THE DEVELOPMENT OF HAND-MOUTH COORDINATION IN EARLY INFANCY

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I declare that this thesis has been composed by myself and that it embodies the results of my own research.

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Abstract

The aim of the thesis is to offer a comprehensive account of the developmental course of hand-mouth (HM) coordination from birth until a mature form of the coordination is attained. Questions relating both to the structure and function of the coordination were addressed.

Three studies are reported. The method of observation was the same in each case; video records of two perpendicular views of the infant were obtained and a micro-analysis of movement structure was carried out. The main question addressed in **study 1** was whether spontaneous HM contacts in newborns are related to hunger. HM contacts were compared before and after feeding in a group of newborn babies.

There was no change in the relative distribution of locations of contacts on the mouth and face before and after feeding, but anticipatory mouth opening prior to HM contacts only occurred before feeding.

Study 2 sought to obtain detailed measures of transitions taking place between 1-5 months in the structure of HM coordination, and to investigate what factors could be responsible for the changes observed. A longitudinal design was employed where babies were observed at monthly intervals. A small object was placed in the hands of infants to promote oral contacts.

At 4 months of age, contacts began to be centred on the mouth (as opposed to other parts of the face) and the

frequency of contacts was significantly higher when the object was present relative to the frequency of spontaneous contacts. Anticipatory mouth opening only occurred at 5 months of age, suggesting that this aspect of the coordination follows a U-shaped developmental trajectory. There was evidence that vision was playing a role in motivating HM contacts by 5 months of age. Consistent individual differences between babies were found in different aspects of HM coordination raising the possibility that more than one developmental route is followed in the achievement of mature HM coordination.

Study 3 investigated HM coordination cross-sectionally between the ages of 5-9 months. The possibility that the development of reaching was influencing the development of HM coordination was investigated. Two situations were compared, one where the infant had to reach for an object prior to transportation to the mouth and another where the object was placed in the hand of the infant.

Although HM coordination and reaching and grasping were already integrated at 5 months, the two coordinations appear to develop independently of each other.

The development of HM coordination was found to be marked by motivational and structural shifts and apparent regressions. The results are interpreted within a dynamic systems view of development.

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CHAPTER 1

HISTORICAL CONTEXTS IN WHICH HAND-MOUTH COORDINATION HAS BEEN STUDIED

1.0 Introduction

The general aim of the present study is to investigate the claim that the development of behaviour during early infancy consists of identifiable patterns of movement which from the outset assume the hallmarks of coordinated action. By coordinated action is meant movements that are ordered in space and time relative to a specific task or goal. In order to investigate this claim the study focuses on a striking and frequently occurring feature of the behavioural repertoire of young infants, namely, hand-mouth movements. The question is whether such movements already have some of the characteristics of coordinated action in the newborn, as claimed previously by Butterworth and Hopkins (1988). Furthermore, it can be asked if these movements undergo subsequent developmental change and what are the mechanisms of such change.

Answers to these questions are sought with the aid of a theoretical framework which differs radically from the more cognitive approaches that have been inspired by Piaget's thinking and observations relative to his sensorimotor period. This framework, engendered by the application of complex systems theory to the study of movement coordination, is derived from autonomous (self-law) theories of control based on principles of self-organization (pattern formation) in open systems. As such, it dispenses with allonomic (external law) theories of control consisting of machine models requiring pre-established stored instructions contained in rules, programmes or schemas that have typified cognitive and information-processing approaches to coordination and development in the past. This approach is referred to as the **dynamic systems approach.**

In the present chapter a brief overview will be given of Piaget's account of development during the sensorimotor period. In doing so, his observations on hand-mouth movements will be discussed in terms of how he envisaged them to develop within the broader context of acquiring sensorimotor knowledge. This discussion will culminate in identifying the shortcomings of a Piagetian account for studying the development of coordinated action. In chapter 2 an alternative account, based on the dynamic systems approach, will be presented which offers some solutions to these shortcomings. This chapter ends with delineating the research questions to be addressed by three studies on the development of hand-mouth coordination. The findings of these studies are reported in chapters 3, 4, 5 and 6. In the final chapter, the findings will be summarized and interpreted in terms of the insights they offer for understanding the development of coordinated action from a dynamic systems perspective.

1.1 Piagetian theory: Hand-mouth coordination as an example of a primary circular reaction

The following section will briefly consider Piaget's account of development during the sensorimotor period from birth until 18 months of age with respect to the origins of intelligence. It is within this general framework that Piaget studied early behaviour patterns. His definition of goal-directed, or intentional, behaviour will be considered in anticipation of later sections where evidence which is contrary to Piaget's account of development will be discussed. Piaget's observations of hand-mouth coordination and reaching for objects will be described together with the mechanisms he suggested were responsible for the development of these behaviours. These accounts will also be critically examined in following sections.

1.1(i) Piagetian formulation of the problem of intelligence and its development in the child

In his studies of the sensorimotor period of development Piaget was concerned with the problem of how the world comes to be experienced as consisting of objects having permanence in space and time, subject to physical laws which have an existence independent from that of the perceiver (Piaget, 1955, 1977). Eventually this "knowledge", of space, time, object permanence and causality, comes to be mentally represented and operations combining these representations to create novel solutions to problems is possible.

This knowledge of the world is conceived as a psychological construction. Sensory perception is considered to be fleeting and unstructured. Stimulation from different sensory modalities acquires coherence and the ability to perceive, recognize, remember, plan and direct voluntary action has to be imposed on this sense data. In classical empiricism, the newborn infant is seen as having to carry out this work of construction. Initially there is the "blooming, buzzing, confusion" described by William James (p.448, 1890). While Piaget accepted this starting point for development he rejected the idea that knowledge could be constructed through the accumulation of learned associations that impress themselves on a passive subject. He argued that such a mechanism contains an implicit assumption that the organization of the environment into categories of knowledge is "ready-made", waiting to be impressed on the subject. He also rejected an innatist position which postulated some kind of intelligence faculty responsible for imposing particular organizations onto sense-impressions.

Piaget's starting point for development, while considering sensory impressions including proprioception as being fragmented, experienced neither as internal or external but "half-way between the body and the external environment" (p.404, 1977), nevertheless does allow for some pre-existing organization. This organization is contained within the **activity** of the infant, initially in innate reflex-schemes such as sucking. Through a process of **functional assimilation**, the exercise of these reflex schemes allows for new elements to be incorporated, both in terms of the situations to which the schemes are applied and in terms of their constitutive behavioural elements. This process differs from one of new behaviours arising through passive association in that it is the activity of the infant itself which generates the opportunities for new associations to occur. This activity, even when it is a reflex scheme such as sucking when the mouth has come into contact with the breast, has a tendency to repeat itself in order for pleasurable outcomes to be prolonged. Sucking can be observed in situations other than in contact with the breast.

The exercising of schemes gives rise to what Piaget refers to as **circular reactions**, where new situations are eventually assimilated to familiar schemes through the repetition of these schemes. A complementary process of **accommodation** occurs whereby schemes are changed as a result of adaptation to challenges from the environment. Initially this accommodation is purely practical, consisting of new elements incorporated into particular schemes. These have meaning only in terms of the totality of the action schemes and the situations to which they are applied. Gradually however, as schemes are enlarged and generalized to an increasing number of contexts a process of differentiation takes place. Objects which can be felt, heard and seen, which can be grasped, shaken and followed with the eyes come to be objectified in a way which is increasingly independent from the schemes in which they have been embedded. The end-point of this process will be the ability to represent an objective, external world and to act creatively in an adaptive way based on a mental combination of these representations. This occurs at the end of the sensorimotor period of development at about 18 months of age.

The driving force of assimilation and accommodation is the process of **equilibration.** This is a process that Piaget suggested was general to all living organisms. The relationship between the organism and the environment is one of progressive disequilibrations and re-equilibrations. For example a disequilibration caused by the need for food can be temporarily remedied by ingesting food. In terms of mental structures in the developing infant, new experiences which do not quite fit previous instances where reflex schemes were employed lead to changes in these schemes (accommodation). These changes temporarily restore equilibrium. The concept of equilibration is a dynamic one, in the sense that the potential for change is always present as a result of the interactions between the organism and the environment.

Piaget identified six stages in the development of intelligence during the sensorimotor period, although as Russell (p.3, 1981) points out these stages are superimposed on a continuous process of change. The first of these (lasting from about 0-2 months) is the reflexive stage, where action schemes are bound to a relatively narrow set of triggering situations to which they are innately linked. The second stage (2-4 months) is that of the **primary circular reactions.** Through the repetitive exercise of the reflex schemes new elements are either included in a particular scheme, such as bringing the thumb to the mouth becoming incorporated to the sucking scheme, or different schemes become linked together by a process of reciprocal assimilation. The most important of these is the development of reaching for objects through the reciprocal assimilation of the prehension scheme with visual tracking. The third stage (4-8 months) comprises the coordination of the acquired adaptations of the second stage, through **secondary circular reactions.** The desire to prolong an interesting result originally obtained fortuitously leads to new combinations of behaviours, for example movements in the cot lead to mobiles attached to the cot also shaking. Eventually, by the fourth stage (8-12 months), the cot is shaken **in order to move the mobiles,** so that action has become differentiated by the baby into schemes constituting **means** and desired outcomes forming **ends.** During the third stage the distinction between means and ends exists but happens **after** the event of a fortuitously discovered result. The fifth stage (12-18 months) is that of the discovery of new means by active experimentation. The **tertiary circular reactions** belong to this stage and are formed by the coordination of earlier schemes but interesting results are no longer completely dependent on chance environmental events, they are actively sought by the baby who has come to be interested in objects for their own sake, rather than as "aliments" for the action schemes. The final, sixth stage is that of the invention of new means through mental combinations. Intelligence and representation of the environment has become sufficiently "free" of overt action for creative means to be thought of in order to achieve particular goals.

A detailed account of Piaget's observations of primary circular reactions, with particular reference to hand-mouth coordination and visually guided reaching, will be given. Before this, Piaget's definition of intentional or goal-directed behaviour will be considered. This issue will be returned to when challenges to Piaget's starting-point of development are discussed.

1.1(ii) Piagetian definition of intentional behaviour

There are two main ways in which intentional behaviour could be defined. The first of these can be thought of as a negative definition in that movements which cannot be explained as being the result of a chain of learned or innate associations are considered intentional. This in itself is not sufficient however, there is also an adaptive aspect to intentional movements which can be hard to pinpoint. They have a functional meaning, hence the term goal-directed, and tend to be sensitive to changes in the environment affecting the attainment of a goal.

The definition given above of intentional movements is one where a particular class of movements (those thought to be explainable through a chain of associations) is excluded, no mechanism is proposed for movements **within** the intentional category. It focuses on the adaptive qualities of intentional movements. Another way to define intentional behaviours would be through **process** or mechanism. This is the form of definition chosen by Piaget (Piaget, 1977). He defined an intentional behaviour as being one where a dissociation **within the mind of the subject** exists between which part of a behaviour-environment interaction can be designated as means and which as ends. In development, according to Piaget, this begins to be the case with the appearance of the secondary circular reactions. Prior to this stage, action schemes may simply be set in motion by the appropriate circumstances. Attainment of desirable outcomes is direct, and no particular element in the scheme is given a different status than any other element. The transition between acts which are intentional and those which are not is not seen as an abrupt, qualitative change:

> "Intention is thus determined by consciousness of desire, or of the direction of the act, this awareness being itself a function of the number of intermediary actions necessitated by the principal act. In a sense, there is therefore only a difference of degree between the elementary adaptations and the intentional adaptations." (p.170, 1977).

The reason that Piaget chose this definition for an intentional act was that his main interest was not with mechanisms of movement production for their own sake but with how knowledge arises in the child. He contrasts his own definition with one in which the intentional act is "determined by representation" (p.169, 1977). The basis of his theory is to show how intelligence first exists within acts, the increasing complexity of which drive changes in consciousness, first there are actions and then thoughts. Thus he argues,

> "The mental image is a product of the internalization of the acts of intelligence and not a datum preliminary to these acts." (p.169, 1977).

It will be argued in later sections that the difference in emphasis of the two definitions of intentional acts described above, reflecting a difference in research interests, underlies many of the debates concerning the status of recent evidence for the existence of neonatal coordinations with respect to Piagetian theory.

1.1(iii) Hand-mouth coordination as an example of a primary circular reaction

Piaget begins his description of the development of hand-mouth coordination at birth. The following observation is of Laurent within the first few hours after birth,

> "From birth sucking-like movements may be observed: impulsive movement and protrusion of the lips accompanied by displacements of the tongue, while the arms engage in unruly and more or less rhythmical gestures and the head moves laterally, etc..As soon as the hands rub the lips the sucking reflex is released. The child sucks his fingers for a moment but of course does not know either how to keep them in his mouth or pursue them with his lips." (Obs.1, p.37, 1977).

Gradually arm movements leading to a hand contact with the mouth become more directed as the sucking schema is expanded to include movements to the mouth. The following observation is of Lucienne at the end of the first month of age,

> "The coordination between arm movements and sucking was only definitely established at 0;2(2). At 0;1(25) and 0;1(26) the hands touch the mouth constantly but I still observe Lucienne's incapacity to hold her thumb between her lips for a long time and above all to find it again once it has left...at 0;2(2) when her hand escapes her mouth it approaches it again and coordination is re-established...The following day...coordination was re-established during the whole morning and for several moments during the evening...(he observes) hand groping in the right direction, then an abrupt movement of the fingers into the mouth which was already open and motionless." (Obs.23, p.69, 1977).

Piaget emphasizes that the coordination described above can be achieved without a conception of the thumb as existing outside of the modified sucking schema. He contrasts this with the coordination of two independent schema,

> "In effect, through the very fact that for the nursling the bottle belongs to two series of schemata capable of giving rise to adaptations and functions independent of each other (vision and sucking) and through the fact that it realizes the coordination of these two schemata, it is necessarily endowed with a certain externality. On the other hand, thumb sucking does not realize this condition. Even though this sucking presupposes for the observer coordination between the movementL of the hand and those of the mouth, the thumb is at first only known by the child to the extent that it is sucked and there is no coordination between two independent schemata for the subject himself." (p.76, 1977).

The following section will describe the coordination of two independent schemata, that for visual tracking and that for prehension giving rise to grasping of objects. This coordination forms the highest achievement of the second stage of development. Piaget's account of the development of reaching and grasping will be examined critically together with that of hand-mouth coordination in later sections concerned with the starting-point of development.

1.1(iv) The development of reaching for objects as a primary circular reaction

Piaget gives a highly detailed account of the development of reaching (Piaget, 1977), identifying several stages towards the integration of vision with prehension in the behaviour of his children. This account can be summarized as the reciprocal assimilation of the visual tracking scheme with the prehension scheme. Both these schemes undergo elaboration from their reflexive form prior to their mutual assimilation. By about the middle of the second month the infant can direct and maintain his gaze on an interesting sight, and often observes the hands. Prehension is initially reflexive and can either be observed as a clenching of the fist during arm movements or as a response to a stimulus on the palm of the hand. Grasped objects are then held for longer periods of time and eventually incorporated into the sucking scheme by being transported to the mouth.

The reciprocal assimilation of the schemes of vision and prehension is led by the hand in the sense that the infant will first of all look at an object that has already been grasped but will not grasp at an object that is being looked at. This develops when initially fortuitous movements resulting in contact with an object which is already being looked at are repeated in order to prolong the interesting effects of the contacting. This leads to the grasping of a visually regarded object where the hand is also in the field of view at the time that the object is seen. Finally, vision can "control" prehension so that any seen object can be grasped. The age at which this stage is reached varied between about 3.5 months (Laurent) to 6 months (Jacqueline) for Piaget's children. Piaget accounted for the accelerated development of Laurent by the fact that Laurent discovered hand-clasping very early on, which allowed him to observe the visual effects of grasping at an early age. Jacqueline on the other hand, due to being born during the winter months, had less opportunity to observe the visual effects of her own hand movements.

It should be emphasized that for Piaget the mechanism described above for the development of visually guided reaching does not imply either the ability to see in depth or the existence of intentionality. The object can be reached through the hand appearing to be progressively closer to the object as it is moved until finally it is next to it. The act is not necessarily intentional because there are no obstacles between the infant and the desired object which require actions not directly linked to this goal to be performed. These issues will be discussed in section 1.2(vi).

1.2 Challenges to the Piagetian starting-point of development - HM coordination as an innate, goal-directed behaviour

One of the problems of investigating aspects of Piaget's account of development empirically is that the theory refers to cognitive events. Cognition is deduced from observed behaviour. A question which has concerned infancy researchers is how to distinguish between failures to respond in experimental situations because necessary cognitive factors are not developed, as opposed to a lack of response due to motor immaturity. Techniques which are sensitive to the infants' level of motor competence have been developed over the last 15-20 years in order to overcome this problem. These techniques have been applied to the study of newborns. Newborn cognition is considered to be of unique importance in that any observed competencies can be attributed to innate mechanisms rather than to learning or construction through experience. Findings from work carried out in this area will be described in the following section. Recent studies of HM coordination will be reviewed within this context. The degree to which findings of "newborn competence" challenge Piagetian theory will be discussed. A critique of the Piagetian account of the genesis of HM coordination and reaching for objects will follow from this discussion.

1.2(i) Intermodal coordinations in the newborn

According to Piaget, intermodal coordinations have to develop in infancy from an original state where there are only fragmented and uni-modal sense impressions. Several studies provide evidence that some degree of intermodal coordination is present at birth however. Evidence that newborns will make a head-turning response to a sound source was provided by Butterworth and Castillo (1976), in this study infants turned away from a loud sound on a majority of trials. Muir and Field (1979) found that newborns would orient towards a sound source if it was below a certain level of loudness. According to Piaget, this coordination between sound and vision does not develop until the third month of life. Meltzoff and Borton (1979) reported that newborns will look longer at a shape which they are familiar with through oral exploration than at an unfamiliar shape. They suggest that this visual recognition of an object that is only known through tactual experience demonstrates that certain equivalences between the modalities of touch and vision are innate.

1.2(ii) Intentional behaviour in the newborn

A controversial claim was made by Bower, Broughton and Moore (1970) that newborn infants will make "reach-like" forward extensions of the arms with some anticipatory grasping posture of the hand when presented with an attractive object. Although these forward reaches did not culminate in the actual grasping of the object, according to Bower et. al. they often led to contact or near misses. Subsequent research (von Hofsten, 1982) has confirmed that more arm extensions do occur in the region of space between the baby and the object than in other areas, although the hit and near miss rate is not as high as that suggested by Bower et al.

Several conclusions were drawn from these results by Bower et al. The first of these was that visuomotor coordination could be present in the newborn and did not necessarily have to be constructed by experience. They also claimed that the level of reaching behaviour produced by the infant varied depending on the distance between the object and the infant. This would suggest that the infant was sensitive to depth information, an ability which only appears at about 10 months of age within a Piagetian framework, after substantial visuo-tactual experience has taken place.

The most striking conclusion of the researchers was that the reaching behaviour observed could properly be described as intentional. According to Bower et. al., when the infants were presented with a virtual object, created using a stereoscopic shadow caster, they showed upset when they made no tactual contact with the object when visually they "should" have done so. The fact that the infants had **expectations** about what was supposed to happen as a result of their movements was thought to show that these movements were goal-directed or intentional.

It should be noted that the results on which these conclusions are based are controversial, a point which will be discussed further in section 1.2(v).

1.2(iii) Representation and existence of a "body schema" in the newborn

Meltzoff and Moore (1977) reported that neonates would produce significantly more tongue protrusions when they were presented with a human model of a tongue protrusion than when the model was one of lip pursing or mouth opening. The same applied with respect to these latter two behaviours in comparison with either tongue protrusion and mouth opening, or tongue protrusion and lip pursing. The imitative ability implied by these results of imitation using parts of the body never seen by the infant is one that developed after about one year, according to Piaget, after experience with mirrors or tactual exploration of the mouth in conjunction with exploration of the mouths of others. Meltzoff and Moore suggested that the imitation found in their study was achieved by an active matching of the mouth gesture perceived visually with an amodally specified body schema which could then be translated into a proprioceptive modality for the production of the response. Given the age of their subjects, the existence of this body schema was considered to be innate.

1.2(iv) Recent studies of HM coordination within the context of neonatal coordinations

Taken together, the studies described above seem to call into question the basic tenets of the Piagetian starting-point of development. Different sense modalities are not uncoordinated, visual perception of the world is more structured than the previous assumption of a world of no depth or coherence. The distinction between the self and the outside exists, at least to the extent that a distinction can be made between stimulation generated by self-movement and that due to external factors. An extension of this separation is the existence of a body schema. Finally, movement is not only reflexive or impulsive but can be goal-directed, such that it is based on expectations of particular results, and can be adjusted adaptively with respect to these results.

Butterworth and Hopkins (1988)investigated HM contacts in neonates and considered their results in terms of whether some newborn behaviour can be described as intentional. By studying the conjunction of mouth postures with movements to the mouth, face or just short of the face they could see whether those that contacted the mouth were different in movement structure from those which did not. 15 newborns were filmed lying in a supine position approximately 2 hours after a feed. A maximum of 20 movements to either the mouth, face or just short of the face were analysed for each infant. They found that there was significantly more mouth opening prior to movements which resulted in a mouth contact than to those which did not. They argued that if HM contacts were a fortuitous occurrence, no difference would be expected between mouth postures found prior to movements to the mouth relative to any other part of the face. In addition to this evidence that some form of coordination between the hand and the mouth exists at birth, they argued that mouth opening in anticipation of an arm movement constituted an expectation of results in the same way as the reaching movements described by Bower and colleagues. In this sense the movement could be regarded as intentional.

Evidence that newborn HM contacts are not simply fortuitous was also provided by Rochat, Blass and Hoffmeyer (1988). While carrying out a study on the conditioning of newborns to various sounds using delivery of sucrose to the tongue as a reward, the authors noted that HM behaviour changed considerably after sucrose delivery. They re-analysed their data measuring the frequency and duration of HM contacts as well as those of hand-face contacts. This was done for ten newborn infants in a semi-reclining position who were exposed to an initial baseline period of 5 minutes, a sucrose delivery phase of 14 minutes, and finally a second baseline period of 7 minutes. They found that the mean duration of HM contacts almost doubled in the sucrose phase relative to other periods. The frequency of HM contacts, at the expense of HF contacts was also significantly higher during the sucrose phase. The authors argued that if HM contacting could be controlled experimentally it was unlikely to be due to fortuitous or accidental factors.

1.2(v) Interpretations of findings from studies of newborn babies

There are different levels at which the studies reported in section 1.2 have been discussed. The first is methodological, where the existence of the phenomena described is questioned. This point was already encountered with respect to neonatal reaching movements. Authors who measured the rate of hitting the object showed lower rates than found by Bower et. al., 1970 (DiFranco, Muir and Dodwell, 1978 and Ruff and Halton, 1978). Yet, if measurement is based on forward extensions of the arm in the area of space around the object, as opposed to other areas (von Hofsten, 1982), thus controlling for general movements, then newborns do appear to make reaches directed at the object.

The existence of neonatal imitation has also been questioned (McKenzie and Over, 1983, Koepke, Hamm and Legerstee, 1983), although several authors have been able to replicate the results of Meltzoff and Moore (Vinter, 1986, Reissland, 1988, Heimann, 1988). A consensus appears to be emerging that under the right conditions of alertness and posture newborns will imitate certain facial gestures, the more robust of these being tongue protrusions (Meltzoff, 1990). The debate over the existence of imitation, as well as that of other findings such as neonatal reaching movements, does highlight the fact that these phenomena are not readily observable, but require statistical comparisons between experimental situations and appropriate controls.

A second level of debate accepts the existence of neonatal coordinations but questions the mechanisms claimed to underlie them. Specifically, reflexive mechanisms are proposed. Such mechanisms would not carry implications of active intermodal matching and do not attribute purposeful behaviour to the newborn. In the case of imitation, Jacobson (1979) has proposed that apparently imitative tongue protrusions arise through an innate releasing mechanism (IRM). She found that she could elicit tongue protrusions by moving an object such as a pen in and out on a horizontal plane and suggested that this showed that the newborn was not making a match between its own tongue and that of another person, but rather making a response to dynamic stimuli of a particular kind. Abravanel and Sigafoos (1984) also support an IRM interpretation arguing that they could only obtain reliable imitations of tongue protrusions and not other facial gestures. It should be noted that their youngest subjects were one month of age, rather than newborns as in the other studies referred to above. The IRM account for imitations of tongue protrusions raises some problems, however. As Meltzoff (1981) argues, it is hard to understand why there should be an IRM specifically for tongue protrusions. He considers that Jacobson's results demonstrate that the salient features of the model from the point of view of the infant are the shape and movement of the tongue, an interpretation supported by the results of Vinter (1986), who found movement to be a crucial factor in eliciting neonatal tongue protrusions.

Bullinger (1981, 1983) has suggested that neonatal reaching can be accounted for by the postural changes that arise when visual tracking of an object engaging the eyes and head occurs. He argues that a dynamic form of the asymmetric tonic neck reflex is present whereby as the head turns from one side to the other the arm that was initially flexed on the contralateral side from the head becomes extended, thus giving the appearance of a reaching movement towards the object being followed by the head. Von Hofsten (1982) did not find evidence for this hypothesis in his experiments in that reaches with the arm contralateral to the head were significantly better aimed than those with the ipsilateral arm, in terms of the direction of the target.

A final argument which has been used to support a reflexive interpretation of neonatal coordinations is that these seem to follow a U-shaped developmental function. The behaviours seem to disappear after the neonatal period and re-emerge at a later stage of development (Bever, 1982). The newborn behaviours are very different in character from those observed later in development, a point already encountered with respect to neonatal reaching. One idea that has been put forward to explain these apparent regressions is that the behaviours are initially reflexive and under sub-cortical control. These control mechanisms are inhibited as cortical control of effector systems develops. There is some evidence for this form of explanation in the case of orienting visually to a sound source. This behaviour declines after one month of age and appears again after the fourth month. The newborn behaviour has a far greater latency than the mature response and the head turning itself has a rather slow and laborious appearance. Muir, Clifton and Clarkson (1989) discuss results of a study testing preterm infants on auditory localization which found that the age at which localization reappeared corresponded to gestational age rather than chronological age. Together with the emergence of the **precedence effect** at the same time (where input to a sound into one ear followed by another at the other ear after a few milliseconds is perceived in adults as one sound from the "leading" ear), which is thought to be cortically mediated, this data supports a sub-cortical to cortical control hypothesis. An assumption made by some authors however, such as Abravanel and Sigafoos (1984) in the case of imitation, that a U-shaped developmental function **per se** implies reflexive mechanisms underlying the initial behaviour is not valid. Prechtl (1982) and Butterworth (1988) discuss the various ways in which regressions could occur in development, a reflexive to voluntary control model being one of several possibilities. Independent evidence, such as in the case of auditory localization, is required to support a reflexive hypothesis. A final level of discussion over neonatal coordinations accepts their existence and their mainly non-reflexive character, but does not accept that they challenge the tenets of Piagetian theory. This argument, encountered in different areas of study, is that Piaget was principally concerned with the development of **knowledge**, thus the fact that a certain kind of cognitive elaboration or construction is not necessary for particular behaviours to occur is not of principal interest. An illustration of this point in the field of depth perception comes from Ball and Vurpillot (1981),

> "That babies can see displacements as movement in space at an early age does not necessarily mean that mature sensorimotor knowledge of space results from repeated visual exposure to movements. Action may be required as a "glue" for incorporating isolated, visually perceived displacements into a structured whole." (p.134).

It is this "structured whole", including objects with permanence and properties including reversible displacements that Ball and Vurpillot suggest is of most fundamental interest in Piagetian theory.

A final example of this level of argument concerns the evidence for neonatal reaching and HM coordination. It should be remembered that for Piaget, even the **mature** forms of these behaviours were not considered intentional (see section 1.1(iii), p.10 and section 1.1(iv), p.12). His examples of HM coordination include anticipatory mouth opening and his descriptions of reaching also include anticipatory hand posture components in the movement structure, elements considered important in the characterization of these behaviours as being goal-directed or intentional by the researchers of the neonatal behaviours. The argument can now be reversed. If the main interest of a researcher is to discover the mechanisms by which certain behaviours are produced or become coordinated, then the fact that they can occur without particular cognitive elaborations being necessary would be very relevant. From this point of view, the Piagetian account of the genesis of HM coordination and reaching involves an **under-estimation** of the problems involved in the production of coordinated movement, as well as an over-estimation of the work of construction required for such abilities as depth perception. These points will be illustrated below in a critique of the Piagetian account of the development of reaching and of HM coordination.

1.2(vi) Critique of the Piagetian view of the genesis of HM coordination and reaching

This section will consider whether successful reaching and grasping can actually occur through the mechanism proposed by Piaget, described in section 1.1(iv). It should be remembered that this mechanism consisted in the integration of two schemes, that of visual tracking and that of prehension. The hand is brought into contact with the desired object by a principle of proximity, it is moved until it appears to be next to the object, no perception of depth is involved at this stage. One problem with this account is that if the infant cannot see the hand and the object in perspective, there would be an infinite number of positions along a straight line perpendicular to the infant where the hand would appear to be in contact with the object, but would not in fact be making contact. Perhaps more fundamentally, within Piaget's mechanism the concept of **feedback** is implicit in the visual guiding of the hand movement. This surely means that the goal of grasping is organizing the movement, no accumulation of previous reaching experiences could lead to successful grasping in a new situation. It is this feature of a behaviour such as reaching which has led authors other than Piaget to define them as being goal-directed or intentional.

Similar arguments can be applied to many other behaviours described by Piaget, including HM coordination. The problem is one of movement patterning, a question with which, as Thelen (1987) points out, Piaget was not primarily concerned. This is the question of what is that being associated during the integration of different schemes, is it sequences of activation of specific muscles or more abstract, environment-specified variables? It is no surprise that Piaget neglected this question, as will be discussed in chapter 2 issues of movement patterning were neglected generally within the discipline of psychology until relatively recently.

Section 1.2 has discussed empirical evidence which is contrary to Piaget's view of the starting-point of development. There will be further discussion of what kind of perceptual and coordinative abilities must underlie any coordinated action at a theoretical level in chapter 2. What emerges from this section is that the body of work on neonatal coordinations is unified by the challenge it presents to a particular conception of the newborn and the work of development. If such a conception is not adhered to, or is shown to be flawed at a theoretical level, then the neonatal coordinations form a **heterogeneous** group of behaviours, each with its own developmental history and function. The question arises as to how HM coordination should be viewed outside of the "competent newborn" framework. It will be argued that the development of HM coordination should be studied within the context of issues in the field of **coordinated action.** This context will be described in chapter 2.

CHAPTER 2

HAND-MOUTH COORDINATION AS A TOOL FOR THE STUDY OF COORDINATED ACTION IN INFANCY

2.0 Issues in the field of coordinated action

A coordinated movement is one in which there is an ordered relationship, with respect to spatial coordinates and gravitational forces, between the body being moved and particular aspects of the environment. This order is itself a result of ordered relationships existing between the muscles or muscle groups producing the movement, where these are otherwise capable of independent functioning. The question of psychological interest is which factors determine these relationships between muscles for a given coordinated movement. The developmental question concerns whether and how these relationships are constructed during infancy.

Questions of how skilled movements are produced and how coordinations are built up during development are clearly inter-related. The way in which problems of coordination are defined will have consequences for what is considered to be the work of development, and for how behavioural changes occurring during development are interpreted. Conversely, observations of how coordinations emerge in development influence how mature behaviours are viewed in terms of the relationships that might exist between elements. A brief overview will be given of current and historical perspectives on problems of coordination and skill acquisition in adults. The field of infant motor development will then be considered. The influence of work from the adult literature on developmental perspectives will be referred to. Finally, a summary of current frameworks for the study of coordination development in infancy will be given. Studies of HM coordination and questions arising from these will be discussed within this approach. These questions form the basis of the experimental work reported in the following chapters.

2.1 Mechanisms of movement coordination and control

Until the last 20-30 years, the problem of how sequences of muscles are activated to produce adaptive and coordinated movements was considered to lie mainly within the field of physiology. The programme of investigation consisted in isolating a basic unit or component in the neural structure responsible for activating a specific muscle. Through an understanding of the workings of this basic unit and the possible physiological results of the action of one unit on another it was hoped that the mechanisms underlying complex movements could be understood. This unit was termed the reflex arc, which consists of a receptor neurone linked to a muscular effector neurone through intermediate neurones in the brain or spinal chord.

Sherrington (1906) stressed that in the intact organism reflexes were almost never found in isolation. It was only through the study of animals where the brain had been lesioned at the base of the spinal chord, referred to as "spinal" animals, that such simple reflexes could be found, and even in such cases care had to be taken that the animal was maintained in an identical position each time a reflex was elicited. He reports work which investigated how such simple reflexes could interact with one another. He described processes such as inhibition and facilitation, whereby one reflex changed the reactivity of another. He recognized that the programme of research which looked at these interaction effects had a long way to go before it could account for the production of complex movements, although he maintained that this should be possible in principle.

The ideas described above were used by psychologists as a way of accounting for the production of any movement. A learned or innate skill was considered to be a series of muscular activations each one triggered by the preceding movement. As Provine (in press) points out, issues of movement patterning and coordination were neglected by psychologists in favour of perception and cognition. This neglect continued during the behaviourist era:

> "...it went unnoticed that there was little **behaviour** in behaviourism or elsewhere in psychology. Despite our rich choreography of everyday movement, empirically inspired psychology left us with that meagre, generic unit of motor behaviour, the response.".

Lashley (1917, 1951) challenged the idea that all movements are controlled by sensory feedback. He put forward two main arguments. The first was based on a comparison of the speed at which certain movements are carried out. For example an experienced pianist plays arpeggios in less than the time thought necessary for sensory feedback to occur. He argued that these movements were simply too fast to be controlled by sensory feedback and suggested that a sequence of instructions for muscular activation could be produced by the brain without feedback loops being necessary. The second critique was a logical one. He argued that coordinated movements had syntax, in a way analogous to language. Initial stages of a movement, for example a reaching movement, are adapted in anticipation of later stages of the movement. Movement segments which are the same can be inserted into different sequences of movements, in the same way as syllables or words can form parts of different sentences. These phenomena cannot be accounted for by a mechanism whereby the results of the movement of one element activates the following element of a sequence.

As a result of the popularity of information-processing approaches in the 1960's some research on motor skill learning was carried out within this framework. Keele (1968) modeled the process of skill acquisition where the organization of the motor response was carried out by a motor programme. This consisted of a sequence of instructions for the activation of specific muscles. The rationale for this form of motor control was based on the considerations raised by Lashley discussed earlier, relating to the limitations of feedback loops as explanations for movement control. Skilled behaviour consisted of the selection of the appropriate programme for a given situation.

The argument put forward by Lashley that coordinated movements possess a kind of syntax can also be used to challenge the idea that movements can be coded at the level of specific muscle activation sequences, whether through response chaining or by motor programmes. The reason for this is that each instance of a particular movement, whether triggered reflexively or otherwise, will have unique components which will require the use of **different** muscles or muscle strengths in order for successful, adaptive movement to occur. Later information-processing models of skill learning recognized this issue. Schmidt (1975) referred to it as "the novelty problem",

> "If the response is to be programmed...the sequence of muscle commands would be appropriate for only one movement, beginning with the body in a specific position, and with an identical goal..." (p.230).

Bernstein (1967) offered an extensive criticism of the idea that movements could be programmed at the level of specific muscles. He also argued that environmental forces acting **during** the execution of the movement would be variable,

> "These forces are...not foreseeable, and because of this they cannot be overcome by any sort of stereotyped movements directed solely from within." (p.115).

Fukson et. al. (1980) provide an illustration of how even a wiping reflex carried out by a "spinal frog" varies according to the relative positions of the site of skin irritation and hind-limb. Through a kinematic analysis of the movements involved the authors concluded that after an initial phase where the hindlimb is flexed to reach the base of the head the relative positions of the hindlimb and the skin irritation were expressed in the degree of rotation that occurred at the hip joint just prior to wiping.

We may conclude that coordinated movements are organized with respect to **spatial coordinates** when they are directed towards features of the environment, and with respect to a proprioceptive **body schema** in the case of movements directed towards parts of the body. How these spatial or body-centred coordinates are perceived, represented and mapped onto actual sequences of muscle activation, can be considered one of the most fundamental problems of movement patterning, as **every** kind of coordinated movement contains a displacement in space directed at aspects of the environment or the body.

Taking this universality of spatial sensitivity in coordinated movement into account, von Hofsten (in press) has suggested that goal-directedness should be considered a property of **any** coordinated movement. It can now be seen that the distinctions made in section 1.1(ii), p.8, between ways in which goal-directed movements can be defined is a crucial one. The idea that certain stereotyped movements can be produced without the components of the movement having reference to a goal or end-point may no longer be tenable.

2.2.1 Information-processing approaches to the study of coordinated movement

Studies of movement control in the information-processing tradition have typically investigated specific tasks, for example tracking or pointing tasks, under controlled conditions, where measures of the effects of altering variables such as speed and degree of sensory feedback available to the subject can be taken. The behaviour of subjects can then be modeled. These models often use the idea of a spatial representation which is compared to a proprioceptive body map representation in order to account for spatially appropriate behaviour.

Coordinated movements are carried out within a functional context and involve more than displacements in space. For example picking up an object involves an approach phase of the arm and an anticipatory opening and then "closing-in" movement of the hand prior to grasping. The timing and magnitude of the parts of the movement are highly interdependent, so in the example of reaching and grasping the hand-closing occurs at a particular point of the approach trajectory, and at a particular point with respect to the target object (Jeannerod, 1984, 1988). The problem of how the integration of elements is achieved in these goal-directed behaviours raises similar issues to those discussed with respect to spatially appropriate behaviour. In particular, questions of how appropriate context-dependent alterations in movement parameters are achieved are investigated, such as the effects of object size on the timing relationship between reach and grasp elements when the object is being reached for.

Many studies on motor skill acquisition were carried out after the early information-processing inspired studies of Keele (1968) referred to in the previous section. The most widely used theoretical paradigm, developed by Schmidt (1975) is that of **schema theory** or the **generalized motor programme.** Schema theory takes into account the problems of motor programmes as instructions to specific muscles discussed in section 2.1 by suggesting that specific motor tasks are represented by certain essential kinematic variables such as the sequence in which components are activated, and that parameters such as force and speed could be set each time the programme is initiated. Through **knowledge of results** after movement execution the subject can build up representations of appropriate parameter settings for particular environmental conditions (and starting postures) and behaviour becomes more skilled. As Schmidt (1988) points out however, schema theory does not address the issue of how a generalized programme can be developed from other existing programmes, which would be a requirement of a full account of skill acquisition.

The work of Fitts (Fitts, 1964, Fitts and Posner, 1967) considers the question of how new skills are developed. The principles proposed by Fitts are very general ones which are applicable in any domain of skill learning. He identifies three phases during skill learning, although he emphasised that the transitions between phases are continuous rather than abrupt. The first phase is a "verbal" one, where an attempt is made to **understand** the task and the inter-relation of the components involved. Feedback from attempts at this stage are very important as an aid to this understanding. The second phase is one where new associations between elements of the task, for example breathing and arm strokes during swimming, are formed and consolidated. The final phase is that where the combination of elements becomes "automatic", and the programme of movements for the skill form part of the repertoire of the learner. The data on which these principles were based came from extensive interviews with sports instructors on the kinds of teaching methods they used.

Fitts and Posner (1967) argue that skill learning carried out by adults is based on a "library" of existing programmes and routines, such that learning new skills essentially consists of new combinations of these existing programmes. In addition, the first phase of skill learning outlined above relies on the idea of conscious verbal processes as a way of organizing the elements of the task being learned. They therefore suggest that skill development in infants should be treated as a somewhat separate research area. These points highlight the difficulty of identifying learning processes in infant motor development. As von Hofsten (in press) remarks,

> "In spite of the fact that learning factors may be at least as important for the development of action systems as maturational factors, they do not stand out as clearly in developmental studies...The reason is that the growth of the organism is determined by age while learning is determined by experience. As soon as the brain is ready for a certain kind of experience, the environment is always there to supply that experience.".

Despite the difficulties of demonstrating that interactions with the environment are altering the form of a particular coordination in infants, some researchers are making comparisons between skill development in adults and infants. An example of this can be found in the work of Connolly and Dalgleish (1989) who studied the development of the use of a spoon for self-feeding during the first half of the second year of life. They refer to Fitts' model as a way of describing changes in how the different elements involved in spoon use become progressively more integrated and efficient. Initially, isolated elements of the full behaviour can be observed, such as the loading of food onto the spoon or the transport of the spoon to the mouth, but according to Connolly and Dalgleish (1989) these episodes appear more like instances of play than attempts at self-feeding. Eventually, these elements become more efficient and are integrated to produce functional behaviour. The authors emphasize that these changes contain an important cognitive component in that spoon-feeding poses a problem-solving task for the infant where there has to be some understanding of how the spoon can be used as a tool. They argue that this component of the task can be compared to the first "cognitive" stage of skill learning described by Fitts.

In summary, neither the methods or the theoretical frameworks used within the information-processing approach to motor skill development are readily applicable to the study of infant motor development. The following section will consider dynamic systems approaches to problems of coordination. This approach has been applied to motor development in infancy, and it will be argued that it forms a valid framework within which to approach research questions addressed in this thesis. The application of dynamic systems theory to the study of development will be discussed in following sections reviewing the literature on infant motor development.

2.2.2 Dynamic systems approaches to the study of coordinated movement

An approach to the study of coordination which differs radically from the information-processing framework, with influences from a variety of sources including the work of Bernstein referred to earlier, is the **dynamic systems approach** (Kugler et al., 1980, Reed, 1982). Ideas derived from **complex systems theory**, itself a branch of the applied mathematics of homeokinetic sytems, are used to try to address the issue of movement organization (Kugler et al., 1980). Complex systems theory is concerned with how order emerges from the activity of systems which have many interacting parts, where these systems could be physical, chemical or biological. If there was simply an additive relationship between the activity of elements in the system then the number of possible emergent behaviours would be a function of the number of different states each individual element could assume. In practice, however, the linkages between elements act to constrain the number of possible emergent behaviours that would be stable. For this reason such systems are referred to as "self-organizing".

In terms of movement coordination the activation of one part of the skeletomuscular system creates constraints on the possible activation of connected parts such that movement synergies are formed which do not need to be completely programmed at a central level. The existence of input-output loops operating at a peripheral level (nested within other loops in the peripheral and central nervous system) acting to modulate on-going movements are emphasized (Reed, 1982, p.105).

With respect to the issue of spatial coordinates this approach refers to J.J. Gibson's theory of direct perception (Gibson, 1966, 1979, Reed, 1982, p.108 and p.110). Questions as to how a particular perceptual ability occurs are approached by considering what feature of the spatio-temporal structure of the light entering the eye varies in a lawful way with the perceptual feature under consideration, **given the evolutionary history and present ecological environment of the perceiving animal**. For example, for terrestrial animals, the size and position of light reflected from texture elements of the terrain varies in a lawful way with distance from the observer. Studies can then be carried out to see if such features, or invariants, in the structure of the light entering the eye are actually the ones being used by the perceiver. In terms of coordinated movement the question of interest concerns which features of the assemblage of muscle and joint tensions vary in a lawful way with position in space.

Several authors (Kugler, Kelso and Turvey, 1980, Newell, 1986 and Whiting, Vogt and Vereijken, 1992) have argued that basic distinctions between **coordination, control** and **skill** define the dynamic systems framework. **Coordination** is defined as the way in which degrees of freedom, in terms of the dimensions along which assemblages of muscles and joints can vary, are constrained so that particular "behavioural units" are obtained. Certain parameters which do not define the kinematic form of a "behavioural unit", for example force as opposed to sequence of movement, are free to vary once a coordinative structure has been assembled. **Control** refers to the assignment of values to these parameters. **Skill** refers to the optimal assignment of values for particular tasks or contexts.

The difference between this definition of coordination and a generalized motor programme or schema is that the regularities observed in the form of the behavioural unit are not thought to be represented in some form of programme which exists outside the context in which the coordination has been assembled. Rather, the form of the movement is thought to be "soft-wired" (Thelen, 1989a), a result of the self-organization of interacting elements. The emphasis on coordination being a process of **constraining** degrees of freedom means that much more attention in given to organization at the periphery within a dynamic systems approach (Newell, 1986). For example Thelen and Ulrich (1991) argue that in skilled walking the swing phase of the movement is largely due to the release of potential energy stored during the streching back of the leg during the stance phase. Thus this part of the movement would emerge or "fall-out" as a result of the bio-mechanics of the leg, it would not need to be specified through "instructions" at a central level.

Within this framework, a research programme can be carried out which seeks to describe behavioural units in terms of **order parameters** (Haken, 1983 in Thelen and Ulrich, 1991), sensitive to changes in **control parameters.** An order parameter, or **collective variable,** refers to an observable characteristic of the behaviour of a complex system which describes a **pattern** of behaviour sensitive to changes in one or more of the interacting elements of the system. Scalar changes in certain elements of the system can cause qualitative shifts in the patterns of behaviour than can be observed, that is changes in the order parameter or collective variable. Such elements are referred to as **control parameters**, because they can cause these qualitative shifts in the behaviour pattern of the system. Scalar changes in the control parameter can be non-specific, such as amount of energy delivered, although they cause specific changes in the patterm of behaviour of the system, including the collective variable expressing this pattern.

The first stage in the investigation of a complex system is to select a suitable collective variable. In the case of walking, the phase relationship between both legs carrying out symmetrical movements, in a phase relationship of 180 degrees, is one defining characteristic of the coordination (Thelen and Ulrich, 1991). Factors which affect this phase relationship, control parameters, can then be studied, thus helping to clarify normal mechanisms of coordination in walking. As Thelen and Ulrich point out however, the choice of appropriate collective variables is not always straightforward, and might require experimental study prior to the search for control parameters. Control and skill, as defined above, can then be investigated in particular task contexts.

The dynamic systems approach is attractive for various reasons as a framework within which to study motor development in infancy. It is suitable for investigating naturally occurring movement. The focus on qualitative shifts in behaviour patterns arising through changes in control parameters provides a way of accounting for change in basic motor skills. The idea that movement organization is an *a posteriori* consequence of self-organization rather than contained, *a priori*, in schemas or programmes avoids the pitfalls attatched to defining the content of such schemas, whether they are found in information-processing approaches to adult skills, or in Piagetian formulations of skill development. The following section will review traditional and contemporary literature on infant motor development. It will be argued that findings which challange traditional views of causes of change in behaviour fit well within a dynamic systems framework.

2.3 Motor development in infancy

During the first two years of life many changes in movement patterns can be observed. Basic postural adaptations are acquired as well as essential, species-specific skills such as locomotion and the ability to manipulate objects. Various factors could be responsible for the changes observed, one not necessarily exclusive of the other. These are body growth, maturation of the central and peripheral effector system, maturation of sensorimotor coordinations, learning processes (for behavioural sequences and/or for sensorimotor coordinations) and functional changes in which behaviours are appropriate in the environment of the infant at a given age. This section will consider how different factors have been given preeminence in accounting for change in motor development in both historical and modern contexts.

2.3.1 Historical perspectives on causes of change in motor development

One influential view of coordination development which has already been discussed is that of Piaget (section 1.1, p.2). New coordinations are constructed out of existing sensorimotor schemes through a process of accomodation arising from the exercise of these schemes in novel situations. This process can occur independently from mental constructions such as the object concept and perceptual abilities such as perception of depth. These constructs arise as a result of the exercise of reflex schemes. Empirical evidence concerning the perceptual and representational abilities of infants discussed in section 1.2, p.14, and the changes described in this chapter (section 2.1, p.29) with respect to the abilities thought necessary for any coordinated movement challenge this view of coordination development.

Another traditional view of motor development comes from the work of McGraw (1946) and Gesell (Gesell and Thompson, 1934, Gesell, 1945, 1946). This work consisted in highly detailed descriptive accounts of the development of a large variety of behaviours including postural changes, locomotion, prehension, and in the case of Gesell language development and interactions with specific objects (such as a small pellet) were also investigated. This research produced normative data on the age of appearance of particular achievements, such as prone locomotion. Longitudinal methods were also employed in order to see to what extent performance at an early stage was predictive of behaviour at later stages. The influence of ideas and methods from the field of embryology is clear in the case of both Gesell and McGraw (Gesell, 1946, McGraw, 1946). In embryological research, measures of **movement patterns**, for example swimming movements in Salamanders (Coghill, 1929), were correlated with changes in brain structure in developing organisms. It was hoped that analogous correlations would be possible in the case of human infants.

The structure-function relationships envisaged by Gesell and McGraw differed in several important respects, a point developed by Thelen (1987). McGraw saw the locus of change in the behaviour patterns of the infant in the growing structures of the Central Nervous System (CNS). She also considered that histological evidence indicated that neonatal behaviour had to be sub-cortically controlled, with cortical control developing during the 3rd and 4th months,

> "In evaluating the observations on changing behaviour patterns an attempt was made to point out those qualities which indicate when an activity is (1) under infracortical dominance, (2) when inhibitory influences from the cortex become apparent, (3) when cortical participation in muscular movements is involved, and (4) when the activity attains a comparatively mature state of cortical functioning." (p.359, 1946).

This view of what is determining changes in behaviour in the early months is still current, particularly as a way of accounting for apparent regressions in development, an issue already encountered in section 1.2(v), p.20. Gesell was less specific about the nature of the maturing structures responsible for changes in observed behaviour. He emphasised that coordinated movement was the product of a complex "interweaving" of component elements, each of which could develop and change with a degree of independence, so that new forms of behaviour would result. An example of this would be a proximal to distal form of maturation of the arm leading to a change in the form of a reaching movement. Thelen (1987) views this wider concept of maturation as foreshadowing later, dynamic systems based approaches to motor development which will be discussed in the following sections.

Gesell's description of the genesis of reaching and grasping is interesting in that it has many similarities with Piaget's account. In the latter case however the observations are considered to reflect processes whereby the actions of the infant shape the later developments of the behaviour, whereas Gesell maintains a maturationist interpretation of the changes observed. Gesell claimed that the crucial developments necessary for prehension to occur were the control of distal arm movements and the coordination of eye and hand,

> "Directed manual prehension does not occur until the elbow and distal segments acquire, through maturation, more mobility and until the eyes coordinate with the hands in the act of

> appropriation." (p.276, Gesell and Thompson, 1934).

Eye-hand coordination develops during the 2nd and 3rd months while a tonic neck reflex posture predominates when the infant is in a supine position,

> "His gaze (in t-n-r) at first has no relation to the hand or the arm; but he is becoming predisposed to look at least in the general direction of any activity he may initiate. His arm brushes time and again across his field of vision...Later, at 10 or 12 weeks, he takes defined, even transfixed, note of forearm or hand." (p.276, Gesell and Thompson, 1934).

This account of a progressive ability to track the hand with the eyes is again very similar to Piaget's, the difference being that Gesell and Thompson's use of the word "predisposed" implies that the cause of change lies in the maturation of a visual attention and tracking mechanism. Piaget emphasised that change occurred as a result of the use of a sensorimotor scheme, in this case for visual tracking, leading to modifications of the scheme.

Although the views of Piaget and those of Gesell and McGraw described above seem opposed to each other in the sense that one views the causes of change as involving learning while the other focuses on processes of maturation there is an important similarity between them. This is because the locus of change, whether through learning or maturation, is seen as being at the level of changes in the control of movements by the CNS. This is particualrly true of the work of McGraw, as discussed above. The following section will review some current approaches to the study of motor development. It will be argued that these approaches are more pluralistic with respect to causes of change in movement patterns, with factors such as physical growth and change in functional contexts being taken into account as well as CNS changes.

2.3.2 Current approaches to mechanisms of change in motor development

Changes in the way in which infant motor development is approached have arisen through work from three main directions or research areas. These are ideas from the field of evolutionary theory, in particular the idea of **ontogenetic adaptations** (Gould, 1977, Oppenheim, 1981), the application of **dynamic systems theory** to development (Thelen, 1989b) and work on the constraints imposed by weak **postural tone** on the kinds of movement coordinations which can be expressed (Grenier, 1981, Amiel-Tisson, 1985). These three areas will be summarized. Taken together, they argue for a pluralistic approach to causes of change in motor development. No general cause can account for change across different coordinations, or at different stages within the development of a skilled behaviour.

2.3.2(i) Ontogenetic adaptations: Coordinations as adaptations to developmental environments

There are two basic assumptions underlying the theoretical outlook of the work discussed in the previous section. The first is the essentially reflex and reactive nature of behaviour during the first two months of life. The second is the idea that the movements observed during this period are **immature** with respect to later, mature behaviours such as upright posture or prehension. Neonatal behaviour does not fit comfortably with either of these assumptions however. When awake and in a supine position neonates make general movements (GM's) such as whole body flexions or more localized movements of the limbs. These movements were traditionally thought to be indications of general arousal, which was determined by a combination of internal and external factors. This idea was reflected in the way general movements were measured, a methodological necessity in any study of newborn behaviour, which consisted in some measure of displacement (either trunk or limb) per unit time.

Current views of general movements, where these are considered to be spontaneous, that is generated endogenously by the central nervous system, and where the uniqueness of the environment of the newborn is taken into account, have led to a new understanding of neonatal behaviour. Behavioural state is now regarded as consisting of "finite and discrete vectors representing distinct and qualitatively different conditions" (Prechtl, 1974, p.185). For example waking states are divided into those where the infant is quiet and alert, able to take in stimulation from the surroundings, and those where the infant is engaged in spontaneous movements and is relatively unreceptive to external events. These states are thought to reflect CNS processes which are self-regulated and unique to the developing neonate.

The use of ultrasound scanning techniques as a routine part of antenatal care has provided the opportunity for detailed study of the spontaneous movements of fetuses during the first 4-5 months of gestation (de Vries, Visser and Prechtl, 1984, Ianniruberto and Tajani, 1981, Comparetti, 1981). Hopkins and Prechtl (1984) argue that the spontaneous movements in newborns are of the same type as those observed in utero. They suggest that these movements serve the function of changing the position of the fetus so that adhesion to the wall of the uterus does not occur. Their occurrence in newborns could be a "residue" of this once functional behaviour,

> "With the continuation into postnatal life, their immediate adaptive value is no longer obvious...In fact, seen in the context of the infant's environment of evolutionary adaptedness, in which he is depicted to be almost continually carried more or less upright, such movements would be decidedly maladaptive. Perhaps it is only in Western cultures, where typically infants are placed in the supine position, that this GM pattern becomes clearly manifested." (p.194).

Hopkins and Prechtl do not account for **all** spontaneous movements observed during the first three months of life in terms of fetal adaptations. A shift in CNS functioning at the end of the second month is hypothesized to account for observed changes in the quality of spontaneous movements, as described by the authors, from global flexions to smaller, smoother "fidgety" movements. The principle that some behaviours observed in a developing organism are adaptive for a particular environment existing only during a stage of development, known as ontogenetic adaptations, remains valid (Gould, 1977, Oppenheim, 1981).

A feature of ontogenetic adaptations which is highlighted by the example of neonatal spontaneous movements described above is that movement patterns related to particular developmental environments do not neccessarily need to be actively inhibited at the CNS level. A change in environmental conditions can be sufficient in itself to inhibit the behaviour pattern. Another example of this comes from the work of Bekoff and Kauer (1984) on hatching movements in chicks. If chicks, up to 61 days post hatching, were folded into glass "eggs" of a particular size then thrusting movements of the legs, as observed during hatching, could be elicited. Thus no active inhibition of the CNS pattern generator for these movements was necessary directly after hatching. Environmental context, in this case a particular postural configuration in a confined space, can determine whether an available movement pattern is expressed or latent.

The examples given above illustrate that neonatal behaviour patterns need to be understood within the functional contexts that occur during development. Apparently similar functional contexts might have different functional meanings at different points in development. For example von Hofsten (1982) remarks that neonatal "pre-reaching" could be interpreted as an orienting response by the baby to an interesting sight rather than as an immature form of later reaching and grasping. Another point arising from these examples is the way in which the environment can act to control the kinds of behaviour patterns that are expressed. This feature of the interaction of the baby with the environment will be discussed further in the following section which considers the application of dynamic systems theory to the study of motor development in infancy.

2.3.2(ii) Growth and environmental constraints as control parameters in the expression of coordinated movements

Thelen and her collegues (Thelen, Kelso and Fogel, 1987, Thelen, 1989b) discuss how a dynamic systems approach can be applied to the study of motor development. One property of complex systems is that a change in the behaviour of few, or even one, of the interacting elements forming the system (e.g. control parameters) can shift the system as a whole into a new stable state. Thelen (1989b) argues that environmental conditions, or physical growth can be considered as control parameters in the sense described above.

Thelen and Fisher (1982) have used the idea of body growth as a controlling parameter in movement patterning to challenge a traditional view of the relationship between the newborn stepping reflex and unsupported walking at the end of the first year of life. McGraw (1940) suggested that the disappearance of the stepping reflex, an alternating movement of the legs when the infant is held upright and the feet touch a supporting surface, at about 3 weeks of age is a result of cortical inhibition of the behaviour pattern generated subcortically. A cortically controlled pattern of alternating leg movements emerges prior to the appearance of unsupported walking.

By various manipulations of contextual variables Thelen and her colleagues were able to obtain stepping movements from infants of up to 7 months old. By submerging 3-4 month old infants waist-deep in a tank of warm water, stepping movements could be observed (Thelen, Fisher and Ridley-Johnson, 1984). Seven month old infants will make alternate stepping movements when held over a moving tread-mill (Thelen, 1989a). From these results the authors suggest that the CNS pattern for alternate stepping movements does not become inhibited but is available throughout the first year of development. Its apparent disappearance in the situation where the infant is held over a supporting surface is accounted for by suggesting that towards the end of the first month the ratio of muscle to fatty tissue in the legs becomes smaller as relatively more fat is accumulated. This altered ratio makes it increasingly difficult for the leg muscles to lift the legs in stepping, unless the weight of the legs is lessened as in the case of being submerged in water.

Environmental constraints can also be considered as control parameters (Thelen, 1989c provides a discussion of ontogenetic adaptations within a systems perspective). The hatching movements of chicks when placed in glass "eggs" described in the previous section is one example of this. Within a dynamic systems perspective, order emerges as a result of the interaction between elements, rather than as a result of a pre-determined motor programme. A system will settle into preferred states of **dynamic stability**, called **attractor states** (Thelen, 1989a and b). The system can be "pushed" from one stable state to another by a shift of state in one element, such as environmental context. A consequence of this view is that particular stable movement patterns are likely to arise given particular conditions, but different states are possible, for example due to a change in environmental conditions.

An illustration of how such variability within likely, stable outcomes can occur comes from the work of Largo (in press) on pathways towards upright locomotion in normal infants. A large majority of infants from a longitudinal sample (87%) showed a classical progression from crawling on hands and knees, to upright standing and walking. Other infants showed different patterns however, either missing the crawling stage or showing a variety of sitting/shuffling forms of movement prior to walking.

The importance of longitudinal studies for understanding the nature of the interactions involved in particular coordinations is emphasized by the example given above. In dynamic systems terms, the degree of variability observed can be an indication of the "strength" of an attractor state. Which aspects of a coordination are variable and which are stable across different individuals and contexts can also help to reveal how elements of the coordination are organized.

Thelen and Ulrich (1991) argue that variability should not be treated as unwanted "noise" in developmental data. Rather, it should be exploited as a valuable research tool. Maximum levels of variability in behavioural outcomes are expected to occur during periods of transition from one stable attractor state to another. It is during these periods that appropriate experimental manipulations can shift behaviour from one dominant pattern to another, thus allowing possible "candidates" for control paramenters to be investigated. For example, Thelen and Ulrich (1991) found that the stabilization of a stepping pattern on a treadmill was correlated with a weakening of flexor dominance in the legs in pre-walking infants. Other factors such as fat to muscle ratio were not correlated with the stabilization of the stepping pattern.

2.3.2(iii) Importance of postural tone and head support for the expression of coordinated behaviour in infancy

A factor which is being increasingly recognized as crucial to what kind of behaviour is observed during the first few months of life is that of posture, particularly with respect to head support. Grenier (1981) found that if the head was held in newborns in such a way that the infant did not have to bear the weight of the head, after about half an hour the infant was still, with spontaneous movements greatly diminished. Some extraordinary observations could be made at this point with respect to reaching movements, where some infants would make smooth and accurate reaches to an attractive object placed in front of him/her. These findings support the idea that motor immaturity (as opposed to eye-hand coordination) is the main obstacle towards successful reaching and grasping in neonates and young infants, contrary to both Piaget's and Gesell's account of the development of reaching.

The findings described above could have implications of for a wide variety of early behaviours and more research is needed using this method of postural support. In terms of spontaneous movements the suggestion has been made by Auzias and Ajuriaguerra (1982) that some of the general movements observed in the supine position are attempts to regain posture, given an initial destabilizing movement generated spontaneously (in this case the authors suggest that the main destabilizing factor is the loss of support points at the shoulders when an arm movement is made).

2.4 Summary of dynamic systems framework for the study of motor development

The literature reviewed above shows that changes in behaviour during development will be the result of complex interactions between functional contexts, maturation of neuromuscular and skeletomuscular systems and learning processes. No generalized mechanisms of movement control can explain behaviour across different domains, and no general mechanism can be responsible for all changes observed during development. The results of studies which investigate ontogenetic adaptations and posture fit well within dynamic systems perspectives, a point made by Thelen (1989c). Posture and environmental context can be considered as potential control parameters which can shift the behaviour of the infant from one attractor state to another.

In a systems framework, change occurs through changes in control parameters (often scalar such as growth) which lead to shifts in which behaviour pattern becomes most stable (expressed in collective variables). Behaviour is the outcome of the self-organization of interacting elements, and while certain behavioural states are "preferred" by the system, there are no hard-wired programmes or schemas containing the instructions for behaviour patterns. Like the Piagetian concept of equilibration, such a framework does not make any predictions about mechanisms of change in particular instances of coordination. These have to be investigated empirically (Thelen and Ulrich, 1991). It does however provide a way of formulating research questions, and suggests an empirical research strategy. This consists of exploiting periods of relative instability during behavioural transitions to discover control parameters responsible for observed behavioural changes.

Hand-mouth coordination is particularly suitable for study within a dynamic systems framework. It is a naturally occurring behaviour which undergoes change throughout the first months of life. The following section will summarize findings from studies of HM coordination which indicate that the development of the coordination is not one of a progressive improvement based on the strengthening of associations between hand and mouth as described by Piaget, but rather qualitative changes in the structure of the movement can be observed.

The main collective variables of interest are the contexts (and points in development) in which HM movements become a stable behavioural pattern, the accuracy of movements and the degree of integration existing between hand and mouth. Possible control parameters which could be responsible for any changes observed will be considered. These could include motivational factors, general motor maturity (for example posture), more specific motor variables controlling arm movements and perceptual or cognitive factors such as visual guidance during movement. Research questions adressed in the thesis, based on the search for transitional periods in HM coordination and the possible control parameters involved, will then be outlined.

2.5 The development of hand-mouth coordination in early infancy

Two main questions are addressed in this section. One concerns changes during development in the functional contexts in which hand-mouth contacts occur. The other relates to changes during development in the structure of the coordination itself. Factors leading to the observed changes can then be investigated.

2.5.1 Functional contexts in which HM contacts occur

Two main hypotheses have been put forward with respect to the function of HM contacts in the newborn. The first of these suggests that HM contacts are a form of self-comforting behaviour, much like thumb-sucking in an older infant. The second is that HM contacts are related to feeding. Three alternative models concerning the nature of the link between HM behaviour and feeding have been proposed. They vary in the strength of the link made between feeding and HM contacts. The last of these is related to a self-comforting hypothesis in that hunger could be one factor leading to behaviours such as sucking on the hand and non-nutritive mouthing.

The idea that HM contacts are a self-comforting behaviour in the newborn was popular among some researchers working in the 1960's (Kessen, Williams and Williams, 1961 and Korner, Chuck and Dontchos, 1968). Reliable individual differences in measures such as frequency and duration of HM contacts were sought in order to measure what were considered innate differences in the ability to reduce tension without intervention from the caregiver. Both studies found that inter-individual differences were greater than intra-individual differences over different observation periods (separated by hours or days).

Researchers then wanted to see if such behaviours as HM contacts were correlated with situations that could be thought of as creating a high degree of tension. Hendry and Kessen, 1964 and Korner, Chuck and Dontchos, 1968 investigated whether there was an increase in HM behaviours as a function of time since last feed, on the assumption that experiencing hunger was a high-tension situation. Overall, they did not find such correlations. These studies will be examined in more detail in section 3.1.1, p.72, as they are clearly relevant to the question investigated in study 1. That is, whether spontaneous HM contacts are related to feeding.

Hopkins et. al. (1988) in a recent study of self-quieting point out that in order to test whether hand-mouth contacts do serve a self-calming function, the conjunction of hand-mouth contacts with self-quieting needs to be measured experimentally. A group of 11 newborns was filmed while lying in a supine position. Another group of 14 babies was studied longitudinally at 3, 6, 9, 12, and 18 wks. while lying in their cots at home. The occurrence of a change of state from crying to quiet wakefulness with a hand-mouth contact spanning the transition was measured.

In the newborn group there were a total of 35 state changes, 14 of which occurred in conjunction with an HM contact. At 3 and 6 weeks in the longitudinal group there were no such conjunctions but from 12-18 weeks the majority of quieting episodes occurred together with an HM contact. Hand-mouth and hand-face contacts occurred in all states, but no quieting occurred in conjunction with HF contacts at any age.

Hopkins et. al. interpret these results as showing that there is a link between HM contacts and self-quieting in newborns but that the distinction between active and opportunistic contacts cannot be clearly made at this age. This is because the frequency of HM contacts did not vary between crying and non-crying states. A greater frequency would be expected during crying states due to active efforts at self-calming. The "dip" at 3-6 wks. in quieting with an HM contact was interpreted in terms of the common flexed arm posture of the newborn facilitating HM contacts, this posture lasting for about one week after birth. After the second month of age the infant has a greater control of arm movements from a variety of starting postures.

The authors of the study go on to examine whether the idea of an innate self-comforting mechanism involving HM coordination makes sense in evolutionary terms. Crying is an adaptive behaviour signalling that intervention is needed. It could thus be considered mal-adaptive to end crying before such intervention has taken place. They suggest that the child-rearing practice of leaving infants alone for long periods could be giving rise to the behaviour of sucking on the hand, leading to soothing, which would not otherwise take place. In conclusion it can be said that there is no clear evidence that hand-mouth contacts leading to self-quieting are due to active coordination as opposed to "opportunistic" mechanisms.

Various hypotheses have been proposed suggesting that HM contacts in the newborn are related to feeding. The first hypothesis, which can be considered as the strongest in terms of the directness of the link proposed, was suggested by Butterworth and Hopkins (1988) and Rochat et. al. (1988) as one possible function of newborn HM behaviour. These authors suggested that HM behaviour in the newborn could be a pre-functional expression of later self-feeding behaviour. Such pre-functional patterns can be observed in the fetus, for example breathing movements. The term pre-functional has also been applied to some movement patterns in the newborn such as pre-reaching movements (von hofsten, 1982).

A distinction should be made between movement patterns which resemble later functional movements but might not be pre-cursors to the mature behaviour, and those where the pre-functional movements can be viewed as "practice" for the later behaviour, as in the case of fetal breathing movements. It would be difficult to show experimentally that newborn HM behaviour was linked to self-feeding towards the end of the first year. Longitudinal studies correlating measures at the newborn stage with later self-feeding behaviour could be carried out, but it is not clear what relationships would be predicted by a pre-functional self-feeding hypothesis for newborn HM behaviour. In evolutionary terms, it is not clear why pre-functional movements specifically related to self-feeding would be necessary. By the time weaning occurs and the infant is successful at self-feeding (at some stage during the second year) the infant has generalized abilities with respect to reaching for targets and manipulation of objects, so that the specific demands of HM coordination are not great within the context of these general abilities.

Another hypothesis put forward by Blass et. al. (1989), which relates HM behaviour in newborns to feeding, is based on the effects of sucrose on HM contacts. A two-stage model is proposed to account for the effects of sucrose on HM behaviour in the newborn. The first stage refers to the calming effect of sucrose, which they account for by suggesting that endogenous opiate production increases as a result of sucrose ingestion leading to calming and pain reduction. The second stage consists in the activation of the suckling system. This refers to the special posture adopted by infants prior to and during suckling, including the resting of the hands on either side of the breast. If such a posture is adopted in the absence of the breast or bottle, it could be very easy for the hands to go in the mouth. Blass et al. do not suggest how such a mechanism could be extended to spontaneous HM contacts. It would be possible to observe whether "spontaneous" suckling postures occur and whether HM contacts result from these postures.

Finally, a third link between HM behaviour and feeding can be considered as the most indirect hypothesis. Hunger could be one factor giving rise to non-nutritive mouthing and sucking on the hand, as suggested in the self-comforting literature. The results from studies which have investigated the effects of hunger on **spontaneous** HM contacts in newborns are equivocal. They will be discussed further in chapter 3. It should be noted that the hypotheses described above are not necessarily exclusive of one another.

The frequency of spontaneous HM contacts appears to decline after the newborn period. In the longitudinal study by Hopkins et. al (1988), the frequency of contacts to the mouth and face declined so that by the oldest age studied (18 weeks) it could take half an hour rather than 5 minutes to obtain 20 contacts. Rochat and Senders (1991) report that in a longitudinal study of infants aged between 1-3 months on the effects of sucrose delivery to the tongue, there was a large difference in the reaction to sucrose relative to that found in newborns. Sucrose gave rise to upset or expressions of disgust rather than to calming and an increase of HM contacts. A study by Rochat (1989) on the exploration of objects in 2-5-month-old infants found that even at the youngest age of 2 months, infants would transport an object placed in their hands to the mouth for exploration. Based on these findings, Rochat and Senders (1991) suggest that there is a functional transition at about 2 months of age in HM coordination, where it becomes controlled by the motivation to explore objects orally, rather than being related to hunger or a suckling system.

2.5.2 Changes in the morphology of HM contacts during development

The association found by Butterworth and Hopkins (1988) in newborns between mouth open postures and arm movements ending in the mouth (section 1.2(iv), p.18) suggests that some degree of integration between the hand and the mouth exists at birth. This level of integration is interesting in that it occurs in the absence of clear control of arm movements. Movements to the mouth are embedded within larger, whole body general movements and arm trajectories to the mouth tend to be circuitous and made up of several acceleration-deceleration elements. In this respect, the association between mouth and hand movements found in newborns can be compared to pre-reaching in newborns. This behaviour is also carried out within a context of general movements and does not result in successful reaching and grasping.

Piaget (1977) and Bruner (1969) both argue, on the basis of naturalistic observations, that HM coordination develops early, prior to the development of reaching and grasping. Bruner suggested that HM coordination not only developed prior to reaching and grasping but that it played a crucial role in its development. The mouth was the goal or "tertium quid" of early reaches and anticipatory mouth opening occurred not only prior to the object being placed in the mouth but prior to the reach itself. The question of the possible relationships existing between HM coordination and reaching and grasping are considered in chapter 6. There is some evidence from unpublished data from the study by Hopkins et. al. (1988) that HM coordination follows a more complex and extended development than that suggested above. Using the same comparison of mouth opening prior to mouth and face contacts utilized by Butterworth and Hopkins (1988), they found that the association between mouth contacts and mouth open postures only occurred at the oldest age studied, that of 18 weeks. Thus the integration of mouth and hand movements could follow a U-shaped developmental function.

Rochat and Senders (1991) made further analyses on the data obtained by Rochat (1989) on object exploration where the form of arm movements during the first transport of the grasped object to the mouth was analysed with respect to whether the transport was bi-manual or uni-manual. They found that at 3-4 months of age a majority of first instances of transport of the object to the mouth were carried out bi-manually. The reverse was the case in the 2 month group and in the 5 month group. The authors suggest that by three months of age asymmetric reflex postures give way to symmetric postures, for example the infant lying in a supine position with both arms extended to the side of the head at the midline. They argue that these postural changes allow a synergy in the action of both arms to be expressed. This synergy eventually gives way at 5 months to uni-manual transport to the mouth, freeing one hand to carry out haptic exploration of objects that are grasped.

The role of visual regard in HM coordination has received little attention. Rochat (1989) measured the association between looking and tactual exploration and looking in conjunction with mouthing. At 5 months there was an association between visual regard and tactual exploration of the object but not between mouthing and looking. It is possible that there is an association between looking and movements to the mouth, rather than with mouthing once the object has been placed in the mouth. This possibility will be considered in study 2 of the thesis.

Many questions remain both at a descriptive level and in terms of the mechanisms behind the transitions observed during the development of HM coordination. At a descriptive level, a more detailed account of the morphology of the coordination in terms of arm movement trajectory and accuracy, and the timing relationships between arm and mouth movements at different stages of development is required. Factors that could be responsible for the transitions observed need to be studied together with aspects of HM coordination. The possible effects of postural changes have already been mentioned with respect to bi-manual and uni-manual movements. Possible relationships between changes in accuracy of movements and the re-emergence of anticipatory mouth opening could be investigated. Whether visual regard plays a role in the integration of hand and mouth movements could also be studied.

In dynamic systems terms, the developmental trajectories of collective variables can be identified (e.g. the occurrence of HM coordination, accuracy of movements and degree of integration between arm and mouth). Periods of relative stability and instability in the behaviours observed can be identified, and hypotheses relating to control parameters investigated. These control parameters could include both the motor and cognitive factors outlined above. Section 2.6 will give a brief introduction to the questions addressed in the studies reported in the following chapters.

2.6 Research questions addressed in the thesis

The studies reported in the thesis are wide-ranging in the age range of babies studied and the problems addressed, including questions relating to both the function and structure of HM coordination. A variety of experimental designs are employed, including longitudinal and cross-sectional designs. The method of observation is the same for all the studies reported and is derived from the method used by Butterworth and Hopkins (1988). Video records of two perpendicular views of the infant are obtained with a timer superimposed onto the film. From these records, measures such as movement duration, final location of the movement, mouth opening and degree of visual regard can be obtained.

Study 1: The main question addressed in study 1 was whether spontaneous HM contacts in newborns are related to hunger. HM contacts were compared before and after feeding in a group of newborn babies. It was thought that if the behaviour was related to hunger there should be observable differences between the two conditions.

Study 2: This study sought to obtain detailed measures of the transitions taking place between 1-5 months in the structure of HM coordination, and to investigate which factors could be responsible for the changes observed.

For this reason a longitudinal design was employed where babies were observed at monthly intervals. Due to the transition in functional orientation discussed by Rochat (see previous section) at about 2 months, where spontaneous contacts decline and oral exploration of grasped objects emerges, study 2 sought to use the motivation to explore objects as a way of generating HM contacts. A small, light and easily graspable object, especially designed so as to interfere minimally with the hand-to-mouth movement, was placed in the hands of infants to promote oral contacts.

Study 3: This study was based on findings from study 2, where mature HM coordination occurred later than suggested by previous authors. The hypothesis that the development of reaching and grasping could be causing transitions to occur in HM coordination was investigated, an idea opposite to that proposed by Bruner (1969) where HM coordination is aiding the development of reaching and grasping. Two broad age groups, one of 5-7-month-olds and one of 7-9-month-olds were compared in two conditions. One condition involved having to reach for an object (the same objects as those used in study 2). The first HM contact after the reach was analysed. The other condition involved placing the object in the hand of the infant. Again, the first transport of the object to the mouth was analysed. Four trials in each condition were given to each infant. It was thought that HM coordination could have a different structure in the reaching condition in the younger subjects but not in the older ones.

Study 1 is reported in chapter 3 of the thesis, study 2 is reported in chapters 4 and 5 and study 3 is reported in chapter 6. Chapter 7 will summarize the results from all the studies and give an overview of the development of HM coordination in the age-range studied. The relationship between these findings and general issues of coordination development will be discussed.

CHAPTER 3

HAND-MOUTH BEHAVIOUR IN NEWBORN INFANTS BEFORE AND AFTER FEEDING

3.0 Introduction

The study by Rochat et. al. (1988) showed that sucrose delivery to the tongue led to an increase in the frequency of HM contacts at the expense of hand-face (HF) contacts in newborns. This led the authors to suggest that sucrose delivery activated a "suckling system", leading to a greater number of HM contacts (see section 2.5.1, p.59). It remains to be seen whether the motivation for **spontaneous** HM contacts is related to hunger. Such a link would not only give information about the **function** of newborn HM contacts but would also provide further evidence that **active** mechanisms are responsible for these contacts, as opposed to fortuitous or "opportunistic" mechanisms resulting from the general activity of the infant.

Studies of the effects of hunger on HM contacts will be reviewed here. Problems of interpretation will be discussed with respect to whether mechanisms underlying HM contacts can be distinguished with the measures used in these studies. It will be argued that the experimental design used by Butterworth and Hopkins (1988), also used in study 1, takes into account such problems. Another aim of study 1 was to characterize more fully the morphology of HM contacts in newborns.

3.1.1 Effects of hunger on HM contacts

An HM contact in the newborn could arise fortuitously through general movements or, a fortuitous contact with the face could then lead to "capture" by the mouth. In the first case, care has to be taken that if an increase in HM contacts is measured it is not simply due to an increase in general activity. In the second case, care has to be taken to distinguish HM contacts where the hand first went to the face, from direct mouth contacts. It is possible that an increase in HM contacts could be due to more face contacts becoming face-to-mouth (HFM) contacts from a greater motivation to capture the hand. Such a mechanism would not necessarily imply an active HM coordination where the initial goal of the arm movement was "aimed" to the mouth.

Studies which have looked at the effect of hunger on HM contacts have used measures which do not fully control for the possibilities outlined above, or they use measures which are not related to movements to the mouth, such as the duration of a contact once established. An early study by Hendry and Kessen (1964) measured the total duration of an HM contact during an observation period and the average duration of a contact (obtained by dividing the total duration of contacts with the number of contacts made) as variables to compare with hunger level, measured by time since last feed. They found that both these measures decreased significantly during the second hour after feeding. Because of this, it is not possible to say whether the decrease in the average duration of contacts was due to a decrease in frequency of contacts as well as the duration of contacts, or if it could be accounted for only by the decrease in the total duration of contacts. Only a measure of frequency would be related to the question of whether an increase in **movements to the mouth** was taking place as a result of hunger.

Two studies measured the frequency of HM contacts during an observation period in relation to time since last feed. Korner, Chuck and Dontchos (1968) measured the frequency of HM and HF contacts, although they did not control for changes in behavioural state. Their HF category was derived differently than in other studies, in that they excluded HF contacts which were due to "random batting of the face". They did not specify in more detail how these distinctions were made. Contacts which first went to the face and then the mouth (HFM contacts) were counted as HM contacts. They found that there was a trend towards increasing frequency of HM contacts (but not HF contacts) in relation to time since last feed but this trend was not significant.

Feldman and Brody (1978) measured frequency of HF and HM contacts as a function time since last feed, where these frequencies had been weighted with respect to frequency of occurrence for any given behavioural state. They made a distinction within the HM category of those contacts which only touched the outside of the mouth (hand-at-mouth or HAM contacts) and those where the hand was placed inside the mouth (hand-in-mouth or HIM contacts). Contacts which first touched the face and then the mouth were counted twice, once as HF contacts and once as HAM, or HIM, contacts. HIM contacts was the only measure that consistently increased with time since last feed when behavioural state was taken into account, although not by a large amount. This increase could have been due to a genuine increase in HIM contacts, or, more HF, HFM and HAM contacts could have become HIM contacts than was the case with lower hunger levels.

Finally, two studies sought to overcome the problems of using frequency of HM contacts as an experimental variable (e.g. the confounding effect of state or increased general activity) by taking as a principal measure the number of mouth contacts that occurred during an observation period as a proportion of all contacts to the mouth and face. Thus an increase in both contacts to the mouth and face arising through an increase in general activity would not be measured as an increase in the proportion of HM contacts. Wolff (1966) found that there was a significant rise in the proportion of HM contacts between the first and second hour after feeding. He suggested that hunger had "an initially augmenting and subsequent disorganizing effect" (p.55) on HM coordination. HFM contacts were counted as HM contacts in this study so it is possible that the increase in HM frequency between the first and second hour was a result of more HF contacts being converted to HFM contacts.

Korner and Kraemer (1972), in a re-analysis of the data obtained by Korner et. al. (1968) used a measure which they termed "sure aim", defined by the number of HM contacts which go directly to the mouth as a proportion of those which first go to the face, arguing that this would be an index of how efficient HM coordination was, if it was assumed that the original goal of the movement was the mouth. However, this last measure is **not** the same as an HFM contact, since the authors divided their observation period into 32 frame (cine-camera frames) units. A contact which first went to the face and then the mouth was scored when adjacent units were scored as HF and then HM. Thus, no account was taken of whether there was a loss of contact altogether between observation units. They found no significant difference in "sure aim" as a function of time since last feed.

Given the problems of interpretation of the results from the studies described above, can any general conclusions be drawn as to the relationships between level of hunger and HM contacts? Neither the study by Feldman and Brody (1978) or Korner et. al. (1968) found any large effects on frequency of HM contacts as a result of hunger. It remains to be seen whether the distribution of types of contacts, e.g. HF, HM and HFM contacts, vary as a result of hunger level.

The design used by Batterworth and Hopkins (1988) in their study of newborn HM coordination is very suitable for investogating the effect of hunger on HM contacts. In terms of the problem of distinguishing changes in levels of contacts from changes in general activity levels, the method of analyzing the first 20 contacts to any part of the face allows the relative proportions of HF and HM contacts to be measured. Unlike all the studies described so far, that of Butterworth and Hopkins analysed contacts as events, rather than dividing an observation period into small time units, each of which was labelled depending on what kind of contact took place during that period. This method allows for the morphology of individual contacts to be described. For example whether the initial location of a contact was on part of the face, how long it was there and whether the hand was then moved to the mouth can be analysed. Any changes in movement morphologies which vary with hunger level can thus be measured.

3.1.2 Morphology of newborn hand-mouth coordination

Butterworth and Hopkins (1988) based their argument that HM contacts were coordinated, and thus due to different mechanisms than those responsible for HF contacts, on the finding that HM contacts differed in their morphology to HF contacts (i.e. there was more anticipatory mouth opening associated with HM contacts). These comparisons can also be made in study 1. In addition, other aspects of movements to the mouth can now be observed, such as the timing between mouth opening and the initiation of the movement to the mouth. Contacts to the face which subsequently go to the mouth can also be examined in detail.

Butterworth and Hopkins found that HFM contacts were more similar to HF contacts than to HM contacts with respect to anticipatory mouth opening, something that would not be expected if HFM contacts were "failed" HM contacts, as Korner et. al. (1968) suggest. They also found that the hand did not reach the mouth as a result of head turning after contact (which could be considered as a "rooting" movement), rather the hand was moved in the direction of the mouth. These aspects of HFM movements were also investigated in study 1.

Observation of the morphology of movements goes beyond the issue of whether some kind of HM coordination exists at birth and addresses the question of the form such a coordination takes. Comparisons with movements at later stages in development can then be made.

3.2 Method

3.2.1 Subjects

Subjects were recruited from the maternity wards of the Stirling Royal Infirmary between March and August, 1989. The babies were 1-7 days old, born at between 38 and 42 weeks gestational age and had been judged as normal by hospital assessment procedures. These procedures included a physical examination, an assessment of muscle tone and testing of neonatal reflexes by a paediatrician within 24 hours of birth.

The mothers were approached to see if they wished to volunteer for the study. They were told initially that the study was concerned with the spontaneous movements of newborns. More detailed information was provided if desired once their participation was over. A total of 30 babies were filmed of whom only 18 were included in the final sample. Of the infants excluded from the sample, 11 cried during one or both filming sessions and 1 infant was discharged from the hospital before filming was completed. At least 2 minutes of film, both before and after feeding, where the baby was not crying had to be obtained in order for the baby to be included in the study.

Table 3.1 gives details of the 18 subjects included in the study. Of the initial 30 volunteers, the number of male and female subjects was equal, however the greater tendency for upset in male infants meant that the number of females was greater in the final sample. Upset was common as the first filming session took place just before a feed was due. The greater average age of the female subjects was due to the fact that 3 of the female babies had caesarian births and were thus kept in hospital until 1 week of age, the time at which they were filmed.

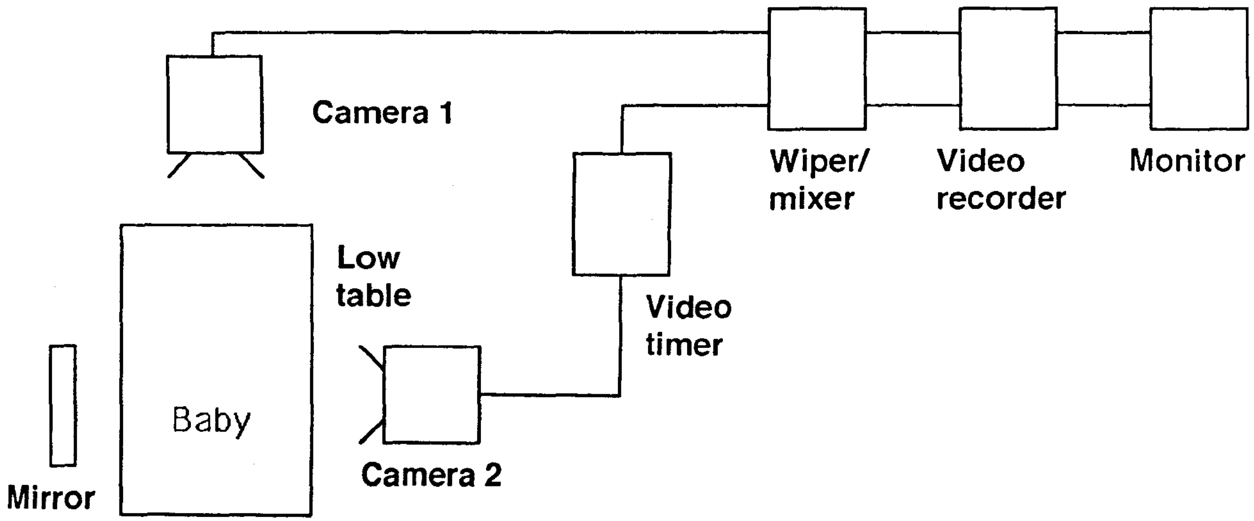
Sex	N	Mean age/ days	Weight/lbs Mean, SD	Delivery		Feeding	
				Caes	Norm	Bre.	Bot.
Males	6	1.5	8.5 ± 1.1	0	6	5	1
Females	12	4.5	7.0 ± 0.8	3	9	6	6
All Subs.	18	3.5	7.5 ± 1.2	3	15	11	7

Table 3.1 Sex, age, weight on day of filming, form of delivery and method of feeding o^E subjects in study 1.

3.2.2 Apparatus

Filming was carried out using two portable panasonic video cameras(model WVP-F10E). As in the study by Butterworth and Hopkins (1988) the aim was to obtain two perpendicular views of the infant, one a view of the whole body so that arm movements could be observed, and the other a close-up view of the face. In the Butterworth an7 Hopkins study, one camera was placed directly above the infant (the whole body view) and the other was placed to the right side of the infant, to give a close-up view of the head. A mirror was placed on the left side of the infant in such a way that if the infant turned to the left, the face could still be observed in the side camera. A similar arrangement was used in study 1 (see diagram 2). It was not possible to place a camera

Diagram 1. Circuit arrangement, studies 1,2 and 3.



Camera 1 - Full body view of baby, above and front (Panasonic F10).
Camera 2 - Close-up view of baby's head, side view (Panasonic F10).
Mirror - The mirror was positioned so that the reflection of the left view of the baby's head was recorded on camera 2.
Video timer - Maximum sensitivity 0.01 secs (model 4A).
Wiper/Mixer - Mixer yielded two simultaneous views of the infant (Electrocraft VMC-85).
Video recorder - Panasonic NV 180.
Video monitor - J.V.C. CX 60GB.

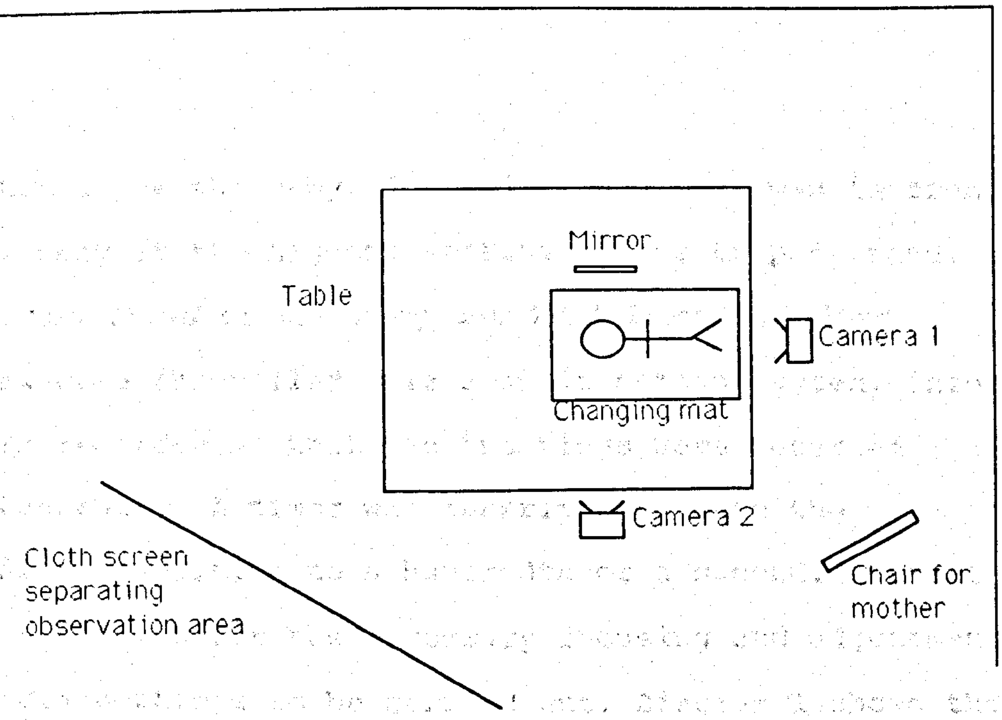


Diagram 2a). Observation room layout - view from above

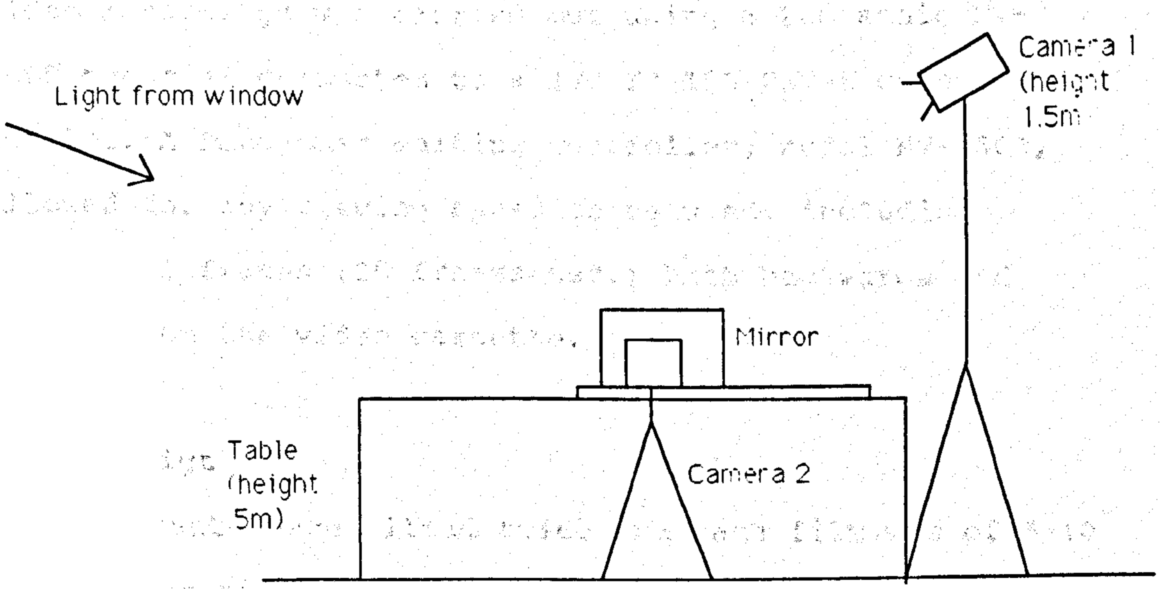


Diagram 2b). Filming apparatus - side view

directly above the baby, instead, the camera was in front of the baby at the highest setting of the tripod stand.

The two views of the baby obtained from the video cameras were channelled, via a split screen system, into a video recorder so that the two views were recorded simultaneously. A timer was superimposed onto the recording, sensitive to a hundredth of a second. A small monitor allowed for the necessary focusing and adjustment of camera settings to be carried out. Diagram 1 shows the details of the circuit arrangement. The analysis of the video recordings was carried out using a Panasonic NV-8500 recorder connected to a JVC TM-150 PSN-K colour monitor. A Panasonic editing controller, model NV-A500, allowed for any viewing speed to be used, including individual frames (25 frames/sec.) both backwards and forwards on the video cassette.

3.2.3 Design

All infants were filmed twice and each film was of 5-10 minutes duration. The first film was taken just before a feed, and the second was taken just after the same feed. An initial design which balanced the order of filming with feeding was abandoned after piloting. This was because the design resulted in great variation in the interval between the two filming sessions. Those babies starting filming after feeding waited a greater interval until the next filming session than those starting filming before a feed. In the former case there might be a delay of 3-4 hours until the next feed was due and in the latter case feeding might only take 15 minutes to complete. The films obtained for each baby were analysed with respect to differences between hand-face and hand-mouth contacts. A full description of the method of video analysis will be given in section 3.2.5.

3.2.4 Procedure

Volunteer mothers and their babies were brought to the room where filming took place. This was a day room in one of the maternity wards, although it was very rarely used as such. The baby was placed in a supine position on top of blankets placed over a changing mat, on a low table. Babies were filmed wearing a nappy only and the room was kept warm. Butterworth and Hopkins (1988) recommended that the head of the infant should be held gently at a midline position for about 20-30 secs. so that he/she should settle into a preferred posture once released (e.g. with the head to the left or right). It was found during pilot trials that this practice caused upset, so instead of the head being held the first 20 seconds of film were not scored, this period being treated as a settling-down period.

The mother was present throughout the filming sessions and sometimes fed the baby in the day room as well. If an infant became upset then filming was stopped to see if he/she could be comforted. Another attempt would be made to film the baby. If this was not successful then filming would be re-scheduled for the next day's morning feed if this was possible.

Filming always took place in the morning, between 8.00 a.m. and 1.00 p.m., the exact time depended on when each baby's feed was due. Since babies were fed on demand and they would vary in the amount of time they took to feed, there was some variation in the interval between the beginning or end of a feed and filming, and in the interval between the two filming sessions. Most babies were filmed within 5 minutes prior tos and then after being fed. A few babies were delayed, due to hospital routine checks, by up to 20 minutes between the end of the first filming session and feeding. The duration of feeds varied from 15 minutes to 1 hour, with one exception of a breast fed baby who took two hours to finish feeding. Bottle fed babies tended to take less than 30 minutes to feed while breast fed babies (with one exception) took between 30 minutes and 1 hour.

3.2.5 Video analysis

3.2.5(i) Contacts to the face or mouth: Each film was viewed until a maximum of 20 consecutive contacts with the mouth or face were analysed. An enterval of 20 seconds was allowed for the baby to settle down before the first contact was scored. If there was a crying spell during the filming interval, 10 seconds was allowed for settling after the crying period before any contacts were scored. No contacts made during crying spells were analysed. Contacts due to sneezes were also excluded. The location of contacts to the face were divided into the following categories:

Back of head
Top of head
Forehead
Eyes (Right or Left)
Nose
Ears (Right or Left)
Cheeks (Right or Left)
Chin
Perioral region.

Contacts to the mouth were divided into Hand-In-Mouth (HIM) contacts and Hand-At-Mouth contacts (HAM), following Blass et. al. (1989).

3.2.5(ii) Kinematic aspects of arm, head and mouth movements: The time of initiation of an arm Xovement, and the termination of the movement when contact was made with the face or mouth was noted. Newborns can be in almost continual motion, and so judging when an arm movement leading to a contact begins is not a trivial problem. Attention was given to tw features of the arm movement prior to a contact; trajectory and speed. A relatively constant speed and direction following a movement with a different trajectory and/or speed was taken as the unit of movement relevant to a contact. The first video frame where the hand appeared to be in contact with the mouth or face was taken as the time of contact. In practice, it was helpful to locate the frame at which a contact occurred first. The film could then be studied backwards, frame by frame, until either a pause or a change in direction of movement was located. This frame could then be taken as the time of initiation of the movement towards the mouth or face.

The time at which a contact ended (measured by the first frame where there no longer appeared to be contact between the hand and head) was also noted, thus allowing the duration of contacts to be measured. If the location of the hand on the mouth or face changed to another location, then the time at which the change took place and the new location was noted. If a head movement was involved as well as (or instead of) the hand in the change of location then this was also noted. The body posture of the baby at the start of the movement leading to a contact was recorded, together with the arm involved in the movement (R or L). The possible categories of body posture were:

Side posture, R or L (this is not a full side posture with one arm fully underneath the body, as newborns cannot spontaneously assume such a posture. The upper arm is half hooked under the body and the lower arm remains mobile)

Asymmetric Tonic Neck Reflex (ATNR) posture, R or L (the body is in supine position, the head is to the R or L, the ipselateral arm is extended and the contralateral arm is flexed)

Body and head at the midline (usually a rather unstable posture).

The posture of the mouth (Open or Closed) was noted at the beginning of an arm movement leading to a contact, and just prior to contact (one frame before contact). Whether the mouth was opening or closing (or remaining in the same posture) during the arm movement could be derived from these measures. When mouth opening did occur, prior to or during an arm movement, the time at which the mouth started to open was noted. The timing relationship between arm and mouth movement could then be derived. A few babies maintained their mouths in a slightly open posture for large amounts of the observation period. This "baseline" position was scored as a Closed mouth posture.

3.2.5(iii) Tests for mechanisms of HM coordination: In their analysis of movements leading to contacts Butterworth and Hopkins (1988) noted the posture of the hand (Open or Closed) at the initiation of movements. This was because they suggested that it was possible that the baby could self-stimulate the Babkin reflex by clenching the fist, leading to mouth opening. They tested for this by seeing if movements where anticipatory mouth opening occurred were associated with clenched fist postures. No such association was found in their study.

A further possibility, one that was not explored by Butterworth and Hopkins, is that the typical newborn posture where the arms are flexed and very near the mouth could facilitate HM coordination, as suggested by Mounoud (1982). In order to test this possibility, the posture of the arm at the initiation of movement was noted. The arm could be:

Extended (whether the arm was above or below the shoulder was also noted)

Flexed (where the arm was completely flexed at the elbow joint so that the hand was near the shoulder).

Partial flexions were counted as extended postures, given that only a fully flexed arm posture would result in very close proximity with the mouth. Thus, if a flexed posture was facilitating HM coordination, there should be a difference in terms of anticipatory mouth opening and/or the ratio of HF to HM contacts between movements starting with a flexed, rather than extended arm posture.

3.2.5(iv) Baseline levels of mouth opening: In the experimental design of Butterworth and Hopkins baseline measures of how long the mouth was open irrespective of arm movements were not taken. It was assumed that HF contacts which occurred in conjunction with mouth open postures represented a baseline of "chance" conjunctions, since HF contacts could be regarded as a by-product of general movements. This design was also used in study 1, but in addition baseline levels of mouth open postures were measured. These were then compared with the proportion of mouth open postures found in both HF and HM contacts. Differences in baselines of mouth open postures were also compared before and after feeding.

The video-tapes were scored so that the times of change in mouth posture were recorded from Open to Closed or vice versa. Mouth opening due to crying or yawning was excluded from this analysis. Instances where the mouth was open while a HIM contact was taking place were noted. These instances could then be subtracted from a final total of mouth open time and observation period duration. The time spent with a mouth open posture as a proportion of the observation period could then be derived and compared to the proportion of HF or HM contacts associated with mouth open postures.

3.2.5(v) Behavioural state: In order to assess behavioural state, the following categories were used, taken from Brazelton (1984):

1. Deep Sleep. No movement except startles, deep, regular breathing.
2. Active sleep. Movement during sleep, rapid eye movements, irregular breathing.
3. Drowsy. Slow body movements. Eyes could be closed or "dazed" in appearance if open.
4. Alert Inactivity. Eyes open and bright, infant quiet and inactive.
5. Waking activity. Generalized motor activity, with possible vocalizations or isolated cries.
6. Crying.

The observation period was divided into 10 second intervals and one of the state categories listed above was assigned to each interval. This analysis allows a comparison to be made between state measures before and after feeding during the observation periods. In addition, state at the time that contacts were made could be derived, since it is possible that even if there is one predominant state during an observation period (for example state 3, drowsy) the state in which most contacts occur may be a different one (for example state 4 or 5).

3.2.6 Inter-observer agreement

The video analysis of the main observer was checked by a second observer who analysed approximately 10% of the data (51 contacts out of a total of 564 contacts BF and AF). After an intensive training period a random selection of contacts was analysed by the second observer and agreement with respect to a) the location of the contacts and b) the mouth posture prior to contact was computed using Cohen's Kappa (Cohen, 1960, Bakeman and Gottman, 1986). This statistic takes into account the agreement that would be expected to occur by chance. The selection of contacts was made so that the numbers of HF and HM contacts would be roughly equal, as were the number of contacts associated with mouth open and mouth closed postures. This was to allow enough contacts in different categories to be represented within the 10% of the data corpus analysed by the second observer.

In computing agreement over location, three categories were considered. HF, HFM and HM contacts (comprising HAM and HIM contacts). The second observer was given a list of times referring to particular films and was asked to analyze the contacts occurring at those points. These same contacts were used to compute agreement over mouth postures prior to contacts. In this case agreement was computed across all contacts, regardless of location category. The contacts were then separated into two categories, HF contacts, as defined by the main observer (and including HFM contacts) and HM contacts. Agreement was computed separately for these two location categories. This would allow a comparison to be made between HF and HM contacts with respect to degree of inter-observer agreement. When agreement about mouth posture prior to contact was being computed, disagreements over location of contacts were ignored. For example if the main observer scored a particular contact as an HFM contact associated with an MO posture, and the second observer scored an HM contact associated with an MO posture, this would be counted as an agreement in terms of mouth posture prior to contact.

The confusion matrix for agreement over location categories shows that the only location category that produced difficulties was that of HFM contacts. From this table, Cohen's Kappa was calculated using the formula:

Confusion matrix for inter-observer agreement on location of contacts.

Main Observer

	HF	HFM	HM	Tot.
HF	24	1	0	25
HFM	0	1	0	1
HM	0	3	22	25
Tot.	24	5	22	51

$$K=\frac{P_o-P_c}{1-P_c}$$

where P_o is the proportion of agreement that occurred and P_c is the proportion of agreement that would be expected by chance given the frequency of occurrence of each location category. The value of K was 0.82, signifying relatively good agreement over distinctions between location categories.

The confusion matrices of agreement for a) mouth postures prior to contacts at any location, b) mouth postures prior to HF contacts and c) mouth postures prior to HM contacts are given below:

a) All contacts

Main observer

	MO	MC	Tot.
MO	17	3	20
MC	3	28	31
Tot.	20	31	51

b) HF contacts

91ain observer

	MO	MC	Tot.
MO	10	1	11
MC	2	17	19
Tot.	12	18	30

c) HM contacts

Main observer

	MO	MC	Tot.
MO	7	2	9
MC	1	11	12
Tot.	8	13	21

The Kappa values associated with these matrices are as follows:

a) For all contacts, K = 0.75, b) for HF contacts only, K = 0.79 and c) for HM contacts only, K = 0.79. Thus, agreement over mouth postures prior to contacts was reasonably good and did not differ across location categories.

3.2.7 Statistical analysis

All comparisons carried out in study 1 were within subjects, either across the two experimental conditions (before feeding, after feeding) or across different categories within conditions. A non-parametric test was selected as the normality of distributions and equivalence of variances could not be assumed for all the measures studied. This was the Wilcoxon signed rank test for related measures. All tests of significance were 2-tailed. Significance level is indicated on tables by * (5% significance level) or ** (1% significance level).

3.3 Results

3.3.1 Distribution of locations of contacts before and after feeding

A total of 260 contacts were obtained before feeding and 304 were obtained after feeding. Table 3.2 shows the number of contacts obtained for each individual subject before and after feeding. It can be seen that for some infants fewer contacts were obtained before feeding (BF). This was because some observation periods were cut short due to crying. One infant, subject 18, did not cry, but hardly made any contacts. The general movements of this infant tended to be of smaller amplitude than those of other infants.

Sub	N, BF	N, AF
1	20	19
2	20	16
3	18	11
4	20	20
5	20	20
6	7	20
7	16	20
8	6	18
9	20	18
10	6	20
11	20	17
12	14	16
13	20	20
14	13	17
15	17	18
16	19	20
17	4	13
18	0	1

Table 3.2. Number of contacts obtained for each subject before and after feeding.

The first question to be addressed was whether hunger altered the distribution of locations of contacts, for example if there was a greater proportion of HM contacts before feeding relative to HF contacts. Four categories of locations were used: Hand-Face (HF) contacts, Hand-Face going to Mouth (HFM) contacts, Hand-At-Mouth (HAM) contacts and Hand-In-Mouth (HIM) contacts. Figure 3.1 shows the means and standard deviations of the proportion of contacts in each location category over all subjects before and after feeding.

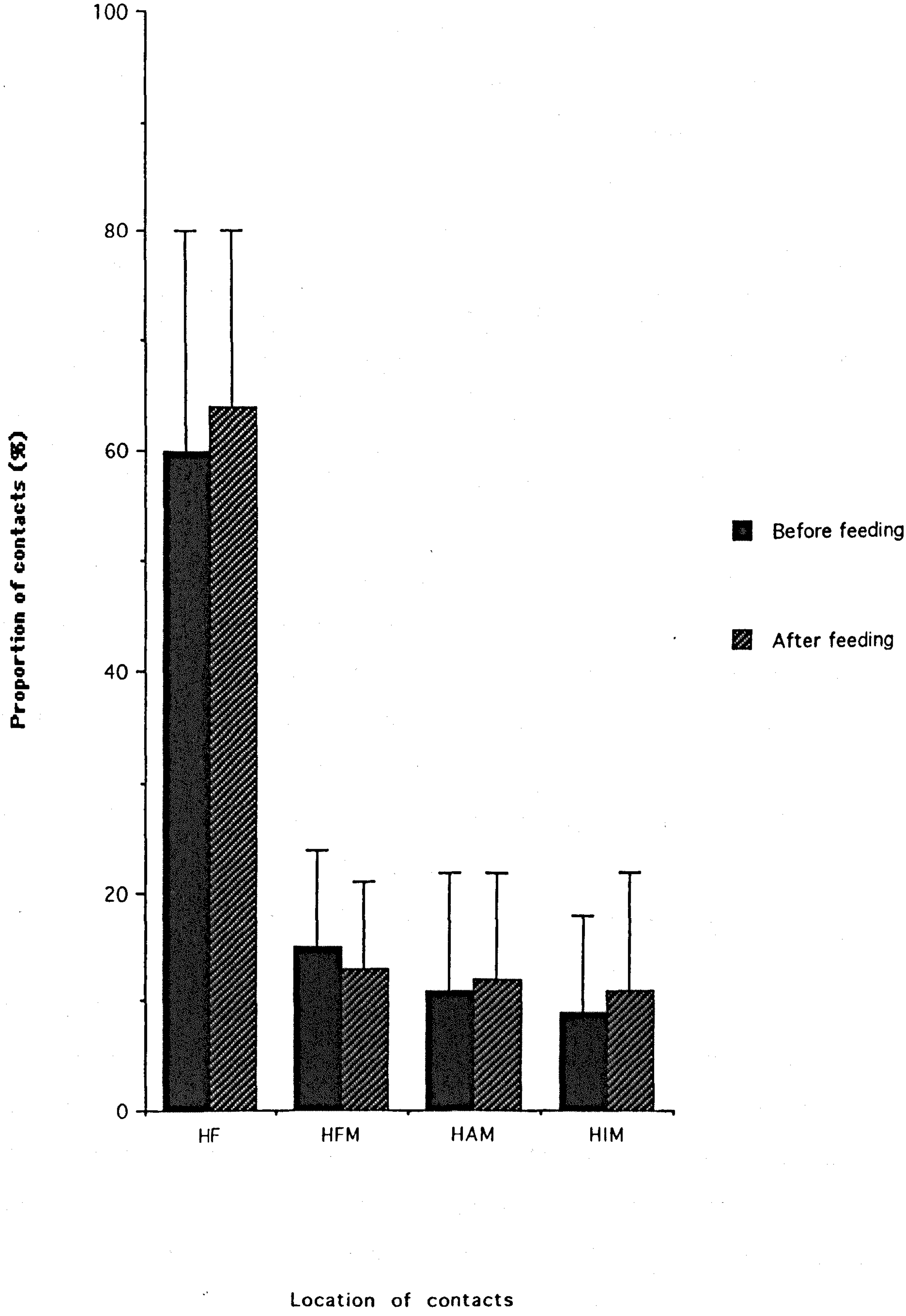
It can be seen from figure 3.1 that there was very little difference in the distribution of location of contacts before and after feeding. The proportions obtained were similar to those of Butterworth and Hopkins (1988), where 58% of contacts were HF contacts and 18% were HM (HAM + HIM) contacts.

	HF BFvAF	HFM BFvAF	HAM BFvAF	HIM BFvAF
N	17	17	17	17
Z	.3	0.9	-0.4	-1.0
P level	≤.8	≤.3	≤.6	≤.2

Table 3.3. Z values and associated probability levels for the comparison of proportions of contacts in each location category before and after feeding.

The Wilcoxon signed rank test was used to test whether there were any significant differences between the proportions of contacts at each location category before and after feeding (table 3.3). No significant differences were found.

Figure 3.1. Means and standard deviations of the proportion of contacts at each location category before and after feeding.



The distribution of locations of contacts **within** the HF category are shown in table 3.4. Contacts from all subjects have been pooled to obtain these proportions. Back of head and top of head contacts have been pooled together into one category. It can be seen that even at this detailed level the distribution of locations was very similar before and after feeding.

	Back	Fore-head	R/L Eye	Nose	R/L Ear	R/L Cheek	Chin	Peri-oral
BF	24%	5%	1%	3%	11%	37%	10%	7%
AF	18%	1%	3%	2%	17%	40%	11%	8%

Table 3.4. Proportion of contacts within the HF category in different areas of the face, before and after feeding.

3.3.2(i) Associations between mouth posture and location of contacts before and after feeding

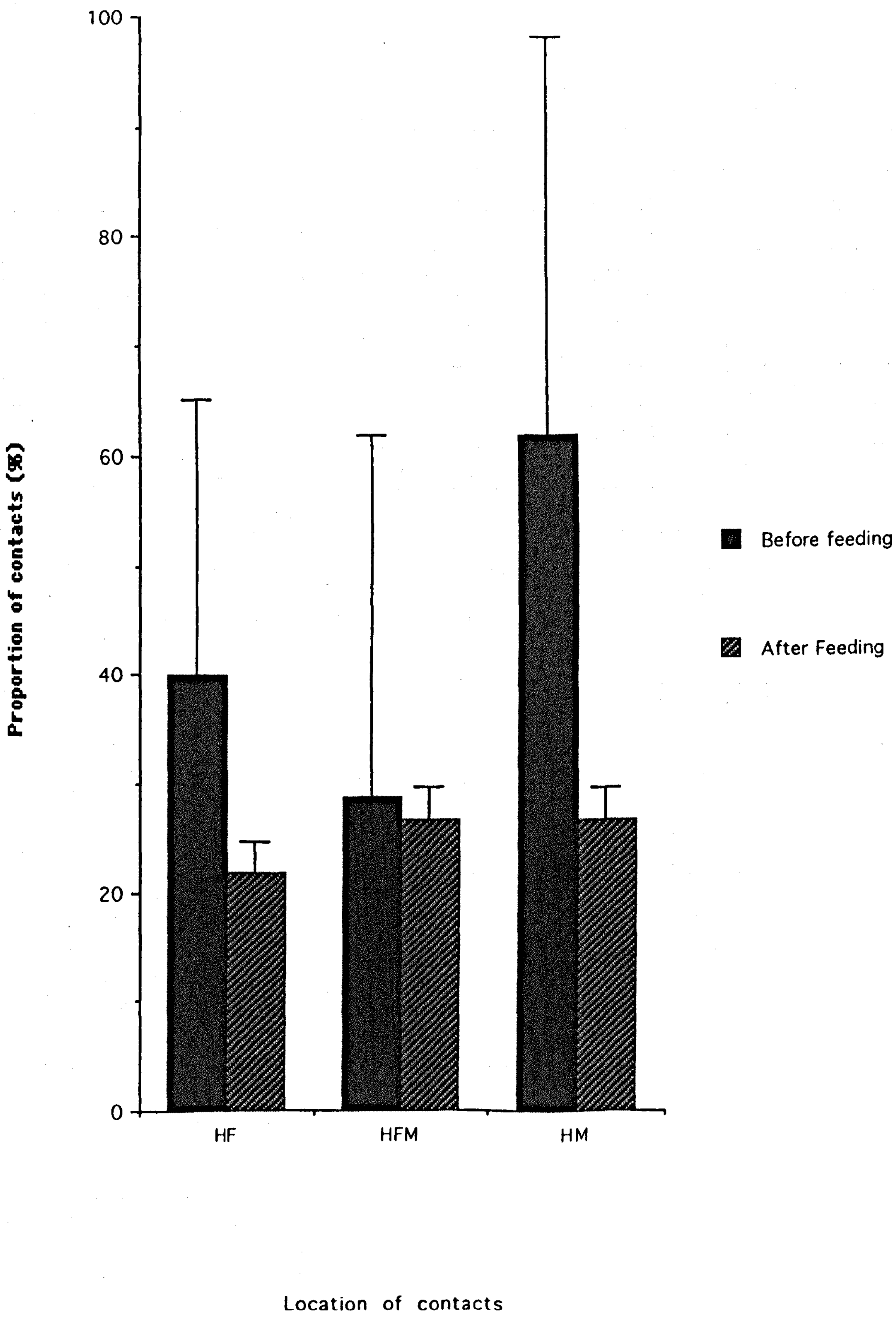
The question addressed in this section is whether there was a greater association of mouth open postures with contacts that went directly to the mouth compared with other kinds of contacts, as in the study by Butterworth and Hopkins (1988), implying that some form of HM coordination exists at birth. The total number of contacts included in the analysis of mouth posture was 236 before feeding and 284 after feeding. This is less that the number included in the analysis of location of contacts because some mouth open postures were excluded due to; a) crying (this was an isolated cry rather than a crying spell), b) rooting to a previous contact (this was scored when a contact to the cheeks was followed by head turning, mouth opening and an HM contact, this does not mean that a rooting mechanism was necessarily responsible, just that this was a possibility), and c) a mouth open posture occurring due to an ongoing HIM contact with the other hand. Table 3.5 shows the data excluded for the reasons listed above.

Feeding condition	Cry	Rooting	Other HIM contact	**Total exclusions**
BF	4	6	14	**24**
AF	1	2	17	**20**

Table 3.5. Number of contacts excluded from the analysis of mouth posture before and after feeding.

Tables 3.6a) and b) show the total number of contacts across all subjects at each location where the associated mouth posture was either Open (MO), Opening (MOO), Closed (MC) or Closing (MCC). It can be seen that the majoriy of HAM and HIM contacts before feeding were associated with MO and MOO postures, whereas the majority of HF and HFM contacts were associated with MC and MCC postures. After feeding however, the majority of contacts at all locations were associated with closed mouth postures. Given the very small numbers of contacts involved, some categories were collapsed so that the statistical analysis could be carried out. Figure 3.2 shows the means and standard deviations of the proportions of contacts associated with mouth open postures at different location categories. MO and MOO categories have been added together to form one mouth open category, similarly MC and MCC postures form one mouth closed category. In

Figure 3.2. Means and SD's of the proportion of contacts at each facial location associated with MO postures, before and after feeding.



addition, HAM and HIM location categories have been added together to form one hand-mouth category.

a) BF	HF	HFM	HAM	HIM
MO	27 (18%)	10 (26%)	9 (37.5%)	7 (26%)
MOO	20 (15%)	4 (10%)	5 (20%)	10 (27%)
MC	75 (51%)	19 (49%)	9 (37.5%)	8 (30%)
MCC	24 (16%)	6 (15%)	1 (4%)	2 (7%)

b) AF	HF	HFM	HAM	HIM
MO	26 (15%)	2 (5%)	1 (3%)	3 (9%)
MOO	16 (9%)	4 (10.5%)	7 (18%)	11 (31%)
MC	111 (65%)	28 (74%)	27 (69%)	19 (54%)
MCC	19 (11%)	4 (10.5%)	4 (10%)	2 (6%)

Table 3.6a) and b). Total number of contacts at different facial locations associated with mouth open, opening, closed and closing postures, a) before feeding and b) after feeding.

	BF			AF		
	HFvHM	HFvHFM	HFMvHM	HFvHM	HFvHFM	HFMvHM
N	16[1]	17[2]	16	16	17	16
Z	2.6	1.5	2.4	.2	.5	.06
P	≤.01**	≤.2	≤.01*	≤.8	≤.6	≤.9

Table 3.7. Z values and associated probability levels for the comparison of the proportion of contacts associated with MO postures at different locations, before and after feeding.

The results of Wilcoxon signed rank tests comparing proportions of contacts associated with mouth open

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[1]S8 made no HM contacts, S18 made no contacts

[2]S18 made no contacts

postures at different locations before and after feeding are given in table 3.7. It can be seen from this table that before feeding, significantly more HM contacts were associated with mouth open postures than HFM or HF contacts, thus replicating the results of Butterworth and Hopkins. After feeding however, this difference was no longer found. Possible reasons for this unexpected effect of hunger will be considered in the discussion section.

3.3.2(ii) Comparison of proportions of contacts associated with mouth open postures with baseline levels of mouth opening

The analysis of baseline levels of mouth opening allowed for the proportion of time spent with the mouth open in the period where hand movements were analysed to be calculated. The time when the hand was in the mouth was subtracted both from the mouth open time for each baby and also the whole movement period, so that a baseline of mouth open postures independent of hand contacts was obtained (i.e. (MO time - HIM time)/(Observation time - HIM time)). Before feeding, the mean proportion of time spent with the mouth open was 32% (±23%). After feeding the mean was 15% (±24%). Thus, the baseline level of mouth opening after feeding was roughly half that existing before feeding. This accounts for the smaller proportion of contacts with a mouth closing (MCC) posture after feeding compared with before feeding (see tables 3.6a) and b)). There was simply less mouth movement overall after feeding.

Table 3.8 shows the results of Wilcoxon signed rank tests on the differences between baseline proportions of mouth open postures with the proportion of mouth open postures associated with HF, HFM and HM contacts, both before and after feeding. The only significant difference is that between baseline mouth open levels and the mouth open postures associated with HM contacts, before feeding. This result reinforces the conclusion reached in the previous section, that a special association exists between the mouth and arm movements resulting in mouth contact before feeding.

	BF			AF		
	N	Z	P	N	Z	P
HF,MOvBsLn	17	1.4	≤.2	18	1.9	≤.05
HFM,MOvBsLn	17	.5	≤.6	17	.3	≤.8
HM,MOvBsLn	16	2.8	≤.005**	16	1.1	≤.3

Table 3.8. Z-values and probability levels for the comparison of the proportion of contacts at different facial locations associated with mouth open postures with baseline levels of mouth open postures, before and after feeding.

3.3.3 Tests for mechanisms underlying the association between the hand and the mouth in HM contacts

This section considers whether mechanisms which do not imply any active coordination between the hand and mouth can account for the associations between HM contacts and mouth open postures found before feeding. Butterworth and

Hopkins (1988) considered the possibility that the greater degree of association between MO postures and HM contacts in their study could be "the accidental consequence of reflex responses" (p.306). They suggested that fist clenching could stimulate the Babkin reflex causing the mouth to open (although the subsequent carrying of the hand to the mouth would still need to be explained). They tested for this possibility by looking at the distribution of hand postures (open or closed) at the initiation of the arm movement leading to a contact, to see if the hand closed posture occurred more frequently in HM as opposed to HF contacts. No significant differences were found, suggesting that self-stimulation of the Babkin reflex was not responsible for the observed mouth open postures.

The distribution of mouth open postures across contacts where the initial hand posture was closed and those where the hand was open should be different, irrespective of the final location of the contact, if the hypothesis described above were valid. A greater proportion of MO postures would be expected in contacts where the hand was closed than in those where the hand was open. Figure 3.3 shows the means and standard deviations before and after feeding of the proportion of contacts where the mouth was open and the hand was closed (out of all contacts where the hand was closed), compared to the proportion of contacts where the mouth was open and the hand was open (out of all contacts where the hand was open). There were no significant differences in these proportions either before or after feeding, using Wilcoxon signed rank tests. This suggests that a "chain of reflexes" mechanism was not responsible for the association between HM contacts and mouth open postures reported in section 3.3.2.

Another possible difference hetween HF and HM contacts, which could lead to the difference in the distribution of mouth postures, concerns the initial position of the arm prior to a movement leading to a contact. It is quite normal for newborns to have a flexed arm posture with the fists very near to the head. The confined space of the womb during the later stages of pregnancy appears to create a flexor dominance after birth which lasts for one or two weeks (Prechtl and Nolte, 1984). It is conceivable that a greater proportion of HM contacts could be associated with a flexed arm posture, so that a hand-mouth "coordination" could in fact consist of a visible fist being moved distances of only a few centimetres towards an open mouth. In order to test for this possibility, the distribution of flexed arm postures across HF and HM contacts was analysed. A greater proportion of flexed arm postures in HM contacts would be expected if the mechanism proposed above were valid.

Figure 3.4 shows the means and standard deviations of the proportion of HF and HM contacts where the arm was flexed, both before and after feeding. In this analysis, HFM contacts were pooled together with HF contacts, given

Figure 3.3. Means and SD's of the proportion of contacts where the mouth was open and the hand was either closed or open, before and after feeding.

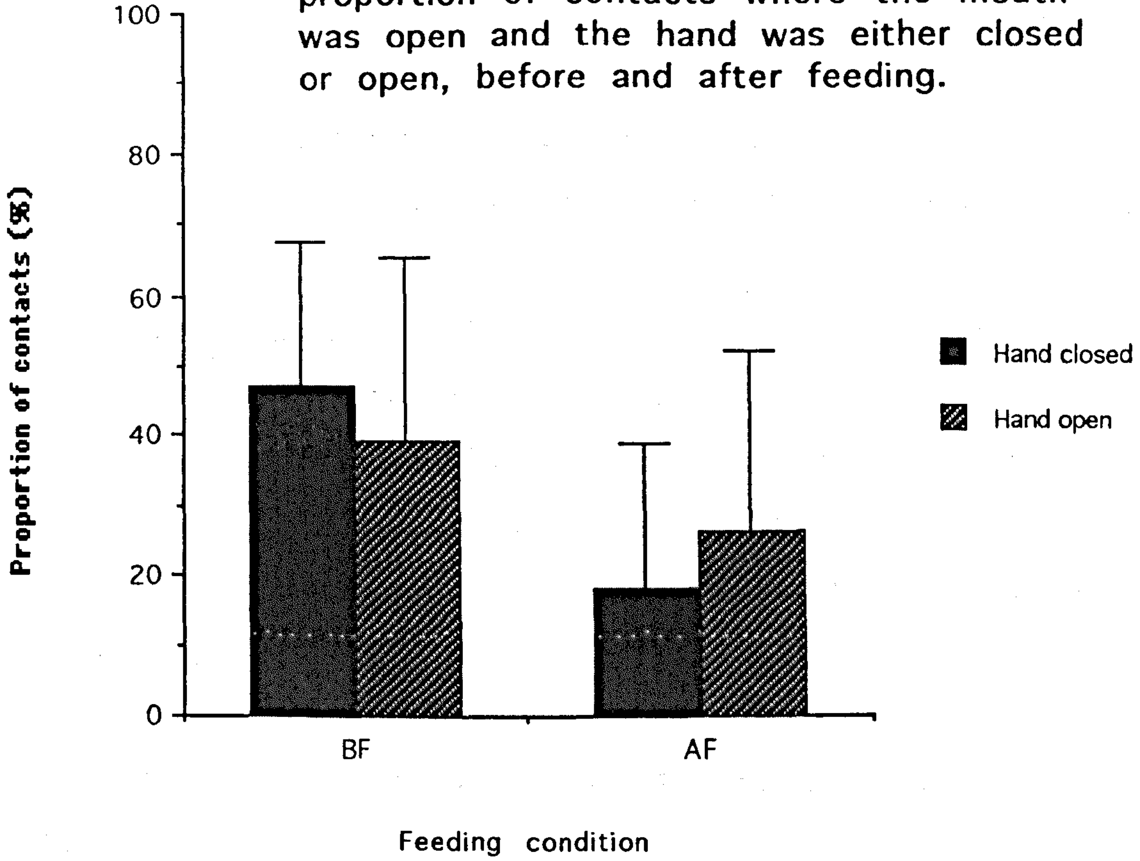
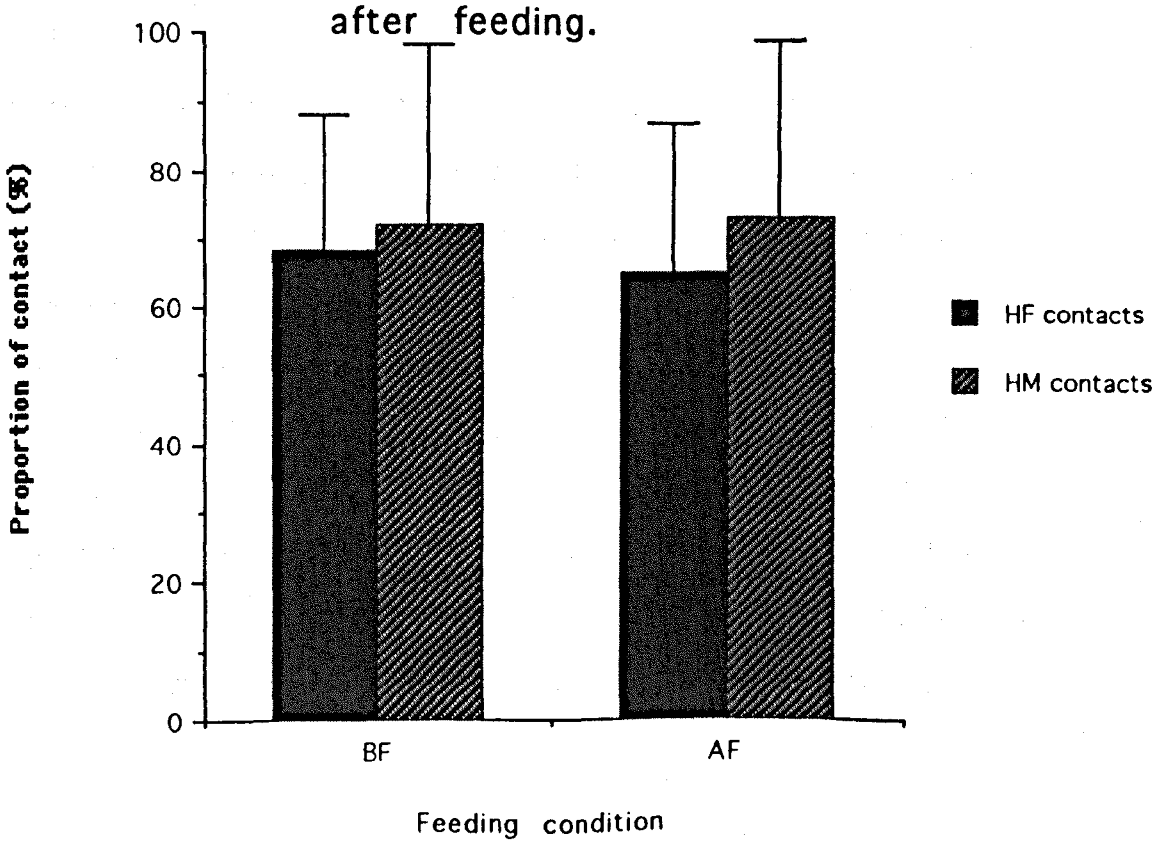


Figure 3.4. Means and SD's of the proportion of HF and HM contacts where the arm was initially flexed, before and after feeding.



the small number of HFM contacts and the fact that in terms of associated mouth postures they resemble HF contacts rather than HM contacts. It can be seen that there was very little difference between HF and HM contacts with respect to initial arm flexed postures, either before or after feeding. No significant differences were found using Wilcoxon signed rank tests, suggesting that flexed arm postures cannot account for the difference between HM and HF contacts with respect to anticipatory mouth opening.

3.3.4 Changes in behavioural state before and after feeding

As discussed in section 3.1.1 (p.72), a measure of **frequency** of contacts is at least partially dependent on behavioural state, so that if state varies with time since last feed it can be considered as a confounding variable with respect to the effects of hunger. The design used in study 1 does not rely on frequency of contacts as a dependent variable but it is nevertheless useful to know what differences in behavioural state occurred before and after feeding. Figure 3.5 shows the means and standard deviations of the proportion of time spent in each state, during the experimentally relevant period. It can be seen that before feeding the large majority of time (98%), was spent in states 4 and 5 (awake alert and awake active). After feeding this was also the case, although to a lesser degree (76%).

It is possible that the state in which the majority of time is spent is not the one in which the most contacts are made. Figure 3.6 shows the means and standard deviations of the proportion of contacts which occurred in a particular behavioural state. It can be seen by comparing figures 5 and 6 that more contacts occurred in state 5 (at the expense of state 4) than would be predicted by the time spent in each state, something that would be expected given that making contact with the face involves movement, and state 5 is the more active state. This difference between the amount of time spent in state 5 and the proportion of movements which occurred in state 5 was significant (Using a Wilcoxon signed rank test, before feeding: $Z=2.4$, $P\leq.02$*, after feeding: $Z=2.5$, $P\leq.01$*).

It can also be seen that the differences in state measures before and after feeding were small. There were no significant differences in the proportion of time spent in states 4 and 5 before and after feeding or in the proportion of movements associated with states 4 and 5 before and after feeding, using Wilcoxon signed rank tests. The main difference was the existence of a very small proportion of state 1 and 2 (quiet and active sleep) measures after feeding. It should be noted that crying states were excluded from study 1, a factor which greatly reduces the differences in state occuring as a result of hunger. No such exclusions were made in the early studies of HM behaviour discussed in section 3.1.1.

Figure 3.5. Means and SD's of the proportion of time spent in each behavioural state before and after feeding.

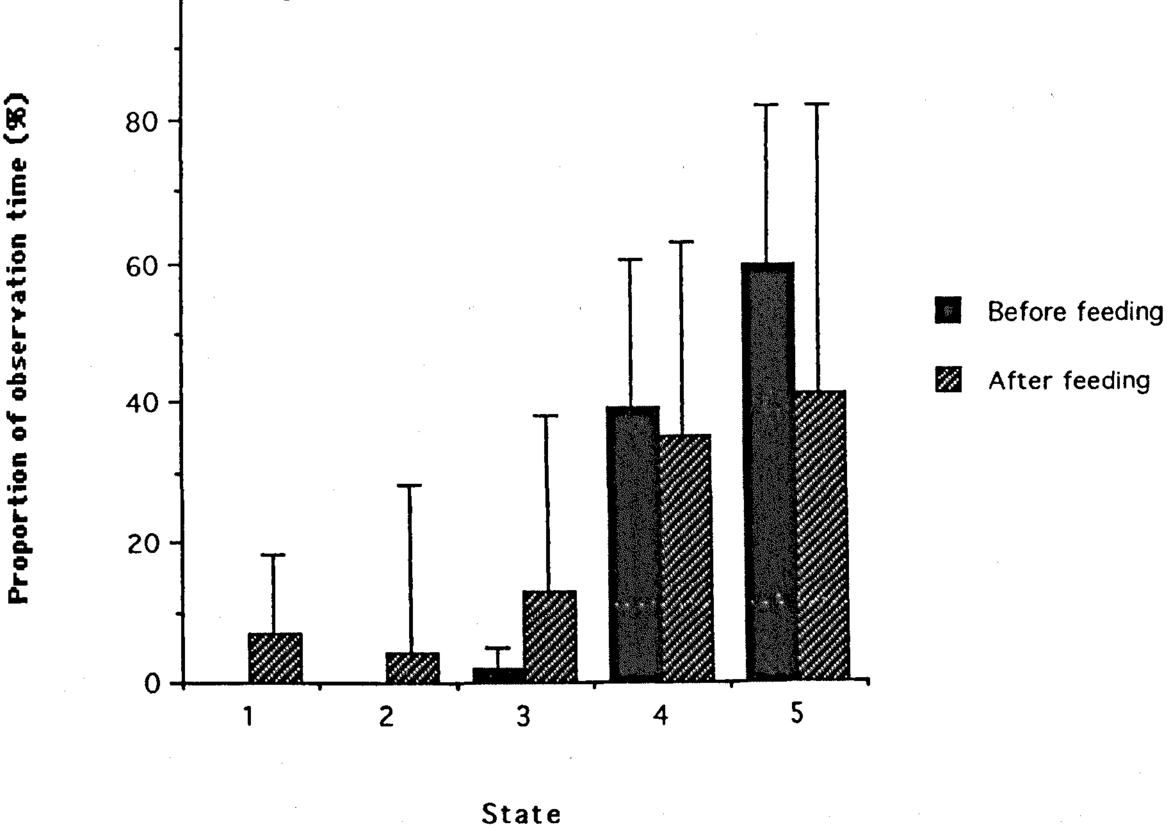
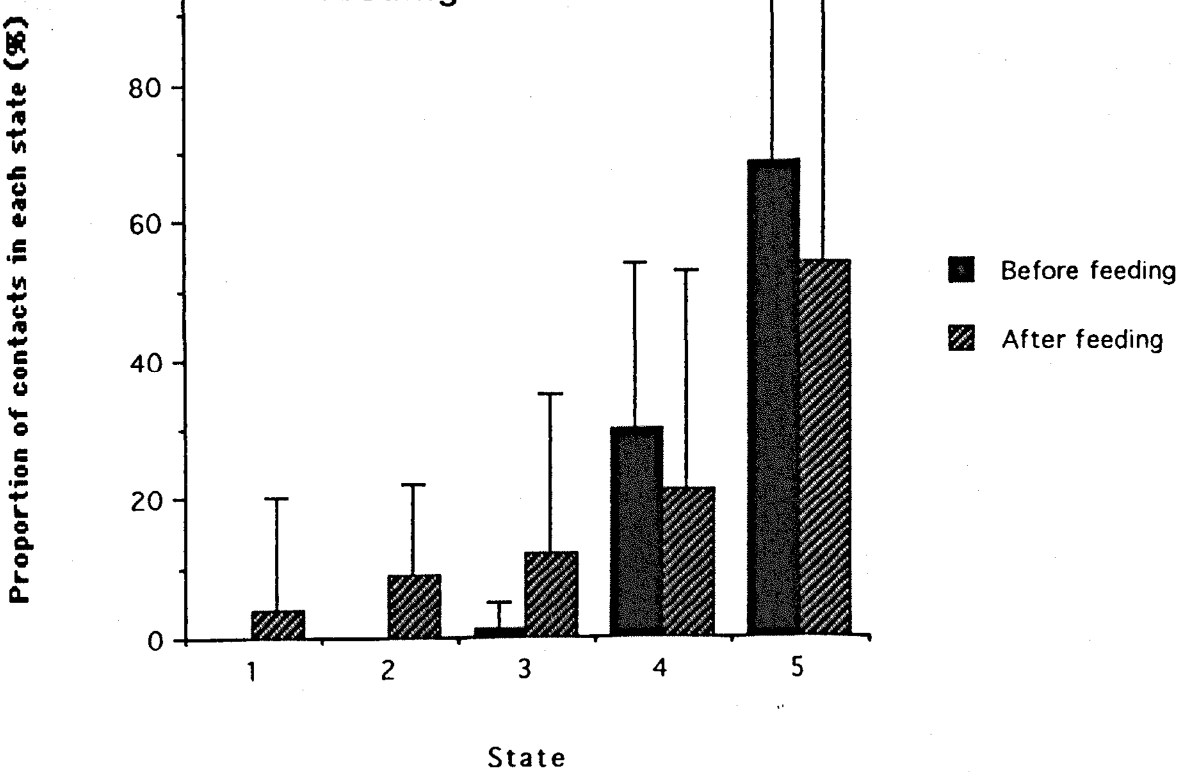


Figure 3.6. Means and SD's of the proportion of contacts associated with each behavioural state before and after feeding.



These results indicate that differences in state are unlikely to be able to account for the differences found in HM behaviour before and after feeding.

3.3.5 Morphology of HF and HM contacts

This section examines some aspects of the morphology of contacts to the face and mouth. The timing relationships between movements of the arm and mouth are discussed. Measurement of spatial aspects of contacts such as the trajectory of the arm movement and the number of acceleration-deceleration elements it contained was beyond the scope of the study 1. However, the body posture adopted by the infants and the effects of this on the form of movements to the face and mouth could be observed. The movement patterns that occurred in HFM contacts, for example whether the head would respond to a contact by turning (as in rooting), or whether the hand would move towards the mouth, could also be investigated.

	ATNR-right	ATNR-left	Side-right	Side-left
BF	12	3	1	2
AF	11	2	1	4

Table 3.9. Number of infants in each body posture before and after feeding.

Table 3.9 shows that the predominant body posture both before and after feeding was an asymmetric tonic neck reflex posture with the head to the right, a posture typical of newborns (Casaer, 1979). Only two infants adopted a different posture after feeding than they were in before feeding (one from an ATNR, left posture BF to side left AF, and the other from an ATNR, right posture BF to side left AF). Some postures where the body and head were at the midline were also observed but these postures were unstable and were not the postures during which a majority of contacts occurred for any of the infants. There were a few instances when an infant was in a side posture that could be said to reemble a feeding posture, i.e. the infant was still, calm and sucking on the hands, but these instances were rare.

The relatively large number of contacts to the back of the head (see table 3.4, p.95) were due to movements of the hand contralateral to the head when infants were in an ATNR posture. Other HF contacts occurred with both the ipselateral and the contralateral hand when the infant was in an ATNR posture. Before feeding 66% of HF contacts (excluding contacts to the back of the head, but including HFM contacts as the initial location of the contact is on the face) were with the ipsilateral hand and 34% were with the contralateral hand. After feeding the sa7e proportions were obtained. Both hands were also responsible for HF contacts when the infants adopted a side posture. In this case the hand on the same side as the infant, the "bottom hand" was responsible for 50% of HF contacts before feeding and 52% of HF contacts after feeding. The "top hand" was responsible for 50% of HF contacts before feeding and 48% of HF contacts after feeding.

The pattern differed when HM contacts were considered. When infants were in an ATNR posture the vast majority of HM contacts occurred with the ipsilateral hand (before feeding, 97.5% of HM contacts were with the ipsilateral hand and after feeding 94% of HM contacts were with the ipsilateral hand). When infants were in side postures 62% of HM contacts before feeding were with the bottom hand. After feeding 100% of HM contacts were with the bottom hand.

These results are similar to those reported by Butterworth and Hopkins (1988) and by Hopkins et al. (1987). They indicate that the kinds of movements that can be carried out in terms of contacts with the mouth are constrained by the postures associated with the supine position in newborns. Specifically, only the ipsilateral hand to the face tends to be involved in HM contacts. Whether the association between HM contacts and ipsilateral hand movements is greater than would be expected compared to the association of HF contacts with ipsilateral movements is a difficult question to approach experimentally. Such a difference would strengthen the evidence for the existance of a specific coordination or synergy between the hand and the mouth, a point discussed by Hopkins et. al. (1987). Even if contacts to the back of the head are excluded from the analysis, as in the data given above, the HF category includes a much wider area compared to the mouth. If only HF contacts at the midline are considered, for example those to the nose or perioral area, then the actual numbers of contacts involved are small. A larger sample of contacts would be needed for such a comparison to be made.

It is possible that HFM movements could occur if some HF contacts, arising through general movements, were then to be "captured" by the mouth. In this case the morphology of the movement would be expected to look like rooting, with head turning and mouth opening towards the hand. In order to see if this is what occurred, HFM movements were classified in three ways:

1. Only the hand is moved towards the mouth after HF contact.

2. Only the head is turned to the hand after HF contact.

3. Both head and hand are involved in making the mouth contact.

Table 3.10 shows the proportions of movements in each category, pooled across all subjects.

BF/AF	Hand movement only	Head movement only	Head and hand movement
BF	57%	10%	33%
AF	75%	2.5%	22.5%

Table 3.10. Proportion of HFM contacts involving hand movement only, head movement only and both hand and head movement before and after feeding.

It can be seen that the majority of HFM contacts, both before and after feeding, involved a hand movement only. Very few "rooting" type of contacts were observed, e.g. HFM contacts where only head movement occurred. In the cases where both hand and head movement was involved the head movement was often accompanied by mouth opening, particularly before feeding. Butterworth and Hopkins (1988) also noted that HFM contacts in their study were generally achieved through hand movement to the mouth. These results would suggest that non-reflexive mechanisms are involved when HFM contacts are made, the hand is actively involved in seeking the mouth.

Mov./ secs.	BF			AF		
	HF	HFM	HM	HF	HFM	HM
Mean	0.9	1.1	1.2	1.1	1.1	1.3
SD	± 0.3	± 1.0	± 0.5	± 0.3	± 0.5	± 0.4
Range of M's	0.4-1.5	0.4-4.5	0.5-2.5	0.6-1.7	0.4-1.9	0.6-2.1
Range of SD's	0.2-1.0	0-1.0	0.2-1.1	0.3-1.0	0.1-1.2	0.2-1.5

Table 3.11. Means and standard deviations of individual means for the duration of movements leading to HF, HFM and HM contacts, before and after feeding.

A final question concerns the timing relationships between hand and mouth movements. Table 3.11 gives the mean duration of movements leading to contacts at different facial locations, computed from individual means for the movements made by each infant. For all types of movements, the mean duration of the approach to the head was about 1 second. These duration times can be compared to the means for the time of mouth opening prior to contact. It can be seen from table 3.12 that these times were highly variable and often very much greater than the duration of the movement leading to a contact.

These figures reflect the fact that spontaneous mouth open postures occur frequently in newborns and that although the evidence presented in this chapter and from earlier studies indicates that there is an active coordination between the hand and mouth, it does not have the skilled appearance of later, mature HM coordination.

MO time/ secs.	**BF**		**AF**	
	HF	HM	HF	HM
Mean	4.4	6.8	6.5	14.8
SD	± 5.2	± 17.0	± 17.0	± 28.0
Range of M's	0.8-14.6	0.3-46.7	0.5-60.2	0.6-70.7
Range of SD's	0.4-15.7	0.9-63.6	0.1-52.9	0.1-94.5

Table 3.12. Means and standard deviations of individual means for the time the mouth was open prior to HF and HM contacts, before and after feeding (HFM contacts have been pooled together with HF contacts).

3.4 Discussion

The results of study 1 showed that hunger did not have any effect on the distribution of facial locations at which hand contacts occurred. A surprising effect of hunger was that the difference in distribution of mouth open postures between HF and HM contacts obtained by Butterworth and Hopkins (1988) was only found before feeding (Butterworth and Hopkins observed infants about half-way between feeds). This difference was also found between baseline proportions of mouth open postures and mouth open postures associated with HM contacts before feeding. This could not be accounted for by reflexive mechanisms or facilitating effects of flexed arm postures.

A possible interpretation of these results is that hunger is one factor motivating spontaneous HM contacts, which has the effect of engaging the participation of the mouth. Perhaps there is a threshold level of motivation below which mouth movements anticipating the arrival of the hand do not occur. Whether the relationship between hunger and HM contacting is a direct one, or whether some more indirect mechanism is involved, such as hunger leading to a need for self-comforting, cannot be established from study 1. Few postures which could be interpreted as feeding postures were observed however. It would thus be difficult to account for spontaneous HM behaviour by making direct comparisons with HM behaviour after sucrose delivery, where postures resembling feeding postures do arise.

It remains to be explained why hunger does not alter the pattern of distribution of contacts at different facial locations. This remains remarkably consistent between observation periods even when details of which areas of the face are contacted are considered. One possibility is that the distribution of locations of contacts is mainly determined by patterns of general movements and postural constraints which are not under voluntary control. If this were the case the infant might be able to anticipate where a contact was going to land but not be able to convert more HF contacts into HM contacts. This possibility could be investigated by studying the effects of different postures on HM contacts. For example, a posture where the head is supported such as that discussed in section 2.3.2(iii), p.56, could be compared to HM contacts in a supine posture.

The data reported in section 3.3.5, particularly with respect to the timing relationships between mouth opening and arm movements in HM contacts, show that at least under conditions where the infant is lying in a supine position, HM behaviour has a very "unskilled" appearance. The trajectories of the arm prior to contacts are often very round-about and the time at which mouth opening occurs prior to contacts is highly variable. These points raise the question of how newborn HM coordination should be viewed with respect to the development of mature HM coorination. This question will be returned to in chapter 7.

CHAPTER 4

THE DEVELOPMENT OF HAND-MOUTH COORDINATION BETWEEN ONE AND FIVE MONTHS OF AGE

4.0 Introduction

In the previous chapter, some evidence was presented which supported findings from earlier studies that HM coordination is present in newborns and is at least partially related to hunger. There is evidence discussed in section 2.5.1 (p.59) that HM coordination undergoes a functional shift away from a feeding function after the newborn period. Hopkins et. al. (1988) found a decline in levels of spontaneous HM contacts between 3-18 weeks and Rochat and Senders (1991) found that sucrose administration to the tongue at 1-3 months gave rise to expressions of disgust rather than to an increase in HM contacts.

Rochat and Senders (1991) argue that at 2 months the motivation to make HM contacts becomes embedded within the context of the oral exploration of grasped objects. The evidence for this comes from a study by Rochat (1989) in which he placed an attractive object in the hands of 2-5 month old babies and measured their subsequent exploratory behaviour. Even at 2 months of age, the babies in this study would carry the object to the mouth for exploration. The older infants would do this, but visual and manual exploration would also take place at these ages. Mouthing of objects placed in the mouth has been observed as early as the newborn period (Rochat, 1983, 1987). This mouthing is considered to be exploratory, resembling exploratory mouthing at later stages of development. These observations would suggest that a motivation to explore objects orally exists at the earliest stages of development. However a link between this motivation and the active transportation of the hand to the mouth might not occur until after the first few months of life, as Rochat and Senders suggest. The mouthing of grasped objects continues thoughout the first year of life, although the frequency of this behaviour declines in favour of visual and haptic exploration during the second half of the first year (Ruff, 1984).

Evidence was described in section 2.5.2 (p.65) which suggested that HM coordination underwent structural as well as functional changes after the neonatal period. Unpublished data from the study of Hopkins et. al. (1988) indicates that the association between HM contacts and mouth open postures disappears by 3 weeks of age and only re-emerges at 18 weeks of age. Rochat and Senders (1991) report that at 3 and 4 months the majority of contacts in their study were bi-manual. At 5 months a minority of contacts were bi-manual. They suggest that changes in postural factors are responsible for this pattern of results.

The aim of study 2 was to obtain a detailed account of changes in the structure of HM coordination between 1-5 months of age. As well as investigating changes in measures of anticipatory mouth opening and bi-manual engagement, changes in frequency and accuracy of movements and the timing relationships between arm and mouth movements were measured. The age range studied was selected to span the transitions described above and cover the emergence of mature HM coordination, occurring at about 5 months of age according to previous authors (Piaget, 1977, Bruner, 1969). Once a descriptive account of the transitions in HM coordination occurring between 1-5 months is available, then some hypotheses can be tested with respect to the factors responsible for producing these transitions. For example the relationship between accuracy of contacts and anticipatory mouth opening, and the role of vision in the coordination can be investigated. This concern with processes of change meant that a longitudinal experimental design was employed. Babies were studied once a month, for a maximum of 5 sessions, starting at 1 month and ending at 5 months.

In order to generate the maximum possible amount of data with respect to numbers of HM contacts, an experimental design was used which took into account the motivational shift away from spontaneous contacts towards exploration of objects described by Rochat and Senders (1991). A set of objects was especially constructed so as to interfere minimally with the execution of hand-mouth movements. They were small, light and easily graspable. Babies were placed in a semi-upright position and after an initial baseline period, where any spontaneous contacts to the mouth or face could be observed, an object was placed in the hand of the baby by the experimenter and again, any movements to the mouth or face were noted. A second baseline observation was made after the period where objects were presented. This procedure was repeated for each monthly observation session for each baby. It was hoped that the objects would generate HM movements that would not otherwise occur spontaneously. The method of film analysis employed was adapted from that used in study 1, to yield detailed information about the structure of HM movements.

The rest of this chapter will give an account of the method employed in study 2 and report results with respect to descriptive data concerning the development of HM coordination between 1-5 months. Chapter 5 will go on to examine processes of change, focusing on transitions between 4 and 5 months.

4.2 Method

4.2.1 Subjects

Subjects were recruited through Parentcraft classes held at the Stirling Royal Infirmary in the winter and spring of 1990. Information concerning study 2 was given to couples attending the classes at the antenatal stage. If they were interested in volunteering for the study they were asked to contact the Infant Study Unit at the University of Stirling after the birth of their child. They were told that the study was about the early development of object exploration and more detailed information could be provided once the study was over, if desired.

A total of 14 infants participated in study 2. Not all of these infants were observed from the earliest age of 1 month, however. This was because some parents wished to participate in the study, but could not manage to do so until their baby was older. Six babies were observed between 1-5 months, four babies were observed between 2-5 months and four babies were observed between 3-5 months. Table 4.1 gives details of the sex of subjects and the average age at each observation session. An effort was made to observe infants within one week of their monthly birthday and this was done in about two thirds of the observation sessions. Due to parental holidays, illness or in a small number of cases, upset leading to a rescheduled appointment, the other observation sessions occurred within 2 weeks of the monthly birthday of the infants. 13 out of the 14 infants in the sample were firstborn children. They were all fullterm, i.e. born between 38-42 gestational age.

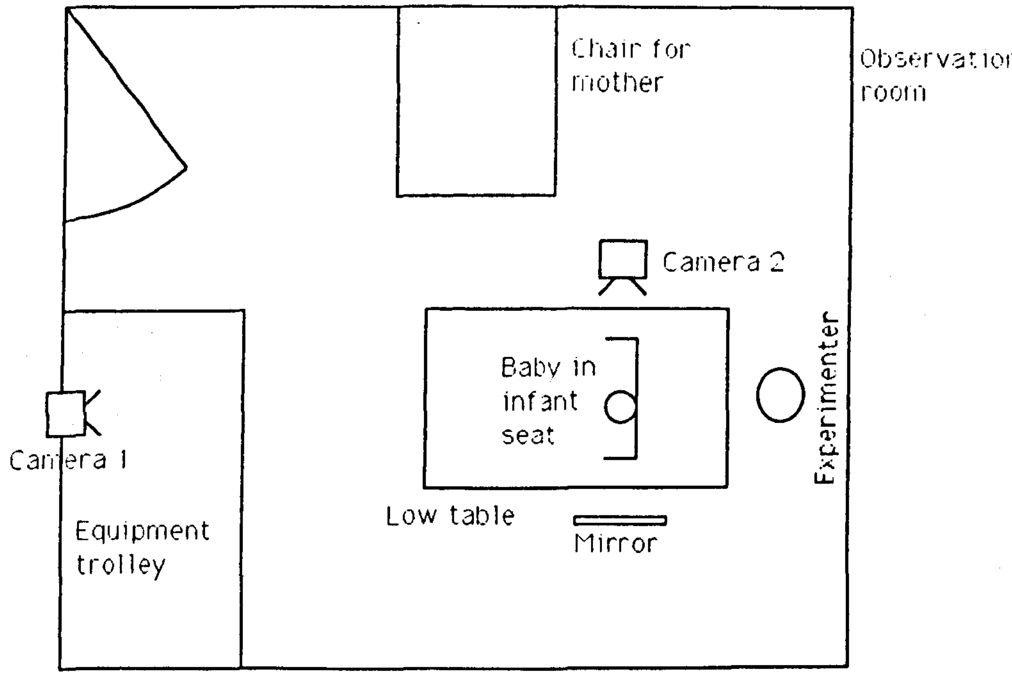
	Obs. 1	Obs. 2	Obs. 3	Obs. 4	Obs. 5
Males	5	7	10	10	10
Females	1	3	4	4	4
N	6	10	14	14	14
Age/days Mean(SD)	25 (±7)	54 (±6)	88 (±6)	115 (±7)	145 (±7)

Table 4.1. Sex and average age of infants at each observation session in study 2.

4.2.2 Apparatus

The arrangement of the video recording equipment was the same as that used in study 1 (diagram 1), with one camera recording a full body view and the other recording a close-up view of the right and left side of the infant's head (the left view is obtained from the reflection of a mirror on the baby's left). Diagram 3 shows the layout of the observation room at the Infant Study Unit (ISU) used for study 2. The equipment used to analyse the video material was the same as that used in study 1 (section 3.2.2, p.80).

Diagram 4 shows the objects used for study 2. These objects were designed with three main objectives. The first was safety and hygiene. They were thus made by a dental technician from denture material. Dummy guards taken from commercial dummies were fitted between the handle of the object and the "teat" part of the object to



Testing room - The room in which babies were filmed in studies 2 and 3 was within the ISU, approx. 2.5x2.5 m., with white walls.
Camera 1 - Camera 1 was attatched to a bracket on the wall at a height of approx. 2m., yielding a full body view of the baby.
Camera 2 - Camera 2 yielded a close-up view of the right side of the baby's head, and the reflection from the mirror of the left view of the baby's head.
Infant seat - A Kangol "Carrytot" chair was used, suitable for babies between 0-9 months. This chair has low sides allowing free arm movements and is inclined at about 135 deg to the vertical.
Experimenter - The experimenter stood behind the infant where objects could comfortably be placed in the hand of the infant.

Diagram 3. View from above of the laboratory layout used for studies 2 and 3.

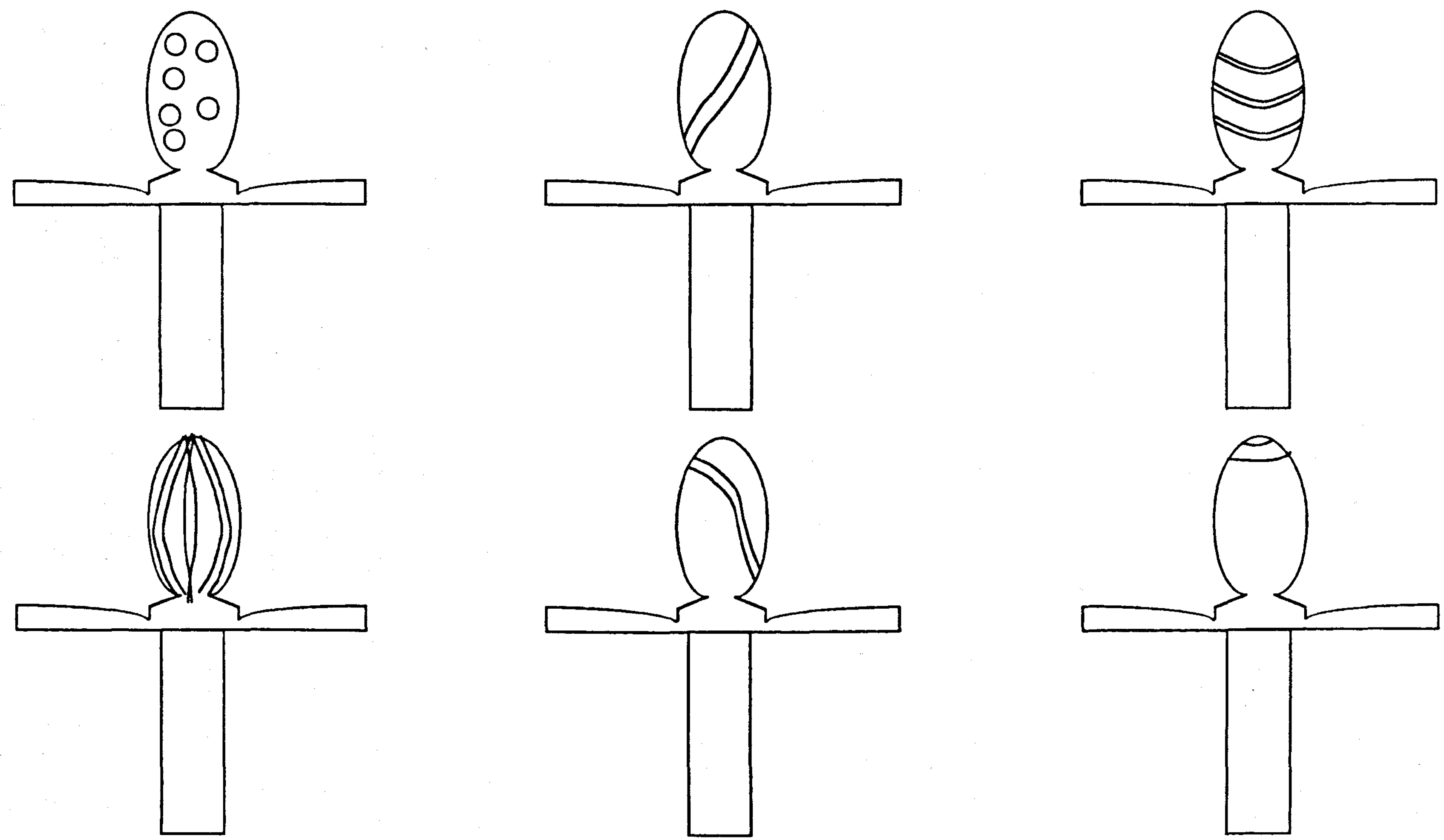


Diagram 4. Objects used in studies 2 and 3, approximately life size (see section 4.2.2 for details).

prevent swallowing. A second objective was that the morphology of movements to the mouth should be altered as little as possible by the objects. They were thus small and light, with a handle that fitted across the length of the palm and was thus easily graspable by fist closure (diameter of handle = 1 cm.). Finally, as the main purpose was to motivate movements to the mouth, an attempt was made to promote exploratory mouthing, rather than non-nutritive sucking which might give rise to relatively little transportation to the mouth and long contact durations. The hardness of the denture material, and the fact that the teat of each object was scored differently seemed to be successful in promoting relatively short but frequent bouts of exploratory mouthing during pilot testing of the object on a 3-month-old baby.

4.2.3 Design

A longitudinal experimental design was used in study 2. Due to the availability of subjects recruitment was "staggered", so that more infants were seen at the older ages that at the younger ages. Babies were observed once a month between 1-5 months of age. Each observation session consisted of a 2 minute baseline period, where spontaneous movements to the mouth and face could be observed. After this initial baseline, a testing session followed where an object was placed in the hand of the infant. The hand into which the first presentantion of the object occurred (left or right) was counterbalanced between subjects. If the object was dropped, another object would be placed in the hand, the right hand if the previous presentation had been in the left and vice versa. This was done until a maximum of 5 minutes had elapsed during which the infant was holding an object. Finally, a second 2 minute baseline period was recorded after the object presentation phase of the observation session. An original design which counterbalanced the number of object presentations to each hand within each testing session had to be abandoned after piloting as infants would get upset if the object was removed from the hand. Thus in some testing sessions the infant might have only held 1 or 2 objects for several minutes, and in others he or she might have held 5 or 6 objects for shorter periods.

A comparison of movements to the mouth and face between baseline periods and the testing period allowed judgements to be made about whether the object was successful in eliciting HM contacts. Since the level of spontaneous contacts might rise with the time the baby spent in the chair as a result of an increase in restlessness, a comparison between the different baseline periods provided a control measure.

4.2.4 Procedure

All observation sessions took place at the Infant Study Unit (ISU) at the University of Stirling. After arriving at the Unit, the mother and baby would spend a few minutes in the waiting area together with the experimenter to allow the baby to become familiar with the surroundings. The baby was then placed in the baby seat so that the observation session could begin. The mother was present throughout this period, although she was asked not to interact with the baby unless the baby was upset, in which case filming would be stopped. When the baby had been comforted the observation session was resumed. Upset became a rare occurrence in the older infants but was common at 1 month of age. The experimenter stood behind the infant and placed the object in the hand by putting the handle across the palm and allowing the baby to close the fist around the object.

4.2.5 Video analysis

All contacts to the face or mouth occurring during baseline and object presentation periods were analysed for each observation session and each infant. During object presentation periods, only contacts with the hand containing the object were considered, however. This meant that any contacts occurring with the empty hand were not included in the analysis. There was thus a slight under-representation of the frequency of contacts during the object phase relative to baseline periods.

The locations of contacts on the mouth and face and kinematic aspects of movements such as the initiation and termination times of movements, mouth opening, and the timing of changes of location on the face were measured in the same way as for study 1 (section 3.2.5(i) and 3.2.5(ii), pp.83-86). Judgements concerning when a movement began were generally more straightforward than for the newborns. In addition, spontaneous mouth opening, common in the newborns, was very rare in the subjects of study 2, so measures of baseline levels of mouth opening were not taken in study 2.

Various additional measures concerning the trajectory of the arm to the mouth or face were measured. One of these was whether the movement to the mouth was bi-manual. If the hand not holding the object came into contact with the other hand containing the object, or the object itself, at any point between the initiation of the movement leading to a contact and the time of contact, then this movement was classified as bi-manual. Another aspect of the movement to the face or mouth which could be measured from the video records concerned the parts of the arm involved in executing the movement. Three possibilities were identified:
The elbow was already flexed at the start of the movement and was flexed further in order for contact to occur; the arm was extended at the elbow at the start of the movement and was flexed in order for contact to occur; finally, the upper arm between the shoulder and the elbow was involved in the movement as well as flexion at the elbow so that the whole arm moves up and then round to

the mouth. A final aspect of the morphology of movements leading to contacts that could be measured was whether head movement occurred, either during the arm movement to the face or mouth, or after contact in an HFM contact.

The degree of visual regard of either the object during object presentation periods or the hands during baseline periods was recorded. Onset and offset times for visual regard were noted so that a measure of the proportion of time (out of the total observation period) spent in visual regard could be obtained, as well as the conjunction of looking with movements to the face and mouth.

4.2.6 Inter-observer agreement

Inter-observer agreement was computed using Cohen's Kappa statistic as in study 1 (section 3.2.6, p.88). The measures analysed were a) location of contacts (face contacts or mouth contacts, where mouth contacts includes HM and HFM contacts), b) mouth posture prior to contact (open, closed), c) looking at object during movement to the mouth (looking, no looking), d) degree of bi-manual contacts (bi-manual, uni-manual) and e) type of trajectory (flexed, extended, upper arm involved). A "pool" of 71 movements was used, comprising approximately 10% of the data set of contacts occurring during object presentation periods at all ages. About 35 movements were selected (comprising 5% of the data set) for each analysis. The selection of movements was random, within the constraints of representing movements from all ages and categories. Thus if a movement scored as an HF contact by the main observer was required, movements would be selected in a random fashion until an HF contact was selected. The values of kappa obtained for the measures listed above were as follows; a).90, b).66, c) .82, d).94 and e).80. Agreement was reasonably high in most measures. The lower value of kappa obtained in this study relative to study 1 on the analysis of mouth posture could be due to a more intensive training period given to the second observer in study 1.

4.2.7 Statistical analysis

All comparisons in study 2 were within subjects, either across ages or across different measures within one age level. Wilcoxon signed rank tests for related samples were used for these comparisons. Some tests were carried out to see to what degree one measure correlated with another, either across ages for the same measure or within one age level for different measures. Kendall's coefficient of rank correlation was used in these cases. All tests for significance were 2-tailed.

4.3 Results

Between 2-5 months the babies in the study were willing to hold the objects presented to them for long periods. Of the six infants studied at 1 month, three would not settle in the infant seat. Of the remaining three, although they would hold the objects for relatively long periods (of about half a minute) no contacts to the mouth or face occurred. One infant made spontaneous contacts during baseline periods. With hindsight, either a supine position, or a semi-upright position with stronger postural support, would seem to be more appropriate to test infants at this age. All data reported in the following chapters will therefore be based on the 2-5 month age range.

The mean number of presentations to the left and right hand was 2, ± 1, and the average amount of time spent with the object in either hand was about 2 minutes, ± 1.5 minutes, at all ages. At 5 months of age, some infants would pass the object from one hand to the other, a behaviour noted by Rochat (1989), so in these cases the hand into which the object was presented did not necessarily correspond to the hand in which subsequent HM contacts occurred.

4.3.1 Frequency of HF and HM contacts during baseline and object presentation periods

The first question to be addressed is whether the objects used in study 2 were successful in eliciting

Figure 4.1. Means and SD's of the frequency of contacts to all facial locations at each age, during baseline (B1, B2) and object presentation (OP) periods.

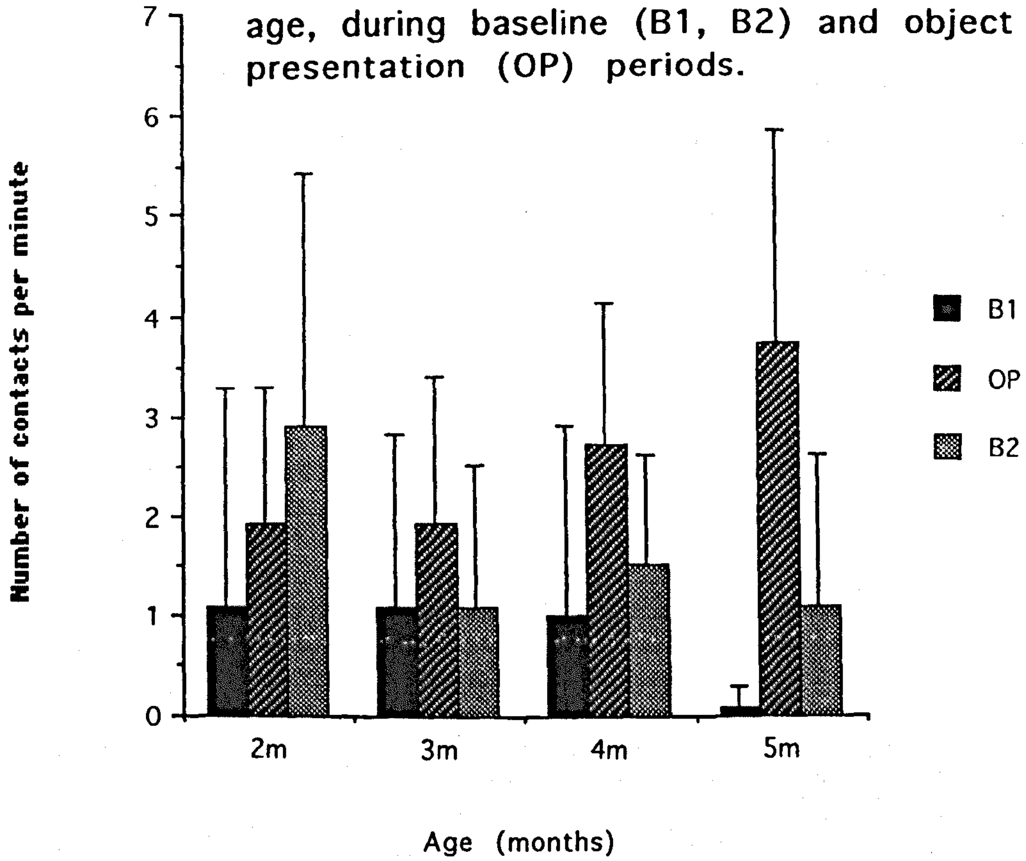
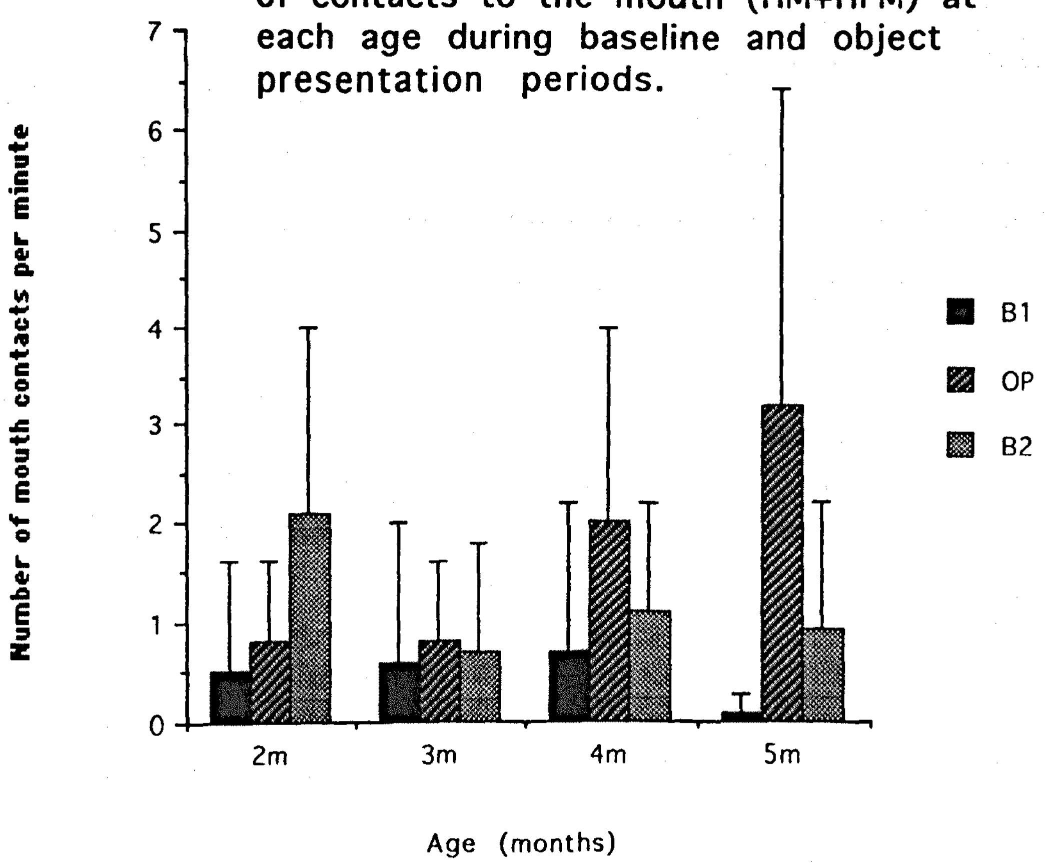


Figure 4.2. Means and SD's of the frequency of contacts to the mouth (HM+HFM) at each age during baseline and object presentation periods.



contacts to the mouth, relative to spontaneous levels of HM contacts during baseline periods. Figure 4.1 shows the means and standard deviations of the frequency (in terms of number of contacts per minute) of contacts to all locations on the face and mouth during baseline and object phases.

Table 4.2 shows the results of comparisons between the frequency of contacts during object phases (OP) and baseline periods (B) using Wilcoxon signed rank tests.

	2 months		3 months		4 months		5 months	
	OPv B1	OPv B2	OPv B1	OPv B2	OPv B1	OPv B2	OPv B1	OPv B2
N	8[1]	5[2]	13[3]	12[4]	13[5]	11[6]	13[7]	13[8]
Z	2.4	.1	2.1	1.6	2.5	2.1	3.2	2.7
P	≤.02*	≤.9	≤.04*	≤.1	≤.01 *	≤.03 *	≤ .001 **	≤ .008 **

Table 4.2. Z-values and associated probability levels for the differences in frequencies of contacts to all facial locations between baseline and object phases, at 2,3,4, and 5 months of age.

At two months of age there was a significant difference (at the 5% level) between the first baseline period and the object phase. However, the highest frequency of

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[1]No B1 or OP for S4 and no OP for S15 due to upset.

[2]No OP for S15, no B2 for S9,12 and 14.

[3]No OP for S7.

[4]No OP for S7, no B2 for S11.

[5]No B1 for S1.

[6]No B2 for S4,5 and 15.

[7]No B1 for S1.

[8]No B2 for S13.

contacts occurred during the second baseline, suggesting that time spent in the infant seat rather than the objects was responsible for the observed changes in frequency of contacts. At three months, there was a significant difference (at the 5% level) between the first baseline and the object presentation period, but no significant difference between the second baseline and the object phase. At four months, a clear difference begins to emerge between the frequency of contacts with the objects and baseline periods. At five months the difference between the object phase and baseline periods is highly significant.

Figure 4.2 shows the means and standard deviations of the frequency of contacts to the mouth (both HM and HFM contacts).

	2 months		3 months		4 months		5 months	
	OPv B1	OPv B2	OPv B1	OPv B2	OPv B1	OPv B2	OPv B1	OPv B2
N	8	5	13	12	13	11	13	14
Z	2.0	1.2	1.9	.1	2.3	2.1	3.2	2.7
P	≤.05 *	≤.2	≤.06	≤.9	≤.02 *	≤.04 *	≤ .001 **	≤ .006 **

Table 4.3. Z-values and associated probability levels of the comparison between frequency of mouth contacts during baseline and object presentation periods at 2,3,4 and 5 months of age.

From the statistical comparison of these frequencies shown in table 4.3 it can be seen that there were no significant differences at 3 months between baseline and object phases. Differences emerge at 4 months and are highly significant by 5 months of age. Differences in age in the frequency of contacts and the distribution of locations of contacts will be considered in the following section. In conclusion, by four months of age, the objects were successful in eliciting contacts to the mouth. Most of the data reported in subsequent sections will concern contacts occuring during object presentation periods.

4.3.2 Changes with age in rates and relative distributions of contacts at different facial locations

An inspection of figure 4.1 shows that after a slight dip at three months of age, the frequency of contacts to the mouth and face during object presentation periods increases, being highest at 5 months of age, at an avarage of about 3.5 contacts per minute over the whole sample. The only significant difference in frequency of contacts is that between 3 and 5 months of age (table 4.4).

	3m v 2m	4m v 2m	5m v 2m	4m v 3m	5m v 3m	5m v 4m
N	8	8	8	13	13	14
Z	0	1.3	1.1	1.7	2.1	1.4
P	≤ 1	≤.2	≤.3	≤.09	≤.04*	≤.1

Table 4.4. Z-values and associated probability levels of comparisons between the frequency of all contacts during object presentation periods at different ages.

If only mouth contacts are considered however (table 4.5) then there was a significant difference between 3, 4 and 5 months, with contacts to the mouth increasing with age.

There was no significant difference between frequencies of mouth contacts at 2 and 3 months of age.

	3m v 2m	4m v 2m	5m v 2m	4m v 3m	5m v 3m	5m v 4m
N	8	8	8	13	14	14
Z	1.4	2.0	2.5	2.8	3.1	2.0
P	≤.9	≤.04*	≤.01*	≤.005**	≤.002**	≤.05*

Table 4.5. Z-values and associated probability levels of comparisons between the frequency of mouth contacts (HFM + HM contacts) during object presentation periods at different ages.

	3m v 2m	4m v 2m	5m v 2m	4m v 3m	5m v 3m	5m v 4m
N	7[9]	7	7	13	13	14
Z	.1	1.5	2.0	2.0	3.1	2.9
P	≤.9	≤.1	≤.05*	≤.04*	≤.002**	≤.004**

Table 4.6. Z-values and associated probability levels for the differences between ages in the proportion of mouth contacts (HM and HFM contacts) occurring during object presentation periods.

In order to ensure that this increase in mouth contacts is not a result of a general increase in frequency of contacts to all locations, it is necessary to look at the relative proportions of HF, HFM and HM contacts at each age. Figure 4.3 shows the means and standard deviations of the proportion of HF, HFM and HM contacts at each age. It can be seen that at 2 and 3 months of age, approximately half of all contacts were face contacts. By 4 months, this figure was reduced to about a third of all contacts. At 5 months the proportion of mouth contacts (HFM + HM contacts) had risen to over 80% of all

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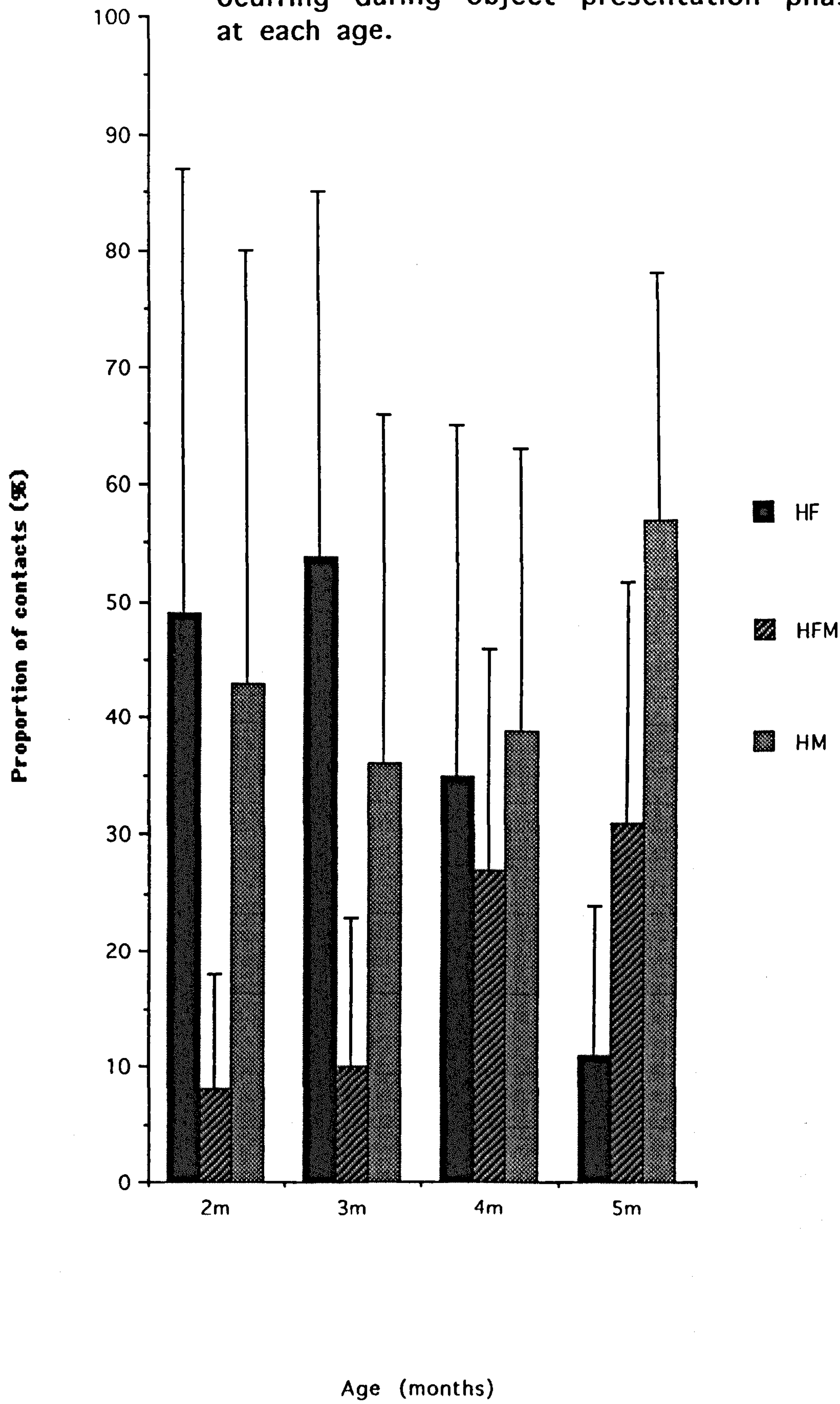
[9] S13 made no contacts during OP to any location at 2 months of age

Figure 4.3. Means and SD's of the proportion of HF, HFM and HM contacts ocurring during object presentation phases at each age.



contacts. From table 4.6 it can be seen that the increase between 3 and 4 months in the proportion of mouth contacts was significant, and that this proportion also increased significantly between 4 and 5 months.

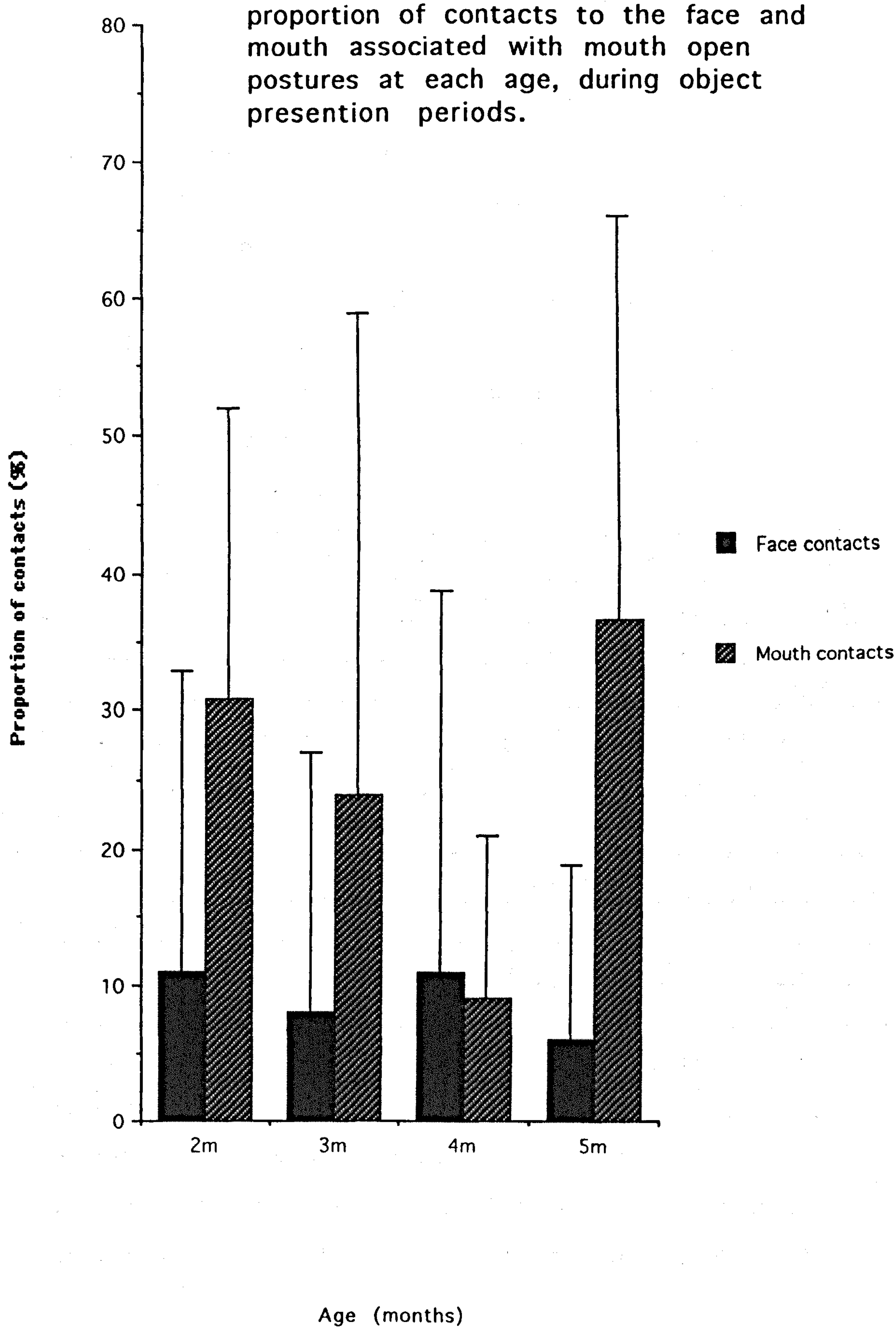
4.3.3 Morphology of contacts

The following sections will consider changes with age in how movements to the mouth were executed. Data concerning the integration of arm and mouth movements will be reported as well as aspects of the arm movements themselves, such as whether arm movements were unimanual or bimanual and whether the arm was flexed or extended at the beginning of the movement.

4.3.3(i) Integration of arm and mouth movements

Figure 4.4 shows the means and standard deviations of the proportion of HF and HM (HFM and HM pooled together) contacts where anticipatory mouth opening occurred. This proportion was highly variable at all ages. It should be noted that at two months of age the actual numbers of HM contacts were small compared to other ages (see previous section). This meant that the actual number of HM contacts associated with mouth open postures could be small, for example 1 or 2 contacts, but that this could still yield a proportion of contacts with anticipatory mouth opening of 50%, if only 3-4 HM contacts occurred in total. At 5 months, a 50% proportion of contacts with anticipatory mouth opening would be more likely to mean

Figure 4.4. Means and SD's of the proportion of contacts to the face and mouth associated with mouth open postures at each age, during object presention periods.



5-10 contacts where anticipatory mouth opening occurred. Thus the data concerning proportions of anticipatory mouth opening becomes more reliable at older ages.

It can be seen from figure 4.4 that at 2 months of age anticipatory mouth opening occured in about 30% of contacts on average. This was reduced at 4 months to about 10% and rose again to about 40% at 5 months. This difference was significant (table 4.7). Even at 5 months, the majority of contacts occured without anticipatory mouth opening. The only significant difference (at the 5% level) between face and mouth contacts occurred at 5 months of age (table 4.8).

	3m v 2m	4m v 2m	5m v 2m	4m v 3m	5m v 3m	5m v 4m
N	6	7	7	10	11	13
Z	.3	1.8	.5	1.4	.4	2.7
P	≤.7	≤.07	≤.6	≤.2	≤.8	≤.006**

Table 4.7. Z-values and associated probability levels of comparisons between the proportion of anticipatory mouth opening occurring prior to mouth contacts at different ages.

	2m(HM v HF)	3m(HM v HF)	4m(HM v HF)	5m(HM v HF)
N	7	9	12	9
Z	1.8	0.7	1.4	2.4
P	≤.08	≤.5	≤.2	≤.02*

Table 4.8. Z-values and associated probability levels of comparisons between the proportion of mouth and face contacts associated with mouth open postures at each age.

These results show a later development of HM coordination, at least with respect to anticipatory mouth opening, than that described by earlier literature summarized in section 4.0. This point will be considered further in the discussion section and in the following chapter.

The relationship between arm and mouth movements can be analysed further by considering the time at which mouth opening occurs relative to arm movements. Tables 4.9a) and 4.9b) show the average duration of movements to the face and mouth (HFM and HM contacts) at each age. This is averaged across the mean duration of movements to the face and mouth for each subject. It can be seen that movements last about 1 second at all ages both for HF and HM contacts.

Table 4.10 shows the mean of the individual means for the point in the trajectory to the mouth where mouth opening occurs, in those movements where there is anticipatory mouth opening. This measure was derived by taking the time at which mouth opening occured for a particular movement as a proportion of the duration time of the arm movement. Thus proportions of 1 or more mean that anticipatory mouth opening occurred on, or prior to movement initiation, whereas a proportion approaching zero means that most of the arm movement had elapsed before mouth opening took place. It can be seen that mouth opening occurred **after** the initiation of arm movements at all ages, begining about half-way through the trajectory. This contrasts strongly with the pattern found with newborns where the mouth could be open for many seconds, or even minutes, before the arm movement to the mouth began.

	2m	3m	4m	5m
Mean and SD of indiv. means	0.9± 0.4	1.0± 0.3	1.1± 0.4	0.6± 0.3
Range of indiv. means	0.5-1.5	0.5-1.6	0.6-1.3	0.3-1.1
Range of indiv. SD's	0.4-1.0	0.1-0.9	0.2-1.0	0.1-1.1

Table 4.9a). Mean and SD's of individual means for the duration of HF movements at each age (seconds).

	2m	3m	4m	5m
Mean and SD of indiv. means	0.9± 0.4	1.1± 0.4	1.0± 0.2	0.9± 0.3
Range of indiv. means	0.3-1.3	0.6-1.7	0.8-1.2	0.4-1.7
Range of indiv. SD's	0.03-1.0	0.3-1.2	0.2-0.9	0.2-1.5

Table 4.9b). Mean and SD's of individual means for the duration of HM (HFM and HM) movements at each age (seconds).

	2m	3m	4m	5m
Mean and SD of indiv. means	0.6± 0.3	0.4± 0.1	0.6± 0.3	0.6± 0.3
Range of indiv. means	0.5-1.0	0.3-0.5	0.2-1.2	0.1-1.2
Range of indiv. SD's	0.1-0.3	0.08-0.6	0.2-1.2	0.1-1.8

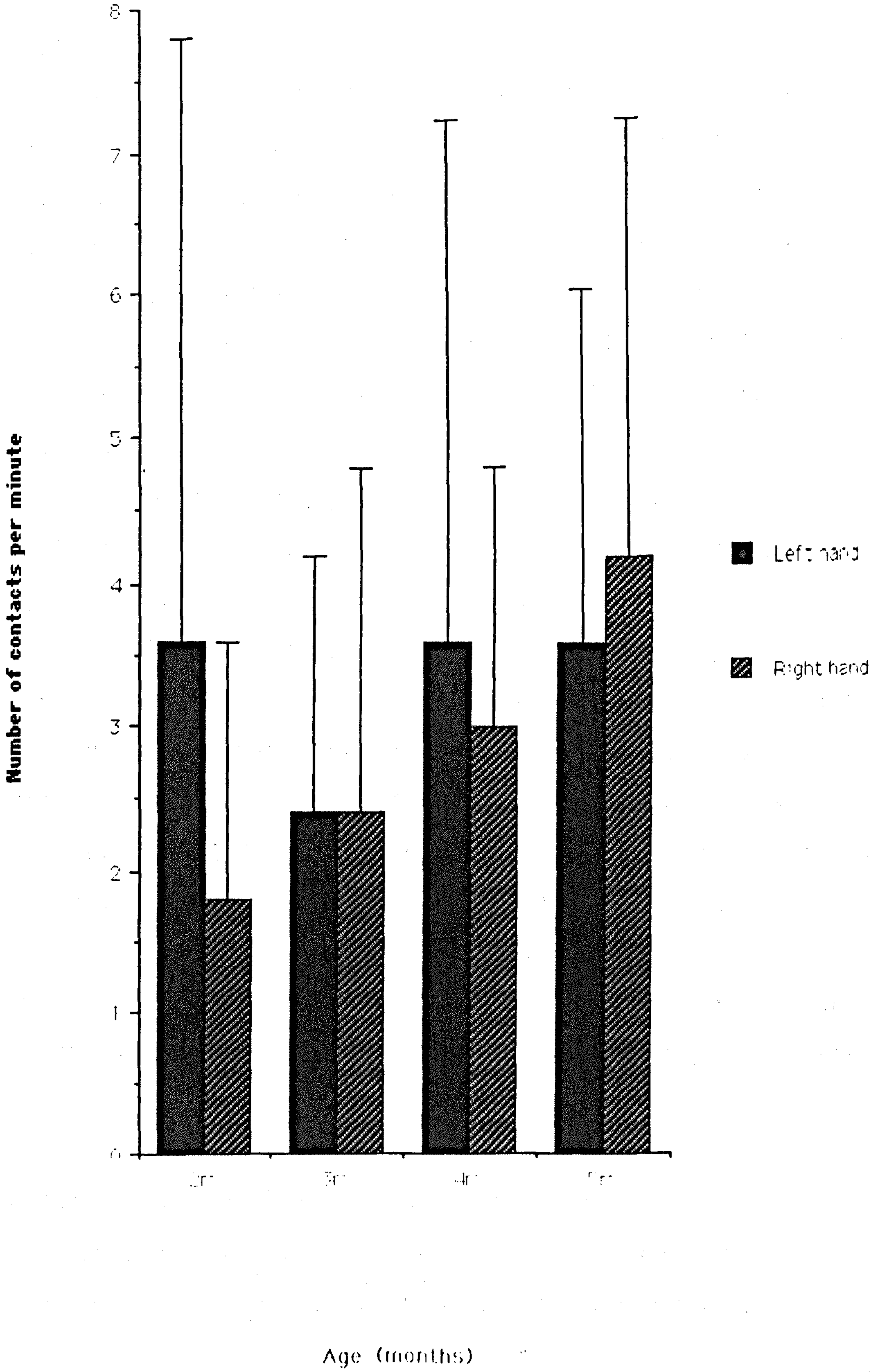
Table 4.10. Means and SD's of individual means for the point at which mouth opening occurs as a proportion of movement duration in mouth contacts at each age.

4.3.3(ii) Form of arm movements to the face and mouth

The first question to be addressed is if there was a tendency to make more contacts to the face and mouth with one or other hand. The number of contacts made by each baby at each observation session with the left or right hand was divided by the total time spent with the object in that hand. Figure 4.5 shows the means and standard deviations for the frequency of contacts occurring when the object was placed in the left or right hand at each age. If there was no tendency for one hand to be associated with a greater level of contacts than the other, then there should be no difference in the proportions of contacts made with each hand, within one observation session. No significant differences were found using Wilcoxon signed rank tests.

A second question concerns the degree to which contacts where uni-manual or bi-manual. Only one infant made bi-manual contacts at 2 months of age so that only the 3, 4, and 5 month observations were analysed statistically with respect to bi-manual contacts. At 3 months, the mean proportion of bi-manual contacts to any location on the mouth and face was 13%, ±25%. At 4 months the mean proportion of bi-manual contacts was 30%, ±29%, and at 5 months the proportion of bi-manual contacts was 24%, ±24%. There were no significant differences between different ages in the level of bi-manual contacts, using Wilcoxon signed rank tests. These results do not fully correspond to those of Rochat and Senders (1991) described in section 4.0. Reasons for this will be considered in the discussion section. There was large individual variation in the amount of bi-manual contacts,

Figure 4.5. Means and SD's of the frequency of contacts occurring when the object is in the left or right hand at each age.



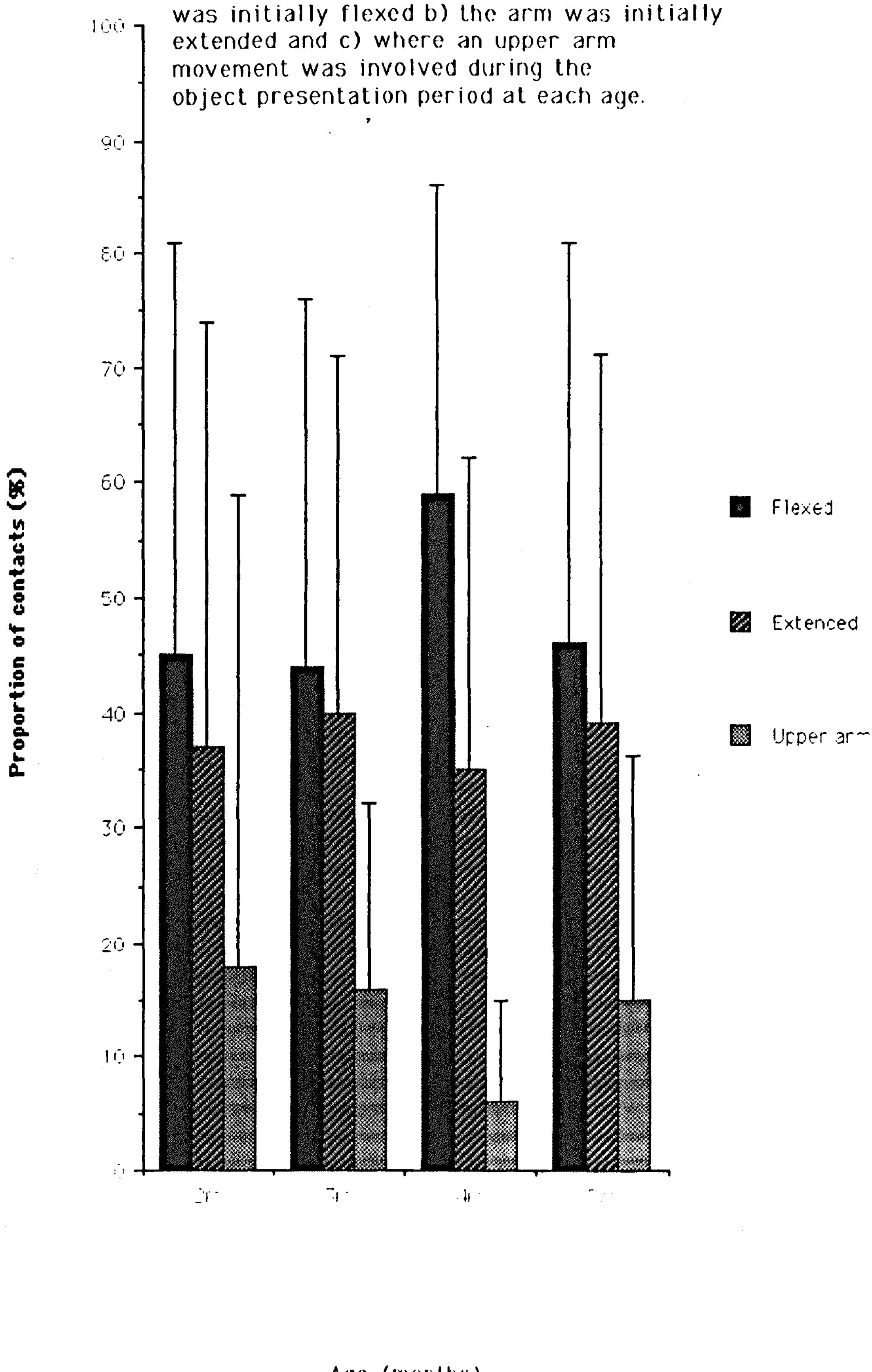
an issue that will be returned to in the following chapter where individual differences in HM coordination will be discussed.

Finally, types of arm movements leading to contacts (either to the face or the mouth) were analysed. The large majority of contacts were carried out by a flexion at the elbow joint of the lower arm. The arm could be extended at the beginning of the movement or it could already be partially flexed. In a relatively small number of cases, upper arm movement was also involved. Figure 4.6 shows the means and standard deviations for the proportions of each type of movement (initially flexed, initially extended, upper arm movement involved) at each age. It can be seen that the proportion of movements where the arm was flexed was similar to that where the arm was extended. There were no significant changes with age in the distribution of types of movement, using Wilcoxon signed rank tests. Although on average the proportions of flexed and extended postures were similar, however, if distributions **within** babies and within observation sessions are considered, then a pattern where one or other type of movement dominates was found. This point will be considered in the following chapter, where individual differences will be discussed.

4.3.4 Exploration of objects

This section concerns the changes with age in exploratory behaviours such as mouthing and looking.

Figure 4.6. Means and SD's for the proportion of contacts where a) the arm was initially flexed b) the arm was initially extended and c) where an upper arm movement was involved during the object presentation period at each age.



Rochat (1989) found that such behaviours increased with age, particularly when comparing the 2 month age group with the 4 and 5 month age groups. Figure 4.7 shows the means and standard deviations for the proportion of time (as a function of the total time where an object was being held) where an object was in the mouth at each age. Table 4.11 shows the results of a comparison using Wilcoxon signed rank tests of the proportion of time spent mouthing at each age.

	3m v 2m	4m v 2m	5m v 2m	4m v 3m	5m v 3m	5m v 4m
N	9	9	9	14	14	14
Z	1.0	2.0	2.7	2.2	2.5	.7
P	≤.3	≤.05*	≤.008**	≤.03*	≤.02*	≤.5

Table 4.11. Z-values and associated probability levels for a comparison of the proportion of time spent in oral exploration of the objects at different ages.

It can be seen from figure 4.7 and table 4.11 that there was a large difference between the two younger ages and the two older ages, with an increase in mouthing occurring at 4 months. This result is very similar to that obtained by Rochat (1989).

Figure 4.8 shows the means and standard deviations of the proportion of the total time an object was in the hand where the infant was looking at the object. It can be seen that there was practically no looking at 2 months, in fact only 2 infants visually inspected the object at this age. None of the differences between the 3, 4 and 5 month observations were significant, using Wilcoxon signed rank tests. In terms of age effects,

Figure 4.7. Means and SD's of the proportion of time spent in oral exploration of objects during the object presentation period.

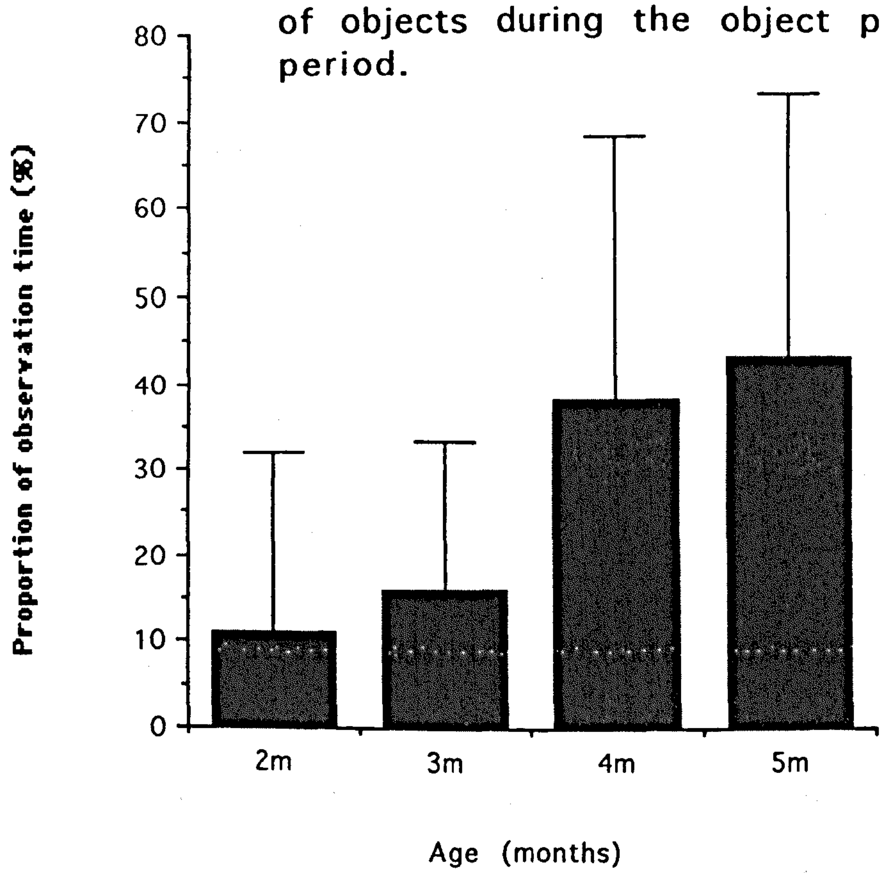
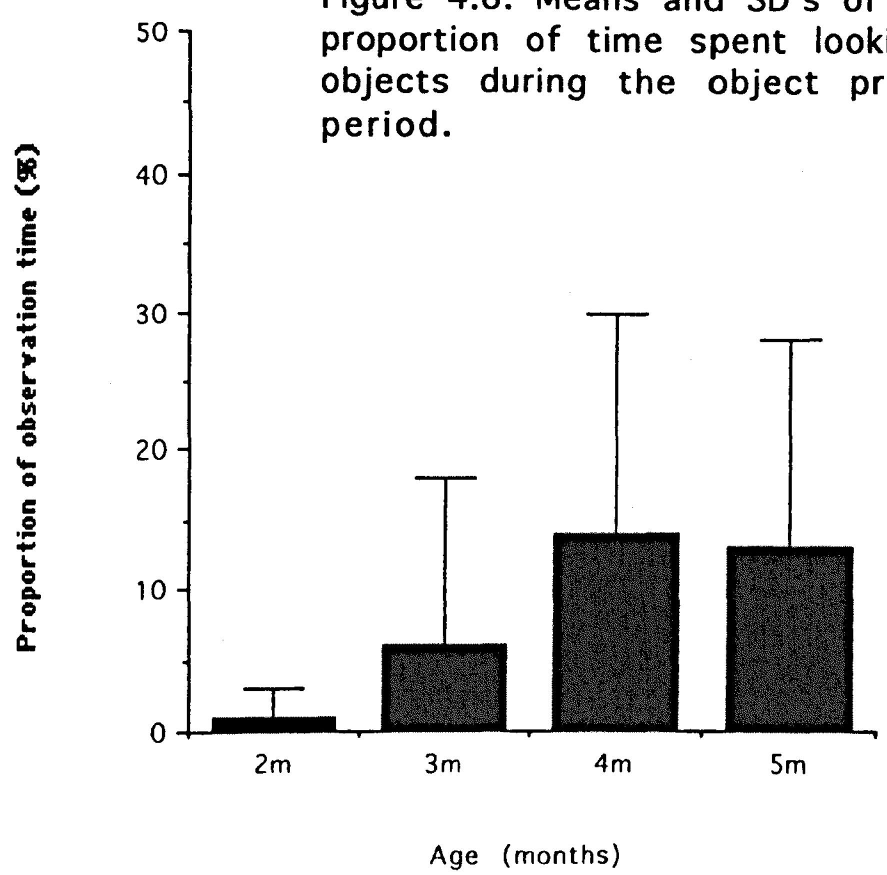


Figure 4.8. Means and SD's of the proportion of time spent looking at the objects during the object presentation period.



these results correspond to those of Rochat (1989) who found that there was a significant difference between 2 month olds and 4 and 5 month olds in proportion of looking time. The actual amounts of looking as a function of the duration of the experimental period differed in the two studies however. In the study by Rochat, 2-month-olds looked at the object for about 9% of the time and this rose to about 30% at 4 and 5 months. This difference could be due to the fact that Rochat selected an object that would be visually salient. It was also larger than the objects used in study 2. It should be noted that looking at the hands either during baseline periods or during experimental periods was very rare. A final point with respect to looking concerns the large individual differences between infants in when, and how much, they looked at the object. This point will be addressed in the following chapter.

4.4 Discussion

One of the aims of study 2 was to obtain a view of the developmental changes which take place in HM coordination after the newborn period. The design was successful in generating HM contacts from the age of 2 months onwards. Two main points of change in HM coordination were identified between 2-5 months, both in terms of motivational change and morphological change.

The first point of change occurred between 3-4 months. By four months, the level of contacts to the mouth was significantly higher than during baseline periods. This suggests that there was a motivational shift towards the oral exploration of objects between 3-4 months. Rochat and Senders (1991) also argue that a motivational shift occurs, but at 2 months of age. However this hypothesis was based on a study by Rochat (1989) where baseline measures of spontaneous HM contacts were not taken. The fact that a difference between baseline and experimental periods was only obtained by four months does not necessarily mean that there was no motivation to explore the objects prior to this age. As discussed in section 4.0, there is evidence that even newborn infants are motivated to explore objects placed in their mouths. A more likely explanation is that the difference between baselines and experimental periods at 4 months reflects a consolidation of the exploration function so that the infant is able to direct actively, not only oral exploration, but other forms of exploration as well. In both study 2 and the study by Rochat (1989) the transition between 3-4 months was marked by an increase in visual regard and duration of mouthing. Rochat also found an increase in tactile exploration between 3-4 months.

Rochat and Senders (1991) argue that the motivational shift that they suggest, from a feeding orientation to an object exploration orientation in HM coordination, is also accompanied by changes in the structure of the coordination. Specifically, they focused on postural changes leading to changes in the expression of synergistic action in the two arms. Structural changes were also found in study 2 between 3-4 months of age. The distribution of locations of contacts on the face changed in such a way that the proportion of HF contacts diminished and the majority of contacts became direct or indirect mouth contacts.

The pattern of bi-and uni-manual contacts described by Rochat and Senders was replicated in that there were few bimanual contacts before 3 months of age. The level of bimanual contacts did not change significantly between 3-5 months however, and the levels of bimanual contacts were lower overall than found by Rochat and Senders. There were various methodological differences in the experimental design and form of analysis between the study by Rochat and Senders and study 2 which could account for these differences. Rochat and Senders used a larger object (a toy key ring) and only included the first transport to the mouth occurring during their free exploration period in their analysis of synergistic arm action. They also defined any contact with the object by the non-grasping hand in the 2 seconds preceding contact with the mouth and in the 2 seconds following contact with the mouth as being bi-manual. In study 2, only the period between the start of a movement to the mouth and the point of contact was included in the definition of a bi-manual contact. The proportion of bi-manual contacts reported in study 2 can thus be taken as a conservative measure.

The change in the distribution of locations of contacts on the face occurring between 3-4 months found in study 2 could be considered as a reflection of a change in the postural and motor context in which HM contacts are carried out. While infants are making spontaneous general movements, from birth until the end of the second month, any goal-directed movements of the arms are superimposed onto these movement patterns. Levels of HF contacts can be considered to reflect the action of spontaneous general movements. When the neuromuscular systen stabilizes and a certain degree of postural control is achieved the task of transporting the hand to the mouth changes accordingly. In summary, between the ages of 3-4 months motivational and structural changes in HM coordination can be postulated to account for changes in the difference between baseline and experimental levels of HM contacts, and in a change in the relative distributions of HF and HM contacts.

Another transition point found in study 2 occurred between 4-5 months. Although HM coordination was **functional** at 4 months in that contacts were clearly motivated by the object and centred around the mouth, there was no integration of arm and mouth movements. The mouth would open **after** the arrival of the hand. By 5 months of age some anticipatory mouth opening began to emerge, but the coordination could not be considered skilled even at this age. A majority of contacts to the mouth were still without anticipatory mouth opening. Questions can be raised as to what factors are responsible for the changes in HM coordination observed between 4-5 months, as well as how HM coordination at 5 months should be characterized, given that the behaviour is not yet mature at this age. The following chapter will examine the data from study 2 with regard to these questions, focusing on the data from the 4-5 month observation sessions.

CHAPTER 5

MECHANISMS OF CHANGE IN HAND-MOUTH COORDINATION BETWEEN FOUR AND FIVE MONTHS OF AGE

5.0 Introduction

This chapter will examine the changes occurring between 4-5 months in the integration of mouth and arm movements in HM coordination. As reported in chapter 4, these included an increase in the frequency and proportion of HM contacts and the beginning of anticipatory mouth opening at 5 months. In particular, two factors will be considered which could be related to these changes. The first of these is whether greater control of arm movements, as measured by accuracy of contacts, was related to the appearance of anticipatory mouth opening. The second is whether visual regard of the object played a role in HM coordination at these ages. Broadly, the first of these factors could be considered as a reflection of neuromuscular maturation and the development of motor control of arm movements. The second could be considered as a cognitive factor, either in terms of the attention given to the object prior to movement to the mouth or in terms of visual guidance of arm movement.

Individual differences will also be considered, with particular attention to the 5 month age group. Inter-individual differences can be used to investigate hypotheses concerning mechanisms of change in HM coordination. For example, the inter-relationships between factors such as visual regard and frequency of contacts or anticipatory mouth opening can be investigated by analysing whether those babies that showed high levels of one factor were also those with high levels of another. A characterization of HM coordination at 5 months would also be useful so that comparisons could be made in further studies with a mature form of the coordination, in older infants or adults.

The degree to which babies had consistent "styles" of movements to the mouth will be discussed. This refers to consistency across movements within one observation session in the measures already considered, such as visual regard or type of arm movement. There is also a sense of style of movement for each baby that arises from a Gestalt impression of the whole movement, and which cannot be quantified across any single dimension. Hopkins and Prechtl (1984), in their study of early, spontaneous general movements (discussed in section 2.3.2(i), p.48) argued that Gestalt perception can be a valuable tool in the study of movement patterns, particularly with movements that do not have a narrow, stereotyped spatiotemporal sequence but can nevertheless be recognized as similar. Some examples of movements to the mouth will be given to illustrate these points, constructed from photographs of video frames selected at different points of particular movements. Consistency of style in some specific measures can be investigated quantitatively between the 4 and 5 month observation sessions.

The issue of how consistent babies are in their styles of movement, and whether such consistencies continue over time across observation sessions, is an important one in that such differences between babies could suggest that a variety of developmental routes are possible towards the achievement of skilled HM coordination. This point was mentioned with respect to the development of walking in section 2.3.2(ii), p.52). The implication of these differences between babies for mechanisms of change in HM coordination development will be considered in the discussion section of this chapter.

5.1 Accuracy of HM contacts at 4 and 5 months of age

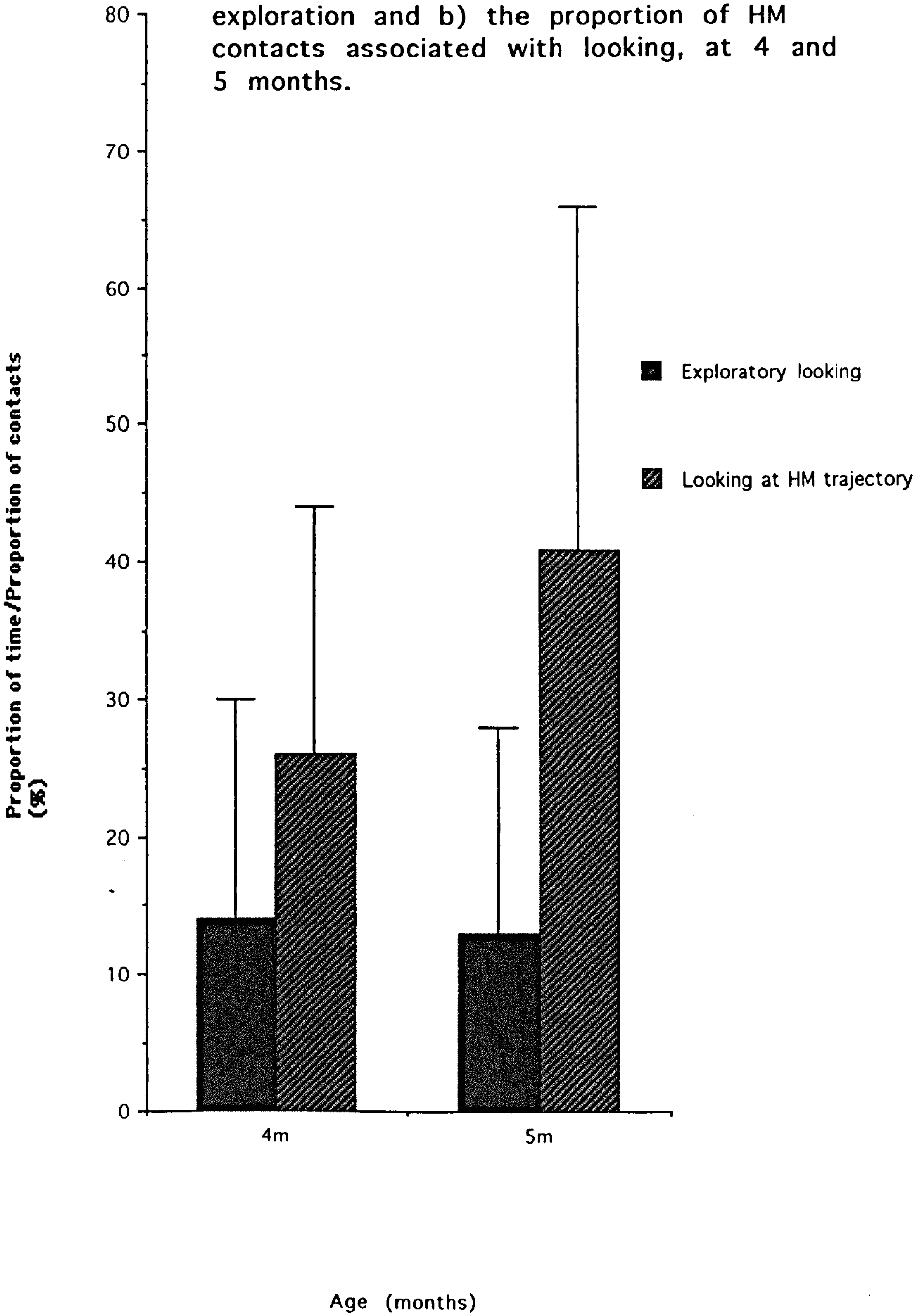
The data reported in section 4.3.2 (p.129) showed that at 5 months of age there was an increase in the frequency and proportion of contacts to the mouth relative to 4 months of age. One question which arises is whether this increase in contacts to the mouth is accompanied by changes in the form of arm trajectory to the mouth, for example if it is smoother or more controlled at 5 months compared to 4 months of age. A very rough measure of control of arm movements available in study 2 is that of accuracy of HM contacts. This refers to the proportion of contacts that went directly to the mouth, as a proportion of both direct mouth contacts and contacts which first landed on another part of the face and then moved to the mouth (HM/(HM+HFM)). At 4 months, the mean proportion of direct mouth contacts was 56%, ±26%. At 5 months, the mean proportion of direct contacts was 65%, ±23%. A comparison of proportions of direct contacts between 4 and 5 months was not significant (Wilcoxon, $P \leq .1$). These results do not necessarily mean that changes in how arm movements are carried out do not occur between 4 and 5 months. Methods which could measure the number and direction of trajectory elements would be required in order to answer this question.

5.2 Relationships between visual regard of the object and HM contacts

As reported by Rochat (1989) and in section 4.3.4 (p.136), at 4 and 5 months there is an increase in the degree of visual exploration of a grasped object that occurs relative to earlier ages. Rochat measured the conjunction of looking at the object with mouthing and tactual inspection of the object. Only tactual inspection was found to be related to looking. The problem with taking mouthing as a measure within the context of looking at the object is that by the time the object is in the mouth looking becomes difficult. In order to find out whether looking was associated with **movements to the mouth** in study 2, a comparison was made between the proportion of movements to the mouth where looking occurred at any point between the beginning of the movement and contact with the face or mouth, and the proportion of time spent in visual inspection of the object during the observation period. If the association between visual regard and movements to the mouth was simply a result of chance, no difference would be expected between the proportions of time spent in visual regard and movements associated with looking.

Figure 5.1 shows the mean proportion of time spent looking at the object compared to the mean number of movements to the mouth associated with looking at 4 and 5 months. The infants were already looking at the object **before** the initiation of movement in the overwhelming

Figure 5.1. Means and SD's of a) the proportion of time spent in visual exploration and b) the proportion of HM contacts associated with looking, at 4 and 5 months.



majority of cases. The degree to which the trajectory of the object to the mouth was followed visually varied greatly, in some cases babies would look away soon after movement initiation and in others the object would be followed until contact was made. At both ages the mean proportion of movements associated with looking was greater than the mean time spent looking. This difference was significant at 5 months, using a Wilcoxon-signed-rank test and failed to reach significance at 4 months (at 4 months: $N=13$, $Z=1.8$, $P \leq .07$, at 5 months: $N=14$, $Z=3.2$, $P \leq .001^{**}$). At 5 months, the proportion of contacts associated with looking was greater than at 4 months, although the proportion of time spent visually regarding the object did not differ. This difference was significant (using a Wilcoxon-signed-rank test, $N=13$, $Z=2.6$, $P \leq .01^{**}$).

The results reported above indicate that by the age of 5 months, visual regard was related to movements to the mouth. The question can be raised as to what role visual regard is playing in HM coordination at these ages. This question will be investigated further in following sections where individual differences in HM cordination will be considered.

5.3 Inter-individual differences in HM coordination at 4 and 5 months of age

The hypotheses put forward above concerning the role of changes in accuracy and visual regard in changes in HM coordination between 4 and 5 months (specifically changes in frequency of mouth contacts and the appearance of anticipatory mouth opening) can be tested within each age. This is because great individual variability exists in both the ratio of HM to HFM contacts between babies, and in the degree of visual regard that occurs. There was also a large degree of variability in frequency of contacts both at 4 and 5 months, and in anticipatory mouth opening at 5 months. Sections 5.3.1 and 5.3.2 will report whether high levels of accuracy and visual regard are correlated with high frequencies of mouth contacts at 4 and 5 months, and with high levels of anticipatory mouth opening at 5 months.

5.3.1 Individual differences in accuracy of HM contacts and changes in HM coordination between 4 and 5 months

The correlation between accuracy of HM contacts (as measured by the HM/(HM+HFM) ratio) and frequency of mouth contacts (HM+HFM contacts) was measured at both 4 and 5 months using Kendall's correlation test. No significant correlation was found at either age. The correlation between accuracy of contacts and anticipatory mouth opening at 5 months of age was also measured using Kendall's correlation test. This correlation was significant at the 5% level ($N=14$, $Tau=.4$, $Z=2.0$, $P \leq .04^{*}$). Thus at 5 months of age, those babies who were more accurate also tended to be those with a greater degree of anticipatory mouth opening.

5.3.2 Individual differences in visual regard and changes in HM coordination between 4 and 5 months

As discussed in section 5.2, at 5 months of age there was a relationship between visual regard and movements leading to mouth contacts. Two non-exclusive possibilities could be considered with respect to the role of visual regard in HM coordination at this age. The first is that visual regard acts as a motivating factor for subsequent oral exploration of the object. The second possibility is that visual regard is playing a role in the formation of the movement to the mouth, for example through visual guidance of the hand.

It is possible to examine the first of these possibilities by seeing whether those babies who spent the greatest amount of time looking at the object were also those who showed high frequencies of contacts to the mouth.

	4m(looking v frequency of contacts)	5m(looking v frequency of contacts)
N	14	15
Tau	.05	.4
Z	.2	2.2
P	$\leq .8$	$\leq .03^*$

Table 5.1. Values of Tau and associated probability levels for a correlation between amount of time spent looking at the object and frequency of contacts to the mouth (HM+HFM contacts) at 4 and 5 months of age.

Table 5.1 shows the results of this comparison using Kendall's coefficient of rank correlation. It can be seen that by 5 months of age, there was a significant correlation between time spent in visual regard and frequency of HM contacts. This suggests that by 5 months of age vision can play a motivating role not only in tactual exploration, as Rochat (1989) suggests, but in the initiation of oral exploration as well. The question whether visual guidance of arm movements occurs and what form this takes is difficult to investigate experimentally. Methods can be employed which manipulate the availability of visual information about ongoing movements, allowing differences in movement trajectory to be measured (for example through the use of infra-red cameras which can film movements in the dark). Some qualitative observations on the data from study 2 will be discussed in the following section with respect to visual guidance, suggesting that this could be a promising area for further investigation. In terms of anticipatory mouth opening, no significant correlation was found with respect to visual regard at 5 months of age. There was also no significant corrrelation between accuracy of contacts at either 4 or 5 months of age and visual regard at these ages. It should be noted that non-significant results with respect to correlations between different aspects of HM coordination should be treated with caution in that the size of the sample available in study 2 was relatively small given the degree of variation that occurred in all aspects of HM behaviour.

5.4 Intra-individual differences at 4 and 5 months of age

The correlation of frequency of HM contacts, proportion of time spent in visual regard, type of arm trajectory and proportion of bi-manual contacts was measured between the 4 and 5 month observation session using Kendall's coefficient of rank correlation. No significant correlations were found. As discussed in the previous section, this lack of significant results should be treated with some caution, given the size of the sample available. Some qualitative data which will be presented appears to indicate that there could be consistencies of movement styles within babies even over an observation interval of one month.

Some examples of movements taken from 6 infants from the 5 month observation session will be given. In the case of 4 of these infants, some examples of movements taken from the 4 month observation session will also be given. All the infants selected carried out more than 10 movements to the mouth at 5 month of age (from 13-32 movements). In total, there were 9 infants at 5 months of age who carried out more than 10 movements to the mouth. It was thought that 10 movements was a sufficiently large number for judgements to be made about how consistent an infant was in a particular movement style. At 4 months of age, 6 babies carried out more than 10 mouth contacts.

Each movement is represented by three photographs, arranged in series, of the initiation of the movement, a moment just prior to contact and a moment just after contact. A description of the movement will be given, together with an indication of how representative this was of all the movements carried out by the infant. The degree to which aspects of the movement, for example type of arm movement, were representative of dominant movement patterns in other infants at the relevant age (who made more than 10 mouth contacts) will also be indicated. The significance of the patterns illustrated in the examples for mechanisms of change in HM coordination will be considered in the discussion section.

Plate 1a) and b) shows two movements from subject 1 at 4 months of age. In both movement a) (above, left to right) and b) (below, left to right) the movement pattern consists of a trajectory where the arm is initially flexed and moves rather slowly towards the face. In 10 out of a total of 17 movements the object lands slightly above and to the side of the mouth. The object is then moved down into the mouth. There were no bi-manual contacts at this age and looking occurred in only 3 movements. Of the 6 infants who carried out more than 10 HM contacts at 4 months of age, 3 had over 70% of contacts where the arm was initially flexed and the contact was uni-manual.

Plate 1c) and d) shows two movements from subject 1 at 5 months of age. It can be seen that the structure of the movements are very similar to those shown in plate 1a) and b). In movement 1d) anticipatory mouth opening occurs, but within the context of the familiar movement structure. Anticipatory mouth opening occurred in 9 out of a total of 32 movements. Seven contacts were bi-manual and looking occurred in 11 movements at this age. Two out of the nine infants who made more than 10 mouth contacts at 5 months of age had a dominant movement pattern where the arm was initially flexed and the movement to the mouth was uni-manual.

Plate 2a) and b) shows two movements from subject 2 at 4 months of age. The large majority of movements involved visual regard of the object, followed by a slow and segmented movement to the mouth. The object is held bi-manually and the arms are initially flexed. The object is followed visually until contact. Only 2 out of 18 movements were without visual regard. Eight movements were uni-manual. The movements tended to be accurate (12 out of 18 contacts were direct mouth contacts). At 4 months of age, 2 out of 6 infants had a dominant pattern of bi-manual contacts where the arms were initially flexed. No other infant had a dominant pattern of visual regard during movements at this age.

Plate 2c) and d) shows two movements from subject 2 at 5 months of age. It can be seen that in terms of visual regard and type of arm posture the movements are similar to those shown in plate 2a) and b). At 5 months the movements were uni-manual however. They were accurate and anticipatory mouth opening occurred in all except 2 movements (from a total of 21). As at 4 months of age, the trajectory to the mouth was segmented rather than ballistic, with visual regard occurring throughout the trajectory. Three out of 9 infants showed a dominant movement pattern at this age where visual regard occurred, although in one case (subject 4) this visual regard tended to take a different form. Instead of the object being followed throughout the trajectory the infant looked away after movement initiation.

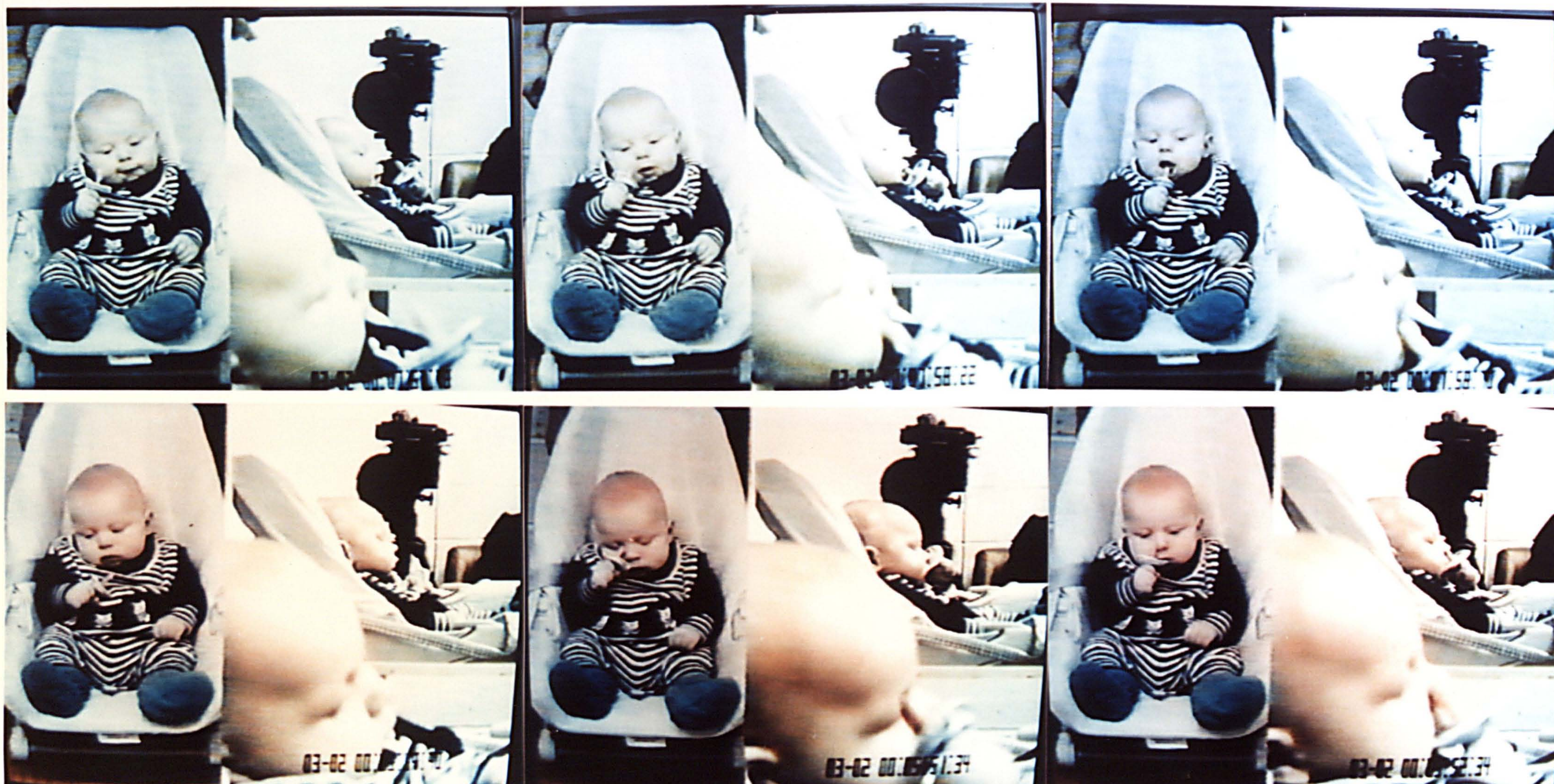
Plate 3a) and b) shows two movements from subject 3 at 4 months of age. Out of a total of 6 movements to the mouth, all began with a flexed arm posture and were bi-manual. Looking occurred in half of the movements (as in 3a)).

Plate 3c) and d) shows 2 movements from subject 3 at 5 months of age. As with the movements shown on plate 3a) and b) these movements are bi-manual with an arm posture that was initially flexed. Looking occurs in movement c) but not in d). In all, looking occurred in just under a third of movements (4 out of 14). In both the movements, anticipatory mouth opening occurs. Overall, 10 out of the 14 movements were with anticipatory mouth opening. Movements tended to be accurate, with 12 out of 14 contacts being direct mouth contacts. Two infants showed a dominant pattern of bi-manual contacts with flexed arm postures at 5 months of age.

Plate 4a) and b) shows two movements from subject 4 at 4 months of age. The majority of movements (7 out of a total of 8) were bi-manual with a flexed arm posture at the initialtion of the movement. Looking also occurred in 7 out of 8 movements.

Plate 4c) and d) shows two movements from subject 4 at 5 months of age. The observation session for this infant could be roughly divided into two halves. During the first half 11 movements were made resembling those shown in plate 4a) and b) in the sense of short trajectories with visual regard being present, although these movements were uni-manual at 5 months of age. During the rest of the observation session (a further 15 movements), movements resembled 4c) and d). The object is held up for visual inspection and then a fast, over-reaching movement of the arm is carried out, sometimes with the head tilting upwards to "catch" the object. About half of these movements occurred with anticipatory mouth opening. Anticipatory mouth opening occurred in movement d) but not in c). It can be seen that the structure of both movements is very similar. In the case of movement d), head tilting occurs fractionally earlier relative to the arm movement than in c), thus leading to anticipatory mouth opening. In general, mouth contacts involving upper

1a) and b)



1c) and d)

2a) and b)


08-02 00:07:59:03
08-02 00:07:59:11
08-02 00:08:01:07
08-02 00:09:02:15
08-02 00:09:03:31
08-02 00:09:03:33

2c) and d)

3a) and b)

3c) and d)

4a) and b)

4c) and d)


02-05 00:02:35:01
02-05 00:02:36:53
02-05 00:02:37:33
02-05 00:02:49:47
02-05 00:02:50:03
02-05 00:02:50:47

5a) and b)

6a) and b)

5.5 Discussion

The main question raised at the beginning of this chapter concerned the mechanisms responsible for the changes observed between 4 and 5 months in HM coordination. One possibility was that changes in aspects of the coordination, such as anticipatory mouth opening, were linked to a change in the ability to control arm movements. Specifically, the hypothesis that movements were more accurate at 5 months than at 4 months was tested. There was no significant difference between 4 and 5 months in this measure. There was a relationship between accuracy and mouth opening at 5 months in that those babies who showed high levels of anticipatory mouth opening tended to be those that were more accurate. The mechanism behind this link could be complex however, not necessarily involving greater control of arm movement.

There was some evidence that by 5 months of age there was a change in the role of visual regard with respect to HM coordination. At 5 months of age, there was a significant relationship between movements to the mouth and visual regard, and there was a relationship between frequency of HM contacts and amount of visual regard. These results taken together could suggest that vision is "organizing" all forms of exploration at 5 months, including mouthing as well as tactual exploration. Rochat (1989) argued that mouthing is independent of vision at 5 months. This argument was based on results from a study of object exploration in the dark. This situation inhibited all tactual exploration but did not affect mouthing. It is possible however that mouthing, as a form of exploration, **is available** without vision but that by 5 months vision becomes a controlling factor in free object exploration. Mouthing is the earliest form of object exploration to develop, so it is perhaps not surprising that it can occur independently of vision under circumstances where visual inspection is not available. The relationship between vision and movements to the mouth at 5 months raises the interesting possibility that visual guidance of arm movements is involved in HM coordination at this age, as well as playing a role in motivating HM contacts.

The qualitative data presented in section 5.4 suggests that consistent individual styles of movement, which can persist over periods of one month are present in HM contacts. Thus it is possible that different developmental routes are followed in the achievement of skilled HM coordination. Thelen's concept of a "state space" of possible behavioural outcomes given a particular set of controlling parameters and conditions (Thelen, 1989a and b) could be a useful model within which to view the data presented in section 5.4. When considering the example of locomotion development, Thelen (1989a) argues that once static, upright posture is attained towards the end of the first year there follows a period of exploration of possible movments and postural configurations until dynamic balance is achieved. She refers to this as the exploration of the state space of possible configurations. Eventually, there is a stabilization and a few successful patterns become dominant.

In terms of HM coordination development the following elements need to come together in order for the behaviour to be skilled:

The control of arm movements so that the movement is neither too slow or too fast, leading to problems with the braking of the movement;

The movement has to be spatially accurate;

The timing of mouth movement should be coordinated with arm movement.

It is possible that at 4 and 5 months of age, the coordination is not yet skilled, so that "trade-offs" between different elements takes place. Thus some infants might sacrifice smoothness and speed of trajectory for accuracy of contact, possibly aided by visual guidance (see subjects 2 and 3 for examples of accurate, segmented trajectories and subject 4 at 5 months for an example of a ballistic trajectory). In these cases sufficient time would be allowed for mouth opening to occur. Such a mechanism might be able to account for the association found between accuracy and anticipatory mouth opening discussed earlier. Different infants will settle into different, transiently stable states covering a range of behavioural solutions to the problem presented by HM coordination.

One consequence of this view is that at 5 months of age, HM coordination might be considered to be in a transitional state. The infants showing anticipatory mouth opening at this stage cannot necessarily be considered more skilled than those that did not. One of the striking features of the data was that the emergence of anticipatory mouth opening tended to occur within the context of familiar movement structures. This could be observed both across the 4 and 5 month observation session and between different movements within the 5 month observation session (see subjects 2, 3 and 4). In order to investigate whether such different developmental routes are being followed, studies which focused on the 4-6 month age range, using shorter observation intervals would need to be carried out.

Several methodological problems arise when trying to assess these hypotheses quantitatively. One problem concerns sample size. As well as the difficulties of recriuting longitudinal samples it is impractical to carry out time consuming micro-analyses with large samples. Several researchers have dealt with this problem by using very small, longitudinal samples, but observations are taken intensively, for example on a weekly basis. Connolly and Dalgleish (1989 and in press) used such a method in their study of the development of spoon use. They also identified characteristic styles of spoon use in the 4 infants observed in the study. Another fundamental methodological problem concerns the translation of Gestalt perceptions of movement patterns and styles into quantitative measures. In a study of pointing movements in children, Hay (1984) makes such a translation by using 3-dimensional trajectory analysis techniques. She identified three main types of velocity patterns which varied in the profile of acceleration peaks, reflecting the degree to which braking activity occurred.

In conclusion, the data presented in this chapter suggests that different routes could be followed by different individuals in the development of HM coordination. Further studies which focus on the 4-6 month age group, perhaps with techniques for measuring velocity profiles, could investigate this question in a quantitative fashion. The possibility that visual guidance could form part of a transitional phase in the development of the coordination, at least in some infants, is particularly interesting. Such a transitional phase is also thought to occur during the development of reaching and grasping, based on the results of studies manipulating the visual feedback availabe with regard to the hand during movement (McDonnell, 1979, McDonnell and Abraham, 1981 and Lasky, 1977). In order to investigate whether visual guidance was taking place a combination of methodologies would be required. Once longitudinal, detailed analyses had established that visual regard was a characteristic which remained consistent within infants, studies which manipulated the availability of visual feedback could be carried out to see how HM coordination was affected. The study reported in chapter 6 takes as a starting point the finding from study 2, that skilled HM coordination appears at a later age than was thought previously. The development of HM coordination after 5 months of age, as well as the possible interactions that could occur between HM coordination and reaching and grasping, are investigated.

CHAPTER 6

RELATIONSHIPS BETWEEN HAND-MOUTH COORDINATION AND REACHING AND GRASPING IN FIVE-TO-NINE-MONTH-OLD INFANTS

6.0 Introduction

The possibility that HM coordination aids the development of reaching and grasping has been considered by a few researchers. Piaget (1977) argued that hand-mouth coordination usually developed before reaching and and grasping, but there was no **logical** reason for this to be the case. HM coordination was the result of the reciprocal assimilation of schemes for grasping and sucking, and reaching was the result of the reciprocal assimilation of schemes for visual tracking and grasping. Many more intervening stages are involved in integrating vision with prehension however. Once HM coordination and reaching and grasping have developed a reciprocal assimilation of these schemes takes place so that the grasping of seen objects is followed by transport to the mouth, or alternatively objects which are in the mouth are then removed and visually regarded.

Bruner (1969), in contrast, argued that HM coordination not only developed prior to reaching and grasping but that it played a crucial role in its development. He suggested that oral contact with an object was the main goal of a reach until about the end of the sixth month, when visual exploration became dominant. He described observations of a 4-month-old baby reaching for an object waved in front of him,

> "The child's mouth had opened typically just as he began to approach the object and served as a kind of "anticipatory binding" to the grasp and retrieval...One has the strong impression that the mouth, before described as the *tertium quid*, is

> priming the sequence by opening in advance."
> (1969, p.229).

Anticipatory mouth opening **during reaching** was thus seen by Bruner as serving some kind of cognitive function whereby the infant was "reminded" of the goal of the reach.

Rochat and Senders (1991) agree with Bruner that oral capture serves as the terminus for early reaches, although the results of the study by Rochat (1989) on object exploration in 2-5-month-olds indicated an earlier age for the initiation of visual exploration, at about 5 months of age. Rochat and Senders report observations of 3-5-month-old infants reaching for objects by leaning forwards and opening the mouth when their arms were restrained from making reaching movements. The behaviour of the mouth during reaching when the arms were not restrained as in the situation described by Bruner was not reported. These observations lead to an alternative interpretation of mouth opening during reaching than the one proposed by Bruner. That is, that the infant is reaching for the object **both** with the hand and the mouth.

The results of study 2 reported in chapters 4 and 5 present some problems for Bruner's account of the links between HM coordination and reaching and grasping, as well as raising some alternative possibilities concerning the interaction between the two coordinations. At 4 months of age, there was no anticipatory mouth opening when an object placed in the hand was transported to the mouth. Even at 5 months of age, HM coordination could not be said to have reached a mature form. Only some infants were showing anticipatory mouth opening and contacts were often not accurate. These results challenge the idea that HM coordination with anticipatory mouth opening is fully developed prior to the development of successful reaching and grasping. Rather, the anticipatory mouth opening observed at 4-5 months by Bruner was a particular response to the context of reaching and grasping for an object.

Some alternative hypotheses can be outlined concerning possible interactions between HM coordination and reaching and grasping. The first of these is that it is the development of reaching and grasping which aids the development of anticipatory mouth opening in HM coordination. Mouth opening during reaching may occur through "reaching with the mouth", or because of a heightened visual salience of the object. The mouth open posture may be retained during transportation of the grasped object to the mouth and eventually occurs as part of HM coordination in isolation of reaching. In this case, mouth opening during reaching would be expected to occur prior to anticipatory mouth opening in HM coordination. The observations of Bruner and the results of study 2 suggest that this could be the case. A simpler way in which the development of reaching and grasping could affect HM coordination is that once objects are grasped successfully a large increase in practice of HM coordination takes place, and this increase leads to development of the skill. This possibility does not of course exclude other forms of interaction.

The fact that HM coordination and reaching and grasping appear to develop at about the same age could be a reflection of the development of some factor which is common to both coordinations, rather than an active interaction of the kind suggested above. For example, maturation of arm control and postural development could be a factor which leads to developments in both coordinations at roughly similar ages. Finally, the two coordinations could develop independently of each other but become integrated into one smooth reach-grasp-transport-to-mouth sequence.

The aim of study 3 was to investigate the hypotheses concerning possible relationships between reaching and grasping and HM coordination outlined above. Other aims were to study the integration of the two coordinations into one movement sequence and to obtain data concerning HM coordination after 5 months of age. Two groups of infants were studied cross-sectionally. The first was aged 5-7 months and the second was aged 7-9 months. Two situations were compared, one where the infant had to reach for an object (the same ones as those used in study 2) and another where the object was placed in the hand, as in the study 2. Each infant was given 4 trials in each situation, the order of the 8 trials being randomized. Only the first transport of the object to the mouth was analysed, either after a reach on reaching trials or after object presentation to the hand on non-reaching trials.

The measures of particular interest were those of visual regard and mouth movements during reaching and/or transportation to the mouth, and the degree to which reaching and HM transportation were integrated in reaching trials. In terms of the interaction between reach and grasp and HM coordination, the hypothesis was that if reaching was "feeding-back" into HM coordination development there should be evidence in the younger group of infants that the behaviour of the mouth was different during reaching trials when compared to non-reaching trials. This difference should no longer occur in the older group as HM coordination would be skilled independently from the context in which it occurred.

6.2 Method

6.2.1 Subjects

Mother and baby volunteers were recruited through advertisments in the local press between November 1990 and July 1991. The ages of the infants ranged from the beginning of the fifth month to the end of the eighth month, a range of 4 months. Infants were then devided into 2 broad age groups, the young group aged 5-7 months and the old group aged 7-9 months. Table 6.1 gives details of the sex and average age of infants in each group. All babies were full-term (between 38-42 weeks gestational age). In order to be included in the final sample babies had to carry out a hand-mouth movement (as a first contact with the face) in at least one trial in each experimental condition. Five babies in the younger group and two babies in the older group failed to do this. Thus the number of subjects analysed in the younger group was 13, and that of the older group was 14.

Age group	N	Males	Females	Mean age (days)
5-7 months	13	7	6	172 ± 19
7-9 months	14	9	5	231 ± 13

Table 6.1. Sex and average age of subjects included in study 3.

6.2.2 Apparatus

The laboratory arrangement and recording equipment was the same as that used for study 2 (diagrams 1 and 3). The objects used in all experimental conditions were also those used in study 2 (diagram 4). The equipment used for video analysis was the same as that used in studies 1 and 2 (see section 3.2.2, p.80).

6.2.3 Design

Subjects were divided into two age groups, 5-7 months and 7-9 months. Each observation session with each infant involved a series of 8 trials. In 4 of these trials an object was held up at shoulder-height and reaching distance at the midline in order for the infant to reach for the object. In the other 4 trials the object was placed in the hand of the infant by the experimenter standing behind the infant seat, as in study 2. The order in which trials occurred was randomized for each baby. The hand into which an object was presented during non-reaching trials was alternated between left and right hands. The baby was allowed to handle the object for about 20 seconds after grasping in all trials. The interval between trials lasted between 10-20 seconds.

The behavioural unit of interest during non-reaching trials was the first transportation of the object to the mouth. In particular, visual regard of the object, initiation, termination and handedness (left, right or bi-manual) of the trajectory to the face or mouth, facial location of contact and mouth movements could be measured. The behavioural unit analysed during reaching trials began with the initiation of visual regard prior to a successful reach and ended with the termination of the first HM contact after a reach. The initiation of the reach and whether it was left or right handed or bi-manual together with visual regard and mouth movements were noted. The latency prior to transportation to the mouth could be noted. If there was no pause between the reaching movement and transportation to the mouth, this was considered as being an integrated sequence. The measures of interest associated with the transportation to the mouth were the same as those in the non-reaching trials.

The analysis outlined above allowed a comparison to be made between HM coordination on its own with HM coordination as part of a reach-grasp-transport to mouth sequence. A minimum requirement for inclusion in the analysis for any baby was that at least one episode of transport to the mouth occurred in both reaching and non-reaching trials.

6.2.4 Procedure

After a short familiarization period on arriving to the Infant Study Unit the baby was placed in the baby seat and the observation period began. The mother was present throughout the observation session although she was asked not to interact with her baby during filming. If the baby became upset, filming would be interrupted so that the baby could be comforted before filming was resumed. This was rare however.

During reaching trials, the experimenter held the object out to the infant at shoulder height and at the infant's midline. During non-reaching trials the experimenter stood behind the infant and placed the object in the left or right hand. Once the object had been grasped the infant was left to hold the object for about 20 seconds before it was removed and the next trial began. Observation sessions lasted between 5-10 minutes.

6.2.5 Video analysis

The analysis of the first HM contact (either HM or HFM) in non-reaching trials was analysed in the same way as in study 2 (section 4.2.5, p.122). During reaching trials, all visual regard of the object was measured until the end of the first mouth contact. The time of initiation of the reaching movement and the arm involved (left, right or bi-manual) was noted. A bi-manual reach was defined as those reaches where both hands grasped the object. This could be taken as a conservative measure of bi-manual engagement as instances where one hand grasped the object just before the other arrived would be defined as uni-manual.

The end of a reach was defined as the first frame where the hand made contact with the object. The interval between the end of the reach and the first movement to the mouth was measured. Sometimes no dicernible pause occurred between reaching and grasping and transportion to the mouth. In other words, there were no two adjacent frames between the initiation of reaching and arrival at the mouth where movement did not occur. These movements were considered to be integrated reach-grasp-transportation-to-mouth sequences. The HM coordination component after a reach was analysed in the same way as in non-reaching trials.

Given the similarity of the measures utilized in study 3 compared to study 2 no separate measurement of inter-observer agreement was carried out.

6.2.6 Statistical analysis

Comparisons between the different age groups were carried out using the Mann-Whitney U test for independent samples. Comparisons between different conditions within age groups were carried out using the Wilcoxon signed rank test for related samples. All tests for significance were 2-tailed.

6.3 Results

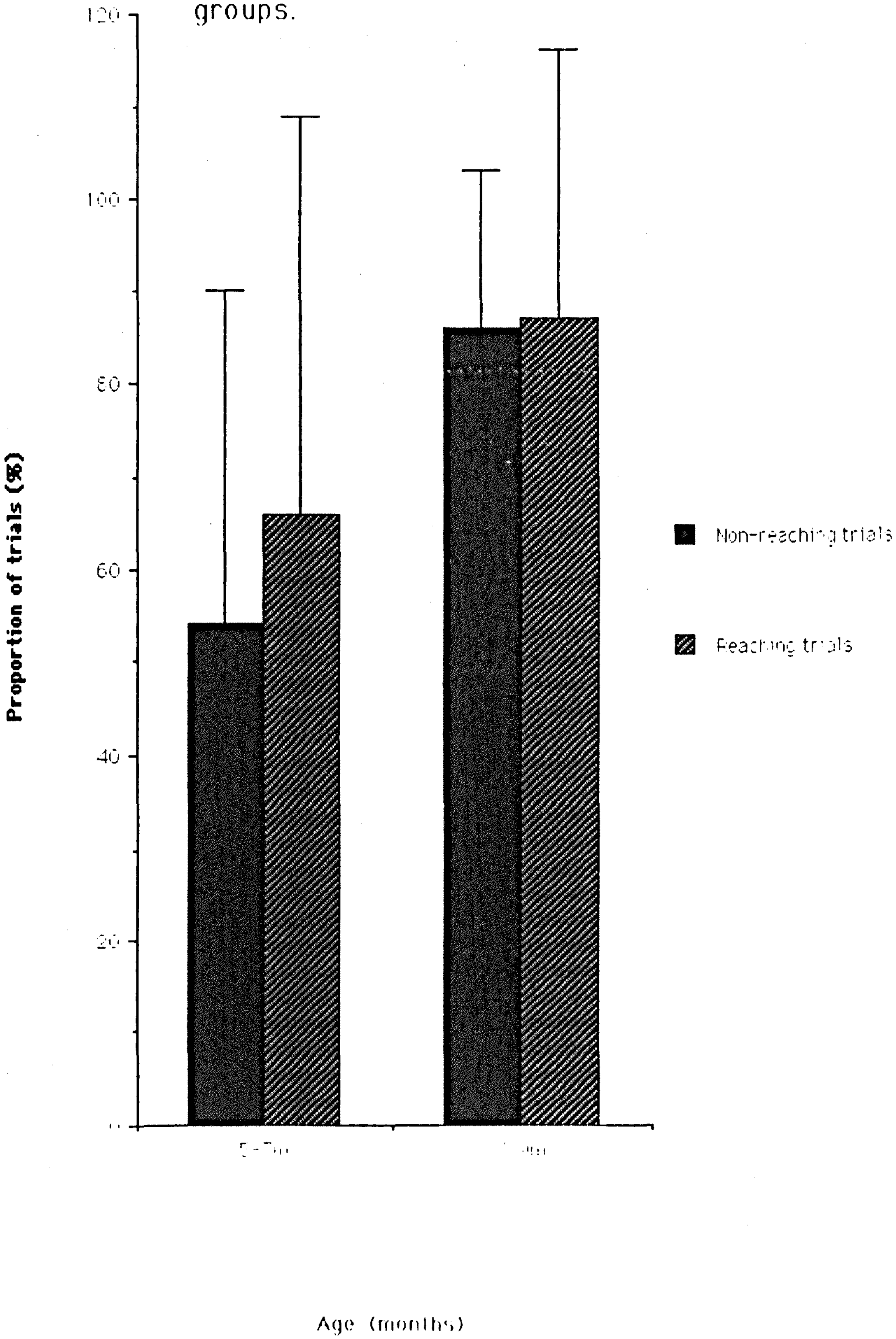
The hypothesis put forward in section 6.0 was that HM coordination in the context of reaching and grasping for an object would be different from HM coordination when no reaching was involved in the 5-7-year-olds, but not in the 7-9-month-olds. In addition, improvements in HM coordination with age should be observable between the two groups of infants. Data concerning the integration of arm and mouth movements, whether contacts were uni- or bi-manual and looking patterns will be presented for HM movements in both reaching and non-reaching conditions. Comparisons across the two age groups within conditions will also be made. The reaching condition will then be examined to see whether any differences identified from the analyses referred to above can be accounted for. The extent to which reaching was integrated with HM movements will be reported. The question of whether mouth movements, uni- or bi-manual movements or visual regard initiated during reaching persist during HM movements can then be examined.

A maximum of 4 trials in each of the two experimental conditions for each baby was available for analysis. Not all babies completed all trials however. The main reason for this was that no movement to the face or mouth would occur at all during a trial, or in the reaching condition, no successful reach would occur. There were only 2 trials from a baby in the 5-7 month group in which the first contacts were just to the face rather than the mouth. There was a total of 40 completed trials out of a possible 52 in the non-reaching condition for the younger group and 46 out of 56 for the older group. There were 35 out of 52 trials available in the reaching condition for the younger group and 40 out of 56 for the older group. Because of this, all measures in study 3 were expressed in terms of proportions out of the number of completed trials for each baby.

6.3.1 Integration of arm and mouth movements

The means and standard deviations of the proportion of trials where anticipatory mouth opening occurred in each age group and condition are shown in figure 6.1. The degree of anticipatory mouth opening that occurred prior to HM contacts increased with age, the difference between the younger and older group in non-reaching trials was significant using a Mann-Whitney U test ($Z=2.7$, $P \leq .01^{**}$). The performance of the younger group during reaching trials in anticipatory mouth opening prior to mouth contacts was better than during non-reaching trials, so that the difference between the younger and older infants during reaching trials was not significant ($Z=1.4$, $P \leq .2$). However, within the 5-7-month-olds, the difference in anticipatory mouth opening between reaching and non-reaching trials did not reach significance (using a Wilcoxon signed rank test for matched samples, $Z=1.5$, $P \leq .1$). There was also no significant difference between conditions in the 7-9-month-olds ($Z=.3$, $P \leq .7$).

Figure 6.1. Means and SD's of the proportion of trials where anticipatory mouth opening occurred prior to mouth contacts in a) the non-reaching condition and b) the reaching condition in both age groups.



It should be noted that the analysis above refers to both direct (HM) and indirect (HFM) mouth contacts. No separate analysis was made of differences in accuracy of contacts because HFM contacts were very rare. There were only 9 cases of HFM contacts in the non-reaching condition in the 5-7-month-olds, and 3 in the reaching condition for this age group. There were only 3 and 2 HFM trials in the non-reaching and reaching conditions respectively for the older age group.

The relationship between arm and mouth movements can be investigated in more detail by considering at what point mouth opening occurred relative to the initiation of arm movement, in those contacts where there was anticipatory mouth opening. This point tended to be highly variable in the newborns in study 1, mouth opening generally **preceded** arm movement, in some cases by minutes. The 5-month-olds of study 2 were less variable than the newborns, and mouth opening generally occurred **after** the arm had began to move to the mouth. Figure 6.2 shows the means and standard deviations for individual mean durations of movements. This was about 1 second for all ages and conditions, as with the 5-month-olds of study 2.

Figures 6.3a) and 6.3b) show the means of the individual means, and the mean SD for individual SD's of the timing of mouth opening with respect to arm movements in the 5-7 and 7-9-month-olds (individual means are derived by averaging the time at which mouth opening occurred, expressed as a proportion of movement duration,

Figure 6.2. Means and SD's of the individual means for the duration of movements to the mouth, for each experimental condition and age group.

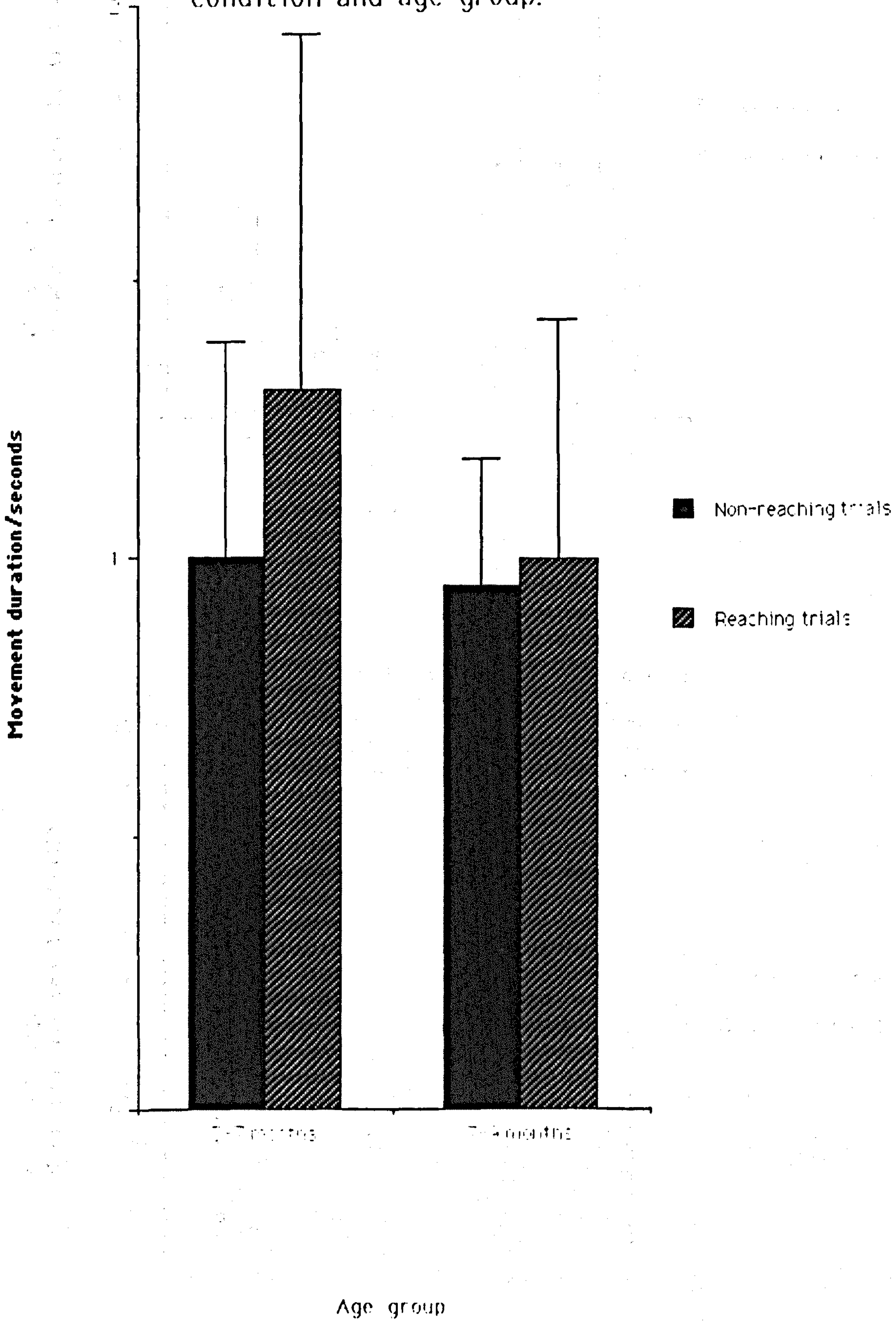


Figure 6.3a). Means and SD's of the time mouth opening occurs expressed as a proportion of movement duration time in the non-reaching (1) and reaching (2) conditions for the 5-7-month-old infants.

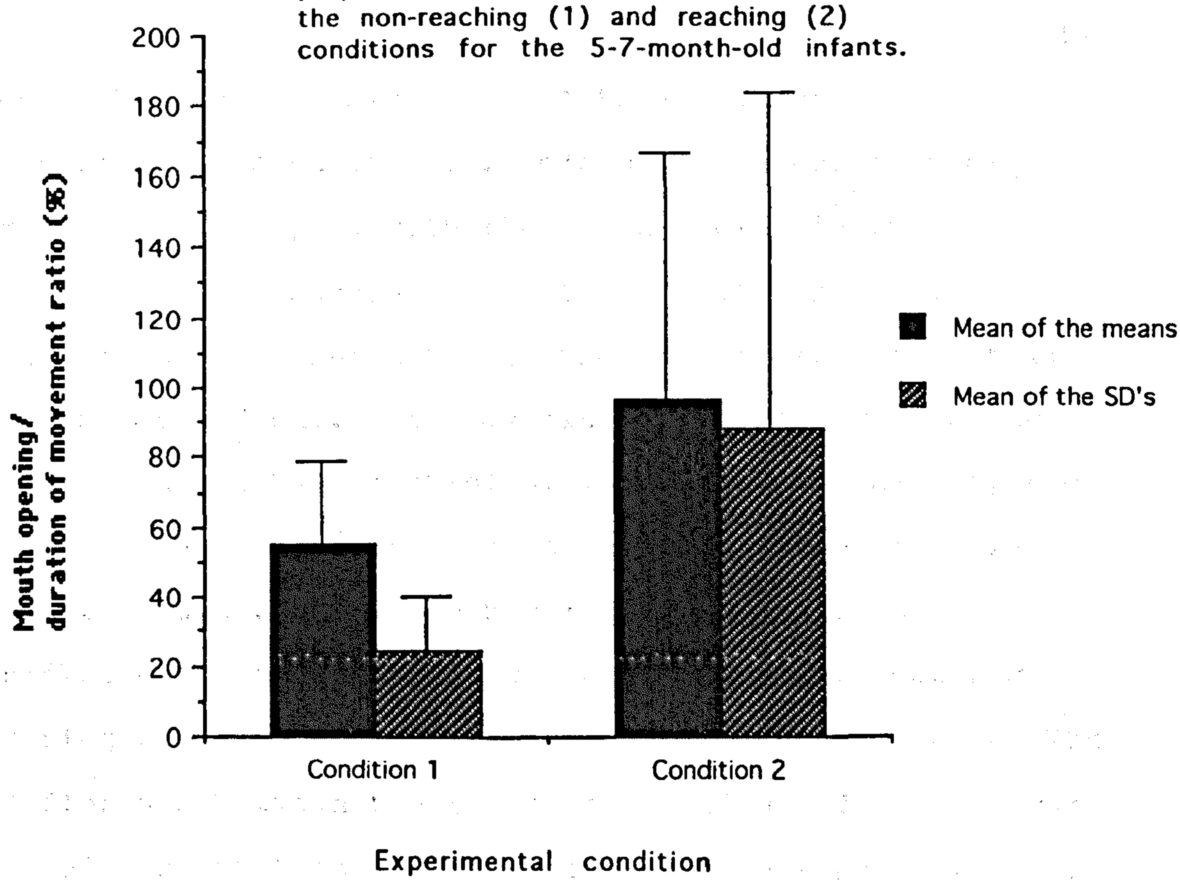
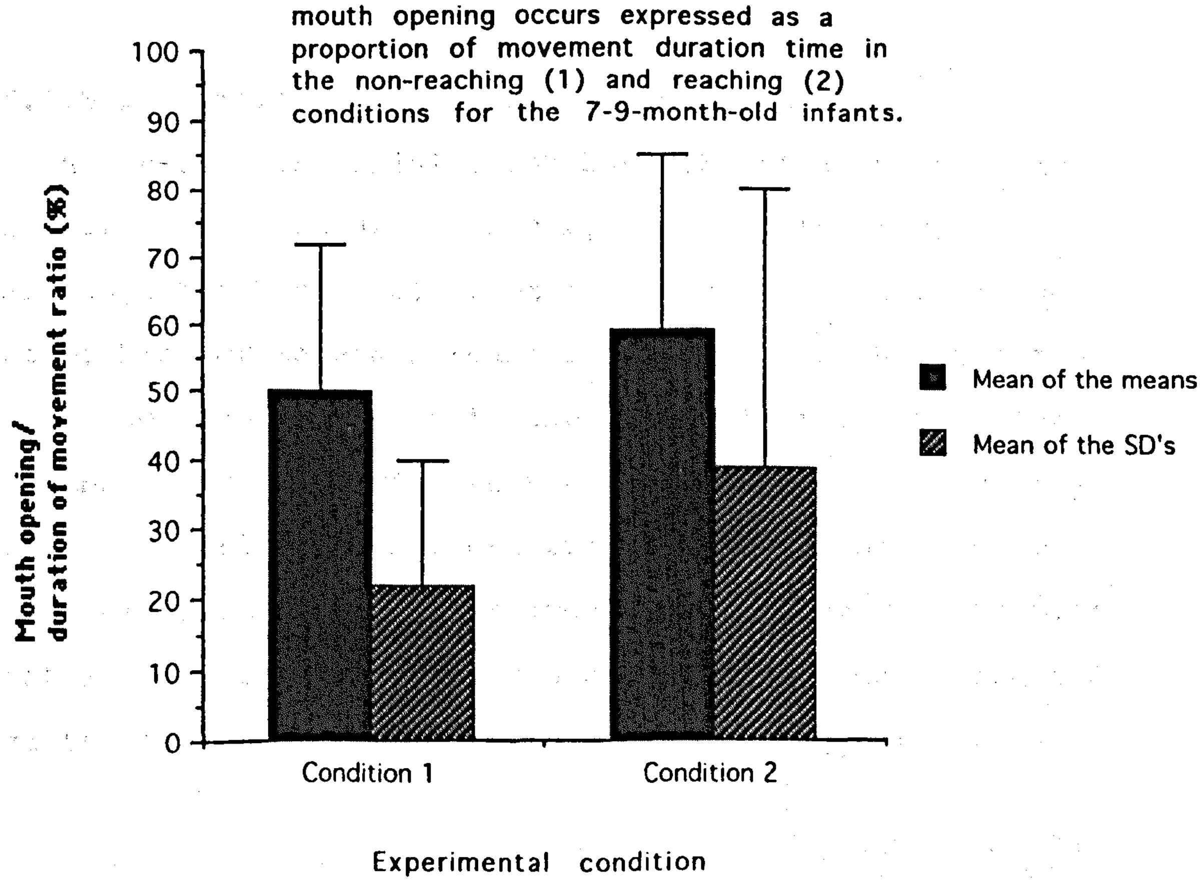


Figure 6.3b). Means and SD's of the time mouth opening occurs expressed as a proportion of movement duration time in the non-reaching (1) and reaching (2) conditions for the 7-9-month-old infants.



over the maximum possible of 4 trials in each experimental condition). It can be seen that in non-reaching trials, as with the 5-month-olds in study 2, mouth opening occurred **after** the initiation of arm movements, when about 50% of the arm movement had still to be carried out. This was also the case for reaching trials in the 7-9-month-olds. In the 5-7-month-olds, the mean mouth opening time to movement duration ratio was about double that in the non-reaching condition, reflecting the fact that some mouth movement occurred during reaching prior to transportation to the mouth. The difference between the means in reaching and non-reaching conditions at this age was not significant however (using a Wilcoxon signed rank test for correlated samples, $Z=1.4$, $P \leq .2$) as the variance was very high in the reaching condition.

6.3.2 Proportions of bi-manual HM contacts

In non-reaching trials, the hand in which the object was presented was determined by the experimenter, although the baby could then transfer the object to the other hand or make a bi-manual contact with the object prior to transportation to the mouth. In fact, transfer to the other hand prior to the first HM contact was very rare, occurring in only one trial in the younger group and one trial in the older group. In the younger group, a total of 19 trials occurred when the object was presented to the left hand, and 21 trials when the object was presented to the right hand. In the older group, there were 27 trials where the object was presented to the left hand, and 19 to the right hand. In the non-reaching condition, the hand with which transport to the mouth occurred was clearly dependent on which hand was used to reach for the object. This data will be presented in section 6.3.6. Only data on bi-manual transport to the mouth will be considered in this section.

Figure 6.4 shows the means and standard deviations for the proportion of trials where bi-manual transportation to the mouth occurred. This was about 10-15% of trials in both conditions at both ages. There were no significant differences either between age groups or between experimental conditions (using a Wilcoxon signed rank test, for the 5-7-month-olds $Z=.5$, $P \leq .6$ for a comparison between experimental conditions, in the 7-9-month-olds $Z=.6$, $P \leq .6$, using a Mann-Whitney U test for comparing age groups in each condition, $Z=.7$, $P \leq .5$ in the non-reaching condition and $Z=.5$, $P \leq .6$ in the reaching condition).

6.3.3 Visual regard of objects during HM movements

Reaching for an object necessarily presupposes that visual fixation has taken place. It is thus possible that this would induce visual regard of the object prior to an HM contact where this regard would not have taken place if the infant had not had to reach and grasp for the object. Figure 6.5 shows the means and standard deviations of the proportions of trials where visual

Figure 6.4. Means and SD's of the proportion of trials where contacts to the mouth were bi-manual for both experimental conditions and age groups.

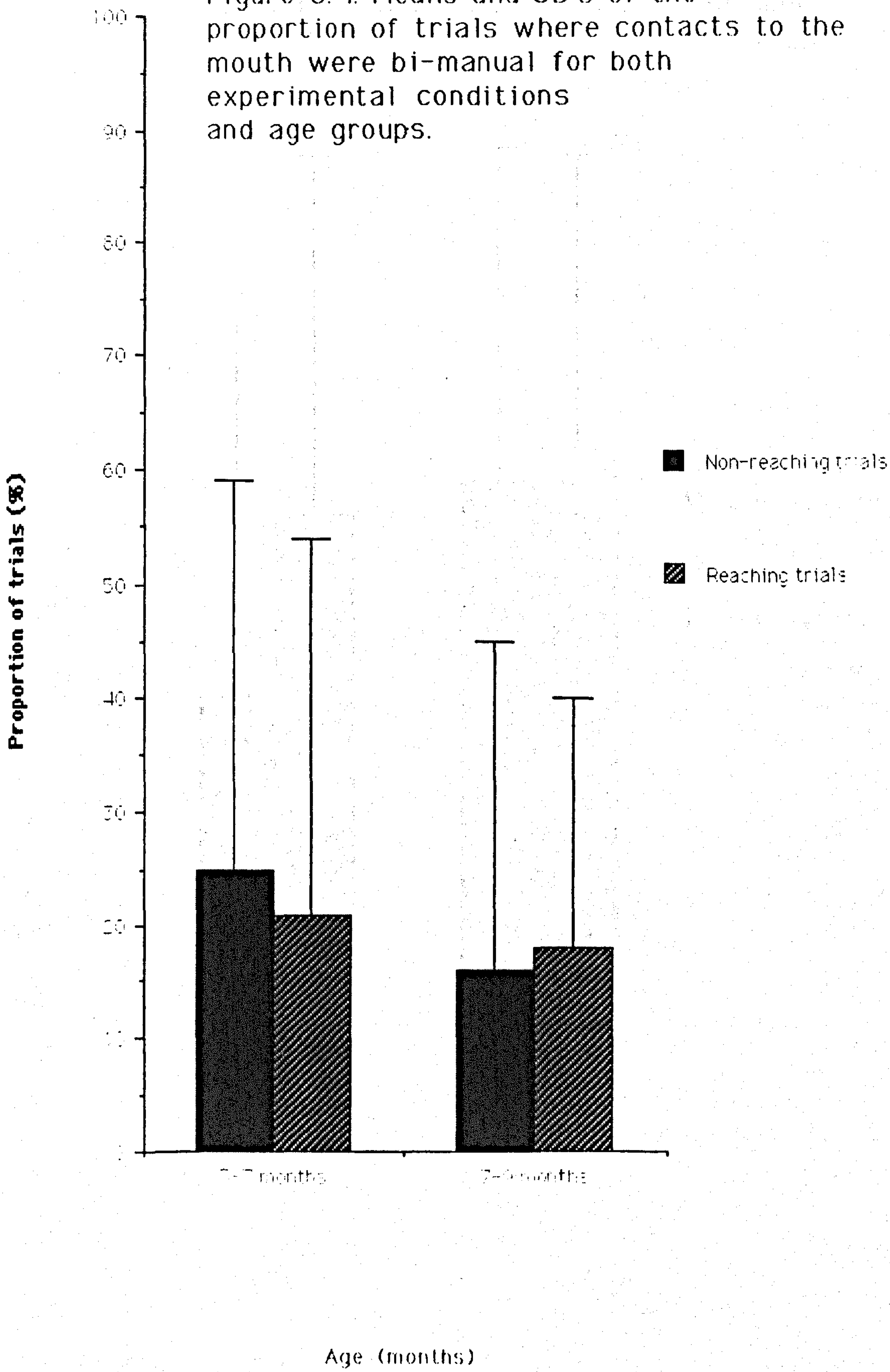
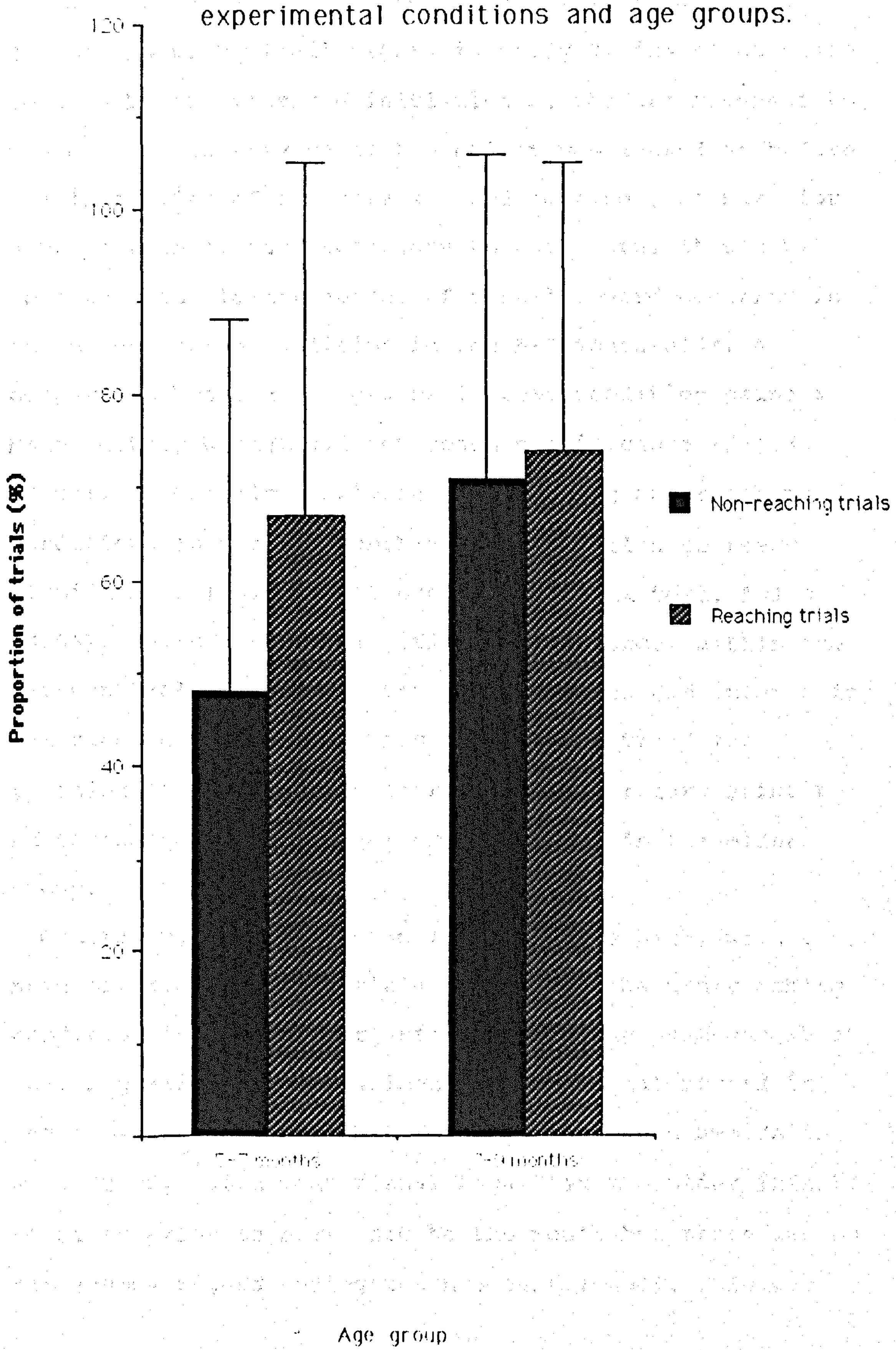


Figure 6.5. Means and SD's of the proportion of trials where looking occurred during movement to the mouth, for both experimental conditions and age groups.



regard of the object occurred during movements to the mouth in non-reaching and reaching trials in both age groups. As with visual regard in study 2, instances where looking began **after** the initiation of the arm movement to the mouth were very rare, the object was looked at before the initiation of arm movement and looking continued for some portion of the trajectory to the mouth. It can be seen that the lowest amount of visual regard occurred in the non-reaching condition in the 5-7-month-olds. A comparison between age groups in this condition using a Mann-Whitney U test did not reach significance ($Z=1.8$, $P \leq .07$). A comparison between non-reaching and reaching conditions in the 5-7-month-olds also failed to reach significance (using a Wilcoxon signed rank test, $Z=1.9$, $P \leq .06$). There were no significant differences within the 7-9-month-old infants or between young and old infants in the reaching condition. Thus there was a trend for reaching and grasping to increase visual regard prior to HM contacts in the younger group but not in the older group.

Generally, levels of visual regard were high, with a mean of around 70% of trials except for the non-reaching condition in the younger infants where the mean was about 50%. A qualitative comparison between visual regard in the older infants and that found in the 5-month-olds in study 2 suggested that visual regard in the older infants occurred prior to movements to the mouth but there was no continuous regard during the movement itself. This was often not the case in the 5-month-olds however where the object was followed during a relatively slow approach to the mouth. In order to investigate whether such a difference between visually guided and visually triggered HM coordination exists between younger and older infants studies which could measure the relationship between acceleration and deceleration during movements and looking would need to be carried out.

6.3.4 The integration of reaching and grasping for objects and HM coordination

This section will investigate behaviours occurring during reaching and grasping which could be altering the form of any subsequent HM contacts. As reported in previous sections, having to reach for an object did have some consequences for HM contacts in the 5-7-month-old infants in terms of anticipatory mouth opening and visual regard, although these effects were not large.

The first question which needs to be addressed is to what degree HM coordination was temporally integrated with reaching and grasping. Clearly if there was a large interval between when an object was grasped and an HM contact, then it is unlikely that the reach would have any direct effects on the morphology of the HM contact. The mean proportion of integrated contacts in the 5-7-month-olds was 48%, ±39%. In the 7-9-month-olds it was 51%, ±37%. The difference between age groups was not significant (using a Mann-Whitney U test, $Z=.2$, $P\leq.9$).

Thus in about half of all reaching trials HM movements formed a final part of a reach and grasp sequence. In the remaining trials, the interval between reach and grasp and movements to the mouth was highly variable, from less than 1 second to a maximum of about 20 seconds. The following sections will examine any mouth movements occurring during reaching and how they affected later HM contacts. The effects of the handedness of reaches on HM contacts will also be examined.

6.3.5 Mouth movements during reaching and grasping

In a large majority of reaches there were no mouth movements. This was particularly the case in the 7-9-month-old group, where there was only mouth activity in 5 trials (from 3 infants) out of the total of 40 trials. In the 5-7-month-old group there were 13 trials (out of 35) where mouth movements occurred during reaching, divided amongst 6 infants. Three of these infants showed the pattern of movement described by Bruner (1969). That is, the mouth opened during reaching and remained open as the object was transported to the mouth. Two of these infants did not show anticipatory mouth opening during non-reaching trials. The higher level of anticipatory mouth opening during HM movements in reaching trials reported in section 6.3.1 was mainly due to these two infants.

An inspection of the morphology of movements where mouth opening occurred during reaching suggests an alternative interpretation to that of Bruner with regard to the causes of this mouth opening. *Plate 7a) and b)* shows one of the infants who demonstrated the pattern of mouth movement described by Bruner (belonging to the 5-7-month-old group). In movement a) (above, left to right) the object is placed in the hand of the infant. An HM contact follows with no anticipatory mouth opening occurring. In movement b) (below, left to right) the infant opens the mouth during reaching and it remains open during transport to the mouth. It can be observed that this infant was leaning forward to a large extent. The mouth opening during the reach can thus be interpreted as "reaching with the mouth". This interpretation would fit with the observations of Rochat (1991) on mouth and trunk movements when the arms are restrained in 5-month-old infants in the presence of an attractive object.

There is further support for viewing mouth movements during reaching as attempted reaches from 3 of the 13 trials in the younger group (and 1 of the 5 in the older group) where mouth opening occurred during reaching but then **closed** towards the end of the reach, in some cases opening again prior to mouth contact. An example of this is shown in plate 8. *Plate 8* shows one reach-grasp-transport-to-mouth sequence from an infant in the 5-7-month old group. The mouth opens during reaching (above and middle) but then closes at the end of the reach (above right and below left), and finally opens again prior to mouth contact (below, middle and right). Thus,

7a) and b)


00-00 00:03:40:03
00-00 00:03:41:23
00-00 00:03:41:63
00-00 00:05:53:45
00-00 00:05:54:61
00-00 00:05:56:13
00-00 00:05:56:89

8

although there is "reaching with the mouth" in this example, it is not having an effect on the subsequent HM contact.

6.3.6 Handedness of reaches

Figure 6.6 shows the means and standard deviations for the handedness of reaches (left, right or bi-manual). The proportion of bi-manual reaches decreased significantly with age (using a Mann-Whitney U test $Z=2.5$, $P\leq.01^{*}$). This result is similar to that obtained by Rochat (1991). This was not reflected in a difference in the proportions of bi-manual HM contacts in the reaching condition (section 6.3.2) between ages because several bi-manual reaches in the younger group were followed by uni-manual HM contacts and a few uni-manual reaches in the older group were followed by bi-manual contacts.

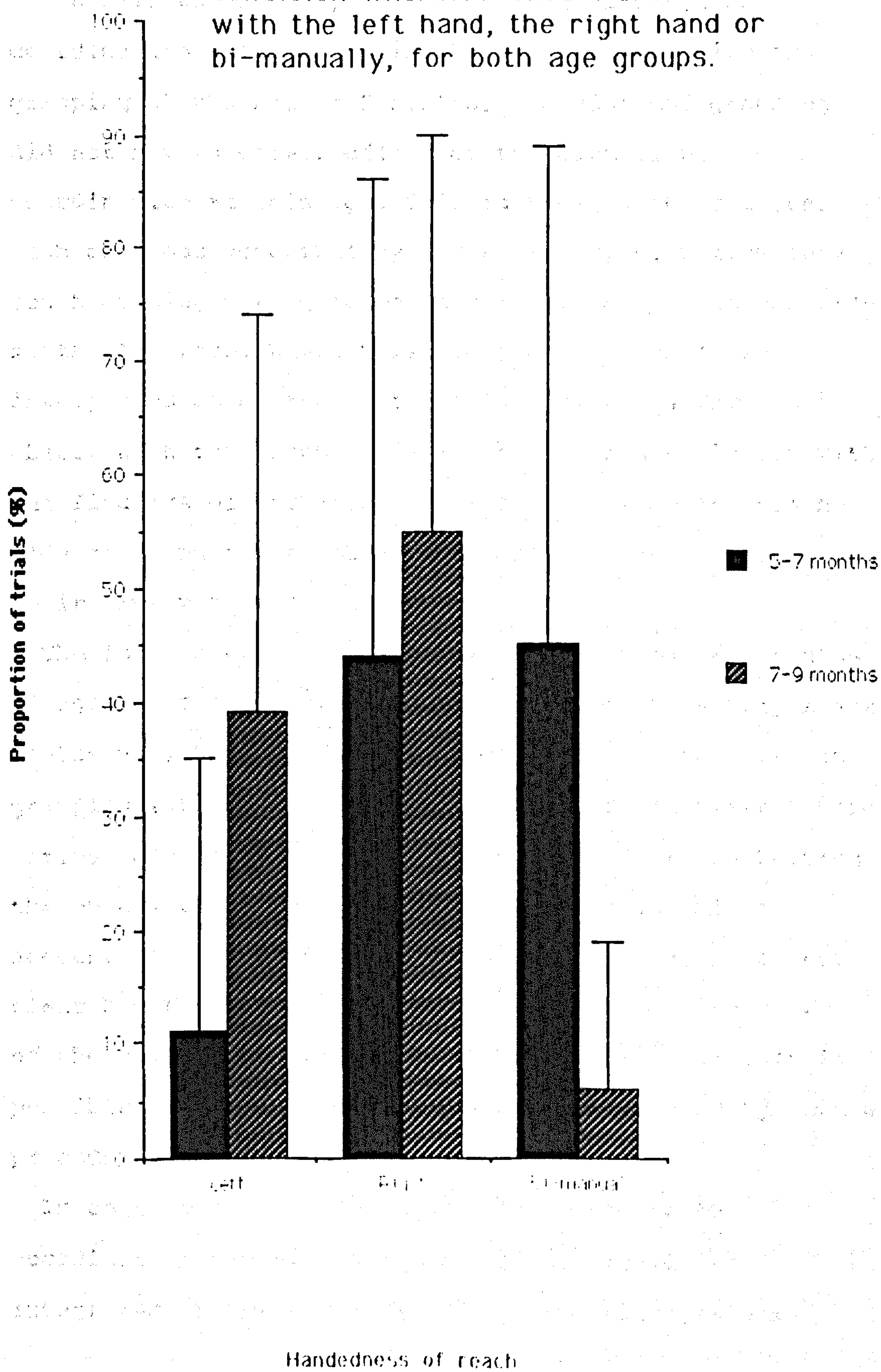


Figure 6.6. Means and SD's of the proportion of trials in the reaching condition where reaches were carried out with the left hand, the right hand or bi-manually, for both age groups.

6.4 Discussion

The results of study 3 suggest that although HM coordination was already integrated with reaching and grasping at the age of 5 months, reaching and grasping did not have a direct effect on the form of HM coordination at this age. This is because observations such as those described by Bruner (1969) of anticpatory mouth opening during reaching were not common in the 5-7-month-old group. Where this did occur, it could be interpreted as a case of the infant reaching for the object with the mouth. This interpretation would fit with the findings of Rochat and Senders (1991) on 3-5-month-olds reaching for an object with the mouth and trunk when their arms were restrained.

The infants observed by Bruner were between 4-6 months of age so it is possible that there is a transitory stage at the very beginning of the development of reaching and grasping (at 4 months of age) when the mouth plays a more active role in reaching. A procedural difference between the observations of Bruner and study 2 which might account for the difference in results is that it is not clear how the object was presented by Bruner. He writes of the object being waved in front of the infant. It is possible that mouth opening would be encouraged by such a procedure.

In conclusion, it would seem that although HM coordination and reaching and grasping are already integrated at the earliest stages, the coordinations develop independently of each other. The clearest examples of this independence were those instances where there was mouth opening during reaching followed by **closure** on contact with the object, followed finally by **re-opening** during transport to the mouth (plate 8).

The higher degree of anticipatory mouth opening in the older infants relative to the younger group confirms the results from study 2 that HM coordination continues to develop throughout the first year of life. A qualitative comparison of visual regard in the 5-month-olds of study 2 and the infants in the 7-9-month group in study 3 suggests that the role of visual regard changes. In the older infants, visual regard followed a predictable pattern in almost all the infants, where the infant looked away once the movement had been initiated. Movements appeared smoother and less segmented. In the 5-month-olds, it was often the case that the object was followed, sometimes with difficulty, throughout the trajectory. If these observations were confirmed using methods which could correlate movement velocities with looking patterns, such a pattern of visual guidance would be of interest as it is similar to that suggested for reaching by some authors (Hatwell and Orliaguet, 1986, Hay, 1984). The model proposed is that after a period of reliance on visually guided movement strategies, a balance emerges between ballistic and guided strategies in the development of reaching movements (evidenced by a decline in the effects of manipulations such as distorting prisms on reaches, McDonnell, 1979). Perhaps such a model could also be applied to the development of HM coordination.

CHAPTER 7

THE DEVELOPMENT OF HAND-MOUTH COORDINATION FROM BIRTH UNTIL NINE MONTHS OF AGE: SUMMARY AND GENERAL DISCUSSION

7.0 Introduction

The first part of this chapter will give an overview of the questions addressed in the thesis and the results obtained. Transition points during the development of HM coordination will then be discussed within a dynamic systems framework, with reference to possible causes of change. Finally, the relevance of the findings to wider issues in motor development will be discussed. Some possibilities for further studies will be considered.

7.1.1 Summary of research questions addressed in the thesis

Issues concerned with changes both in the structure and function of HM coordination were addressed in the thesis. The general aim of these studies was to obtain a comprehensive account of the developmental course of HM coordination and to begin to address the question of what factors are responsible for the changes observed. Although the particulars of processes of change are unique to specific coordinations, it is hoped to show at the end of this chapter that some of the findings related to HM coordination can be applied to other motor coordinations in infancy.

Study 1 addressed the question whether hunger had an effect on spontaneous HM behaviour. Based on the effects of sucrose on newborn HM behaviour, Rochat et. al. (1989) suggested that the motivation to make spontaneous HM contacts could be related to feeding. The evidence with this result further by making a direct comparison between levels of mouth open postures associated with movements to the mouth and face, and baseline levels of mouth open postures. The possibility that the association between movements to the mouth and mouth open postures could be due to facilitating flexed arm postures was also tested.

Few studies have investigated the development of HM coordination after the newborn period. **Study 2** sought to obtain detailed measures concerning the development of HM coordination after the newborn period. In terms of the motivation to make HM contacts, spontaneous HM contacts decline (Hopkins et. al., 1988) whereas contacts when an object is in the hand increase after the newborn period (Rochat, 1989). Rochat (1989) therefore suggested that a motivational shift occurs at about 2 months of age, away from a feeding function towards an object exploration function. The motivation to explore objects orally was thus used in study 2 to generate HM contacts. Changes between 1-5 months in the distribution of locations of contacts on the face, the integration of arm and mouth movements, the form of arm movements and visual regard were measured. Inter-relationships between these measures were investigated.

Study 3 sought to investigate whether there are any relationships between the development of HM coordination and reaching and grasping. Piaget (1977) argued that the two coordinations develop independently of each other, and then become integrated such that objects are grasped and then transported to the mouth. Bruner (1969) argued that HM coordination aided early reaching and grasping through the mediation of movements of the mouth. According to Bruner, by keeping the mouth open during reaching movements, prior to the object being placed in the mouth, infants are "reminded" of the goal of the reach.

The results of study 2 called into question this mechanism. Anticipatory mouth opening did not occur until 5 months of age. Thus if infants do show anticipatory mouth opening in situations where they reach for objects, as Bruner suggested, they do so prior to anticipatory mouth opening when the object is already in the hand. A possibility arises, opposite to the one Bruner suggested, that it is the development of reaching and grasping that aids the development of HM coordination. These questions were tested in study 3 by comparing HM coordination on its own with HM coordination in the context of reaching and grasping for objects, for infants aged between 5 and 9 months. An additional aim of study 3 was to observe the development of HM coordination after the age of 5 months. This was because the appearance of mature HM coordination occurred after 5 months of age, somewhat later than previously assumed.

7.1.2 Summary of results

Study 1: There were no significant differences between the relative distributions of HM and HF contacts before and after feeding. There was a significant association between mouth open postures and movements to the mouth before feeding, both in comparison with HF contacts and with baseline levels of mouth open postures. This was not due to reflexive mechanisms or facilitating arm postures. No such association was found after feeding. Movements tended to have an unskilled appearance and the timing relationships between mouth opening and movements to the mouth were highly variable.

Study 2: The distribution of locations of contacts on the face was similar to that found in newborns until 4 months of age. At 4 months, there were significantly more HM contacts when an object was being grasped than when no object was present. Contacts also became more centred on the mouth rather than other parts of the face, with a majority of contacts being direct or indirect mouth contacts. There was no anticipatory mouth opening at this stage however, or at 2 and 3 months of age. After 4 months, HM coordination became progressively more skilled. A large majority of contacts were mouth contacts by 5 months of age, and anticipatory mouth opening was shown by some infants at this stage. This mouth opening occurred after the initiation of arm movement and there was far less variability in the timing of mouth opening than that observed in newborns.

At 5 months, there was a significant relationship between visual regard and movements to the mouth. In the overwhelming number of cases, infants were already looking at the object prior to the initiation of the movement to the mouth. At 5 months, there was also a significant correlation between amount of visual regard and frequency of HM contacts. Thus, vision appeared to "organize" oral exploration at this age. A qualitative assessment of movement patterns at 5 months suggested that there were distinct styles of movement which varied between babies. These results raise the possibility that there could be several developmental routes towards the achievment of mature HM coordination.

Study 3: Observations of anticipatory mouth opening during reaching for objects such as those described by Bruner (1969) were rare in the youngest age group studied (5-7 months), and did not occur at all in the oldest age group (7-9 months). In those cases where such behaviour was observed it could be interpreted as a case of "reaching with the mouth" by forward trunk movements. Thus, although HM coordination was integrated with reaching and grasping by 5 months of age, the two coordinations appear to develop independently of each other. There was significantly more anticipatory mouth opening in the 7-9-month-olds than in the 5-7-month-olds, showing that the development of HM coordination from a functional to a skilled behaviour is a relatively extended process. By 7-9 months, HM coordination is relatively similar in different babies and consists in visual regard followed by a smooth and accurate movement to the mouth, with anticipatory mouth opening occurring after the initiation of movement.

In summary, the development of hand-mouth coordination from birth until 9 months of age was not found to be a linear process, rather it was marked by functional and structural shifts and apparent regressions. The following sections will discuss these results within a dynamic systems framework. Changes in order parameters will be summarized. Hypotheses concerning which control parameters are responsible for these changes can then be defined. Interpretations of variability observed during transitional periods in HM coordination will be discussed. Suggestions will then be made for further studies, both to clarify the mechanisms involved in HM coordination and to investigate more general issues in motor development.

7.2 Changes in order parameters in HM coordination between birth and 9 months of age

In section 2.2.2, p.38, distinctions were made between **coordination** - invariant, "higher-order" topological features of a behaviour, **control** - the assignment of values to elements which are free to vary within the coordinative structure and **skill** - the optimal assignment of control variables. In HM behaviour, the coordination consists of a trajectory by the arm (although head and trunk movements could also be involved) resulting in the hand coming into contact with the mouth, together with mouth opening to allow the hand to enter the mouth. Features of the movement that can vary are the smoothness and accuracy of the arm trajectory and the timing of mouth opening relative to the arm movement. A skilled movement would be one with the smoothest, most efficient trajectory to the mouth, with anticipatory mouth opening occurring neither too early or too late, but together with arm movement.

The order parameters (variables "expressing" patterns of coordination) in HM coordination that will be discussed are as follows: The contexts in which movements to the mouth are a stable behaviour pattern; the accuracy and smoothness of the trajectory to the mouth, and; the integration of arm and mouth movements.

In the newborn, spontaneous HM contacts when the infant is in a supine position are a frequent occurrence. The frequency of such contacts decline over the first months of life. By 4 months of age, contacts to the mouth occur frequently in the context of the transportation of grasped objects to the mouth. There are also clear changes in the structure of movements to the mouth over this time period. Trajectories can be very circuitous at the newborn stage. At 5 months a variety of trajectories can be observed, some segmented and some more ballistic. Improvements in smoothness and accuracy are observable until the oldest age studied, 7-9 months. Here HM movements have a predictable structure and skilled appearance. After visual inspection, the object is moved smoothly and accurately to the mouth, with mouth opening occurring consistently after movement initiation. In terms of the integration between mouth and arm movements, this appears to follow a U-shaped developmental structure whereby some anticipatory mouth opening occurs during the newborn period. This disappears and begins to re-emerge at 5 months in a more adaptive and less variable form.

Possible control parameters (elements involved in the coordination that can cause changes in order parameters) responsible for these changes will be considered in the following section. First of all, the role of changes in motivation or function will be discussed, as a control parameter responsible for determining the contexts in which HM coordination is observed. It will be suggested that the decline in spontaneous general movements and the decline in the dominance of the ATNR posture are the control parameters responsible for the changes in accuracy and control of HM movements. Finally, explanations for the U-shaped developmental function of anticipatory mouth opening will be considered.

7.3 Control parameters responsible for changes in HM coordination between birth and 9 months of age

Study 1 found that hunger did affect spontaneous HM behaviour in newborns, but not by increasing the relative proportion of HM contacts, as predicted. Rather, anticipatory mouth opening was affected by hunger level such that it did not occur after feeding. These results support the idea that the motivation to make HM contacts is linked to feeding. It is not possible based on these results to make clear distinctions between the different models that have been proposed to with respect to the nature of the link between HM coordination and feeding (see section 2.5.1, p.59). Postures which resembled suckling postures were not generally observed however. Models based on reactions to sucrose might not therefore be appropriate when considering HM coordination, as such models argue that sucrose leads the infant to adopt a suckling posture.

The motivational shift in the control of HM coordination towards an object exploration function occurred later than suggested by Rochat (1989), at the end of the third month rather than at two months of age. Although infants are capable of carrying grasped objects to the mouth by two months of age, a clear difference between spontaneous levels of contacts and levels when an object is present is only found at 4 months of age. As discussed in chapter 4, this result should not be taken to imply that the motivation to explore objects does not exist prior to 4 months of age, rather this motivation might not be expressed in terms of active control of movement until 4 months of age.

Rochat (1989) found that the main difference in exploratory behaviours occurred between the youngest age studied (2 months) and the older ages studied (4 and 5 months). It is possible that this increase and consolidation of exploratory behaviours that occurs at 4 months of age is also expressed by the difference between spontaneous and object related HM contacts. The evidence from study 2 with regard to the correlation found between babies who showed a high level of visual regard and babies who made frequent HM contacts suggests that vision could be promoting and "organizing" oral exploration at this age. This appears contrary to results from earlier studies (Rochat, 1989), but in these studies the association between vision and mouthing, rather than movements to the mouth, were investigated. Thus, motivational changes underlying HM coordiation appear to be responsible for the changing contexts in which the behaviour can be observed.

Whether the relationship between early HM behaviour and feeding is thought to be direct (the expression of a pre-functional self-feeding system or the activation of the suckling posture) or indirect, the nature of the effects found in study 1 need to be accounted for. These effects were the unchanging distribution of locations of contact on the face and the change in anticipatory mouth opening before and after feeding. Also, the disappearance of anticipatory mouth opening after the newborn period needs to be explained.

The distribution of locations of contacts continues to be similar to that found in the newborn period until at least 3 months of age. Rochat and Senders (1991) also report that contacts become bi-manual at this age. These developments coincide with the disappearance of spontaneous general movements, the decline of the asymmetric tonic neck reflex and the ability to maintain the head upright. By 4 months of age, HM coordination is clearly under voluntary control. The infant is successful in transporting an object to the mouth at this age even if the coordination is not yet skilled. Thus, until about 4 months of age, the expression of HM coordination can be thought of as being highly constrained by postural immaturity and the "background" of spontaneous general movements. These determine both the degree to which motivational factors, be it hunger or object exploration, can contol the amount of HM contacts that are carried out, as well as the morphology of those contacts that do occur.

The association between mouth open postures and movements to the mouth disappeared after the newborn period and did not re-emerge until 5 months of age. The question arises as to how this association, and its subsequent disappearance, should be understood.

The issue of U-shaped developmental transitions has already arisen in section 1.2(v), p.20, in the context of the interpretation of newborn behaviour. Two **general** models have been proposed to explain these apparent regressions in behaviour. The first of these, discussed in section 2.3.1 (p.44), consists of an explanation based on sub-cortical to cortical CNS control of behaviour

(McGraw, 1946). Another model proposed by Mounoud (Mounoud and Vinter, 1981, Mounoud, 1982) is that development should be viewed in terms of periods of relative stability followed by periods of fast change or re-structuring (referred to as revolutionary periods). In terms of motor coordination, established behaviour patterns need to be broken up before new combinations of behaviour elements can occur. Such re-structuring could give rise to apparent regressions in behaviour. Prechtl (1982) and Butterworth (1988) have argued that no single mechanism of change needs to be assumed in order to explain transitions across different domains. For example, the disappearance of the stepping reflex could be due to biomechanical factors whereas there could be functional explanations for the disappearance of imitation of facial gestures.

Von Hofsten (1984) argued that his results with respect to the change in morphology of pre-reaching movements after 2 months of age fitted well within Mounoud's model. At the newborn stage there is a synergy between arm extension and hand opening. This synergy breaks up during the early months and adaptive hand shaping emerges slowly during development from 5 months onwards.

The relationship between mouth opening and movements to the mouth in the newborn does not fit this model so well however. If there was a synergistic relationship between arm and mouth movements, a greater proportion of mouth open postures would be expected than those obtained (about 60% anticipatory mouth opening before feeding in study 1), and such a relationship would be expected to occur after feeding as well as before feeding. The relationship between arm movements to the mouth and mouth open postures at the newborn stage should perhaps be viewed in terms of the lability of the mouth at this stage. The mouth opens to capture or "search for" the hand. It is possible that directly after feeding at the newborn stage, and in the months following the neonatal period, this lability is no longer found. In the case of anticipatory mouth opening, an apparently similar order parameter could arise through the action of different control parameters (Hopkins, personal communication). Thus, mouth opening during the newborn period is an attempt to "capture" the hand when little voluntary control of arm movements is possible, whereas at 5 months it is a reflection of increasing control of arm movements.

The control parameters discussed above consist of changes in motivational factors and changes in the ability to produce voluntary movements due to the decline in dominance of spontaneous general movements. It is suggested that these two factors could account for the changes in the contexts in which HM movements occur, the focus on contacts to the mouth as opposed to other facial locations and finally in the U-shaped development of anticipatory mouth opening. A skilled pattern of HM coordination does not become stable for several months after the re-appearance of anticipatory mouth opening however. During the months in which the behaviour is in transition a high degree of variablity can be observed in the coordination. The following section will consider this transitional period and how the variability observed should be interpreted.

7.4 Transitions from functional to skilled HM coordination

A dynamic systems perspective predicts that when a behaviour is in transition from one relatively stable attractor state to another, a maximum degree of variability will occur in observed behaviour (Thelen and Ulrich, 1991). The investigation of periods of transition can be very fruitful in terms of uncovering control parameters because small changes in some interacting elements can lead the system into one behavioural mode as opposed to another. Thus, experimental manipulations can be developed which alter particular hypothesized control parameters. If these manipulations produce new behavioural patterns then the features of the system involved are likely to be acting as control parameters. Alternatively, individual differences leading to "natural" differences in control parameters can be studied to see whether particular parameters are correlated with individual differences in behavioural patterns.

This section will consider the data from the 4-6 month age group with respect to HM coordination. This appeared to be a transitional period in the coordination where there was a high degree of intra-individual and inter-individual variability, as predicted by systems theory. Possible explanations for individual differences will be considered, which if confirmed by further studies could shed some light on the processes responsible for the coordination patterns observed.

At 4 months of age, movements to the mouth were functional and clearly motivated by the presence of an object in the hand. There was no integration between mouth and arm movements at this age however, the mouth opened after contact in the large majority of cases. Often movements were not accurate, reaching other parts of the face before ending at the mouth. By 5 months some anticipatory mouth opening could be observed, although there was a great deal of variation between infants on this measure. The beginning of anticipatory mouth opening did not follow any clear change in the structure of arm movements, levels of accuracy remained similar to those found at 4 months of age.

The data from the 5 month old group was considered to reflect a transition in the development of HM coordination. Some clear and consistent individual differences in movement patterns could be observed at this age. Aspects of arm movements such as whether the arm was flexed or extended at the start of the movement and whether contacts were bi-manual or uni-manual could be measured and were highly variable between babies. Other aspects of movements such as smoothness and speed of trajectory were not measured quantitatively but qualitative differences were noted. Amount of visual regard also varied greatly between infants. Infants who showed anticipatory mouth opening on some movements but not others were particularly interesting with respect to the question of how change occurred in the form of the coordination. These infants also tended to have consistent movement styles. The difference between movements where anticipatory mouth opening occurred and those where it did not were often very small changes in the timing between mouth and arm movements (see plate 4c) and d)). If the movements of infants who showed anticipatory mouth opening in a majority of contacts are considered as a whole they cannot necessarily be classified as more advanced than those of the other infants. Some of these movements were slow and segmented for example. These individual differences were no longer present in the 7-9-month-olds infants observed in study 3. Movements were smooth and accurate. Anticipatory mouth opening occurred in a large majority of movements.

The results described above suggest that there could be more than one developmental route by which skilled HM coordination is achieved. As discussed in section 5.5 (p.158), a study which investigated the 4-6-month age range longitudinally using small observation intervals would be required to show more conclusively that this is the case.

The general questions that need to be asked when investigating alternative routes of development concern the causes of the differences that are observed. One possibility discussed in section 5.5 (p.158) is that different behavioural solutions to the problems of a particular coordination are being expressed in different individuals, or at different times in the same individual. In the case of HM coordination it was suggested that there could be "trade-offs" between speed or smoothness of movement and accuracy.

Another possibility is that differences are determined by factors which are more general than the task demmands of the coordination. Posture could be considered as such a factor. Rochat and Senders (1991) found that degree of postural development (measured by whether infants were sitting independently or not) determined whether reaches towards an object were bi-manual or uni-manual at 5-6 months of age. In terms of HM coordination it is clear that some movement patterns are excluded if certain postures are adopted. For example if the baby is leaning to one side of the chair against one arm, then that arm will be restricted in terms of the type of trajectory that can be made to reach the mouth (see plate 2a) and b)). Visual regard might also be a factor which determines the form which HM coordination takes in different babies. It was suggested in section 5.5 that the continual visual monitoring shown by some babies as the object is carried to the mouth could be responsible for slowing the movement down and causing it to be segmented.

Clearly the idea of alternative developmental routes as "trade-offs" between different problems posed by the coordination and the idea of general factors leading to individual differences are related. There would have to be factors leading some babies to favour some movement solutions more than others. These issues could be investigated by intensive longitudinal studies and by observing the effect of such factors as postural maturity on the expression of HM coordination.

A consequence of coordinations being "soft molded" is that although some "movement solutions" will be preferred by the system (the system settles into more or less stable attractor states), other solutions are not excluded under certain conditions. A process of "exploration of the body-task space through self-generated movement" (Thelen, 1989a, p.271) occurs until the system settles into a new stable attractor state.

The data from the 4 and 5 month observation sessions appears to fit comfortably within this framework. Some "movement solutions" were quite rare while others were common at 5 months of age and became dominant once the coordination was mature. For example, in the case of the type of arm movement used in contacts to the mouth, movements where the upper arm was involved were relatively rare. This was presumably because such movements require more energy and are therefore less efficient than movements involving flexion at the elbow only.

7.5 Further studies and general issues arising from the development of HM coordination

Piaget (1977) used hand-mouth coordination to illustrate certain principles in his theory of development, such as the development of new action schemes through acitive assimilation and circular reactions. As with so many other coordinations and infant behaviours, the account of the development of HM coordination can be recast within current frameworks for the study of motor development. The effects of the interaction of postural, maturational, functional and cognitive factors (such as visual regard) can be observed in the different forms taken by HM coordination during development. Two areas in particular will be discussed with respect to further studies which could help to clarify issues in motor development.

The first area concerns the status of voluntary behaviours in the newborn. Studies which investigated HM behaviour in the newborn under the postural conditions developed by Grenier (1981) might help to clarify whether the stable distribution of locations of contacts is due to a lack of control of arm movements or whether motivational factors are responsible (i.e. hunger does not lead to an increase in HM contacts under any conditions). In this case experimental manipulations (affecting posture) designed to cause itra-individual differences would be utilized in an attempt to uncover control parameters. Such a study would be of interest in terms of issues concerned with the interaction between goal-directed movements and spontaneous general movements in the newborn. Is it the case that general movements are "masking" the expression of goal-directed movements, as Grenier suggests in the case of reaching towards objects, or are other factors also responsible for the form in which goal-directed movements are expressed? In the case of reaching, the synergy between arm and hand is still found even when head support is available and general movements have ceased. It would be interesting to observe whether the integration between hand and mouth in HM coordination, in terms of degree and timing of anticipatory mouth opening, differed from that observed in the supine posture in conditions where the weight of the head was supported.

A second area where results from studies of HM coordination could be useful concerns processes of change in related coordinations such as reaching and grasping. The word related here refers to the fact that there are common aspects to both coordinations, for example they both involve a smooth arm movement to a particular target, rather than meaning that the development of one coordination depends on the other. The results of study 3 would argue against such a hypothesis.

Comparisons could be made longitudinally **within babies** across different coordinations (such as HM coordination and reaching). In this case, natural inter-individual differences during transitional periods would be used in an effort to uncover control parameters. Critical periods of development such as the 4-6 month age range identified in study 2 with respect to HM coordination could be studied (this period would have to be extended in the case of reaching). If factors such as visual regard or visual guidance were common to particular babies across different tasks then some valuable information might be obtained about the function and effects of such factors. Recent studies appear to demonstrate that vision is not critical for successful reaching to occur, as babies of 5 months of age can reach for a sounding object in the dark (Stack et al., 1989). Perhaps the link between vision and an object is due more to an attentional mechanism which finds it hard to "disengage" from an object than to visual guidance of movement. This explanation would fit the observations of visual regard during HM coordination at 5 months, where vision appeared to be "hindering" rather than guiding the movement in some cases.

Another example of how comparisons across coordinations could be useful would be if babies showing segmented trajectories in HM coordination were also those with segmented trajectories in reaching and grasping. This would suggest that a general factor was responsible for such trajectories which was influencing performance over a range of motor coordinations. In conclusion, further investigation of processes of change in HM coordination could be useful in the understanding of other coordinations in early infancy, particularly with regard to common elements that might exist between the different coordinations.

7.6 Conclusion

The studies reported in this thesis provide an account of HM coordination which spans the development of the coordination from birth until it reaches a mature form, during the course of the second half of the first year. A picture of development emerges whereby the motivation to make HM contacts is already present at birth and continues during the first trimester. Postural factors and the immaturity of the neuro-muscular system act to constrain the expression of the coordination during this period. A shift also occurs during this period away from a motivation to make spontaneous contacts towards object-centred exploration. After about 4 months of age, the progressive emergence of skilled HM coordination can be observed.

In the introductory chapters, it was suggested that HM coordination could be a useful tool by which to study processes of change in motor development in early infancy. This suggestion has been borne out by the findings reported in the thesis. Although a relatively simple behaviour, the expression of HM coordination at different points in development was found to be the result of the interaction of many factors. These included maturational and postural factors, as well as more cognitive factors such as visual organization of exploration, and possibly visual guidance of movement. Different styles of movement were found during the transition from functional to skilled behaviour, possibly reflecting different strategies to "solve" the problem posed by the coordination. It was suggested that these individual differences could be exploited to investigate processes of change in motor coordinations in infancy, by seeing whether common elements in the movement strategies adopted by different babies are present across different coordinations.

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