation. *British Medical Journal*, 1954, 1, 175-182, Jan. 23.

Hytten, F.E. and Baird, D. The development of the nipple in pregnancy. Lancet, 1958, *1*, 1201-1204.

Hytten, F.E., Yorston, J.C. and Thomson, A.M. Difficulties associated with breast feeding. *British Medical Journal*, 1958, 310-315, Feb 8.

Isbister, C. A Clinical study of the draught reflex in human lactation. *Arch. Dis. Childhood*, 1954, 29, 66-71.

Jacobson, L., Kaij, L. and Nilsson, A. Post-partum mental disorders in an unselected sample: frequency of symptoms and predisposing factors. *British Medical Journal*, 1965, 1, 1640-1643.

Johnson, P. and Salisbury, D.M. Breathing and sucking during feeding in the newborn. in: *Parent-Infant interaction*, Ciba Foundation Symposium, 33, 1975, Associated Scientific Publishers.

Johnson, P. and Salisbury, D.M. Preliminary studies on feeding and breathing in the newborn. *Taste and development, the genesis of sweet preference*. *8*, 111-124, 1977. Ed. J.M. Weiffenbach.

Kalnins, I.V. and Bruner, J.S. The co-ordination of visual observation and instrumental behaviour in early infancy. *Perception*, 1973, *2*, 307-314.

Kaye, H. Infant sucking behaviour and its modification. Chapter in *Advances in Child Development*, 1968, *3*, 1-52, L.P. Lipsitt and C.C. Spiller, Academic Press, New York.

Kaye, K. Milk pressure as a determinant of the burst-pause pattern in neonatal sucking. Proceedings, 80th Annual Convention, APA, 1972.

Kaye, K. Toward the origin of dialogue. Chapter 5 in *Studies in mother-infant interaction* (Proc. of Loch Lomond symposium, 1977, 89-117. ed. H.R. Schaffer.

Klaus, M.H., Kennell, J.H., Plumb, N. and Zuehlke, S. Human maternal behaviour at the first contact with her young. Pediatrics, 1970, 2, Vol. 46, 187-192.

Kobre, K.R. and Lipsitt, L.P. A negative contrast effect in newborns. J. Experimental Child Psychology, 1972, 14, 81-91.

Kron, R.E. and Litt, M. Fluid mechanics of nutritive sucking behaviour: the suckling infant's oral apparatus analysed as a hydraulic pump. Med. and Biol. Eng., 1971, 9, 45-60. Pergamon Press.

Kron, R.E., Ipsen, J. and Goddard, K.E. Consistent individual differences in the nutritive sucking behaviour of the human newborn. Psychosomatic Med., 1968, 30, 151-161.

Kron, R.E., Stein, M. and Goddard, K.E. A method of measuring sucking behaviour in new-born infants. Psychosomatic Medicine, 1963, 25, 181-191.

Kron, R.E., Stein, M.D. and Goddard, K.E. Newborn sucking behaviour affected by obstetric sedation. Pediatrics, 1966, 37, 1012-1016.

Kron, R.E., Stein, M. Goddard, K.E. and Phoenix, M.D. Effect of nutrient upon the sucking behaviour of newborn infants. Psychosomatic Med., 1967, 29, 24-32.

Lancet, Annotation, 1949, Nerve-endings of the nipple. 2, 205-6.

Levin, G.R. and Kaye, H. Non-nutritive sucking by human neonates. Child Development, 1964, 35, 749-758.

Linzell, J.L. The silver staining of myoepithelial cells, particularly in the mammary gland, and their relation to the ejection of milk. J. Anatomy, 1952, 86, 49-57.

Lipsitt, L.P. Taste in human neonates: its effects on sucking and heart rate. Chapter 9 in: Taste and development: the genesis of sweet preference, 125-142, 1977, US. DHEW.

Lipsitt, L.P. and Kaye, H. Change in neonatal response to optimising and non-optimising sucking stimulation. Psychonomic Science, 1965, 2, 221-222.

Lipsitt, L.P., Reilly, B.M., Butcher, M.J. and Greenwood, M.J. The stability and inter-relationships of newborn sucking and heart rate. Developmental Psychology, 1976, 9, 305-310.

Lucas, A., Gibbs, J.A.H., Lyster, R.L.J. and Baum, J.D. Creamatocrit: simple clinical technique for estimating fat concentration and energy value of human milk. British Medical Journal, 1978, 1, 1018-1020.

Lucas, A., Lucas, P.J. and Baum, J.D. Pattern of milk flow in breast fed infants. The Lancet, 1979, July 14, 57-58.

Luther, E.C., Arballo, J.C., Sala, N.L. Cordero Funes, J.C. Suckling pressure in humans - relationship to oxytocin-reproducing reflex milk ejection. J. App. Physiol., 1974, 36, 350-353.

McNeilly, A.S. Lactation and the physiology of prolactin secretion. *Postgrad. Med. J.* 1965, April, *51*, 231-35.

McNeilly, A.S. Fertility regulation during human lactation. Physiology of Lactation. *J. biosoc. Sci.*, 1977, Suppl. 4, 5-21.

Machlis, L. Analysis of temporal patterning of pecking. *Behaviour*, 1977, *63*, 1.

Macy, I.G. and Kelly, H.J. Human milk and cows' milk in infant nutrition. in: *Milk: the mammary gland and its secretion*, 1961, Vol. 2 , 265-304. Ed. S.K. Kon and A.T. Cowie, New York, Academic Press.

Maller, O. and Desor, J.A. Effect of taste on ingestion by human newborns. in: *4th symposium on oral densation and development in the foetus and infant*. ed. J.F. Bosman, 1973. US Govt. printing office, 279-291.

Malmo, R.B. and Shagass, C. Studies of blood pressure in psychiatric patients under stress. *Psychosomatic Medicine*, 1952, *14*, 82-93.

Mayer, G. and Klein, M. Histology and cytology of the mammary gland. In: *Milk: the mammary gland and its secretions*, 1961, 1, Ed. S.K. Kon and A.T. Cowie, New York, Academic Press.

Mead, M. and Newton, N. Cultural patterning of perinatal behaviour. In: *Childrearing - its social and psychological aspects*. 1967, Williams and Wilkins, 142-244, Ed. S.A. Richardson and A.F. Guttmacher.

Morris, D. *The Naked Ape*, 1969, Dell.

Newton, M. Human Lactation. In: *Milk: the mammary gland and its secretion*, 1961, 1, Ed. S.K. Kon and A.T. Cowie, New York, Academic Press, 281-320.

Newton, M., Egli, G.E. and Jackson. The effect of intranasal administration of oxytocin on the let-down of milk in lactating women. *Am. J. of Obstetrics and Gynaecology*, 1958, *76*, 103-107.

Newton, M. and Newton, N.R. The let-down in human lactation. *J. Pediatrics*, 1948, *33*, 698-704.

Newton, N. and Newton, M. Psychologic aspects of lactation. *New England Journal of Medicine*, 1967, *277*, 1179-1188.

Newton, Niles A. Interrelationship between various aspects of the female reproductive role. *Psychosom. Med. in Obstetrics and Gynaecology*, 1972, 388-390 (3rd int. congr., London, 1971).

Noel, G.L., Suh, H.K. and Frantz, A.G. Prolactin release during nursing and breast stimulation in postpartum and nonpostpartum subject. *J. Clin. Endocrin. & Metab*, 1974, Vol. *38*, 3, 413-425 (March 1974).

Nowlis, G.H. From reflex to representation: taste-elicited tongue movements in the human newborn. Chapter 14 in *Taste and development: the genesis of sweet preference*, 1977, 190-204. US DHEW.

Nowlis, G.H. and Kessen, W. Human newborns differentiate differing concentrations of sucrose and glucose. *Science*, 1976, *191*, 865-6.

Pajntar, M. Obstetrical complications - personality changes and emotional tension during pregnancy. Psychosom. Med. in Obstetrics and Gynaecology, 1972, 133-6. 3rd int. congr. London. 1971. Karger, Basel, 1972.

Peiper, A. Cerebral function in infancy and childhood., 1963, Pitman.

Persky, H., et al. Effect of two psychological stresses on adrenocortical function. Archives of Neurology & Psychiatry, 1959, 81, 219-26. (American Medical Association).

Peterson, F. and Rainey, L.H. The beginnings of mind in the newborn. Bulletin of the Lying-in hospital of the City of New York, 1910, 7, 99-122.

Pitelka, D.R. and Hamamoto, S.T. Form and function in mammary epithelium: the interpretation of ultrastructure. Journal of Dairy Science, 60, (4), 1977, 643-654.

Pitt, B. "Atypical" depression following childbirth, B.J. Psychiat., 1968, 114, 1325-1335.

Pollitt, E., Gilmore, M. and Valcarcel, M. The stability of sucking behaviour and its relationship to intake during the first month of life. Infant Behaviour and Development, 1978, 1, 347-357.

Prechtl, H.F.R., Theorell, K., Lind, J. and Blair, A.W. Behavioural state cycles of normal newborn infants. A comparison of the effect of early and late cord clamping. Develop. Med. Child Neurol., 1973, 15, 597-605.

Richards, M.P.M. Feeding and the early growth of the mother-child relationship. Milk and Lactation. Modern Problems in Pediatrics, 15, 1975, 143-154, Karger, Basel.

Richardson, K. Contractile tissues in the mammary gland, with special reference to myoepithelium in the goat. Proc. Royal Society, 1949, B136, 30-45.

Richardson, K.C. Structural investigation of the contractile tissues in the mammary gland. Colloques Internationaux - Centre National de la recherche scientifique, 1951, 32, 167-169.

Robinson, J.E. and Short, R.V. Changes in breast sensitivity at puberty, during the menstrual cycle, and at parturition. British Medical Journal, 1977, 1, 1188-1191.

Sala, N.L., Luther, E.C., Arballo, J.C. and Cordero Funes, J. Roles of temperature, pressure, and touch in reflex milk ejection in lactating women. J. of Applied Physiology, 1974, 37, 6.

Salazar, H., Tobon, H., Josimovich, J.B. Developmental-gestational and post-gestational modifications of the human breast. Clinical Obstetrics and Gynaecology, 1975, 18(2), 113-37.

Sameroff, A.J. An apparatus for recording sucking and controlling feeding in the first days of life. Psychon. Sci., 1965, 2, 355-6.

Sameroff, A. Non-nutritive sucking in newborns under visual and auditory stimulation. Child Development, 1967, 38, 443-452.

Sameroff, A.J. The components of sucking in the human newborn. J. Exp. Child Psychology, 1968, 6, 607-623.

Sameroff, A.J. Respiration and sucking as components of the orienting reaction in newborns. Psychophysiology, 1971, 7 (2), 213-222.

Sjölin, S., Hofvander, Y. and Hillervik, C. Factors related to early termination of breast feeding. Acta Paediatr. Scand., 1977, 66, 505-511.

Slijper, E.J. Whales, 1962, Hutchinson, London.

Slome, C. Non-puerperal lactation in grandmothers. Journal of Pediatrics, 1956, 49, 550-552.

Sloper, K., McKean, L. and Baum, J.D. Factors influencing breast feeding. Archives of Disease in Childhood., 1975, 50, 165-170.

Smith, C.H. and Merritt, K.K. Rate of secretion of breast milk. J. Am. Med. Ass. 1922, 78, 1750.

Tanner, J.M., Whitehouse, R.H. and Tahaish, M. Archives of Disease in Childhood, 41, 455.

Teichner, W.H. and Krebs, M.J. The laws of simple visual reaction time. Psychological Review, 1972, 78, (4), 344-358.

Tinbergen, N. A study of instinct., 1951, Oxford University Press.

Tulley, W.J. and Campbell, A.C. A Manual of Practical Orthodontics (2nd Ed.) 1965, Chap. 3 "The Development of the oral cavity as a functional unit" John Wright & Sons Ltd., Bristol.

Tyson, J.E. Nursing and prolactin secretion: principal determinants in the mediation of puerperal infertility, 1977. in: Prolactin and human reproduction, 97-108, ed. P.G. Crosignani and C. Robyn, Academic Press.

Vorherr, H. Catecholamine antagonism to oxytocin-induced milk ejection. Acta Endocrinologia, 1971, 1954, 5-38.

Vorherr, H. The breast morphology, physiology and lactation, 1974. Academic Press.

Walker, S., Hibbard, B.M., Groom, G., Griffiths, K. and Davis, R.H. Controlled trial of bromocriptine, quinoestrol and placebo in suppression of puerperal lactation. Lancet, 1975, 842 (Nov 1).

Waller, 1947 Clinical studies in lactation. William Heinman, 1938.

Wolff, P.H. The causes, controls, and organization of behaviour in the neonate. Psychological issues, 1966, 5, 1, Monograph 17. International Universities Press, Inc.

Wolff, P.H. The role of biological rhythms in early psychological development. Bull. Menninger Clinic, 1967, 31, 4, 197-218.

Wolff, P.H. Sucking patterns of infant mammals. Brain Behav. Evol., 1968a, 1, 354-367.

Wolff, P.H. The serial organization of sucking in the young infant. Pediatrics, 1968b, 42, 6, 943-956.

Wolff, P.H. The interaction of state and non-nutritive sucking. 3rd Symposium on Oral Sensation and Perception, 1972, ed. J.F. Bosma, 293-312.

Wolff, P.H. Natural history of sucking patterns in infant goats. J. Comp. and Physiol. Psychol, 1973, 84, 252-257.

Woolridge, M., Lucas, A., Lucas, P.J., Baum, J.D. and Drewett, R.F. Unpublished, 1980.