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Time perception in infants : an exploration using eye tracking methodology

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Time Perception in Infants:

An Exploration Using Eye Tracking Methodology

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Abstract

Using eye tracking methodology, this thesis investigates if four-month-old infants can perceive short time intervals, as sensitivity to temporal parameters underlies cognitive development. Whilst the thesis draws on theoretical frameworks of understanding how animals and humans perceive short time intervals, it extends the framework, enabling the application of one developmental model of timing to be used with much younger children (four-months-old infants, formerly children aged three years old). Six eye tracking experiments investigated how infants perceive time intervals and the factors that might influence that ability. One hundred and nine typically developing four-month-old infants participated in the experiments, from which six main findings emerged.

First, overt behavioural evidence of infants keeping time over several stimulus sequences was obtained by using eye tracking methodology. This is the first time that this ability has been demonstrated using eye tracking which clearly indicates the focus of the infant's attention. Second, using naturalistic stimulus sequences young infants demonstrated a clear ability to perceive a number of different time intervals within one testing session, indicating the importance of using salient stimuli. Third, various influencing factors were observed to facilitate or hinder time perception such as speed of sequence presentation and the simultaneous presentation of both auditory and visual stimulus respectively. Fourth, the use of different information processing strategies to encode the stimuli revealed further differences in time perception. Fifth, and for the first time in these types of experiments, an infant-adapted temporal generalisation task has revealed similar results to children and animals. Sixth, infants demonstrated continued gaze-following over several stimulus sequences after a period of mutual gaze. Several issues concerning the processes underlying infant cognitive development are discussed together with their implications for later learning.

Declaration and acknowledgements

Declaration

This thesis comprises my own original work and due acknowledgement has been made to all material used within this thesis where appropriate. Financial support was provided by an Open University studentship. The thesis comprises less than 100,000 words (inclusive of tables, references, and appendices).

Eileen Margaret Mansfield

28th February 2012

Acknowledgements

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Note about use of numbers

Although usually numbers up to 10 are written as words, with numbers above ten written in numerals, in this thesis two exceptions have been made:

1. ages

2. number of participants

In the first instance, many ages span the divide between below and above ten, which would result in ungainly examples like "three to 99 years" or "four-month, six-month, and 11-month"; accordingly all ages are written as numerals.

Secondly, instances of number of participants look similarly ungainly when mixed, so they also appear in numerals.

Chapter 1
Infants and time perception: An introduction and overview

1.1 Introduction

The concept of time and its measurement has fascinated humans for millennia. Philosophers such as Zeno of Elea (about 490 – 425 BCE), Plato (427 – 347 BCE), Aristotle (384 – 322 BCE) and Augustine of Hippo (354 – 430 CE) all show evidence of meditating on the concept of time (O'Connor and Robertson, 2002). Augustine proposed that time was extremely complex, only existing in the created universe, and that God exists outside time. This is because he believed that time was only discernible in space through motion and change and therefore only discernible within the created universe. The movement of the sun and moon and other celestial bodies across the skies provided information for ancient peoples such as the Druids and the builders of Stonehenge to mark the passing of time externally. The Ancient Mayans, Sumerians and early Egyptian societies (around 3500 BCE) used the sun's shadow to measure external time by gauging its angle as it fell on the ground, thus ensuring the timely execution of sacred ceremonies (Ullmann, 1998). Since then, various methods of marking the passing of external time have been devised, such as sundials, water clocks, pendula, and more recently, atomic clocks (Jespersen and Fitz-Randolph, 1999).

The passing of internal time, or time within the body, is marked by circadian rhythms, from the Latin circa meaning 'about' and dies meaning 'day' (Reber, 1985). These mark time internally within the body via biochemical mechanisms that control different behavioural systems such as the sleep/wake cycle, which is mediated by levels of melatonin. Sleep/wake cycles, which last approximately 24.hours, and are presumed to operate as regular patterns or oscillators, (called endogenous circadian oscillators), have been explored by many researchers including Darwin (1881) and Richter (1922). Endogenous

oscillators reflect the passage of time in two ways: first, transient extrinsic inputs, such as nutritional factors, serve as timing signals to reset the internal clock; second, slow changing extrinsic inputs, such as steadily increasing or decreasing amounts of environmental light, modulate the length or period of an endogenous oscillation, facilitating or inhibiting activity in animals. An interesting example of the second type of input can be observed at dusk when diurnal animals and birds settle down to sleep while nocturnal animals and birds, such as the kiwi, are aroused to begin a night's foraging. During a total eclipse, as the moon's shadow slowly encompasses the sun and light begins to fade, diurnal animals begin to settle for the night only to be aroused a few minutes later when the light returns and they have to face another day!

Much research has focused on the operations and mechanisms underlying internal circadian rhythms as well as on external methods of marking time such as clocks and stopwatches. However, an area that has received considerably less attention is time perception. That is, how people perceive the passing of short time intervals, such as five minutes for an egg to boil, without the aid of external methods of marking time, such as clocks or egg timers.

The study of the internal perception of short time intervals is relatively recent and is referred to as time perception or interval timing. Meck (2003) defines interval timing as "the temporal discrimination processes involved in the estimation and reproduction of...intervals in the range of seconds and minutes" (Meck, Introduction, 2003:[1]). Interval timing is therefore the ability to perceive short time intervals. This line of enquiry originated in animal research but has since been extended to the investigation of human temporal abilities. For example, Fraisse (1963), Gibbon (1977), Wearden and McShane (1988), and Wearden (1999c) have devised methods by which animals and humans either reproduce short time intervals (e.g. 800ms) or to distinguish between either long (e.g.4s) and short (e.g. 1s) intervals or durations, suggesting that they had perceived these time intervals as demonstrated by either key or lever press responses.

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This thesis reports a series of experiments designed to investigate time perception or interval timing in infants. The area of time perception in infancy has been given little attention by researchers, even though sensitivity to temporal parameters (such as rhythm and duration) is known to contribute to cognitive and emotional development (Stern 1977; Wood and Terrel, 1998). One reason for this could be that given the methodological challenges of working with infants, "it is a difficult subject to investigate" (Judd, 1899:210). Although technological progress over the last century has undoubtedly enabled studies to be conducted with animals (Gibbon, 1977; Meck and Church, 1982) and humans from three to 99 years old (Wearden and Shimp, 1985; Droit-Volet, 1998; McCormack, Brown, Maylor, Darby and Green, 1999), there is a paucity of interval timing research with infants (Colombo and Richman, 2002; Colombo, Shaddy, Blaga, Anderson, Haas and Kannass, 2005) as it has proved difficult to identify appropriate tasks and equipment. This thesis therefore seeks to explore the exciting field of infant time perception more fully and thus create a platform for further research.

1.2 Why study Infant time perception?

Whilst fascinating, the proliferation of study into time perception with children aged three years and upwards has only served to highlight researchers' relative neglect of infants' timing abilities. Also, although over the past 30 years, there has been particular focus on other areas of infant development such as face perception (Johnson, 1999, 2007; Slater, Quinn, Kelly, Lee, Longmore, McDonald and Pascalis, 2010) and language development (Aslin, Pisoni and Jusczyk, 1983), little is understood about time perception in infants below 12 months of age. In order to deliver a broader and more balanced view of infant development this needs to be rectified. This thesis therefore seeks to make a contribution in this area.

By investigating how young infants perceive time intervals, a start can be made in understanding the early developmental processes involved in time perception. McCormack et al. (1999) and Droit-Volet (2003) have begun to examine the developmental changes that occur when young children aged three to eleven years

perceive time. However, only two studies (Colombo and Richman, 2002; Colombo et al., 2005) have been completed with infants who were four months old. Hence, given that infants' cognitive abilities and neural bases change exponentially within the first year of life, further research within this age group should illuminate understanding of the developmental course of time perception.

Much work into time perception has been conducted with animals, children and adults, showing that short time intervals, for instance durations of 5 seconds, can be perceived and acted upon by these groups (Gibbon, 1981; Wearden, Rogers and Thomas, 1997; McCormack et al., 1999; Droit-Volet and Wearden, 2001). Several models have been proposed to explain time perception in animals, such as The Behavioural Theory of Time (Killeen and Fetterman, 1988). In humans the dominant model in the field is the Scalar Timing Theory or Scalar Expectancy Theory (SET – see full glossary at Appendix 1) (Gibbon, 1977). A developmental version of the SET model (which this author will refer to as devSET from now on) has been used to explain the findings observed in children from three years of age (Droit-Volet, Clement and Wearden, 2001; McCormack et al., 1999). It has not, however, been applied to infant time perception. In this thesis the applicability of the devSET model will be applied to a much younger group (four month-old infants) for the very first time. Whilst little research has been conducted on infant time perception per se, however, there is a wealth of research exploring infants' sensitivity to temporal parameters in other areas. These include forming expectations (Haith, Hazan and Goodman, 1988; Adler, Haith, Arehart and Lanthier, 2008), rhythm perception (Stamps, 1977) and the temporal aspects of social communication and language (Stern, 1977, 2001; Jaffe, Beebe, Fieldstein, Crown and Jasnow, 2001). How understanding the operation of these various parameters forms a basis for infant time perception will be discussed in Chapter 2. But first, the next section will address the question of when infants might be expected to develop sensitivity to time intervals.

1.3 Time perception in childhood and infancy

Time perception in children has been described in two ways in the literature; either in terms of interval timing, that is their ability to judge short time intervals in the range of seconds or minutes, or by consideration of the cognitive processes involved in reasoning about time. The Piagetian view (Piaget, 1969) for example states that children judge the passing of time by using their ability to understand and reason logically about it (Piaget, 1969). As infants are not attributed with reasoning logically about time in the Piagetian sense, it is assumed, according to this view, that they are unlikely to perceive or be able to judge short time intervals. Indeed, it is reasonable to ask why infants would need to do this.

The experience of infants has been famously described by William James (1890:488) who said "The baby, assailed by eyes, ears, nose, skin, and entrails at once, feels it all as one great blooming, buzzing confusion." For infants to develop socially, emotionally and cognitively they need to be able to make sense of this 'buzzing, blooming' and 'confusing' world. Having some rudimentary understanding of timing parameters may help here. An infant begins this process of understanding in the womb by experiencing regularly occurring events such as the rhythm of her own and her mother's heartbeat, and her mother's voice. Speech and heartbeat are easily distinguishable despite the noisy environment of the womb (Querleu, Renard, Versyp, Paris-Delrue and Crepin 1988). In a study conducted by DeCasper and Sigafoos (1983) the sound of intrauterine heartbeats reinforced bursts of sucking in newborns, whilst in a later study, DeCasper, Lecanuet, Busnel, Granier-Deferre and Maugeais (1994) found that foetal heart rate decreased when foetuses were played audio recordings of their mother reciting a rhyme she had read aloud daily for four weeks during the third trimester of her pregnancy. These studies suggest that foetuses and infants become familiarised to these recurrent sounds within the womb, lending weight to the argument that infants have an awareness of relatively fine-grained regularities, even at this earliest period.

Other more gross regularities of a practical nature are observed when an infant cries. At the sound of crying the caregiver soon appears to address the problem, and in this way the infant begins to build an attachment relationship with the caregiver (Bowlby, 1958), due to the recurrent nature of the caregiver's response. In addition to building attachment relationships, recurrent events also enable infants to learn about their environment in other ways such as intersensory perception (Bahrick, 1987; Lewkowicz, 1994). By associating the sound of the caregiver's voice with the synchronous movement of her mouth, an infant begins to understand that the two are interconnected, being able to link her voice to her face (Bahrick, 2005). This type of understanding is sometimes described as statistical learning, that is, the ability to detect predictable repetitions such as the patterns of sounds in the stream of speech during language acquisition (Saffran, Aslin, Newport, Balota and Marsh, 2004), or the patterns of turn taking in social interaction (Stern, 1974). It is thought that understanding these kinds of relationships are essential for attachment (Bowlby, 1958).

So an ability to learn from and make predictions about recurrent events within the environment enables infants to make sense of their 'buzzing, blooming' and 'confusing' world (James, 1890) by building attachment relationships, learning language and engaging in effective social interaction. These fundamental building blocks of an infant's emotional, cognitive and social development will be revisited in more detail later in this thesis. A further building block that has not been discussed so far is an infant's ability to perceive short time intervals.

1.4 A brief consideration of infant time perception to date

To date, Colombo and colleagues (2002, 2005) have been the only researchers to investigate if infants of four months can keep time. They measured the heart rate responses of infants when presented with an alternating light/dark stimulus sequence at regular intervals. When this sequence was subsequently disrupted, 500ms after the stimulus should have appeared, Infants' heart rate was observed to decrease. These findings suggested that an awareness of timing was present even at this early stage of

development. However, it could be argued that this research really centred on attention rather than time perception with, in the absence of a stimulus, waning of attention being responsible for the observed decrease in heart rate.

Further research conducted by Brannon, Roussel, Meck and Woldorff (2004) measured brain activity in ten-month-old infants when presented with deviant auditory tones (e.g. of 500ms) within a sequence of standard auditory stimuli (e.g. 1500ms) and found different brain activity between the two stimuli, suggesting that infants were able to perceive the difference in duration of the two tones and that, therefore, they had some awareness of awareness of time parameters such as duration.

Neither of these studies was interpreted according to models of time perception. There were also several limitations to these studies, as they did not identify the actual focus of attention, for instance, infants could not point or look to a stimulus or complete key or button presses. Therefore the researchers could not identify whether infants were simply attending to some sort of change in a predictable sequence or the difference between one tone and another without noticing differences in time of the inter-stimulus interval or duration. The research within this thesis seeks to build on Colombo and colleagues' work, and utilise their findings to design further studies into infant time perception; a more detailed discussion will follow in Chapter 2.

1.5 Methodologies and debates

As has already been established, research on time perception in infants is limited with some researchers arguing that it is difficult to ascertain time perception abilities in participants younger than three years of age. Piaget (1969), for example, argued that infants under the age of six months have no sense of time/temporal duration. Crown, Feldstein, Jasnow, Beebe and Jaffe (2002:2) challenge this viewpoint, however, stating that "that temporal coordination of behaviour is the bedrock of all social interaction", therefore, infants must have a rudimentary ability to judge temporal duration as they can engage in finely tuned turn-taking during 'proto-conversations' with their caregivers. This

debate suggests that it is necessary to take into account age, task and methodology used to test the phenomenon when considering the explanations offered to date.

Two main methodological measures have been used to test infant time perception to date: the first is heart rate (Clifton, 1974; Stamps, 1977; Donohue and Berg, 1991; Colombo and Richman, 2002; Colombo et al., 2005) and the second, electroencephalogram event related potential (EEG/ERP) responses to auditory stimuli (Brannon, Roussel, Wolfe, Meck and Woldorff, 2004; Brannon, Libertus, Meck and Woldorff, 2008), both of these are examined in depth in Chapter 2. An important limitation common to both these methodologies is that as they examine internal physiological responses, there is no direct way of ascertaining whether participants are looking at or attending to the stimuli.

Nonetheless, studies employing alternating light/dark sequences (Colombo and Richman, 2002; Colombo et al., 2005) relate directly to this thesis, although, instead of measuring changes in heart rate, an eye-tracking methodology will be used to measure changes in the duration and direction of eye gaze in infants in response to light/dark stimulus sequences. The research reported in this thesis, therefore, endeavours to redress the current imbalance in the literature by gaining an understanding of which specific aspects of the stimuli presented influence time perception, thus offering new insights into how very young infants perceive their temporal world. The following section briefly outlines the key theoretical and methodological debates that have informed the research reported in this thesis.

1.6 Theories and models of time perception

The nature of timing tasks demands that a time interval is estimated, requiring some sort of marking or counting to be performed for a unit of time to be measured. Within the literature it is accepted that an internal mechanism such as an internal 'clock' (Creelman, 1962; Treisman, 1963) is needed to fulfil this function. Numerous types of internal clock models have been proposed to account for timing behaviours in animals (Gibbon, 1977; Killeen and Fetterman, 1988) and humans (Creelman, 1962; Treisman, 1963).

Several ideas have been presented about what drives this internal clock. For instance, Treisman and colleagues (Treisman, Faulkner, Naish and Brogan, 1990; Treisman, Cook, Naish and MacCrone, 1994; Treisman, 1999) proposed a model consisting of a series of oscillators that mark time at regular intervals. Different oscillators mark different durations, for example milliseconds, seconds, minutes, hours, days etc. So to mark the duration of a minute, for instance, the 'minute' oscillator will turn full circle once. Thus durations are estimated by the number of times that the oscillators have rotated (Church and Broadbent, 1990). An alternative view, however, proposes that a 'pacemaker' emitting pulses at regular intervals services the clock component.

The dominant theory of time perception, Scalar Expectancy Theory (SET) (Gibbon, 1977) and the SET Model, and the developmental version of SET, devSET (McCormack et al., 1999; Droit-Volet and Wearden 2001; Droit-Volet 2003) incorporates a pacemaker (see Figure 1.1). As discussed previously, the devSET model seeks to explain how timing responses differ across the lifespan from children to adults and older adults. Notably, this thesis represents the first time that the SET and devSET models have been applied to infants, as to date, application of these models has only ever been made to data obtained from children aged three years and above (Droit-Volet, 2003) and so no previous infant data can be discussed in relation to these models. The second way in which time perception has been accounted for is through the Mode Control Model (Meck and Church, 1983), although this has been used more extensively to explain the connection between number, time and ratio discrimination. These models are briefly outlined below, and discussed in depth in Chapter 2.

The SET model (Gibbon, 1977), was originally formulated to account for animal behaviours, but was later extended to humans (McCormack et al., 1999; Droit Volet, 2003). This model consists of three components: the Clock component, driven by a pacemaker, the Memory component, and the Decision component (see Figure 1.1). At the onset of a to-be-judged duration the pacemaker emits pulses that are stored in an accumulator of the clock component before being passed to the memory component. The

to-be-judged duration is then compared to a stored duration within the decision component and an appropriate response initiated. Figure 1.1 identifies these original components along with later modifications and additions suggested by Lejeune (1998) and Zakay and Block (1996).

Figure 1.1 The SET Model (Gibbon, 1977)
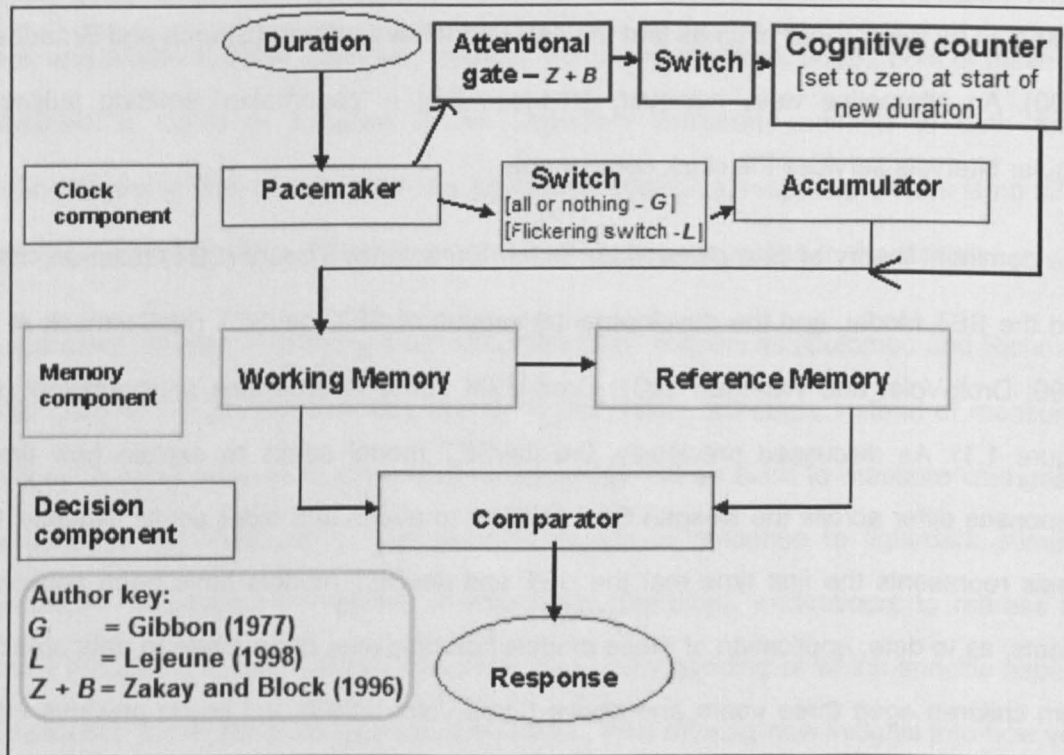
Timing tasks adapted from those used with animals for use with human adults provided similar results; however, when these same tasks were used with children, developmental trends were observed, for instance, response variability. These have been explained using the devSET model (Droit-Volet and Wearden, 2001; Droit-Volet, 2003). The devSET model, accounts for differences in the sources of variance observed for young children compared with adults by proposing that this variance occurs in four ways: first, increased random responding observed in young children; second, wider variability in the reference or standard duration held in reference memory; third, a resulting distortion of the standard duration that influences accuracy in responding; and fourth, a conservative response bias on the part of younger children leading to longer responses.

The information-processing Mode Control model (MCM) has been proposed to account for similarities between number and time discrimination. With three comparable components to the SET model, it works in a similar way but includes a mode switch allowing the model to count either time or numerical magnitude. This model has been used to show that children and infants possess a 'pre-verbal number sense' that is they are able form a rough mental estimation of the magnitude of the number of items in a presented array (Barth, La Mont, Lipton, Dehaene, Kanwisher, Spelke, 2006; Spelke and Tsivkin, 2001; Xu and Spelke, 2000). This model attempts to accounting for infants and young children being apparently able to add and subtract (van Marle and Wynn, 2006) and discriminate ratios (Brannon, Suanda and Libertus, 2007), or notice changes to the number of items in an array before a formal symbolic sense of number is learned. This has led researchers (Brannon et al., 2006; van Marle and Wynne, 2006) to suggest that the numerical and timing abilities of infants and animals are linked and can be accounted for by the MCM; although no study directly testing this hypothesis has been conducted to date.

Figure 1.2 The Mode Control Model (Meck and Church, 1983)
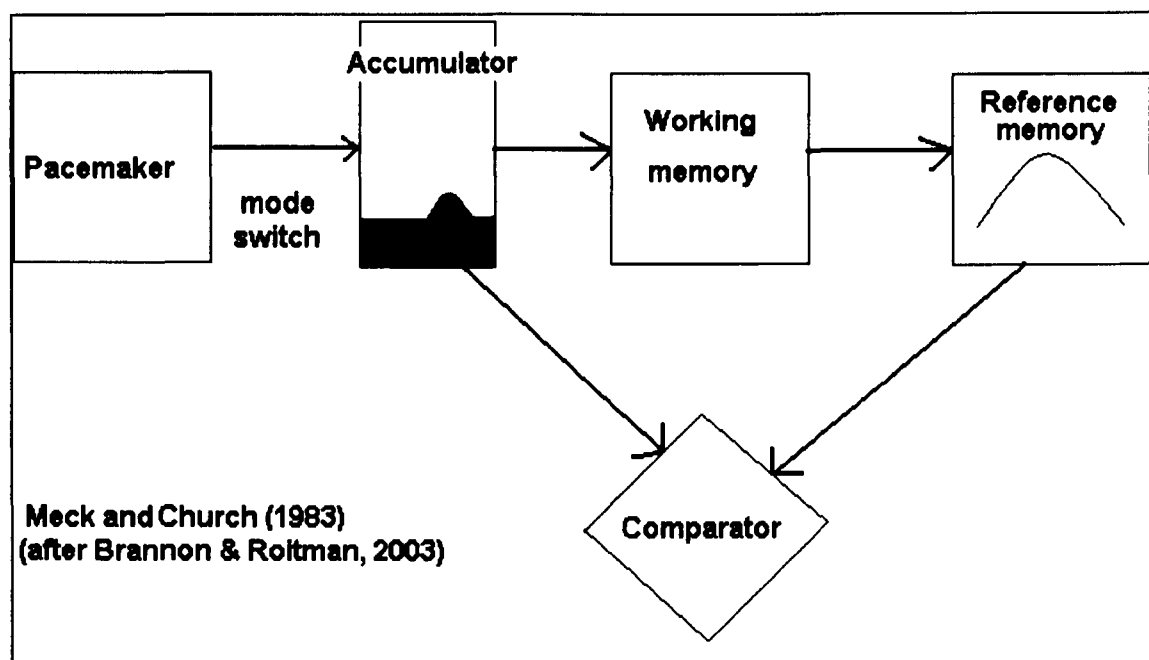
Having briefly outlined the relevant time perception models that focus on the role of memory, it is important that attention should also be considered as this has been shown to

influence the perception of durations (Block, George and Reed, 1980). Notably, attention has received little interest to date and is not directly accounted for within the SET model, presenting an exciting opportunity for further research. This will be discussed within the next section.

1.7 Factors influencing time perception

For completeness, the factors that have been shown to influence time perception are briefly discussed within this section but examined more fully within Chapter 2. These factors are the role of attention, the influence of environmental changes on time perception, the importance of synchrony and time intervals involved in social interaction and finally the roles of expectancies and individual differences within time perception. The discussion begins with the role of attention in time keeping.

In everyday life, events occur all around us that we are not aware of because we do not attend to them. There are two dominant theoretical explanations for this, the first proposes a peripheral attentional filtering mechanism whereas the second a limited capacity central capacitor. . Selective attention theory proposes that incoming information is filtered or selected at an early stage of perceptual processing (Broadbent, 1958; Treisman, 1963) with unattended information either being blocked (Broadbent, 1958) or left lying dormant until required (Treisman, 1963). The second approach proposes that humans allocate attentional resources to a task via a central capacitor at a later stage of information processing (Kahneman, 1973; Norman and Bobrow, 1975). In terms of time perception then, according to this model, the allocation of attentional resources to temporal information per se is completed after the stimulus has been perceived and thus determines the perceived duration of the interval (Block, et al. 1980).

Attentional mechanisms have been divided into four levels within the infancy literature (Richards and Casey, 1991). The four levels are Stimulus Orientation (SO) where an infant orients to the focus of attention to the stimulus; Sustained Attention (SA) where infants are thought to process information most effectively; Pre-Attention Termination (PAT) where infants begin to disengage attention; and finally, Attention Termination (AT) where infants

disengage attention from the object or event (see Figure 1.3, below). Heart rate responses differ for each of these levels, the deepest being SA which is marked by a decrease in heart rate response. During periods of SA, infants have been shown to pay more attention to stimuli as demonstrated by their enhanced recognition abilities and reduced distractibility than during other attentional periods (Richards and Casey, 1991).

Figure 1.3 Levels of attention (Richards and Casey, 1991)
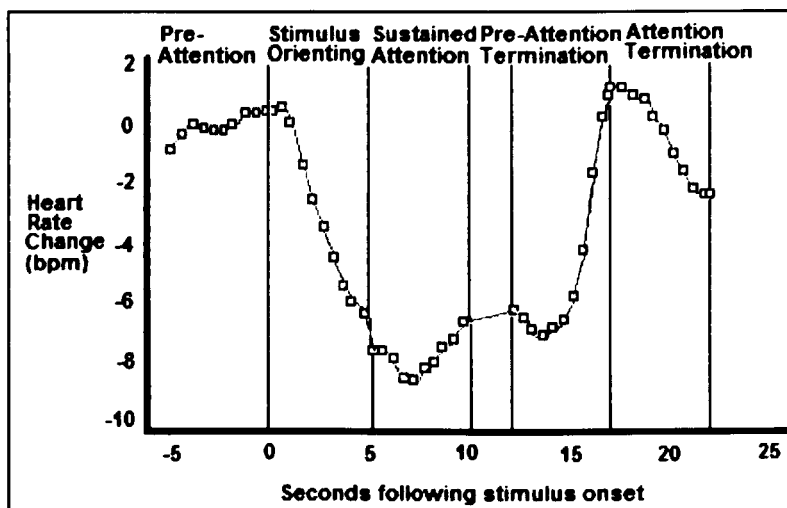
Relating attention to time perception, Colombo and Richman (2002) and Colombo et al. (2005) found that infants who had engaged in deeper levels of SA – as observed by lower heart rate responses in a pre-test – were more accurate time keepers during test trials in comparison to other infants in their sample. This finding suggested that there were links between attention and time perception in infancy. However, as these authors discussed their findings within attention literature rather than time perception literature, they did not explore the possible nature of these links.

The influence of attention on interval timing has not been directly accounted for within either the original SET or devSET models, and has received relatively little investigation compared to the role of memory. Nevertheless, attention is thought to underpin timing (Block and Zakay, 2001) by influencing the pulses that flow from the pacemaker through to the accumulator within the clock component (see Figure 1.1). Various cognitive models such as the Attentional Gate Model (AGM) (Zakay and Block, 1996) and the Flickering

Switch Model (FSM) (Lejeune, 1998) have sought to address this issue and have resulted in additions to the original SET model (see Figure 1.1). Theoretical differences between the FSM and AGM models come from the two approaches to attention discussed above. The AGM favours capacity theories whilst the FSM favours filter theories. Arousal levels have also been proposed by Treisman (1963) to influence time perception leading to the introduction of an arousal centre within the clock component. Whether modulated through a specific arousal centre (Treisman, 1963), an attentional gate (Zakay and Block, 1996) or a flickering switch (Lejeune, 1998), it is clear that attention is an influencing factor in time perception. How has this been tested?

Some initial work has been conducted by Droit-Volet (2003), who used a warning auditory click to alert groups of three-, five-, and eight-year-old children of an upcoming duration in a timing task. The role of attention in children aged five to six years old was also investigated by Zakay (1992). The findings of these studies suggest that attention influences time perception in children. But as there is little infant research in this area, additional investigation with this group would be beneficial. In addition to attention, a further factor discussed within the cognitive models is the role of environmental changes, so what are these and how might they influence time perception?

Environmental or contextual changes have been defined by Hintzman and Block (1971) as being either within the person, e.g. their attentional state (such as being aroused or bored), biological state (such as being hot or hungry), or emotional state (such as being happy or anxious). Alternatively, contextual changes can be external to the person, such as being in a location that is new, noisy, or stimulating. As all of these different changes can influence how time is perceived, contextual change was tested within the experiments reported here.

The foregoing discussion indicates that time perception is mediated by both memory and attention and that initial work has begun to explore the various influencing factors. In everyday life, however, there are other cues that might influence time perception, such as synchrony, for instance, synchronous lip movement with speech sounds, and social

saliency; that is, stimulus that is socially meaningful to a person such as a game of peek-a-boo. Therefore, a brief review of the temporal aspects of social communication and attachment will now follow to ascertain if any particular time intervals might be usefully employed when studying infant time perception.

The temporal characteristics of early interaction between a mother and her infant have been shown to be critical for the development of emotional wellbeing and attachment (Ainsworth, Bell and Stayton, 1974; Brazelton, Koslowski and Main, 1974; Isabella, Belsky and von Eye 1989; Isabella and Belsky, 1991). Attachment is defined by Bowlby (1958; 1969) as the child's close emotional attachment to primary caregivers, usually the parents. Within social interactions, bursts of activity, such as vocalisations and pausing, appear to take place within a three-second (3s) interval (Jaffe, Beebe, Fieldstein, Crown and Jasnow, 2001), and, during this interval, each partner within the interaction works together synchronously (Stern, 1977) to achieve a successfully coordinated interaction. Furthermore, regularity and repetition within interactions allow infants to gain experience of variations on a theme, such as varying pitch and pace when saying 'hello' (Stern, 1974; 1977; 2002). As repetitive sequences are frequently observed in the daily lives of infants it was thought to be important, therefore, to incorporate this feature into the experiments undertaken in this thesis. The ability to learn through familiar events or situations and form expectancies about them has also been identified by Haith and colleagues (Haith, Hazan and Goodman, 1988) to be important for infant cognitive development.

The term 'future oriented processes' or future goals coined by Haith, Wentworth and Canfield (1993:251) refers to the fact that many actions that are performed, such as turn-taking within social interactions, are based on expectancies held about future events, some of which are temporally based. Haith (1993) argues within the first year of life, detecting regularities in the world about them, allows an infant to form expectations based on these regularities. Studies conducted by Haith and colleagues (Haith, Hazan and Goodman, 1988; Wass, Bihun and Haith, 1996; Canfield, Smith, Brezsnyak, Snow, Aslin, Haith, Wass and Adler, 1997) demonstrated that infants form both spatial and temporal

expectancies about forthcoming predictable events. Therefore, it seemed logical to incorporate predictability into the experiments described in this thesis to extend our knowledge of infant temporal perception.

Discussion of the SET and devSET models has generally assumed that all infants behave in an identical manner, but this is not the case. There is a large body of evidence suggesting considerable individual differences, for instance in face recognition and social intelligence (Wilhelm, Herzmann, Kunina, Danthiir, Schacht and Sommer, 2010), and in children's approaches to learning (Li-Grining, Votruba-Drzal, Maldonado-Carreno and Haas, 2010). Pertinent to this thesis is Colombo's (1993) suggestion that during early infancy there are individual differences in look duration that influence perceptual processing of visual stimuli. This position will be discussed next.

Within the infant developmental literature it has been proposed that individual differences in information processing strategies influence a variety of developmental outcomes such as cognitive processing efficiency (Colombo, 1993), IQ at six years old (Rose, Feldman and Wallace, 1992) and eleven years old (Rose and Feldman, 1995), and disengagement of fixation (Frick, Colombo and Saxon, 1999). Furthermore, these individual strategy differences are underpinned by different neural pathways (Colombo, 1995). Individual differences in visual information processing strategies can be characterised by the length of look duration. Short-looking infants, who scan a scene fleetingly, are thought to process information in a global or holistic manner. By contrast, long-looking infants, who make fewer but longer looks to a scene, are thought to process information in a local or featural manner. Since such differences have been documented within the literature over the past three decades, it could be argued that these differences might also extend to time perception. This thesis will investigate whether identifiable base-line differences in look duration between sub-groups of infants have any influence on time perception. This aspect will be developed in more detail in Chapter 4.

The discussion so far reveals that the perception of time involves many factors such as memory and attention. The role of attention within timing literature has received little

attention compared to memory and thus could provide a useful platform for future research. Furthermore, a review of apparently disparate areas of infant literature such as attachment, individual differences and formation of expectancies, reveals that intervals of under 3s are important for successful parent-infant interactions, as are regularity, repetition and environmental cues. The fact that infants are aware of temporal parameters within interactions and that these help build secure attachments, suggest that infants already possess this awareness at birth or that it develops shortly thereafter. The aim of this section has been to introduce these areas in preparation for more detailed discussion in Chapter 2. Importantly though, as the studies reported in this thesis involve infant participants, the ethical and practical considerations when conducting research with this participant group require some attention and are considered in the following section.

1.8 Ethical and practical considerations with infant research

Ethically speaking, infants constitute a vulnerable group and as such great care must be taken to comply with the ethical guidelines laid down by the British Psychological Society (2004; 2006; 2009). For instance, mothers are understandably concerned about protecting their infant within the unfamiliar testing situation, but they may also experience anxiety related to whether their child completes the task to a satisfactory standard, known as performance anxiety (Bishop and Chace, 1971). Furthermore, the needs of any accompanying siblings must also be met.

In addition to the ethical issues, there are many practical considerations such as infants' physical and cognitive abilities (Shirley, 1931; Bayley, 1955). Cognitive maturation of attentional and memory mechanisms is an additional factor that needs to be considered, as it is understandably limited at the age of four months. Although by four months, infants' attentional systems (Mountcastle, 1978; Courage and Howe, 2004; Greenspan and Shanker, 2007) appear to be fairly well developed. Nevertheless, although infants have good ocular-motor control and sit upright with support at four months, they have also 'found' their hands and feet, and these can distract their attention from the task in hand, especially if feet are covered in highly colourful socks. Teething pain is another factor that

can potentially affect their task performance. Further detailed discussion of ethical and practical considerations of infant research is given in Chapter 3.

As discussed in section 1.7, potential individual differences in information processing (Colombo, 1995), that is, the encoding of visual information in the world around us using long- and short-information processing strategies also need to be taken into consideration when carrying out research with young infants. This is examined in more detail in Chapter 4. Having discussed the various areas of research that offer potential avenues to explore in relation to the development of time perception in early infancy, a summary of this chapter now follows.

1.9 Chapter summary and areas for further research

The focus of this thesis is to explore if infants possess an ability to keep time; that is, can they perceive short time intervals in the range of seconds (Meck, 2003). It has been argued that possessing sensitivity to temporal parameters is vital for making sense of the world, as infants learn regularities and use these to form expectations about future events.

The first part of this chapter reviewed initial work undertaken to date investigating infant time perception, noting that while some limited research had been conducted, none of it had been placed within time perception literature. The discussion then turned to exploring theories of time perception and the models used to explain the research findings. It was seen that although many timing theories exist, in reality most are based on the Scalar Expectancy Theory and the SET model. Of particular interest was the devSET model, which seeks to explain the research findings from different age groups and in particular differences between adults and children. Whereas similar findings are observed in the responses of adults and children of eight years and above to timing tasks, the responses of children between the ages of three and eight years differ (Droit-Volet, Clement and Wearden, 2001; McCormack et al., 1999). The devSET model, which seeks to determine the sources of variance that account for these differences, has mainly tested variation in relation to the influence of memory on timing; however, little research has been conducted on the influence of attention. Since to date, the devSET model has not been used to

explain timing behaviour from infancy, this research seeks to extend the application of this model here for the first time.

Although not directly placed within the SET model (although it is briefly mentioned), the work of Colombo and colleagues (Colombo and Richman, 2002; Colombo et al., 2005) has made a start in examining the role of attention in infant time keeping, using heart rate as a key measure. However, neither heart rate nor EEG/ERP (Brannon et al., 2004; Libertus et al., 2008) allow the specific focus of attention to be examined. A means of overcoming this limitation would be to investigate time perception using eye movement responses. As this method has not been used to examine time perception to date, the research conducted in this thesis represents the first time that this has been undertaken.

Further discussion in this chapter, has revolved around the importance of regularity, repetition and predictability within daily life and social interaction (Stern, 1977, 2001) as this facilitates the formation of expectancies and subsequent learning (Haith, 1993). Additionally, the influence of global or featural information processing strategies used by infants, was hypothesised to be an influencing factor in time perception, and has been explored for the first time in this thesis. Finally, the ethical and practical issues arising from conducting research using infant participants were reviewed. The remaining section of this chapter sets out the organization of the thesis.

1.10 The organisation of this thesis

Chapter 2 offers a detailed account and critical discussion of the current models within the field, and an explanation of the empirical work that supports them to show how the main issues, debates and questions have been addressed to date. It reviews the gaps in our knowledge and understanding of infant time perception, and how the research within this thesis endeavours to make a contribution to these areas by investigating the research questions identified.

An outline of the general research design is given in Chapter 3, with an account of the methodological approach taken as well as ethical issues and sampling strategy.

Chapters 4 to 10 are empirical chapters offering detailed accounts of the various experiments designed to answer the research questions identified in Chapter 2.

Chapter 4 describes how a baseline measure was obtained based on length of look duration, in order to categorise the individual differences in information processing strategies used by each participant. These categories were then employed in each of the subsequent experiments to explore the research questions in more detail.

Chapter 5 outlines the first experiment, examining if infants can perceive short time intervals using inanimate stimuli adapted from Colombo and colleagues (Colombo and Richman, 2002, Colombo et al., 2005). The experiment described in Chapter 6 modified the stimuli by including face images, adding interest for the infant. The subsequent experiment, reported in Chapter 7, examines the influence of information processing strategies on time perception, whilst the impact of auditory cues is explored in Chapter 8. Following a change from inanimate stimuli in previous experiments to animate stimuli, Chapter 9 examines the influence of social salience on infant time perception, with the final experiment discussed in Chapter 10, reporting on the influence of stimulus complexity.

A general discussion is provided in the final chapter, examining the experimental findings in relation to the theories and research established in the introductory and methodology chapters, specifically appraising these findings against the framework of the devSET model as well as considering alternative explanations for the research findings. Finally, informed conclusions and proposals are offered for future research.

Chapter 2
Literature review

2.1 Introduction

Having briefly outlined the 'backdrop' for this thesis, this chapter offers a detailed account and critical discussion of the current models within the field, and an exploration of the empirical work supporting them to show how the main issues, debates and questions have been addressed so far. It will review the gaps in our knowledge and understanding of infant time perception, and how the research reported in this thesis will endeavour to make a contribution to these areas.

This chapter covers infant time perception research, models and theories of time perception, visuo-spatial and inter-sensory perception, and individual differences in look duration. Prevailing models and theories within the wider time perception research to date, which offer the greatest relevance to this thesis, will be reviewed, whereas the visuo-spatial and inter-sensory aspects that are less relevant will not receive such detailed discussion.

2.2 Infant time perception research to date

As previously mentioned, a small number of time perception studies have focused specifically on infants and employed two different methodologies: heart rate methodology and EEG/ERP. A handful of studies (Clifton, 1974; Stamps, 1977; Donohue and Berg, 1991; Colombo and Richman, 2002; Colombo, Shaddy, Blaga, Anderson, Haas and Kannass, 2005) have used heart rate methodology, and relate directly to this thesis. Two other studies conducted by Brannon, Roussel, Wolfe, Meck and Woldorff (2004) and Brannon, Libertus, Meck and Woldorff (2008) respectively, have examined EEG/ERP responses to auditory stimuli to provide evidence of neural activity involved in infant time keeping. These studies will now be discussed in more detail.

2.2.1 Infant research using heart rate

Early infant time perception studies used conditioning designs to examine if heart rate responses were temporally sensitive. Both Clifton (1974) and Stamps (1977) worked with newborn infants up to 80 hours old while the participants in the Donohue and Berg (1991) study were seven months old.

In the Clifton (1974) study, newborns were divided into three groups, the conditioning, random control and backward conditioning groups. The conditioned stimulus (CS) was an eight-second tone, and the unconditioned stimulus (UCS) was a ten-second presentation of glucose via a pacifier. During the training phase, the conditioned group received the CS followed by a 6s interval and then the UCS. The procedure for the random control group and the backward conditioning group was exactly the same, except for the administration of the glucose, which was given at random intervals or during the ten seconds prior to the onset of the tone to each group respectively. After the presentation of 30 trials, the UCS was omitted and a significant decrease in heart rate at the time of stimulus omission was observed in the conditioning group only. This suggested that the infants in this group had learned the time interval and were expecting the glucose reward to follow, indicating that heart rate is a useful indicator of infant time perception.

Also using a classical conditioning design, Stamps (1977) investigated gender differences and heart rate variability in temporal sensitivity by examining heart rate responses in anticipation of a tone presented for 2s (UCS). Two groups of newborn infants were presented with the UCS. In the experimental group, this occurred every 20 seconds and was omitted after the 7th, 13th, 18th and 22nd UCS, whilst in the control group, the UCS was presented semi-randomly at 10, 20 or 30 second intervals. The results showed that heart rate levels in both groups increased in response to the UCS, but returned to baseline faster in the experimental group than the control, suggesting that this group perceived the sequence as less ambiguous. During the omission trials, no heart rate deceleration was observed in the experimental group at the time of the omitted UCS, indicating that they had not perceived the time interval. Whilst girls were observed to show more anticipatory

responding than boys in this study, the opposite held true in an earlier study (Stamps and Forges, 1975), so no clear relationship between gender differences and heart rate variability emerges.

Whilst the Clifton (1974) study, as noted above, demonstrated the ability to recognise the arrival of a paired stimulus by its absence, the ability to anticipate its arrival was explored with seven-month-old infants and adults by Donohue and Berg (1991). A "small percussive" toy in a box surrounded by lights (S2) was paired with white noise (S1) in 17 out of the 20 trials in the study. Each trial lasted for 15 seconds. In the control trials S1 was presented for 10s, then S2 was paired with S1 for 2 seconds and S1 presented for the remaining 3 seconds. During omission trials (trials 6, 13 and 17), S1 was presented alone for the whole 15 seconds. As the inter-stimulus-interval (ISI) varied randomly in each trial from 13 to 35 seconds the studies lasted for between 560 seconds (9.33 minutes) and 1,000 seconds (16.66 minutes). The results showed that after 12 trials, heart rate levels of both infants and adults started to decrease just before the arrival of the S2, reaching their lowest point at the time of S2 arrival, thus indicating their anticipation of this event. To analyse the omission trials, the heart rate levels of the last paired trial and the last omission trial were compared. These were called trial sets. The results for the three omission trial sets varied, showing a deceleration in heart rate in the paired trial only for the first two trial sets, but with an observable, yet statistically non-significant, decrease in the third omission trial set. According to the authors, this suggested that participants may have learned the time interval as the decrease in heart rate levels had become "temporally precise". In their discussion of these non-significant results, the authors did not mention infant fatigue which could have been a key factor since the studies lasted between 9 and 17 minutes. Infant researchers in other research centres limit testing time since the attention span of young infants is between 2 and 8 minutes (Johnson, 1999). In recognition of this factor, the experiments reported in this thesis ran for no longer than 8 minutes.

The temporal sensitivity of heart rate responses was further investigated by Colombo and Richman (2002). The responses of two groups of four-month-olds were measured when presented with an alternating light/dark stimulus sequence at predictable timings. The alternating light screen (ON) appeared for 2s, but timings varied for the dark screens (OFF), with the ISI for the first group being 3s, but 5s for the second group. After presenting the stimuli nine times, the sequence was disrupted so the dark screen appeared for 15s: the omission trial. Each group saw only one stimulus sequence. Heart rate responses decreased within 500ms of the onset of the stimulus omission trial for each group at their particular interval (i.e. 3s and 5s) therefore the authors reasonably attributed time perception to both groups.

Further, it was shown that infants who had engaged in high levels of Sustained Attention (SA), as observed by lower heart rate responses in attentional pre-tests, were more accurate time-keepers than those who had demonstrated low levels of SA. That is, the heart rate of the high SA group decreased by four beats per minute about the time of stimulus omission, whereas in the low SA group, this decrease was 2 beats per minute. As previously mentioned, SA is one of four levels of attention defined by Richards and Casey (1991) which, they argue, are characterised by different heart rate responses, the deepest being SA, and indicate different levels of information processing.

The initial infant timing study by Colombo and Richman (2002) was replicated and further extended by Colombo et al. (2005). In this one trial study two groups of both four-month- and nine-month-old infants were shown light/dark stimulus sequences at three different ISIs, 5s, 10s and 15s, and changes in heart rate response noted in the omission trial after trial 9. As in the original study, the infants were allocated to high and low SA groups based on their performance during attentional pre-tests. Although heart rate responses were seen to decrease after the onset of stimulus omission in the 10s and 15s ISI sequences, in the 5s ISI sequence heart rate continued to increase in a linear pattern. As, by contrast with the previous study, a decrease in heart rate response was not observed at this time interval, the earlier findings were not replicated although the authors have not attempted

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to explain this. On looking at whether differences in levels of SA affected time keeping, differences were observed in the 10s and 15s intervals. Those infants who had engaged in higher levels of SA were again shown to be more accurate time keepers than those who did not, showing a greater decrease in heart rate response about the time of stimulus onset.

The studies discussed above using heart rate methodology clearly show that infants are sensitive to temporal intervals when presented with predictable stimulus sequences. Having briefly reviewed heart rate studies, the discussion will now focus on the second methodology used, electroencephalogram (EEG).

2.2.2 Infant research using electroencephalogram (EEG)

The papers authored by Brannon et al. (2004) and Brannon et al. (2008) investigated EEG responses to the auditory 'oddball' paradigm (explained below). EEG is the recording of the brain's naturally occurring electrical activity. Unlike other brain imaging methods such as Functional Magnetic Resonance Imaging, EEG techniques are non-invasive so parents/caregivers are more willing to allow their typically developing infants to participate in research studies investigating brain development. Event related potentials (ERPs) are derived from sections of EEG recordings that relate to a specific event (EEG/ERP). For instance, by examining the pre-determined sections of EEG waveforms either side of a presented stimulus, differences in brain activity (e.g. latency, amplitude and location) to a target or non-target stimulus (such as visual shapes) can be detected (Csibra, 2002; Csibra and Czigler, 1991). Importantly, EEG/ERPs reveal which parts of the brain are active in response to a specific event and when that activity occurs. Although this method has better temporal than spatial resolution, that is provides better information about events involving timing rather than those involving location.

Mismatch Negativity (MMN), a negative ERP component, has been associated with timing and is associated with the automatic detection of durations (in the auditory modality) within the range of milliseconds, seconds and longer (Naatanen, Syssoeva, and Takegata, 2004). MMN waveforms arise from the onset of a deviant stimulus placed within a stream

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of standard stimuli (Naatanen and Winkler, 1999). This paradigm is called the 'oddball' method. The amplitude of the MMN waveform is attenuated when longer ISIs are placed between standard and deviant stimuli (Mantysalo and Naatanen, 1987), but lost completely if the ISI between two deviant stimuli is shortened to under 200ms (Sussman, Winkler, Ritter, Alho, Naatanen, 1999). Whilst there is no difference in amplitude of the MMN between three-month-old infants and adults, the latency has been found to be longer for infants (Cheour, Alho, Ceponiene, Reinikainen, Sainio, Pohjavuori, Aaltonen and Naatanen, 1998).

Building on the association of MMN with timing, Brannon et al. (2004) sought to elicit an MMN in 10-month-old infants using an auditory oddball method. Brannon et al. (2004) presented two age groups, 10-month-old infants and adults, with 50ms tones. These were separated by either a standard ISI of 1500ms or by random intervals, technically termed as 'deviant' intervals, such as intervals of 500ms. Tones that followed random deviant intervals elicited different brain responses from tones following the standard intervals. The data for both adults and infants revealed similar responses with negative components followed by positive components arising in the auditory and right frontal cortices, supporting the findings of Cheour et al. (1998). However, infants' responses revealed longer latency (30ms) and higher amplitudes than the adult responses, which indicated developmental differences in brain activity – findings which differ from those found by Cheour et al. (1998). Additionally, an earlier question – whether the difference in infant EEG/ERP activity in the Brannon et al. (2004) study arose because of a detection of temporal or auditory differences – was raised again here, as the authors could not rule out the possible influence of the concurrent attention keeping activity (watching a silent puppet show) on infant responses.

This work was therefore extended in the later Brannon et al. (2008) studies, which found that the amplitude of the MMN component was mediated by the ratio of the deviant interval compared to the standard interval. These findings support Weber's Law (Weber, 1933), which states that discrimination of an interval depends, not on the actual value of

the difference between two intervals but rather, on the ratio between those two intervals. A comparison of data from adults and 10-month-old infants found similar developmental differences in the latency and amplitude of the infant responses. It is important to note that a limitation of these studies is the age of the infant participants who, at ten months, respond in a more adult-like manner, which will now be discussed.

Changes in the amplitude, latency and location of putative EEG/ERP activity occurs as EEG waves become more adult-like from eight to twelve months. These differences are thought to be due to the maturation of neural connections (Johnson, 1990). For instance, ERPs in young infants (e.g. three-months-old) show a more diffuse activation across a wider brain area, but as infants become more mature at about ten-months-old the spread of activation is confined to the same more limited areas of activation found in adult brains (Halit, de Haan and Johnson, 2003). Therefore the similarity in response between adults and infants in the Brannon et al. (2004) and Brannon et al. (2008) studies is not really surprising given that the infants were ten-months-old, in the middle of the range of the eight to twelve month age bracket. Brannon et al. (2008) account for this by suggesting that infants and adults may be using the same timing mechanisms here, but equally they acknowledge that further work needs to be conducted with younger age groups to ascertain any developmental differences.

Whilst these ERP/EEG studies are of interest, as they suggest differential brain activity during timing-related tasks, notwithstanding the caveat above, it is not particularly relevant to this thesis except on one point. It is clear that a method that measures clear objective observable behaviour highlighting the focus of attention is required for timing studies.

2.2.3 Limitations in the use of heart rate and EEG methodologies

A limitation relating to heart rate methodology is the need for the slow presentation of stimulus sequences in order to detect changes in heart rate responses. An infant's heart rate is approximately 140 beats per minute, with a range of 120-160 beats per minute (Woods, 2003). Thus for the Colombo and colleagues (2002, 2005) studies, the length of a study would be in the order of three to five minutes to include the presentation of a nine

stimulus sequence, depending on the length of the ISI. This period was extended in the Donohue and Berg (1991) study, which lasted between 9 and 17 minutes. This represents a major disadvantage in that, as in the case of the Colombo and colleagues (2002, 2005) studies, only a one-trial sequence could be presented to each group of infants. In reality, more than one stimulus sequence could obviously be presented, but this could result in higher attrition rates. For instance, the slow stimulus presentation rate increases attrition in younger infants causing "infants to cry a lot, getting bored" (Colombo, 2004, personal communication). Thus, Colombo and colleagues used only one trial at one time interval in each of these studies, and so time perception could only be inferred since similar decreases in heart rate responses were seen in each group at different time intervals. Thus, this limitation would suggest that heart rate is not the most suitable methodology to employ when testing infant time perception.

A common limitation to both methodologies is their failure to reveal the focus of attention towards stimuli within any given experimental situation, which would eliminate other explanations for the results obtained. An alternative and seemingly preferable measure of attention, which also captures the focus of attention in infants, is eye gaze. There has been a long history of eye gaze studies used to measure attention in human infants, for example Salapek and Kessen (1966), Farroni, Mansfield, Lai, & Johnson (2003) and more recently with an eye tracker Farroni, Massaccesi, Menon and Johnson (2007). So eye gaze could provide a more suitable method for investigating infant time perception and will therefore be used by the research studies reported in this thesis.

Further, a wider limitation of the afore-mentioned studies is that the findings are not directly located within time perception literature. The exception here is Colombo and Richman (2002) who simply state that attention has been shown to influence time perception in earlier studies (Zakay,1992; Block, Zakay and Hancock, 1999), although they do not expand this discussion.

To summarise, the studies discussed in the above sections raised two methodological issues: first the need for slow stimulus presentations that possibly over-tax infants'

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attention spans and second, the failure of physiological measures to reveal the focus of infants attention. It is proposed, therefore, that eye tracking is an alternative method of investigating time perception in infants that can overcome these problems.

Attention will now turn to a more detailed discussion of the theories and models of time perception. As mentioned in Chapter 1, the main body of literature covers work conducted with animals (Gibbon, 1977) and humans between the ages of three years to 99 years (Wearden, 1991; McCormack, Brown, Maylor, Darby and Green, 1999; Wearden and Droit-Volet 2002; Droit-Volet, 2003). However, the following discussion will have particular emphasis on those models that relate to infants and children (McCormack et al., 1999; Wearden and Droit-Volet, 2002; Droit-Volet, 2003).

2.3 Models of time perception

As was discussed briefly in Chapter 1, developmental trends of time perception in infants and children have been accounted for in two ways. First, through Scalar Expectancy Theory (SET) (Gibbon, 1977), the SET Model (which dominates the field), and its developmental version, devSET, (McCormack et al.,1999; Wearden and Droit-Volet, 2002; Droit-Volet, 2003). As discussed in section 1.6, a number of cognitive models of time perception are based on the SET model, such as the AGM (Zakay and Block,1996); and the FSM (Lejeune, 1998). These simply add components to one section of the SET model. The second explanation, the Mode Control Model (MCM) relates how number, time and ratio discrimination are connected (Meck and Church, 1983). This model however introduces a further source of variance, which could potentially impact time perception, this will be discussed further below.

The discussion that follows will begin with the SET model (Gibbon, 1977 and the devSET models. As discussed in Chapter 1; to date these models have only been applied to explain data from children as young as three years of age (Droit-Volet, 2003). In this thesis, therefore, it is proposed to see whether these models can also explain data obtained from four-month-old infants.

As outlined in Section 1.6, the nature of timing tasks demands that a time interval is estimated. This appears to require some sort of marking or counting to be performed for a unit of time as measured by an internal clock (Creelman, 1962; Treisman, 1963). SET models, therefore, comprise a clock or timer, memory and decision components. Ideas about what drives the clock component range from oscillators (Treisman, Faulkner, Naish and Brogan, 1990; Treisman, Cook, Naish and MacCrone, 1994; Treisman, 1999), to the more predominant notion of pacemakers (Gibbon, 1977).

2.3.1 The dominance of Scalar Expectancy Theory (SET) and the SET model

As seen in Chapter 1, the SET model, or cognitive (Zakay and Block, 1996; Lejeune, 1998) and behavioural (Killeen and Fetterman, 1988) derivations of it, has been used widely to investigate timing in humans and animals (Wearden, 1999:4). Its potential application to infants is therefore of particular interest.

According to the original SET model (Gibbon, 1977) the processes thought to underlie timing responses are assumed to be mediated by an internal clock. It is believed that experienced durations are stored as the duration multiplied by a scalar factor, which remains approximately constant (Catania, 1970) and increases in line with Weber's Law (Weber, 1933). The clock operates by emitting regular pulses, which are the 'raw material' for current time judgements (Wearden, 1999). In Temporal Generalisation tasks, for example, at the onset of a duration, a switch closes so that these pulses pass into an accumulator. At the end of the duration, the switch re-opens. The accumulated pulses then pass to the memory component. So when estimating a duration, the current duration (held in working memory as an accumulated number of pulses) is compared to a reference duration (held in Long Term memory) and responses made based on whether they are similar or not, for instance (see Figure 2.1).

The SET model has been influential within timing research. A developmental version of the model (Gibbon 1977; Droit-Volet and Wearden, 2001; Droit-Volet, 2003) was devised to account for the findings from children from three- to twelve-years-old whose responses

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though similar, differ uniformly from adult timing responses. For clarity, this developmental version has been termed devSET by the current author and a discussion of this model now follows.

Figure 2.1 A typical SET type model after Wearden (1999) and Allan (2001)
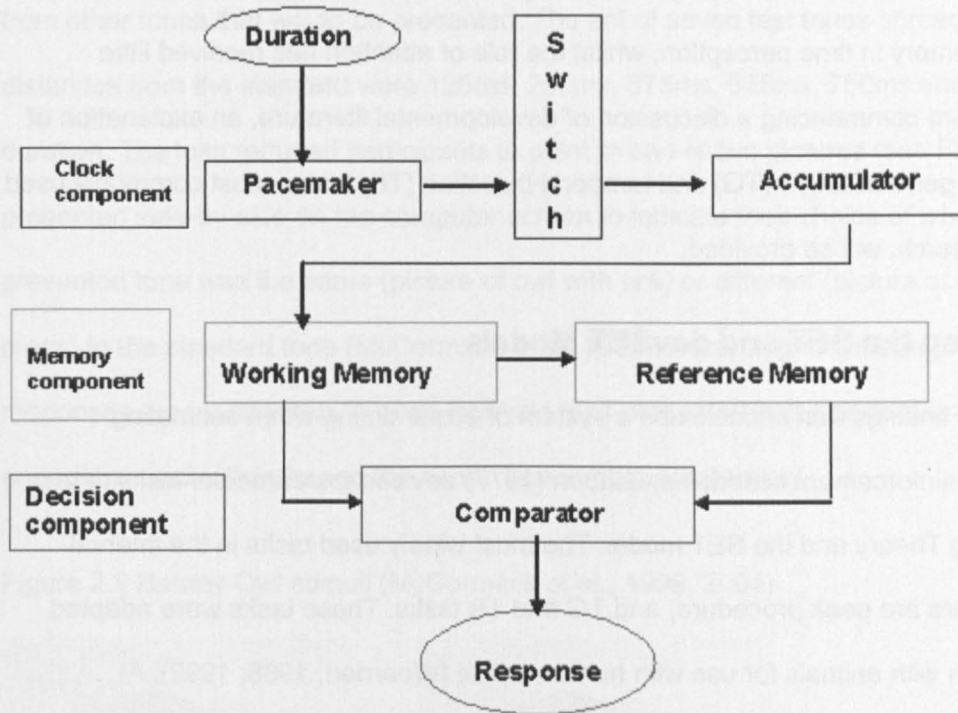
2.3.2 The application of the devSET model within time perception literature

Developmental trends in time perception have been explained using the devSET model (Gibbon 1977; Droit-Volet and Wearden, 2001; Droit-Volet, 2003). This accounts for developmental differences and suggests a potential transition point towards adult responses (Droit-Volet and Wearden, 2001) by children aged eight years old. In order to examine whether any differences exist between children and adults in time perception, temporal generalisation and temporal bisection tasks have been used with a range of populations from three years to 99 years old (Droit-Volet, Clement and Wearden, 2001; Droit-Volet and Wearden, 2001; McCormack et al. 1999). The aim of these studies has

been to investigate whether children are as accurate as adults at temporal estimation and, if not, when developmental transitions might occur.

Additionally, adults up to 99-years-old have been studied to determine whether developmental changes occur within the older adult age bracket (McCormack et al., 1999). Most developmental research has employed the temporal bisection task, which tests the role of reference memory in time perception, whilst the role of attention has received little interest. Before commencing a discussion of developmental literature, an explanation of the temporal generalisation (TG) and temporal bisection (TB) tasks, most commonly used in timing research, will be provided.

2.3.3 Testing the SET and devSET Models

Based on his findings that animals use a system of scalar timing when estimating durations in reinforcement schedules, Gibbon (1977) devised experimental tasks to test Scalar Timing Theory and the SET model. The most widely used tasks in the interval timing literature are peak procedure, and TG and TB tasks. These tasks were adapted from research with animals for use with human adults (Wearden, 1988; 1992). A discussion of these will further aid understanding of the associated literature.

Peak procedure is a simple measure of whether animals have perceived and learned a short time interval. Within the context of research on animal learning using operant conditioning designs (Skinner, 1948), not all trials are reinforced with a food reward. If an animal – usually a rat – has perceived and learned a short time interval that precedes a food reward, any lever pressing activity will increase at about the time the rat has learned that food will become available and will subsequently decrease after the event.

The main temporal discrimination tasks used in children's time perception studies, however, are the TG and TB tasks. The former seeks to ascertain whether learning can be generalised to other durations while the latter relies on memory to distinguish between two different durations.

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In the TG task conducted by McCormack et al. (1999), participants aged between five and 99 years old learned the standard duration of a tone of 500ms. To make the task easier for the children to understand, they were told that the tone belonged to an owl whose picture was presented simultaneously on a computer screen. Once the standard tone was learned, participants were informed that they would have to distinguish the standard tone from other tones that would be presented. The set of seven test tones spread at equal distances from the standard were 125ms, 250ms, 375ms, 625ms, 750ms and 875ms in duration. The task required participants to point to one of two pictures (see Figure 2.2) presented side-by-side on the computer screen to indicate their choice of whether the just presented tone was the same (picture of owl with tick) or different (picture of owl with red cross) to the standard tone (McCormack et al. 1999). According to Gibbon (1977) 'yes' responses are made when 'the two intervals (just presented and standard tone) are close enough' to each other, hence the name 'temporal generalisation'.

Figure 2.2 Barney Owl stimuli (McCormack et al., 1999, 2004)

Current duration present   **Current duration not present**
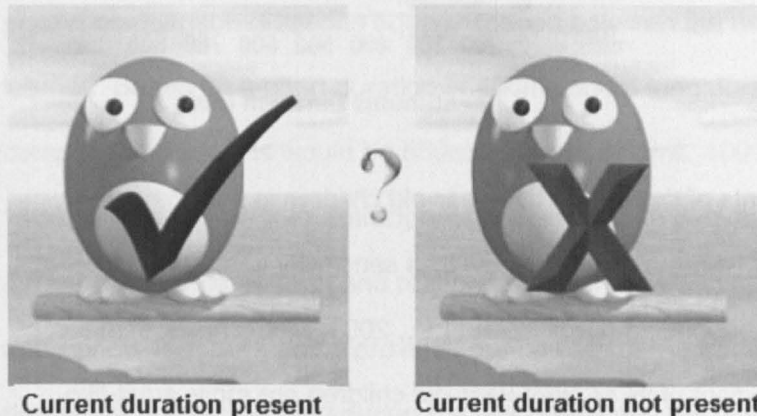
The 'yes' responses made to this task (i.e. the just-presented tone is the same as the standard tone) are plotted on a graph called a Temporal Generalisation Gradient (see Figure 2.3). Peak correct responding should be made around the time of the standard duration if it has been learned, so that accurate time keepers should have steep bell-shaped gradients. In reviewing these gradients, it has been observed that children have a bias towards responding 'yes' to durations which are slightly shorter than the standard, thus producing asymmetrical gradients that are skewed to the left (McCormack et al.,

1999). In contrast, adults have a bias towards making responses that are slightly longer than the standard, producing right skewed asymmetrical gradients (Wearden, 1992). In contrast, animals produce symmetrical gradients (Church and Gibbon, 1982), which may be linked to the long training periods undertaken with animals before the task begins.

Figure 2.3 Temporal generalisation and bisection plots (after McCormack et al., 1999)

Temporal generalisation gradient (after McCormack et al (1999:1146)

Temporal bisection plot (after McCormack et al (1999:1150)

Key
▲ = 5-year-olds
□ = 8-year-olds
△ = 10-year-olds
■ = Undergraduates
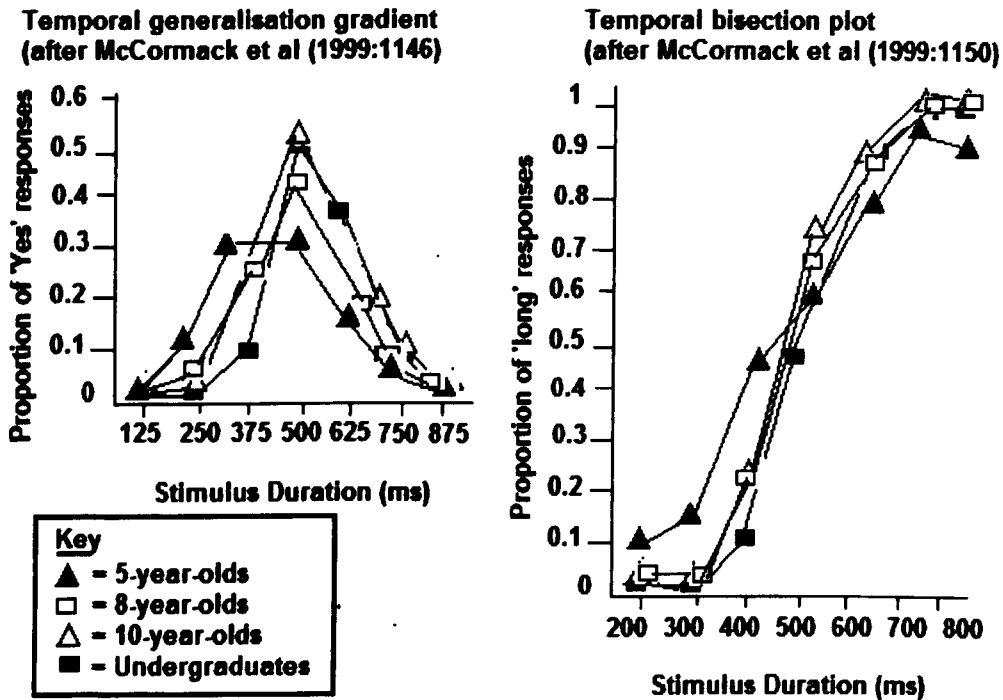
A further feature of the gradients of three- and five-year-old children is that they are slightly flatter, suggesting that younger children show less sensitivity to temporal intervals resulting in more variance in responding (Droit-Volet et al., 2001; McCormack et al., 1999). On the other hand, gradient plots of eight-year-old children are more adult-like showing a similar distribution of responses, indicating a particular developmental shift towards greater sensitivity to temporal intervals at this age.

To date no TG data are available for infants, as research has not been conducted with this age group. But taking the principles of the research referenced above, one might expect to see infants showing less sensitivity to temporal intervals with increased variance in responding resulting in an even flatter temporal generalisation gradient compared to three-year-olds.

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Adapting the TG task for use with infants may prove difficult for several reasons, the greatest of which is that infants are unlikely to tolerate the long periods of training that children and adults engage in, whilst young infants also are unable to make the verbal or manual responses that their older counterparts are capable of. Therefore any adaptation of the TG paradigm should use age-appropriate methods in training and testing phases, and indeed these considerations have been accommodated within the research contained in this thesis.

Whilst TG is essentially a temporal discrimination task, the temporal bisection task (Church and Deluty, 1977) requires participants to determine whether a just presented duration is more similar to either a long or short duration previously learned.

The TB task comprises three phases, two training and one test phase. In the first training phase, participants learn two standard durations, a short (e.g. 400ms) and a long (e.g. 1600ms) duration, pressing different buttons placed in front of them (for instance 'short' to the right and 'long' to the left) to distinguish between the two. During the second training phase, comparison durations equally spaced between the two standard durations are learned. Based on a short duration of 400ms and a long duration of 1600ms, the comparison durations would be 550ms, 700ms, 850ms, 1000ms, 1150ms, 1300ms and 1450ms (see Figure 2.4). Participants are required to decide whether these comparison durations are long or short and respond appropriately by pressing the correct button, with appropriate feedback being provided during both of the training phases. The same procedure is then followed during the test phase and the responses recorded, although no reinforcement is now given.

Figure 2.4 Types of 'yes' responding in the Temporal Bisection task

Bisection point
[Point of indifference
- chance responding]

Short
Duration   Short responses   Long responses   Long
                                                                 Duration

400ms 550ms 700ms 850ms 1000ms 1150ms 1300ms 1450ms 1600ms
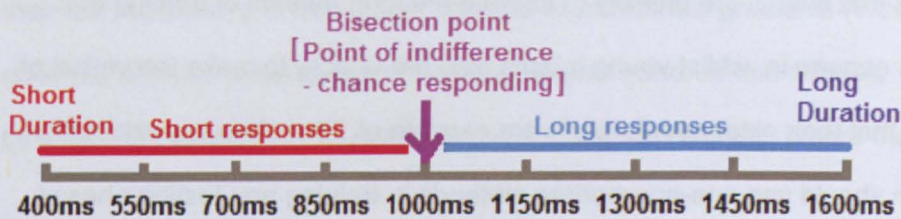
Key
Short duration = 400ms
Long duration = 1600ms
Test stimuli = 550ms 700ms 850ms 1000ms 1150ms 1300ms 1450ms

Researchers are interested in the point along the scale (e.g. 1000ms) where participants

respond at chance level, the point of indifference. That is, they make responses to the

'long' duration (called 'long' responses) 50% of the time. This is known as the bisection

point. According to Jones and Wearden (2004) participants in TB tasks are not comparing

long and short durations to get to the bisection point (the point of chance responding) but

they are comparing the mean of all durations and choosing either short or long responses.

Obviously the further away from the mean the duration is, the easier it is to distinguish

between long and short durations.

The response data from TB tasks are plotted on graphs that produce 'S' shaped plots (see

Figure 2.3). Interestingly, these plots show similar developmental trends to the bell-shaped

temporal generalisation plots. The bisection plots of adults and eight-year-old children are

steep indicating very few short responses (Droit-Volet and Wearden, 2001; Wearden,

Rogers, and Thomas, 1997). At five-years-old, the plots become slightly flatter and

progressively more so at three-years-old, indicating that there is more variation in the

responses of three-year-olds, that is, they make more short responses (Droit-Volet and

Wearden, 2001).

These data support the notion that younger children show less sensitivity to temporal

intervals than eight-year-old children do, but as yet nothing has been captured in terms of

infant data. It was seen from the graphs in Figure 2.3, that greater variance was present in

the responses from adults and children, so attention will now turn to how devSET accounts for these sources of variance.

The devSET model (Droit-Volet and Wearden, 2001; Droit-Volet, 2003), which is predominantly used to explain the results of children, operates in exactly the same way as the SET model (Gibbon, 1977) but accounts for sources of variance in different ways acknowledging that children respond differently from adults. As with adults, responses conform to scalar principles in the age groups tested, which were three-, five-, eight- and twelve-year-old children (McCormack et al., 1999; Droit-Volet, 2002: McCormack, Brown, Smith and Brock, 2004). Younger children of three years old have been shown to display more variance in their responses, thus indicating less sensitivity to temporal information. They make shorter responses to long durations than five- and eight-year-olds and adults. In contrast, under ambiguous circumstances when three-year-olds are unsure of the duration, longer responses are made. Although a general bias towards long responses is seen in adults, it is not specific to ambiguous cases. Therefore, variability is greater in three-year-olds than in eight-year-olds whose responses are at a similar level of accuracy to adults, suggesting that a developmental transition with regard to time perception takes place at about this time or earlier.

As in the adult version of the SET, there is not one single referent duration within reference memory in devSET but a distribution of many versions of a standard duration, all very slightly different, resulting in a margin or band within which any duration is called standard (Gibbon, 1977). To illustrate this point, think about an example from everyday life, the filling of milk bottles. Variability can be seen when buying a bottle of milk, as the switch controlling the flow of milk into the bottles varies slightly each time it is operated, and thus the bottles are not uniformly full. Some bottles contain slightly more milk than others, but all are centred on the mean quantity, for example two pints.

Relating this example back to interval timing, the band for a 800ms duration could actually fall between 780ms and 820ms for adults, but due to greater variance observed in children's responding would be wider, such as 700ms and 900ms. The wider the margin,

the more variability there will be. Droit-Volet (2003) suggests that the variability in younger children is due to a fuzzy representation of the standard duration in long-term memory. However, she fails to consider whether variance could occur during encoding at the clock level of the devSET model. This is important as younger children are more easily distracted and thus may fail to encode durations properly in the first place, which would give rise to more variance for the standard duration in reference memory. Such an explanation, if shown to be correct, may also influence infant time perception, and is explored within Experiment 7 of this thesis.

Three- and five-year-old children also make more random responses than older children, about 10% to 20% of the time (Droit-Volet and Wearden, 2001). In contrast though, it is rare for eight year olds and adults to make random responses, even though this is observed in animals (Church and Gibbon,1982). Bisection and generalisation plots of children (see Figure 2.3) support this, in that they are not as steep as adult gradients when looking at the youngest age groups due to random responding, but show adult-like steep gradients with no random or short responses by eight year olds (Droit-Volet and Wearden, 2001). Again, this supports the view that a developmental transition has occurred by eight years old, and perhaps even earlier. Can this be narrowed down even further in future research to understand exactly when this transition occurs?

It is known that TG tasks are harder for young children to complete than TB tasks, as more comparisons are given with less training and fewer referent durations (Wearden, Denovan and Haworth, 1997). Consequently, TG plots of children are flatter than adults, showing increased variance, random responding (McCormack et al., 1999) and responding to short durations (Droit-Volet et al., 2001), all of which indicate reduced accuracy and temporal sensitivity. Notably, there are also variations between the child age groups; three-year-old children produce flatter, almost symmetrical, plots whereas the plots of five-year-old children rise more steeply to adult-like gradients in eight-year-old children, suggesting that temporal sensitivity increases with age.

As seen above, differences are also noted in the skew patterns of children's plots with a right skew in generalisation plots from eight-year-olds' responses similar to adults (Droit-Volet et al., 2001; Droit-Volet, 2002). On the other hand, McCormack et al. (1999) found left skewed gradients from five- and eight-year-olds indicating more short responses, and, like animals, symmetrical gradients at ten-years-old (Church and Gibbon, 1982), with a skew to the right in adult responses. In order to explain their results, McCormack et al. (1999) added a distortion parameter to the SET model. Using this parameter, if the remembered duration is accurate, that is, it equals 1, the plot will be vertical. But if the distortion in memory of the referent duration was less than 1, the plots will show a leftward shift, as the remembered duration is less than the actual standard. If on the other hand, the distortion is greater than 1, a rightward shift would be observed, as the remembered duration is longer than the referent.

The data discussed thus imply that ten-year-old children and animals have accurate temporal perception but younger children and older adults do not, estimating durations as shorter and longer respectively. So this would seem to deliver the 'U' shaped developmental curve consistently observed in many cognitive processes (Karmiloff-Smith, 1992; Pine and Messer, 1998). These findings also support the Piagetian model of time perception, where Piaget, (1969) posits that children do not grasp the concept of time until they reach the ages of six and seven years. Therefore, Piaget would have predicted similar results in that younger children do not have the cognitive ability to perform well in the task and will therefore respond inaccurately.

Although there is a debate about the timing of this developmental transition, with Droit-Volet and colleagues (2001, 2002, 2003, 2004) proposing that it occurs by eight years old and McCormack et al. (1999) suggesting it occurs much later during young adulthood, the actual stages remain the same.

The devSET model (Droit-Volet and Wearden, 2001) involves four parameters to account for these observed developmental differences. The first parameter is random responding, with a higher proportion of random responses observed in younger children. Second is the

variability of the referent duration in reference memory, which is wider for younger children (three-years-old) than older children (eight-years-old) and adults, as seen in flatter generalisation gradients and wider standard duration margins. The third parameter is a reduced likelihood of long responses being made as younger children are more conservative, unless the case is ambiguous (Nelson, 1996), when they tend to make long responses. Finally, there is a distortion in memory for the standard duration. These parameters will be employed when considering the research results reported in this thesis.

Having briefly discussed the devSET model and the tasks used, an examination of the studies whose data informed the model will now follow.

2.3.4 Foundation studies of the devSET

In a study comparing younger and older adults, Wearden, Wearden and Rabbit (1997) compared responses to temporal bisection and generalisation tasks of undergraduates, 'young-old' people between the ages of 60 and 69 years, and 'old-old' people between the ages of 70 and 79 years. Responses made to the temporal generalisation task, but not the bisection task, showed a decrease with age in correct responding at durations that were close to the referent duration: increased variation was seen in the 'old-old' group, suggesting that the referent duration was distorted in memory. Wearden et al. (1997) also suggest that the temporal generalisation task was more sensitive to age-related differences and thus pertinent when examining developmental trends in time perception.

Further developmental trends have been demonstrated by McCormack and colleagues (McCormack et al., 1999; McCormack et al., 2004), who presented temporal generalisation and temporal bisection tasks to participants whose ages ranged from the very young to the very old (five years to 99 years old). In the first study, McCormack et al. (1999) presented participants between the ages of five years and 99 years with both temporal generalisation (Experiment 1) and temporal bisection (Experiment 2) tasks. Replicating the findings of Wearden et al. (1997), age-related differences in responding were observed only in the temporal generalisation task. As seen above, children's generalisation gradient plots showed left asymmetry while adults showed right asymmetry,

suggesting that children were estimating referent durations as shorter whilst adults were estimating them as slightly longer. These differences indicate that memory for the referent duration is subject to different types of distortion across the age groups, with less distortion observed after childhood and a further decline in older adulthood.

Collectively, the data from these studies (Wearden et al.,1997; McCormack et al.,1999; Droit-Volet and Wearden, 2001; Droit-Volet, 2002; McCormack et al., 2004) indicate an inverted 'U' shaped developmental trend in temporal estimation, with high variability being observed in the responses of young (under eight years old) and old (over 70 years old) participants, and less variability from late childhood (eight years old and older) through to early and mid-adulthood.

The challenge presented by the memory distortion account is that it does not indicate the origin of the distortion of the referent duration. A closer look at the devSET model suggests that it could occur in two places: first, when the reference duration is transferred from short term memory into reference memory; second, on retrieval from reference memory. In order to address this question McCormack, Brown, Maylor, Richardson and Darby (2002) conducted a series of three experiments. Two groups, undergraduates and older adults (no ages were provided), were required to identify the referent tone duration within a group of varying tones or pitches, which increased over two of the experiments (Experiment 1 = 6 tones; Experiment 2 = 9 tones), whilst in Experiment 3, the pitch of the tones varied and the referent pitch had to be identified within them. Older adults made consistently longer duration judgements than young adults in Experiments 1 and 2, but no differences were seen in Experiment 3. Across all three experiments, older adults made more inaccurate responses than the young adults. This was attributed to an increase in noise or variability within either the clock or memory components, due to the general perceptual difficulties encountered by older adults e.g. loss of hearing.

Despite the fact that the older adults participated in groups of up to ten people, the effect of conformity (Allport, 1924; Sherif, 1936) was not discussed in the McCormack et al. (2002) study. Conformity effects induce people to make more conservative judgements

when in groups rather than alone. Sherif (1936) proposed that in times of uncertainty, the emergence of group norms (e.g. group consensus about the value of something, in this case time durations), reduced uncertainty by guiding the individual's behaviour. It is feasible that if older adults were less sure of the identification of the referent duration, then conformity could increase so that a group norm was identified. However, as pitch identification (Experiment 3) entails smaller task demands, older adults may have had more confidence in their own judgement and therefore conformity effects would be less marked. What is clear, however, from these findings is that it is duration rather than pitch judgements that are subject to memory distortion in long term memory, suggesting that duration and pitch may be mediated by two separate processes.

So these findings support the hypothesis that one source of scalar variability is memory distortion within long term memory for durations, but clearly more research is needed to ascertain what developmental changes take place over childhood.

It is well documented (McCormack et al., 1999; Droit-Volet, 2002) that children participating in the temporal generalisation tasks have a systematic bias towards reporting shorter standard durations, thus producing leftward asymmetrical generalisation gradient plots. Several explanations have been proposed. Block, Zakay and Hancock (1999) suggested that young children encountered difficulties in translating the durations into measurable units of time (e.g. "that duration is 375ms long"). Another view is that young children are particularly influenced by environmental (Oates, 1998) or contextual changes (Block, 1982), which could therefore affect attention or other cognitive processes such as time perception. Alternatively, Levin and Wilkening (1989) suggest that for some young children difficulty in counting may explain their inaccurate judgements.

Further reasoning points to developmental changes in the variability or noise when timekeeping. However, as McCormack et al. (2004) note, while this explanation justifies the poorest rate of correct responding, it does not account for the left asymmetrical generalisation gradient, which can be better explained by the notion of memory distortion described earlier.

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2.3.5 The memory distortion account

In order to investigate the memory distortion account and discover potential error patterns related to its task, McCormack et al. (2004) extended their previous research (McCormack et al., 2002). Testing each participant separately across three age groups (six years olds, ten-years old and adults), they conducted a series of four experiments using age-appropriate stimuli with temporal generalisation tasks (see Figure 2.2 above). In Experiment 1, during the demonstration phase, a photograph of Barney Owl was presented in the centre of the monitor screen and the referent tone duration of 500ms sounded, this was Barney's sound. Then the non-standard tones (same tone, but different durations) were sounded with a photograph of Barney Owl with a red cross, this was not Barney's sound.

The following phase, the familiarisation phase, involved a session where the children were familiarised with the task of hearing the different tones (referent and non-referent durations) then indicated whether the sound was Barney's or not by pointing to the appropriate owl picture. During the following practice session, the referent duration was presented five times, and then in the test trials, referent durations interspersed with non-referent durations were presented. Verbal feedback was provided after every response.

An important point here is that the results are based on simple 'yes/no' responding rather than reaction times. Nonetheless, the results from this experiment were consistent with previous findings as described earlier in the chapter.

The second experiment within this series specifically investigated the role of long term memory in duration distortions, using the temporal generalisation task and the same estimation procedure of pointing to photographs but this time of either Marvin the Mouse for the referent duration, or the crossed-out Marvin for the non-referent duration. The ages of the three groups of participants remained consistent at six years old, ten years old and adults. However, the difference between Experiments 1 and 2 (rather than the change in stimulus animal) was that the referent duration was presented five times before the test trials in Experiment 1, ensuring that comparison between the just-presented duration and

the referent duration was always made within long term memory (LTM). In Experiment 2, the referent duration was presented at every trial before the test duration after an ISI of 3000ms. As comparisons were made within working memory, the effects of memory distortion within LTM could therefore be examined.

The main finding from this experiment was that when the task simply required a comparison of the just-presented duration with the referent, in working memory rather than in LTM, the distortion of the referent duration was eliminated. This clearly shows that there is no perceptual difficulty for young children in distinguishing between the comparison durations and the referent duration as previously hypothesised. It also indicates that memory distortion is located in LTM. Whether this distortion is caused by the transfer of the referent into LTM or whether it is a retrieval problem, however, cannot be answered by these data.

To test the memory distortion account further, in Experiment 3, McCormack et al. (2004) varied the spacing of the non-standard stimuli using logarithmic spacing rather than linear spacing, for example for a base of ten the logarithmic scale would be 1, 10, 100, 1000, rather than 1, 2, 3, 4. In practice this meant that instead of being 125ms apart, the spacing between the stimuli varied logarithmically, becoming more spaced out the longer the previous duration. If stimulus spacing were an influencing factor in memory distortion, then using logarithmic spacing should eliminate this effect with generalisation gradients for all groups being symmetrical. The same stimuli and procedure was used as in Experiment 1 (see Figure 2.2). Although there was a higher rate of correct responding, especially in the younger groups, the same pattern of generalisation gradients was obtained as in Experiment 1, indicating that logarithmic stimulus spacing is not an influencing factor in memory distortion for duration.

In the final experiment (Experiment 4) identification of pitch was used to see whether the asymmetry of generalisation gradients would generalise to other aspects. The results demonstrated that it did not.

A valid criticism that could be levelled at the stimuli used in the series of studies described above is that whilst the animal photographs (see Figure 2.2) were certainly age appropriate for six- and ten-year-old children, it could have been confusing having to point to one of two photographs of the same animal. Additionally, participants were unable to indicate whether the non-referent just presented duration was longer or shorter than the referent duration merely that it was different. At first glance this may seem to be a moot point, but the participants are presented with non-referent durations across a large range (e.g. from 125ms to 875ms). In order to investigate the memory distortion account, it is the non-referent durations either side of the referent (e.g. 375ms and 625ms), that are the crucial durations under investigation, as it is these durations that show the transitional change from short to long responding. Future studies should address this limitation by using a method that would enable participants to indicate if the duration was the same, shorter or longer than the referent.

A further problem for these experimental tasks is that they rely on pointing. Although pointing is a valid response to use with young children since it limits any confusion from verbal estimation responses (Hicks, Miller and Kinsbourne, 1976), it would be unsuitable for young infants as pointing behaviours emerge only towards the end of the first year (Bretherton, McNew and Beeghly-Smith, 1981). Therefore, an alternative method utilising a mature infant system would be eye movements, as the ocular-motor system is mature at four months (Bronson, 1974), making this an effective testing methodology for very young children.

Additionally, two different methods are employed here to complete this task. First, auditory tones representing the duration have to be learned, then the participant has to point to the appropriate picture to indicate a response. Therefore variance could arise from either or both sources. To limit this variance, a single method should be employed for learning and responding. One such method would be eye tracking.

A further general criticism that could be levelled at the collective timing tasks undertaken by McCormack and colleagues (McCormack et al.,1999; McCormack et al., 2002;

McCormack et al., 2004) and Droit-Volet and colleagues (Droit-Volet and Wearden, 2001, Droit-Volet, 2003; Droit-Volet, 2003) relates to the feedback provided to participants. Older children received higher levels of positive feedback (a picture of a smiling clown in the Droit-Volet studies and positive verbal feedback in the McCormack studies), which likely increased their motivation for the task. On the other hand the stimulus for the negative feedback in the Droit-Volet studies was an unhappy clown (see Figure 2.5). This could be quite scary for young children as the clown is frowning in an almost menacing way, which may be a de-motivating factor for this group of children. Neutral negative feedback such as the clown with a neutral face may produce different results in the younger children. Or indeed displaying photographs may be a more effective feedback system: a photograph of a smiling woman representing positive feedback or a neutral face representing negative feedback perhaps.

Figure 2.5 Clown feedback stimuli used by Droit-Volet (2003)

Correct response = positive feedback

Incorrect response = negative feedback

Feedback stimuli taken from Droit Volet (2003)
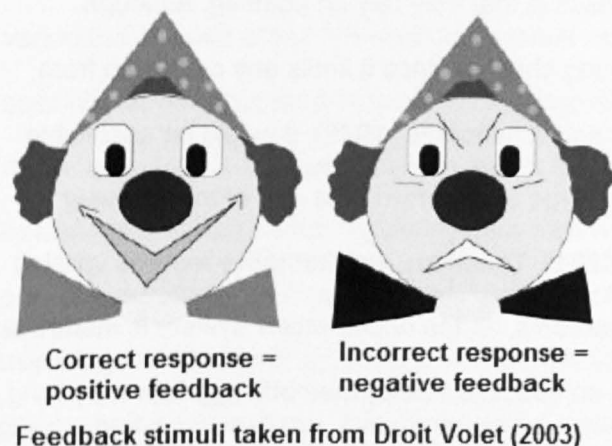
To summarise, most research examining devSET proposed by Droit-Volet and Wearden (2001) and Droit-Volet (2003) has investigated the role of the memory component of the model and the influence of memory processes on timing. Little research has been conducted to investigate the clock component and the influence of attention, revealing a gap in our understanding of the developmental trends in time perception, a subject that will be returned to later in this thesis.

In examining the differences highlighted between child and adult responses in the data just reviewed, it can be seen that these have been accounted for by three of the four parameters of the devSET model outlined earlier. First, that at younger ages increases in random responding are observed; second, younger age groups had increased variation when estimating durations; and third, that younger children make shorter responses than older groups of children (aged eight and above), except under ambiguous circumstances where longer responses are made. Reasons are proposed for these results, such as the older children's better understanding of the task, allowing them to have greater confidence in their responses and so producing few, if any, random responses.

To conclude then, based on the findings discussed above, the devSET model would predict that whilst infants may show some sensitivity to temporal parameters, their responses would reveal greater variance than those of three year olds (Droit-Volet, 2003). In short, the model would expect the following factors: wider response variation in infants, in particular at short durations; an increase in random responses, especially if the task was difficult and the infants were unsure of the response they should make; and conservative responses with no bias towards long responses, as seen in older children and adults. Additionally, temporal generalisation gradients should be fairly flat and bisection plots not as steep, indicating a lower sensitivity to temporal parameters than older children.

An examination of the infant time perception literature shows that no data for this group are available in terms of the SET model, and so no comparisons can be made to this in the discussion above. Comparisons between number and time discrimination, however, have been made, and so a review of the models of time perception would not be complete without a discussion of this, namely the Mode Control Model (Meck and Church, 1983) which has been devised to explain number and time discrimination.

2.3.6 The Mode Control Model: A connection between time and number discrimination

The information processing Mode Control Model (MCM) has been proposed by Meck and Church (1983) to account for similarities between number and time discrimination. Of particular interest to this thesis are the recent advances that have been made in applying this model within the infant literature, although application is not simply limited to infants.

The ability to discriminate number is not restricted to human populations; it has been observed in the foraging behaviours of wild animals (Harper, 1982) and by primates in the lab (Matsuzawa, 1985; Uller, Carey and Hauser, 1996). Human capability in using analogue magnitudes to discriminate differences in number was demonstrated by Moyer and Landauer (1967), showing that reaction times of adults increased when discriminating smaller magnitudes, such as 7 from 9, than larger magnitudes, such as 2 from 9. More recently the use of number has been demonstrated in children (Barth, La Mont, Lipton, Dehaene, Kanwisher, Spelke, 2006) and infants (Barth et al., 2006; Spelke and Tsivkin, 2001; van Marle and Wynn, 2006; Xu and Spelke, 2000) as well as analogue magnitudes (Brannon, Lutz and Cordes, 2006; van Marle and Wynne, 2006; Xu and Spelke, 2000). Barth et al. (2006) suggest that five-year-old children possess a 'pre-verbal number sense', that is, a rough mental magnitude of any number presented to them, accounting for infants' and young childrens' ability to add and subtract. This capability, being evident before a formal symbolic sense of number is learned, and present in animals and humans, forms the focus of the following section.

The use of analogue magnitudes by infants has been demonstrated by Brannon et al., (2006); van Marle and Wynne, (2006); Xu and Spelke, (1998); Xu and Spelke, (2000). Each of these studies has demonstrated that 6-month-old infants are able to discriminate magnitudes of 1:2, that is to distinguish between 2 objects and 4 objects and 4 objects and 8 objects, but not a ratio of 2:3, that is between 4 objects and 6 objects. Using novelty preference procedure, van Marle and Wynn (2006) found a similar ability to recognise the duration of a moving puppet display with a magnitude or ratio 1:2 but not a magnitude of

2:3. In the novelty preference paradigm, infants are familiarised to a particular visual stimulus during the training phase. In the test phase the familiar visual stimulus is placed besides a novel stimulus, and if infants have learned the familiar stimulus, longer looking times will be recorded for the novel stimulus.

As previously described, discrimination of magnitudes of 1:2 but not 2:3 were observed in four experiments outlined in the van Marle & Wynn (2006) paper. In Experiment 1, after habituating six-month-old infants to either 2s or 4s durations, novelty preference was observed suggesting that infants could distinguish a 1:2 magnitude. Experiment 2, used a magnitude of 2:3 but no novelty preference was observed. Experiments 3 and 4 examined short intervals employing durations of 1s and 500ms; similarly novelty preference was seen with magnitudes of 1:2 (Experiment 3) but not 2:3 (Experiment 4). So these results clearly show that infants of six months respond according to Weber's Law functions (Weber, 1933), in that novelty preference was observed only when the variance was proportional.

Similar capabilities were demonstrated in area discrimination by Brannon et al. (2006) in 6-month-old infants. The area of a puppet face (Elmo from Sesame Street, Children's Television Workshop) varied in size in magnitudes of 1:2, 1:3, 1:4 and 2:3. The infants were habituated to Elmo's face at one ratio and then presented with 6 test trials with areas of either novel or familiar ratios. The data revealed that novelty preference was observed when ratios followed Weber's Law functions (Weber, 1933), such as 1:2, 1:3, 1:4, but no differences in looking times were observed when the magnitude was not proportional, e.g. a ratio of 2:3.

Interestingly, animal timing literature reports similar Weber's Law function (Weber, 1933), stating that only durations with proportional magnitudes are discriminated. This has led researchers (Brannon et al., 2006; van Marle and Wynne, 2006) to suggest that the numerical and timing abilities of infants and animals were linked, and further, that they could be accounted for by the MCM (Meck and Church, 1983), although no study directly testing this has been conducted to date.

Originally, the information processing MCM (Meck and Church, 1983) was developed to account for similarities seen in responses by rats to number and timing tasks. Rat responses followed Weber's Law functions (Weber, 1933) using analogue magnitudes of 1:2, suggesting that number and time are linked. Based on this assumption, the model (see Figure 2.6) proposes that a single mechanism is used to account for the processes used in both timing and number tasks using mental magnitudes.

The MCM and SET models operate in a similar manner. However, the MCM has no switch to start counting the pulses, merely a mode control switch, which presumably combines two roles in enabling the function to time or count events or numbers, and count pulses. Pulses emitted from the pacemaker pass over to the accumulator into working memory. The referent durations or numbers held in reference memory vary slightly but have the mean of the standard, providing a normal distribution curve. In order to time durations, the model uses two modes: the run mode, whereby stimulus onset begins the accumulation of pulses in the accumulator until the end of the trial; and the stop mode, which occurs whenever the stimulus marking the end of an interval, such as the ISI, is physically present. As with the SET model, standard referents from reference memory are compared and a response made.

Figure 2.6 The Mode Control Model of timing and counting (Meck and Church, 1983)

Meck and Church (1983)
(after Brannon & Roitman, 2003)
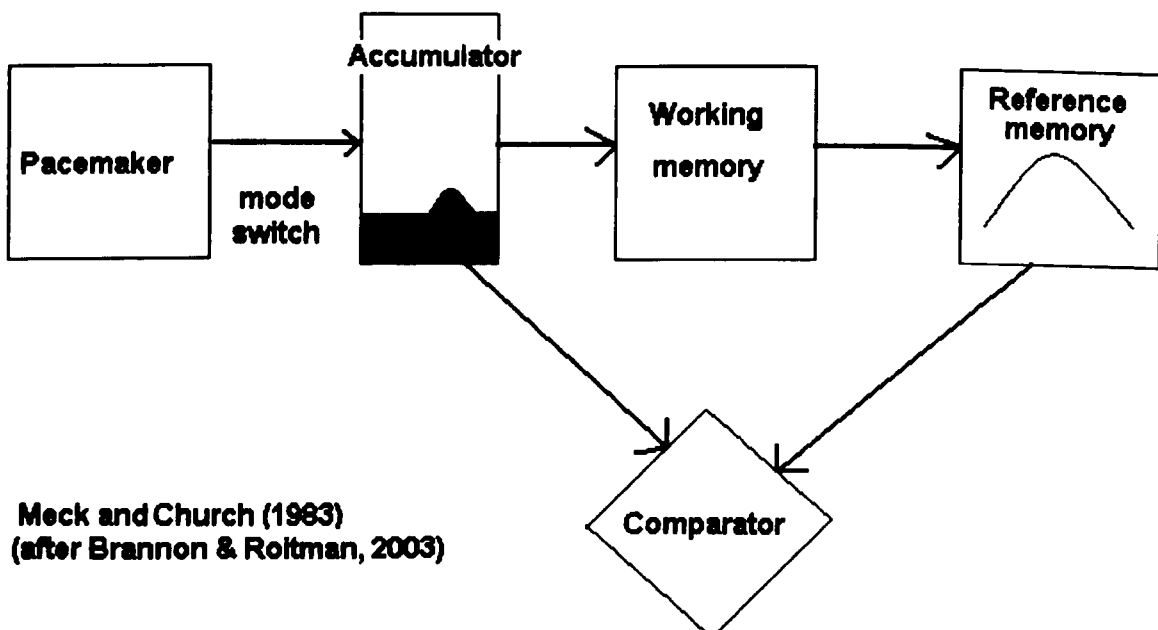
Within the nervous system linear magnitudes represent number (Gallistel and Gelman 2000; Meck, 1997). Thus the MCM explains the data obtained by van Marle and Wynn (2006) and Brannon et al. (2006) by suggesting that infants of six months use analogue magnitudes when discriminating number and area.

The MCM is described by Meck (2003) as showing "an isomorphism between number and duration". That is, a point to point relationship can be observed between the two systems (Reber, 1985). However, there are potential flaws in this model. For instance, an additional source of variance is introduced as only one switch facilitates alternating between modes, e.g. time or number, in addition to starting and stopping the model. It also provides little clarity as to how the influence of attention is accounted for within timing or counting. Additionally, no comment has been made regarding switch latency, which is a key source of variance observed in timing. Presumably within the MCM there are two types of latency. The first is attributed to the decision relating to mode use, either counting or timing, and in the case of time, there is presumably latency associated with the model in deciding between the run or the stop mode. Second, the latency involved with the switch changing from OFF to ON and vice versa. A further point of interest is that whilst animals have been shown to use the ratio or magnitude difference in temporal bisection tasks (Gibbon, 1981), human participants were observed to use the arithmetic mean (Wearden, 1991), thus not supporting the MCM and rough mental magnitudes when estimating time as observed in the van Marle and Wynn (2006) study.

To summarise, the literature reviewed shows that animals (Harper, 1982) and infants (Wynn, 1995; Xu and Spelke, 1998) possess a non-numerical method of counting. Recent studies by Brannon et al. (2006) and van Marle and Wynn (2006) clearly show that discrimination of area and time are based on analogue magnitudes in studies using novelty preference procedures. The mechanism underpinning this ability is thought to be mediated by the MCM (Meck and Church, 1983) whose specific role is to process both numerical and temporal information allowing the perception of rough mental magnitudes. However, concerns have been raised about the additional sources of variance introduced

within the model, how the MCM might accommodate the influence of attention on timing as well as differences at the decision component seen between animals and human adults on temporal bisection tasks. So a further issue that needs to be investigated in future research is whether the same effects of magnitude are observed using alternative methods to novelty preference, and therefore whether the novelty preference method is in fact suitable for examining time perception.

Having examined the relevant time perception models which focus on the role of memory in time perception, the discussion now turns to literature expounding the role of attention in time perception, which has received little interest to date and is not directly accounted for within the SET model.

2.4 Primary theories for the role of attention in infant time perception literature

As noted in Chapter 1, attention theorists, and therefore the associated literature, have fallen into two broad camps. These two broad areas are now reviewed in greater detail.

First, theorists such as Broadbent (1958) and Treisman (1963) discuss attention in terms of filtering or selecting attention, basically deciding what information will be attended to. In Broadbent's view unattended information is blocked out whereas Treisman suggests that it merely sits in the background until required for further processing.

Capacity theorists, on the other hand, such as Kahneman (1973) and Norman and Bobrow (1975) focus more on how attention is allocated. Capacity models assume that there is a finite amount of attention or mental effort available for tasks and that a central capacitor allocates attentional resources to each task. New tasks require a great deal of mental effort (e.g. one's first driving lesson) while familiar tasks require less mental effort. If only limited attentional resources are available, then an allocation system is required. Kahneman (1973) proposed that effective allocation of attention requires a central processor that constantly evaluates the level of attentional resources allocated to each task. In relation to time perception, the allocation of attentional resources to temporal

information per se determines the perceived duration of the interval (Block, George and Reed, 1980).

As described in Chapter 1, Section 1.7, attention in infants has been studied by Richards and Casey (1991) who found evidence of four different levels of attention; Attention Orientation (AO), Pre-Attention (PA), Sustained Attention (SA) and Attention Termination (AT). Heart rate responses were found to differ for each of these levels, the deepest being SA where heart rate decreases significantly and information was thought to be processed more effectively.

In a timing task, infants who engaged in deeper levels of SA, were found to be more accurate time keepers, as observed by lower heart rate responses at the time of stimulus omission (Colombo and Richman, 2002; Colombo et al., 2005). Importantly though, this study was only discussed in terms of attention, not the SET model, so no comparisons could be drawn, meaning that the influence of attention on interval timing has not been directly accounted for within either the original SET model (Gibbon, 1977) or the devSET model. That said, however, attention is thought to underpin timing by influencing the pulses that flow from the pacemaker through to the accumulator (Block and Zakay, 2001).

Various cognitive models have sought to address this issue, but all of these have necessitated additions to the SET model (see Figure 1.1), thus increasing the sources of variance. As has already been noted in Section 2.3.1, increased variance in response times of young children is a feature of the devSET model. So the addition of components to account for the role of attention simply exacerbates the levels of variance within the model. However, in accepting that fact, this thesis seeks to build upon the existing research into the role of attention in infant time keeping, and to place it firmly within the framework of the devSET model.

2.4.1 Further theories addressing the role of attention in infant time perception

The original SET model (Gibbon, 1977) incorporated a switch allowing pulses to travel from the pacemaker to the accumulator when closed (see Figure 1.1). The switch, according to Meck (1983), operates on an all-or-nothing principle once an attentional threshold is reached. Any subsequent drop in attention below this threshold opens the switch preventing any further pulses passing to the accumulator. So the original SET model assumes that attentional resources remain constant at all times, but this is not the case. Arousal can heighten attention to temporal information; hence Treisman (1963) added a specific arousal centre to the SET model to modulate the flow of pulses from the pacemaker. The higher the arousal the faster the rate of pulses resulting in a longer duration being perceived.

Further influential theories have also been proposed to account for attention in time perception, such as a flickering switch (Lejeune, 1998) and an attentional gate (Zakay and Block, 1996), both of which are now reviewed.

Lejeune's Flickering Switch Model (FSM) adapted the switch mechanism of the original SET model so that instead of being an "all-or-nothing" type switch (Meck, 1983), it flickers between closed and open within a duration, depending on the level of attention given to temporal aspects of a task at any given time. In this way, attention levels modulate the number of pulses travelling to the accumulator. As the operation of the switch is not automatic, a small delay occurs each time the switch opens and closes, called switch latency. This is a source of scalar variance (Lejeune 1998). If attention is focussed directly on temporal information there will be little variability or delay in closing the switch, resulting in decreased switch latency and increased temporal accuracy. Conversely, lower levels of attention to temporal information increases variability or delay and results in increased switch latency and decreased temporal accuracy, as estimations become more variable. To illustrate this point an example of the variability in switch latency used earlier in the chapter, was pouring milk into containers during milk production. As the switch

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controlling the flow of milk into the containers varies slightly each time it is operated, the containers are not uniformly full. Some containers contain slightly more milk than others but all are centred on the mean quantity. In a similar way within the SET model (Gibbon, 1977), switch latency results in many different representations of a duration but all are centred around the mean of that duration.

An alternative theory, the Attentional Gate Model (AGM), is proposed by Zakay and Block (1996) and relies on a different method to account for the influence of attention in time keeping (see Figure 1.1). The AGM operates a gate in addition to the switch within the clock component to account for the influence of attention in time perception tasks. Interestingly, although Zakay and Block consider their work to be a cognitive model of timing, it has the same base structure as the SET model (Gibbon, 1977), with the addition of a gate before the switch in the clock component.

In the AGM, the gate opens as a function of the attentional resources allocated to temporal information at any given time (Zakay, 2000). Importantly, the AGM draws heavily on Thomas and Weaver's (1975) model, which assumed the design of the capacity model of attention – that is, attention has a finite capacity available to be allocated to different tasks. In the Thomas and Weaver model, two parallel processors simultaneously review temporal and non-temporal information, such as a time interval and a list of words respectively. They propose that the perception of any given duration depends on the allocation of resources given to the associated temporal information. Therefore, if no attention is given, pulses are lost and durations are perceived as being shorter than they actually are. Critically then, the idea that temporal and non-temporal information is processed independently is pivotal to these models, and will be further explored within this thesis.

In the AGM (Zakay and Block, 1996), as the gate opens indicating that attention is being allocated to time, the switch opens indicating that the stimulus has temporal meaning. This in turn sets the cognitive counter (as opposed to the accumulator in the SET model) to zero before allowing the flow of pulses from the pacemaker. The larger the number of

pulses counted the longer the duration perceived. Conversely when attention is divided between temporal and non-temporal tasks, the opening of the gate is narrowed, allowing fewer pulses through and resulting in a shorter interval being perceived.

In examining the differences between Lejeune's FSM (Lejeune, 1998) and Zakay and Block's AGM (Zakay and Block, 1996), it seems that essentially they depend on different models to explain temporal attentional processes. The FSM favours filter models of attention, where attention is selectively focussed on pertinent information (Broadbent, 1958; Treisman, 1963), whereas the AGM favours capacity models where a central capacitor with a finite capacity allocates attention according to the task (Kahneman, 1973; Norman and Bobrow, 1975). Further differences are seen in the operating triggers that close the switch, or open the gate. The operation of the switch within the FSM is triggered by an external event such as a stimulus onset that has to be observed or attended to by the participant, whereas the AGM's gate operation is triggered by an internal event, namely the allocation of attention to temporal aspects of the stimuli.

Within the FSM, the effect of switch latency is compounded by the frequency of the switch closing and opening. Yet within the AGM, the gate and the switch introduce two additional sources of variance into the system, meaning that only when timing was conducted under conditions where temporal information was being fully attended to, would the gate and the switch operate synchronously. Under all other conditions small delays would occur before the onset of the gate opening and the subsequent opening of the switch setting the counter to zero. As already noted, variance at any point within the timing system reduces the accuracy of a temporal estimation being made, suggesting that the AGM introduces more variability into the system than the FSM. However, both frameworks are useful and are employed to appraise the research findings within this thesis.

Further exploring the properties of switch latency, Witherspoon and Allan (1985) manipulated task difficulty in order to influence the variance in switch operation. Adult participants were presented with data at a rate of one word per second during the training phase, but then at either 30ms or 50ms during the test phase. Here, participants were

required to identify the word and define the duration within one of four categories: very short, short, long or very long. Old words (e.g. those learned during training) were evidently easy to identify (due to the familiarity effect) and were judged to have longer durations. However, new words (e.g. those just presented) required participants to divert their attention away from the temporal task to the non-temporal task, and as such introduced greater variability resulting in these new words being judged as shorter. Experimental tasks where participants' attention is divided between temporal and non-temporal information are called dual task experiments.

Dual task experiments have produced interesting results in adults and could have significance for the infant population. For instance Fortin and Masse (2000) demonstrated that durations are judged as longer if the duration to be estimated was interrupted with an empty period where nothing happens. Further, if this break is cued by an auditory signal such as a click, an even longer duration is then perceived. However, in other dual task experiments, interruption involving processing non-temporal information (e.g. Brown, 1985), as well as task difficulty (e.g. Zakay, Nitzan and Glicksohn, 1983), had a detrimental effect on time perception. So these examples suggest that dual task experiments, may be influenced by variability in switch latency. The dual task principle will therefore be applied to the research studies within this thesis to understand whether the effect of switch latency is common across infant and adult populations.

So to draw some conclusions based on a review of the literature so far, it has been seen that the effect of attention in time perception has focused on the clock component of the SET, FSM and AGM models. Variance due to delays in the operation of the switch or attentional gate occur at this part of the process influencing the encoding of temporal information that ultimately passes through the system to reference memory (Lejeune, 1998; Meck, 1996; Zakay and Block, 1996). The sources of variance have been shown to originate from the length of time it takes for the switch or gate to close or open respectively, and that this is influenced by attention. So for the purposes of this thesis, by

designing experiments that manipulate the clock component, the role of attention in infant time perception could be examined.

Whether modulated through a specific arousal centre (Treisman, 1963), an attentional gate (Zakay and Block, 1996) or a flickering switch (Lejeune, 1998), it is clear that attention plays an important role in time perception. As mentioned in Chapter 1, auditory cues have been used to test the role of attention in children's time keeping within terms of the devSET and cognitive models, and these studies will now be discussed.

2.4.2 The impact of auditory cues on attention and timekeeping

Initial work conducted by Droit-Volet (2003) using a warning auditory click to alert groups of three-, five-, and eight-year-old children of an upcoming duration to be judged in a temporal bisection task found that durations were estimated as longer, and performance showed less variability, compared to the trials without the auditory cue. Droit-Volet suggests two reasons for these results. First, the auditory cues elicited longer responses, supporting previous research demonstrating that durations represented as auditory stimuli are judged longer than visual stimuli (Wearden et al.,1998). Second, reduced variability in switch latency occurs due to the auditory cue raising awareness of the imminent arrival of a to-be-judged duration.

By extension, in applying this to the infant population, a similar methodology could be used to examine whether auditory cues influence infant responses in similar ways. Specifically the question of whether the provision of auditory and visual cues enhances infants' temporal estimation abilities, and indeed if either of these has a particularly significant influence above the other, as will be examined in Experiment 4 of this thesis. Before leaving the discussion on timing in children, a brief discussion of the types of timing examined will be undertaken. These are retrospective and prospective timing.

2.4.3 The roles of Retrospective and Prospective timing in time perception

The role of attention in children aged seven and nine years old was investigated by Zakay (1992) using retrospective timing (RET) and prospective timing (PT). RET is underpinned by memory, whereas attention underpins PT. Eighty seven- and nine-year-old children were presented with a smaller and a larger light bulb burning with different intensities, 4 watts and 12 watts respectively. Durations lasted for between 3s and 6s, and participants were asked to estimate the duration of each occurrence. The children were divided into two groups, one group were tested on RET so received no information about the study. Participants in the second group were tested on PT so were told to pay attention to the temporal elements of the task in order to reproduce the duration of the lighted bulb. Interestingly, the data revealed similar findings to adult studies, in that durations using PT were judged to be longer than durations using RET. This indicated that increased attention to the task in the PT condition influenced the perception of the length of the duration.

Building on his finding that attention influences time perception, Zakay (1993) then investigated PT judgements in four groups of younger children aged five to six years, using the dual task method to reproduce a duration. One group reproduced the duration while completing a drawing task, the concurrent condition with a 'filled' duration, while the second group reproduced the duration without a concurrent task, an 'empty' duration. Each of these two groups were sub-divided into a further two groups, one promised a reward, the other not. The data revealed that the children who had no concurrent tasks (i.e. the empty durations) and were promised a reward produced more accurate time estimations than the children in the 'filled duration condition' who judged the durations as shorter. Zakay reasoned that this was because children with no concurrent tasks, focussed their attention on the temporal information waiting for the duration to end. Therefore, in line with adult data, empty durations were more accurately estimated than filled durations, for example, those durations with a concurrent task, (Boltz, 1998). Zakay (1993) discussed his results within the AGM positing that in empty durations the

attentional gate was opened wide, thus allowing more accurate representations to be made.

As noted in Chapter 1, a further factor discussed within the cognitive models is the role of memory and environmental changes, so these will be discussed in more detail to consider how they might influence time perception and therefore inform the enquiry within this thesis.

2.5 Other possible influences on time perception

2.5.1 The influence of environmental change on time perception

Environmental or contextual changes described in Chapter 1, have been defined by Hintzman and Block (1971) as being either internal, such as changes in homeostasis, or external such as changes in the environment. These changes have been found to influence time perception and are therefore of interest to this thesis.

As observed when learning word lists, contextual information is encoded automatically as a word's temporal position is correctly recalled, even if the word itself is incorrectly recalled and no instruction about temporal order given (Hintzman & Block, 1971; Hintzman, Block, & Summers, 1973). In real life, temporal estimations are rarely made without reference to context, which is encoded automatically as part of the event. Incorporating this, Block and Reed (1978) devised the Contextual Change Hypothesis of timing (CCH), proposing that automatically encoded contextual information influences the remembered duration of an event.

The CCH states that the number of contextual changes within a task rather than the number of events per se, as in Ornstein's (1969) storage size model of memory, influences duration estimation in RET (Block and Reed, 1978). They based their conclusions on work conducted by Hicks, Miller and Kinsbourne (1976) showing that participants who learnt word lists containing both semantic and structural words judged the learning period to be longer than those participants who learned word list containing either semantic or structural words. It was proposed that durations for the mixed word list

were judged as longer because two different types of cognitive processing were required, whereas the semantic or structural word alone list required only one. Therefore, it was not the events per se, (i.e. the new information) which affected recall, but rather the number of contextual changes (i.e. the number of information processes used to remember the word lists) within the duration.

Another aspect of the CCH is that during the first time a task is completed, more contextual changes are encoded. This is called the 'positive time order effect', this explains why 'the first of two equivalent time periods is judged as being longer than the second' period (Block and Zakay, 2001:67). An example of this would be a car journey to a new destination; on the outward journey, the driver would be conscious of road signs and distinguishing features and the journey appears to take a long time. The return journey, on the other hand, is perceived as much shorter as the driver does not encode every feature along the road, only the distinguishing features.

The idea that the first instance of a duration, such as a car journey, is perceived as longer than subsequent durations may also be a phenomenon that could influence infant time perception. Because of the nature of RET, the tasks for adult or child participants are one-trial tasks, as after this the purpose of the study is known, which would influence subsequent responses. Consequently, this phenomenon cannot be explored further with adults and children. This is not the case with infants, who would clearly not understand any questions relating to the perceived duration. Infants therefore remain naïve to the purpose of the task for more than one trial and could be tested by monitoring infants' eye movement patterns. Presenting infants with stimulus sequences at predictable intervals and then disrupting the sequence allows eye movements towards the omitted stimulus to be examined over a number of sequences. If infants are subject to the same phenomenon, that the first of two equivalent time periods is judged as being longer than the second period (Block and Zakay, 2001:67), CCH would predict that the response to the first omitted stimulus in the first sequence would be longer than omitted stimulus trials in subsequent sequences. Further CCH would predict that increases in contextual

changes, such as speed of presentation and number of stimuli presented within a sequence, will have a detrimental effect on infant temporal estimation abilities.

It is clear from the foregoing that time perception is mediated by both memory and attention and that initial work has begun to explore the various influencing factors. In everyday life, however, there are other cues that might influence time perception such as social saliency for instance within communication. The following section examines the literature concerning the temporal aspects of social communication to ascertain if any particular time intervals might be useful to consider when studying infant time perception.

2.5.2 The importance of synchrony and time intervals involved in social interaction

As discussed in Chapter 1, the temporal characteristics of early interaction between a mother and her infant have been shown to be critical for the development of language and emotional well-being of infants. Isabella and Belsky (1991) proposed that the quality of attachment between mothers and their one-year-old infants is conditioned by the level of synchrony in their earlier interactions, whilst the importance for attachment of good timing within mother–infant interactions has been highlighted by Ainsworth, Bell and Stayton (1974) and Brazelton, Koslowski and Main (1974). So timing, or an awareness of temporal parameters within an interaction, is clearly a key factor in secure attachments, suggesting that infants already possess an awareness of temporal parameters at birth or that it develops shortly thereafter.

Patterns of change within mother–infant interactions such as vocalisations and facial gestures (called phrases), are diminutive. When in synchrony Stern (1977) likens the interaction to a waltz, as each partner works at getting to know and anticipate their partner's next move. Successful mother–infant interactions usually occur within 500ms (Stern and Gibbon, 1979) that is, within a burst of interaction with the pause between turn-taking lasting for up to 500ms episodes. It is argued by Stern and colleagues (1974, 1977) that infants are better able to estimate the successive behaviours of their interaction partners at this time interval, with that ability deteriorating with intervals longer than

500ms. These findings indicate that the length of a pause (e.g. 500ms) as well as synchrony is important for successful infant social interaction.

Regularity and repetition of social behaviours are another crucial part of the mother–infant interaction involving timing and may also be useful in interval timing, which Stern (1974, 1977, 2002) labelled the 'repetitive run'. The function of a repetitive run, according to Stern (1977), is to provide an infant with a theme and variations on that theme. The themes and variations can be behavioural, called a content run, or a temporal run involving changes in timing. For instance, a mother might say hello to her infant in several ways by varying the pitch (content run) and the tempo (temporal run). In this way it is proposed, her infant remains alert whilst learning to categorise behaviours as well as learning exemplars of these categories (Brazelton et al., 1974; Stern, 1977; Stern et al.,1977; Messer, 1994). This aspect of social interaction is important as the daily lives of infants are littered with repetitive sequences of events such as games of peek-a-boo. Repetitive runs also create temporal expectancies within interaction sequences. These are important factors to bear in mind when investigating infant time perception.

Furthermore, periods of 2-3s emerged as important factors when temporal expectancies such as rhythms of dialogue during mother–infant, mother–stranger, and stranger–infant dyadic interactions with four-month-old infants were explored by Jaffe, Beebe, Fieldstein, Crown and Jasnow (2001).

Of particular interest to this thesis is the length of the bursts of interactions by each person as they provide evidence of units of time that are important for infants. The bursts of interaction consisted of turn-taking, pausing, vocalising, initiating and terminating interactions. The mean duration of the stranger's response to the mother was approximately 2.38s. The mean duration of mother's response to their infants was approximately 2.24s, while the mean duration of the infants' response to their mothers was approximately 1.69s, almost 1s shorter than the adults. Stern (2001) provides possible reasons why these durations may be important for infants but states that further research is needed to support his ideas. First, infant physiology such as breathing

capacity etc. may limit longest unit of response possible to 2–3s. Second, units of 2–3s are important for chunking and processing information gained through the interaction. These timings provide evidence that a unit or period of response of between 2–3 seconds is important for infants.

To summarise, this section highlighted that four-month-old infants are aware of and use intervals of 500ms and between 2–3s within social interaction, therefore these intervals will be employed in the research within this thesis. Furthermore, successful interaction entails anticipating the sequence of events (the 'repetitive run', Stern, 1977), that form temporal expectancies about that event to be able to interject appropriately. The ability to learn through familiar events or situations and form expectancies about them has also been identified by Haith and colleagues (Haith, 1989) to be important for infant cognitive development and will be discussed further in the following section.

2.5.3 The role of expectancies within time perception

Many future actions performed by humans are based on expectancies of future events which Haith, Wentworth and Canfield (1993) term 'future oriented processes' or future goals. Some of these goals are temporally based, the preparation of a meal for example. Based on the cook's expectations of cooking times required for different dishes, different ingredients will be cooked at different intervals in the cooking process to ensure that the future oriented goal is achieved. That is, that the complete meal is ready to be eaten at the same point in time.

The ability to use future oriented processes forms within the first year of life according to Haith (1993), and is achieved by detecting regularities in the world and forming expectations based on these regularities. In order to examine infants' acquisition of spatiotemporal expectations, Haith, Hazan and Goodman (1988) developed the Visual Expectation Paradigm (VExP), using eye movements to measure infants' ability to make future oriented movements.

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The VExP has been used by Haith and colleagues (1988, 1996, 1998) for over 20 years and in essence involves presenting infants with a series of pictures in a regular left/right alternating pattern. This regularity is occasionally disrupted with pictures appearing sequentially on the same side two or three times before resuming the alternating pattern. Each presentation of a picture constitutes a trial. So a typical sequence of 60 pictures appearing for 700ms with an ISI of 1000ms may thus proceed in the following pattern. Fifty pictures follow the alternating left/right pattern, with extra pictures being positioned on the same side after the 20th, 30th and 40th pictures (e.g. left, right, right, right, left representing disrupted trials). Increased anticipatory saccades (eye movements) during disrupted trials are observed during the following ISI, in the position of the last picture location, suggesting that infants had formed expectancies about the anticipated stimulus that should follow.

Notably for this thesis, the VExP has been used mainly with three-month-old infants (Haith and McCarthy, 1990). However, participants in some studies were two-month-old (Wentworth and Haith, 1992) whilst others have worked with slightly older 3.5-month-old infants (Haith et al., 1988). Evidence that infants have learned the left/right sequence comes from several factors. First, anticipatory saccades, that is saccades made to the next location in the sequence before the arrival of the next stimulus; and second, saccadic reaction times. In this study, infants made anticipatory saccades on 18% of trials, whilst the baseline median saccadic reaction time (RT) to the picture was 472ms for the first five trials, dropping to 327ms for the remainder of the trials. This decrease in reaction time demonstrates that infant reactions benefited from previous experience of the task, indicating the formation of infant expectations. The authors suggest that this decrease in reaction times might also indicate that infants had noted the duration, although in this study timing was not the focus of attention. Notably, the fact that RT dropped dramatically after five trials indicates that sequences in future studies investigating time perception should contain at least five trials in each sequence presented to infants.

In appraising the literature above, it could be argued that these results were purely evidence of conditioning, being a learned motor response, e.g. 'first, I move my eyes left and then right'. So further research using the VExP has tested whether conditioned ocular motor responses account for these previous findings. This later work shows that when presented with simple alternating sequences, infants quickly detect both spatial and temporal regularities (Haith and McCarthy, 1990), forming expectancies from these regularities.

Canfield and Haith (1991) then developed this line of research still further with two- to three-month-old infants, by presenting sequences in three conditions. First, a simple right, left sequence (1:1); second, a 2:1 sequence such as right, right, left; finally, a 3:1 sequence such as right, right, right, left. The results showed that both two- and three-month old infants learned the simple 1:1 sequence, but only the three-month-olds learnt the 2:1 sequence. Neither group learned the 3:1 sequence. The authors attributed this failure to learn the more complex sequences to the observation that infants had learned the spatial relationship rule – that you move your eyes to the other side after a picture has appeared at least once on the first side, hence supporting, at least for 2:1 sequences, the notion that tracking in the VExP cannot be attributed to conditioned ocular motor responses.

The findings from this study are similar to the findings of the later study conducted by Brannon, Lutz and Cordes (2006), which demonstrated that infants showed novelty preference for magnitudes of 1:2 conforming to Weber's Law (Weber, 1933), but not magnitudes of 2:3 (see Section 2.3.6, Mode-Control Model). The Haith studies (Haith, 1989) similarly indicate that infants may have learned magnitudes of 1:2, although Haith and colleagues did not comment on this aspect.

So the VExP allows insight into temporal as well as spatial components (e.g. left/right location of stimuli) of infants' expectations, where again predictability was found to be a key element. For instance, McCarty, Arehart and Haith (1996) observed increased anticipatory saccades to the next location, with a straightforward left-right sequence when

the ISI was regular rather than irregular. Similar results were obtained if the location of the stimulus was unpredictable, provided that the time of the ISIs remained predictable. Wass, Bihun and Haith (1996), on the other hand, posit that whilst anticipatory saccades reflect an infant's expectations about spatial relations, it was reaction times to the stimuli that reflected temporal expectations, as longer ISIs resulted in proportionally slower reaction times. However, in the Wass et al. (1996, 1998) studies the duration of picture presentation increased in ratio to the lengthening ISI and therefore could have influenced infants' reaction times. In order to overcome this, Wass, Lewis and Haith (1998) kept the duration of the stimulus presentation constant whilst varying the ISIs, finding slower reaction times with longer ISIs, thus supporting the earlier finding. The authors suggest that infants' ability to estimate time is limited, as when ISIs were increased to over 400ms infants showed more variability in time estimates. The authors made no comment, however, as to whether response times changed as a function of Weber's Law (Weber, 1933) such as in Scalar Timing, so no direct comparison to the SET can be made.

2.5.3.1 Infant timing within the VExP

Time factors within VExP were explored more fully in a series of three studies with three-month-old infants conducted by Haith, Adler and Wass (1996), which will now be reviewed.

The first study revealed that when the stimulus location was unpredictable but the duration of the ISI was held constant, infants' reaction times to the stimulus were faster than in previous VExP studies (e.g. mainly under 450ms) as described above. Whereas if both the timing and the stimulus location were unpredictable, reaction times were slower, leading the authors to conclude that infants had formed temporal expectations about the sequences. Again the authors did not comment on any theories of timing that may be implied here, but the findings can be accounted for in two ways. First, CCH (Block and Reed, 1978) would posit that contextual changes in both spatial and temporal information accounted for the increased response times. Second, the devSET model would propose that increased ambiguity regarding the sequence resulted in increased response times,

which would appear to offer greater explanatory power when considering the findings of the present research.

In the second study, infants' ability to form temporal expectations with two time intervals was explored. The ISI of stimuli appearing on the left hand side was 800ms whereas the ISI on the right was 1200ms. Infants were observed to make faster eye movements to the left hand stimuli than the right, suggesting that they had discriminated between the two intervals, forming expectations about them. Interestingly, Haith et al. (1996) also found an increase in anticipatory saccades to the faster left hand side, reinforcing the view that the infants had formed expectations.

The last study in the series continued to investigate long and short ISIs, finding that anticipatory saccades, but not reaction times, were sensitive to the length of the ISI with more anticipatory saccades being observed with shorter ISIs. Infants' reaction times were fast within short ISIs of 875ms but did not get faster and thus more accurate with increasing experience, which would have been expected had the infants learned to anticipate the timing of the interval. Additionally, although reaction times of saccades made to the short ISI were faster, they were not necessarily made to the correct location, questioning the formation of spatial expectations. On the other hand, in the long ISI (1200ms) condition, saccades were more likely to be made to the correct location but with slower reaction times. This suggests that infants are more able to incorporate both temporal and spatial information at slower speeds, implying that at faster speeds they attend either to the spatial or temporal information but not to both. Haith et al. (1996) suggest that the longer saccadic reaction times made to the long ISI also indicate that infants were distinguishing the different temporal parameters between the two ISIs.

So what conclusions can be drawn from these findings? The authors (Haith et al., 1996) use these results to argue that infants' temporal expectations are based on the relationship between individual events, rather than the spatial pattern of events. However, in this study, the short ISIs were always to the infant's left hand side whilst the long ISIs were always to the right, so it is not possible to entirely rule out the influence of location. A

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further explanation of these findings could be that the immature ocular motor system of three-month-old infants makes them unable to control faster saccades to the correct location within the shorter interval of 875ms. Having said that, the same effect was observed with the longer 1200ms interval thus making this argument seem unlikely, but it could be that even 1200ms is too brief an interval for the immature ocular motor system of three-month-olds. The pattern of results across the three studies led the authors to suggest that there is an optimal time window between 875ms and 1200ms for three-month-old infants to be able to form temporal expectations. Intervals falling outside this window will elicit wider variations in reaction times, and intervals of between 875ms and 1200ms will be accommodated within the present research design.

Building on the earlier work of Haith, Adler and Wass (1996) and Adler, Haith, Arehart and Lanthier (2008) above, a more recent study conducted by Adler et al. (2008) set out to examine the temporal components of infants' visual expectations. This is now reviewed to understand its implications for this thesis.

Two studies were conducted using a modified VExP paradigm where only the time intervals (ISIs) varied, as opposed to the traditional VExP design where the spatial location of the pictures within the sequences varied. The first study presented either a predictable sequence or an unpredictable left/right sequence to two groups of three-month-old infants. The data reported showed a significant increase in anticipatory saccades (43.4%) within the predictable sequence group, however, saccadic reaction times were faster within the unpredictable sequence group, especially when the ISI decreased from 1200ms to 800ms. The authors reason that longer ISIs gave the infants more time to prepare their saccades resulting in shorter reaction times.

As the above results for the two sequences were contradictory, a further study was conducted to examine whether infants were using "average" temporal flow rate information in order to judge the durations of the ISIs, such as the average rate that stimuli appeared to the right and left of the computer screen. By training infants on a short (2600ms), medium (3400 ms) or long (4200 ms) flow rate, the speed of stimulus

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presentation can be varied. For instance, after 50 pictures in the sequence, altering the speed of the long and short groups to medium flow rate (the medium acted as a control group), the authors proposed that the short flow group would decrease the number of anticipatory saccades they made, whilst the long flow group would increase the number of anticipatory saccades made possibly also producing faster saccades. The actual results showed that whilst there was no change in the speed of anticipatory saccades made, there was a change in number: the number decreased in the long flow group but increased in the short flow group. The authors found no difference to saccadic reaction times before the change of flow rate but afterwards they found that the long flow group had longer latencies overall. So, in drawing conclusions across their studies collectively, the authors posit that an overall flow rate of temporal information is perceived rather than individual time intervals.

Whilst recognising that the VExP goes a long way in elucidating the factors from which infants form spatio-temporal expectations, which could have obvious importance for interval timing, there are a number of difficulties. First, expectations are tested by means of anticipatory saccades and reaction times to sequences of stimuli, which are constantly visible to the infant (except of course in the ISI) despite being disrupted in various ways. Further, Haith and colleagues (1980) debate whether anticipatory saccades or reaction times inform us about temporal relations. In the VExP, an anticipatory saccade is one which is made to the next location in the sequence, either before the next stimulus is presented (that is in the ISI) or up to 200ms after stimulus onset. However, Haith and colleagues note that with the advent of more precise recording and measuring equipment, the 200ms time window may decrease. Supporting this, Canfield, Smith Brezsnyak and Snow (1997) suggest that only saccades initiated up to 100ms after stimulus onset should be classed as anticipatory saccades and those occurring afterwards should be classed as reaction times. Recognising the debate here, the studies reported within this thesis adapt the VExP paradigm using alternating stimulus sequences.

Nevertheless, it is important to recognise that a number of processes precede an eye movement (Haith, Wass and Adler, 1997) that require time to complete. These include disengagement of attention from a previous stimulus, a decision that a new event or stimulus will arrive requiring another saccade, and finally computing the velocity and distance needed to make that new saccade. As all of this takes time, Haith et al. (1997) argue that a longer window is required for anticipatory saccades to accommodate these processes. It could be counter-argued that if an infant is truly anticipating a forthcoming event, she will have already disengaged her attention and begun the preparation for the next saccade soon after the offset of the previous stimulus, that is, in the early part of the following ISI. This could be tested by examining whether or not infants could track a sequence containing short ISIs. Under these conditions, an increase in the number of anticipatory saccades for long ISIs and a decrease during short ISIs, proportionate to the decrease in length of ISI due to the lack of time to complete the necessary pre-saccadic processes, would be expected. Reaction times, on the other hand, could be argued to provide no temporal information, as a saccadic reaction time is an eye movement that is made after stimulus onset and so simply a reaction to the onset of an event, merely confirming that the infant has noted that new event.

The foregoing discussion suggests that the distinction between anticipatory and reaction time saccades made after stimulus onset appears to be unhelpful. If infants were time keeping, it would be predicted that an expectation that the time interval for a new stimulus to arrive would have been formulated. Infants would thus be looking in anticipation of the forthcoming stimulus (although one could argue that this suggests a conscious action on the part of the infant) and have begun the preparatory eye movement processes during the ISI in order to make the next eye movement on time. On that basis, only saccades made in the prior ISI should be classed as anticipatory saccades, as they show that the infant miscalculated their expectation, that is, they looked too early. Research has shown that adults engage in very few anticipatory saccades (Mansfield, Farroni and Johnson, 2003). Further, saccades made close to the time of stimulus onset would indicate that a more accurate temporal expectation was formulated. Thus, these saccades or reaction

times are more "temporally informative" (Canfield et al., 1997). In the same way, saccades made in the latter part of the stimulus presentation merely show a reaction to the presence of the stimuli rather than any temporal expectation or anticipation of it. These late saccades are not temporally informative.

An example of the usefulness of changing the definitions of anticipatory and reactive saccades can be seen in the recent study by Adler et al. (2008), in which they used an upper limit of 167ms after stimulus onset for anticipatory saccades and employed what they described as an 'eye tracking computer programme', (but were not specific about what system they used). When discussing their results no mention was made of how near the anticipatory saccades were to the stimulus onset, which would be clearly seen by the eye tracker. This is an important point as in one of the studies the difference in reaction times between the predictable and unpredictable sequences was 25ms (450ms vs 475ms). This is clearly non-significant and not really temporally informative. A clearer difference between the two groups might have been observed, especially with eye tracking technology, if reaction times were counted nearer to stimulus onset. In this way these saccades may have proved more temporally informative.

Whilst the VExP has been very informative about infants' abilities to form future-oriented expectations, a line of enquiry which has not been followed up is to provide infants with exemplars and then completely stop the sequence for an extended period of time (rather than continuing after the same ISI as in the VExP). Evidence of infants' expectations for the next event could be observed. If infants have merely formed spatial expectations then they will look to the next location in the now disrupted sequence but at random timings. However, if infants have formed both spatial and temporal expectations then saccades to the next 'correct' location will be observed about the time, or just after the time, that the next stimulus in the sequence should have been presented. Therefore a better test of infants' ability to form temporal expectations about the intervals between the stimuli would be to disrupt a predictable sequence for an extended period of time and examine subsequent eye movement patterns.

The discussion in this section emphasises the sensitivity of infants to temporal parameters in varying contexts and their ability to form temporal expectations about the intervals between stimuli in a predictable sequence. The VExP has provided a useful platform on which to examine the development of infants' spatio-temporal expectations. The foregoing studies point to regularity and predictability as being key elements in the ability of infants to form expectations (whether temporal or spatial) about future events (Haith, Hazan and Goodman, 1988; Wass et al., 1996; Canfield et al., 1997), and that at least five exemplars within a sequence are needed before expectancies can be formed (Haith, Hazan and Goodman, 1988). Expectancy, as cued by auditory cues, has also been shown to influence adult time perception (Fortin and Masse, 2000). It would seem logical therefore to incorporate predictability into future studies to extend our knowledge of infant temporal perception. Before concluding the review of the literature on factors that may influence time perception a discussion relating to individual differences will now follow. Individual differences in sustained attention observed by Colombo et al. (2002, 2005) influenced time perception, (see Section 1.2), with infants engaged in higher levels of sustained attention being more accurate time keepers. Can individual differences also be observed using other methods? Might these also relate to infant time perception? These questions will be addressed briefly in the following section.

2.5.4 Evidence for individual differences observed in infant cognitive processing and influence on time keeping

Individual differences in the duration of infants' fixations has been the subject of research for over 20 years and challenges the notion that qualitative changes occur in intelligence from infancy through childhood (Piaget, 1952). Rather, more recent research indicates that intellectual function may be continuous (Colombo, Mitchell, O'Brien and Horowitz, 1987; Colombo, 1993; Colombo et al., 2001). Individual differences in look durations are thought to reflect differences in processing visual information (Colombo, Freeseman, Mitchell and Coldren, 1990; Rose, Feldman and Wallace, 1992) with 'long-looking' infants

engaging in local featural processing and 'short-looking' infants engaging in global holistic information processing strategies.

A link has also been made by Colombo, Richman, Shaddy, Greenhoot and Maikranz, (2001) between individual differences in look duration and the four phases of attention outlined by Richards and Casey (1991). This research linked levels of attention, notably the fourth level of attention, 'attention termination' (AT), to length of look duration. Long-looking infants have been shown to have difficulty disengaging attention, a finding previously demonstrated by Frick, Colombo and Saxon (1999). Further, the Colombo et al. (2001) study showed that length of look duration significantly predicted recognition and sustained attention (SA), a phase where information is thought to be processed most effectively. AT also varied with look duration, but only AT significantly predicted recognition, as the less time infants spent in AT relative to SA predicted higher recognition rates. The authors suggest that disengagement of attention may mediate the relationship between look duration and recognition. Although, long-lookers spent more time in both SA and AT phases of attention, it was short-lookers who performed better on the task. The authors go on to say that it may not be the quantity of time spent in SA that matters, but rather the quality of SA that the infant engages in. This literature reveals some interesting anomalies between infants' use of these looking strategies and levels of attention and the ability to perform certain tasks. The link made in these studies between look duration and heart rate phases of attention allows a further avenue of investigation in exploring the role of attention in infant time perception.

The existence of two looking categories (e.g. long- and short-looking categories) in infants has been questioned in more recent years. Brown, Farran, Cole, Karmiloff-Smith and Houston-Price (2005), have questioned whether these two groups are uniformly divided at the precise cut off point of 9s between groups reported by Colombo and colleagues (1987); 9s being the mid-point in the lengths of longest look recorded for all infants. In addition to this question, Courage, Reynolds and Richards, (2005) and Richards (2006, personal communication) also question whether the categories of long- and short-looking

are stable as reported by Colombo, Mitchell, O'Brien and Horowitz (1987) or whether a third intermediate group should be included as Courage et al. (2005) and Richards (2006, personal communication) found evidence for some infants changing from long-looking to short-looking categories and vice versa depending on the stimulus used in an accumulated looking task. Colombo and colleagues (1987) have consistently used the same stimulus and procedure throughout their research into individual differences in look duration. Richards (2006, personal communication) concludes that if the same stimulus and procedure used by Colombo and colleagues (1987) are adapted, similar results should be obtained; however, any variation to either may alter the results, bringing into question the stability of long- and short-looking categories. If evidence is found for the existence of individual differences in look duration indicating the use of different information processing styles these may influence infant time keeping revealing a further area of enquiry.

Other explanations for individual differences in infant performance have been made by a number of researchers, for instance Siegler (1996) proposes that children use different strategies to solve any given problem and that as strategy choice is highly individualised due to factors such as past experience and the current problem, individual differences are inevitable. Furthermore, Siegler proposed the Overlapping Waves Model to account for the individualised use of different strategies both intra-person and inter-person on the same problem such as learning to spell.

2.6 Summary of main issues and debates

The chapter has covered material from apparently disparate areas of psychology since work on infant time keeping is nascent; however there have been a number of studies which have examined areas that relate to time perception. For instance, research examining social interaction, the formation of spatio-temporal expectancies and individual differences in performance were discussed and revealed important factors that need to be included within the empirical work undertaken in this thesis.

Within time perception literature the SET and devSET models (Gibbon, 1977; Droit-Volet, 2003) were discussed. The devSET model has been used successfully to account for differences in responding on timing tasks between adults and children, and this thesis will endeavour to extend its application for the first time to infants. It was further noted that whilst much work has been conducted in trying to understand the memory mechanisms underpinning time perception in both adults and children, in comparison, little research has been conducted examining the influence of attention on time keeping. The influence of the role of attention on the perception of durations and the role of contextual changes on the recall of durations was discussed in order to ascertain their relevance for this thesis. The following research seeks to make an inroad into this area.

An examination of the infant timing literature revealed that whilst infant data was sparse (Colombo and Richman, 2002; Colombo et al., 2005) it had not been placed within the time perception literature so no links could be made. It was shown that infant timing research had used heart rate and EEG methodologies which have a common limitation; that of the failure to ascertain the focus of attention. Furthermore, heart rate methodologies require a slow rate of stimulus presentation which allows only a limited number of trials to be presented within an experiment and thus limits the number of variables that can be examined. However a question remains, what method is suitable for examining infant time perception? This will be discussed in the following chapter.

2.7 Research questions

Having looked in more detail at the main issues and debates within the field research questions can now be identified.

As the devSET model has not yet been used to explain timing behaviour from infancy, this thesis will seek to extend the application of this model for the first time, raising the primary research question: **Can infants keep time and how might this be accounted for within the devSET model?**

Although not directly placed within the SET model (but briefly mentioned), the work of Colombo and colleagues (Colombo and Richman, 2002; Colombo et al., 2005) has also shown that a start has been made in examining the role of attention in infant time keeping using heart rate measures. Due to the limitations of this method discussed earlier, the use of eye movement responses will be employed to investigate infant time perception, thus overcoming the limitations of heart rate measures by allowing the focus of attention to be observed by providing a precise registration of eye movements. So from this, the second research question can be asked: **Can eye movements provide evidence of infants' temporal estimation abilities?**

Furthermore, as by nature, eye movements are faster than heart rate; studies using this method can employ more than one stimulus sequence at different time intervals. This then allows time perception to be examined more fully by the third research question: **Can eye movements provide evidence of infants' temporal estimation abilities over more than one time interval?**

Having reviewed the literature demonstrating that time perception is underpinned by two cognitive processes, attention and memory, the fourth and fifth research questions arise. Attention underpins prospective timing and influences the clock component of the SET and devSET models. Whilst little is known about the clock component and the influence of attention on children's time keeping, Droit-Volet (2002) demonstrated that alerting participants to a forthcoming duration increased the accuracy of its estimation. So the fourth research question emerges: **When provided with both auditory and visual cues, are infants more accurate at time keeping?**

Additionally, whilst memory underpins retrospective timing, influencing the decision component of the SET and devSET models, which accounts for fuzzy representations of the referent duration (McCormack et al., 1999; Droit-Volet and Wearden, 2001), memory was also considered in relation to the Contextual Change Hypothesis (Block and Reed, 1978). The CCH drew attention to the fact that changes in the environment both internal (e.g. arousal) and external (e.g. changes in stimulus sequence) can affect the perception

of time, resulting in durations being perceived as longer. So from this, the fifth research question arises: **Is there evidence to suggest that contextual changes influence infant time keeping?**

Building on the above question, the research on social communication has elucidated many examples of timing such as in the 'repetitive run' (Stern, 1977) where speech and behaviours were repeated in slightly different formats, allowing infants to learn and form expectancies about them. Further, detailed analyses of mother–infant interactions (Jaffe et al., 2002) demonstrated that intervals of between 2–3 seconds were optimum for interaction and therefore should be employed in future studies. So the influence of social saliency on time keeping forms the basis for the sixth research question: **Is there evidence to suggest that social saliency aids timekeeping?**

Finally, infant literature has been reviewed and the controversies examined (Brown et al., 2006, Courage et al., 2006; Richards 2006, personal communication) in relation to the issue of individual differences in look duration (Colombo et al., 1988). Infants categorised as belonging to either the long- or short-looking categories were observed to process information differently, that is either globally (short-looking infants) or featurally (long-looking infants) and this has been shown to affect later cognitive development. Therefore, the likelihood that individual differences may influence time perception raises the final research question: **Are individual differences in the use of information processing strategies observed, and if so do they influence infants' temporal estimation abilities?**

Tracking eye movements to explore time perception allows any influence of individual differences in look duration to be examined. As long- and short-looking categories are also thought to reflect individual differences in different phases of attention (Colombo et al., 2001, Richards and Casey, 1991), comparisons can be drawn with the Colombo and Richman (2002) and Colombo et al. (2005) studies and elements of their design continued by the research within this thesis.

An outline of the general research design will now be provided in Chapter 3, with an account of the methodological approach taken as well as ethical issues and sampling strategy.

Chapter 3
Methodological and ethical issues

3.1 Aims of chapter

One of several outcomes arising from the review of the literature in the previous chapter was that infant time perception has received little attention. One possible explanation offered for this was the difficulty in devising methods of investigation that would test whether this ability is evident in infants. Different methodological approaches used in both time perception and infant research were examined in order to identify a suitable method that could be used to investigate time perception in four-month-old infants. The evidence points to eye tracking as being a potential method to provide objective information about infant's appreciation of time.

For the purposes of the experiments reported later in this thesis, time perception is defined as infants ability to learn the duration of an interstimulus interval (ISI) during visual tracking tasks when presented predictable sequences of visual stimuli. Eye tracking measures will be used to ascertain whether or not there is evidence that infants have learnt the duration of the ISI. The terms time perception and time keeping (that is the ability to form expectations about the timing of the next appearance of a visual stimulus in a stimulus sequence) are used interchangeably.

The aim of this chapter is to review this methodology and to examine the operation and challenges of eye tracking in relation to testing infants as well as the ethical considerations and sampling strategies used. Second, the general methods pertinent to the experiments reported later in this thesis such as experimental set-up, stimulus creation and data collection are discussed. Finally, an account of the methods of analysis used in

the experiments reported later in this thesis is provided. To clarify the discussion for the reader, the design and rationale of the experiments reported in the thesis will now follow.

3.2 Design and rationale of experiments

The design of the experiments reported in this thesis was based on the same within-participants, repeated measured design. Predictable stimulus sequences were presented to infants and after a predetermined number of stimulus presentations the sequence was disrupted (called omission trials) and the subsequent pattern of eye movements observed. It was predicted that if infants were keeping track of the temporal and spatial information within each sequence, eye movements would be observed at the next location within the sequence and at about the time the stimulus would have appeared had the sequence continued. This is because infants would only look at the next location when they expected the stimulus would appear, that is, at the end of the ISI. Therefore omission trials were taken to start at the end of the previous ISI.

Two types of stimuli were used in the experiments reported here, inanimate (Experiments 1–4) and animate (Experiments 5 and 6) stimuli. The independent variables changed within experimental tasks such as the timing of the ISI within each sequence, the number of stimuli presented in the sequences, for example, five, seven or nine stimuli presentations, and whether the sequence was silent or accompanied by auditory cues. A constant independent variable across all experimental tasks was the infant's use of either long- or short-looking information processing strategies. Order effects were minimised by counterbalancing the order of stimulus presentation in Experiments 1–4, but not in Experiments 5 and 6 as the stimuli in these studies were comprised of single unitary video displays. The dependent variable in all experiments reported within this thesis was the latency of the eye movements during the omission trials and during the inter-stimulus-intervals (ISI) of each stimulus sequence where the infants' capacity to track per se was of concern.

The experiments reported in this thesis were conducted in two phases. Each testing phase involved experiments utilising both inanimate and animate stimuli. Figure 3.1 below

depicts the order in which the experiments were conducted within each phase of testing. At the beginning of each testing session, prior to conducting the experiments, the eye tracker was calibrated and a baseline measure obtained to identify infants' information processing strategies (discussed in full later in this chapter). A brief rationale of each of the experiments now follows.

Figure 3.1 Order of experiments conducted in each phase of testing

Phase one → Baseline Measure - ind diff → Exp 1 C+R adaption (pilot study); Exp 2 Smiley Face; Exp 5 Social Salience

NB: Prior to the baseline measure to categorise individual differences the eye tracker was calibrated. This is not shown here.
[Within each phase the order of experiments presented was counterbalanced]

Phase two → Visit one → Baseline Measure - ind diff → Exp 6 Contextual Changes → Exp 6 - Changes Cond 1 (counterbalanced); Exp 3 - Info Processing

Phase two → Visit two → Baseline Measure - ind diff → Exp 6 Contextual Changes → Exp 6 - Changes Cond 2 (counterbalanced); Exp 4 Auditory cue

The first experiment sought to build on the design of experiments performed by Colombo and colleagues (Colombo and Richman, 2002; Colombo et al., 2005). This experiment presented infants with a predictable sequence of simple dark and white screens as stimuli and examined time perception using heart rate (HR) measures. When the sequence was disrupted, changes in HR were measured. Since eye tracking was the chosen methodology for this thesis, the stimuli used in the Colombo and colleagues studies needed to be adapted to provide a visual focus to attract participants' attention so that the eye tracking equipment could collect meaningful data. Therefore, the stimuli in Experiment 1 changed incrementally from simple dark and white screens to an alternating left/right small white square on a black background over three conditions. The aim of this experiment was to obtain overt behavioural evidence of infant time keeping using eye tracking. It was predicted that the pattern of eye movements would continue alternating

when the predictable sequence was disrupted and infants would look to the location of the missing stimulus at about the time it would have appeared.

Experiment 2 extended the first experiment by incorporating a smiley face into the small white square stimulus to provide a focal point. As faces are appealing to infants (Johnson, 1999) it was predicted that infants would show greater engagement with this type of stimulus sequence, allowing more useable data to be collected and thus offer a potentially better demonstration of infant time keeping.

The third and fourth experiments continued using inanimate stimuli and a design in which a predictable stimulus sequence was disrupted. In these experiments, however, the nature of the stimuli changed. The background colours were changed from black and white to pale blue and yellow respectively. Various cartoon pictures appeared alternately on the yellow screens. Experiment 3 examined whether individual differences in information processing would influence time keeping when infants were presented with stimulus sequences at very fast rates e.g. 750ms ISI. It was predicted that infants using global processing strategies would be more accurate at time keeping than infants using featural processing strategies because global processing allows more rapid adaptation to fast changing stimuli (Frick, Colombo and Allen, 2000). In addition, Experiment 4 sought to examine the influence of additional auditory cues on infant time keeping, as auditory cues have been found to facilitate time keeping in children older than three years (Droit-Volet, 2003). It was predicted that by including auditory cues at the onset of each stimulus presentation in Experiment 4, infants' attention would be more likely to be drawn to the visual stimulus, and that more accurate time keeping would be observed than in the absence of such cues.

The design of Experiments 5 and 6 was changed to include animate stimulus sequences more analogous with the everyday experiences of infants. In Experiment 5 infants were presented with video footage of a woman performing a head turning task, similar to a game of peek-a-boo. As this kind of stimulus is more naturalistic and likely to be more interesting and salient to four-month-old infants, it was predicted that their understanding

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of the temporal components of the task, (that is the timing of the appearance the stimulus and of the duration of the ISI), would increase, resulting in improved time keeping. Experiment 6 extended the previous experiment by examining the influence of stimulus complexity on time keeping. Block and Reed (1978) found that the number of events occurring within durations lengthens the later estimation of that duration. By varying the number and speed of head turns within a sequence, Experiment 6 predicted that duration estimations would increase and become less accurate when both the number and speed of head turns changed between one sequence and the next compared to either just the number or the speed of head turns changing between sequences.

Having briefly reviewed the experimental design and rationale of the empirical work undertaken for this thesis, attention will now turn to other methodological aspects. The discussion begins with a consideration of the ethical and practical issues involved with infant research, and then turns to a discussion of the apparatus used, the calibration process used or the eye tracker and the creation of the stimuli. Finally, the general experimental and analysis procedures are discussed.

3.3 Ethical and practical considerations when conducting research with infants

In addition to practical issues related to infants' physical and cognitive maturation, several ethical issues also need to be taken into consideration. First, infant participants are a vulnerable group who are unable to convey decisions or choices on their own behalf. As the infants who took part in the experiments reported in this thesis were four months old, it was important to be especially vigilant in observing the British Psychological Society's (2004, 2006, 2009) ethical guidelines and code of conduct. Further, the needs of parents or caregivers and any accompanying siblings also needed to be considered, since in unfamiliar testing situations parents may feel very protective and/or anxious about their babies and about how well they will perform the task (Bishop and Chace, 1971).

3.3.1 University Ethics Committee permission

Ethical permission to conduct research with four-month-old infants using the eye tracker was sought and obtained from the Open University Human Participants and Materials Ethics Committee (OUHPMEC) at the beginning of the research project. The first application covered the first experiments in the project provided full information about the use of and safety of the eye tracker and information concerning all procedures to be used in the research. As no additional procedures or equipment were introduced for the subsequent experiments, ethics permission was sought and granted by Chair's Action. Copies of the OUHPMEC consents are included in Appendix A.2.1.

3.3.2 Parental informed consent

Two forms of written informed consent were obtained from parents and caregivers (see Appendix A.2.2). The first consent related to infants' participation in the experimental tasks. Caregivers were required to give their written consent each time they attended the Centre for Childhood, Development and Learning, from now on referred to as the Centre. The second consent form related to the use of photographs taken of infants and caregivers, such as for publicity and conference purposes. The photographs of two infants in particular were used for publicity and conference material. Additional written consent was obtained from their parents for this use and verbal consent was obtained before each publicity campaign.

The discussion will now turn to the practical considerations that need to be taken into account when conducting research with very young infants.

3.3.3 Practical considerations when conducting research with infants

Four-month-old infants were selected to take part in the experiments reported here for the following practical reasons. First, by four months of age, infants are becoming more physically mature. They can reach out by three months; have good ocular-motor control and can hold up their heads because their neck muscles have matured (Shirley 1931; Bayley, 1968). Further, by this age, infants' eye movements have become smoother with

none of the jerky eye movements characteristic of younger infants (Bronson, 1974; Hunnius and Geuze, 2004). These are important factors to consider when using eye tracking measures in order to ensure reliable data collection. Conversely, however, these infants can be frequently distracted by painful gums due to teething which affects their ability to concentrate and willingness to participate. A further problem is that at this young age, infants' attention may be disrupted by the 'discovery' of their hands and feet, which are often covered with brightly coloured socks making them highly fascinating in comparison to the experimental stimulus!

Cognitive maturation is a further point to consider. In order for infants to perform optimally, testing sessions need to be kept short, as despite the maturation of memory and attentional systems (Mountcastle, 1978; Courage and Howe, 2004; Greenspan and Shanker, 2007), their attention span is limited to approximately two to eight minutes (Johnson, 1999).

As described in the previous chapter (Section 2.2.1), Colombo and colleagues (1985) have carried out a series of experiments examining the visual information processing strategies used by four-month-old infants which are thought to influence later cognitive performance (Colombo, 1993). According to this research, infants can be identified as belonging to one or other of two distinct groups depending on the visual information processing strategies used: either a long- (featural processing) or a short-looking (global processing) strategy, (Colombo et al.,1984; Colombo et al.,1987; Colombo et al.,1988; Colombo et al. 1990; Colombo, Mitchell, Coldren and Freeseman, 1991; Colombo, 1993; Colombo et al., 1993). The rationale for taking account of this strategy distinction when designing the experiments reported in subsequent chapters, was discussed in considerable detail in Chapter 2, Section 2.5.4.

Before proceeding to the next section, one final practical consideration warrants attention, that of the practical issues involving any siblings accompanying infants to the Centre. These are fourfold. First, siblings are a vulnerable group usually being young themselves. Second, in order for the infants to remain in a calm alert state rather than a very excitable

state, siblings have to be entertained by the researcher or someone else. Third, as children remain with their parents in the testing room, by talking to the infant during the testing session, older siblings can distract their young brother or sister from the experimental task. This can result in infants looking away from the experimental stimulus and consequently, usable eye tracking data is lost. Further, parents can be concerned about the older child touching the equipment in the testing room. These issues may influence a parent's willingness to participate in the research. Finally, an important consideration when conducting infant research is sampling and recruitment of participants, which is now discussed.

3.3.4 Recruitment of participants

The participants recruited for the series of experiments described in chapters 4–9, were infants aged between 38 and 42 weeks gestation at time of recruitment. A total of 109 infants (accompanied by their caregivers) were recruited. According to caregiver report, all infants selected to take part in the studies were typically developing, of normal birth weight (2500 – 4000 grams) and belonged to families where there was no prior history of visual problems such as colour blindness (excluding parental short- or long-sightedness). Despite much effort to gain a multicultural sample, the majority of infants' mothers were UK-born white mothers of low–medium socio-economic status. Three infants were of Asian origin and one Black Caribbean.

Infants were recruited mainly from the Milton Keynes area, via publicity material through a variety of sources. Recruiting participants proved to be a huge challenge throughout the whole research process with many avenues being explored, including invited talks at Health Visitor professional training days, and post-natal talks at various Health Centres and National Childbirth Trust meetings etc. In the media, radio interviews were given, newspaper and magazine articles and adverts written, as well as publicity material being placed in baby changing rooms in a wide range of shops. The Open University intranet was also used as a means of advertising and was seen by caregivers and relatives around the country. Caregivers responding through the University intranet volunteered

their infants as participants when they were attending meetings at the University. As a result, some infants only came into the Centre once, whereas caregivers who lived in the Milton Keynes area were invited to participate twice. All publicity asked caregivers to telephone or email the Centre for further information about the research.

Once interested parents were located, the purpose of the research project and equipment used was discussed in sufficient detail in order for them to make an informed decision about whether to participate or not. Parents were then invited to come along and participate with their children in the project. If agreeable, an appointment was made after background information about the infant was obtained, such as gestation length, birth date, weight, any problems at birth etc. This information was recorded, and kept securely, to ensure as far as possible that only typically developing infants were included in the sample. Parents were informed that the visit to the Centre would last approximately 45 minutes to 1 hour, with the testing sessions themselves lasting 5 – 12 minutes in total.

The current author tried to ensure that infants were as close to four months as possible at testing, as in the Colombo and Richman (2002) and Colombo et al., (2005) studies. Infants had been recruited for the Colombo and colleagues' studies directly from birth announcements in the local newspaper each week, resulting in many parents accepting invitations to participate and it being feasible to recruit infants of exactly four months at the time of testing. However, as this was not possible with the experiments reported in this thesis a two-week recruitment window was adopted for three reasons. First, a narrow age range of two weeks helped minimize the variation in the level of cognitive development within the infant sample. Second, the lack of parents' enthusiasm to participate in research (despite Milton Keynes having the highest birth rate in the UK) made recruitment of infants of a specific age challenging. A third reason was, cancellation of appointments due to infants teething or poor health, or caregivers work commitments etc. Therefore, appointments were made within one week either side of the infant's four-month birth date, that is, when infants are aged between 3 months 3 weeks and 4 months 1 week old.

Appointments were generally made in the first week so that alternative appointments could be made if necessary.

All infants were brought into the Centre by their caregivers. No travel expenses were paid, except where caregivers who lived locally came to the Centre by taxi, in which case the taxi fare was paid. All parents received an information sheet about the studies their infants had participated in (see Appendix A3.3), and their infants received a certificate and small gift as a token of the author's appreciation after each visit.

Having briefly discussed how the infants were recruited, the discussion will now turn to the apparatus used when testing the infants, in particular the eye tracker.

3.4 Apparatus

The discussion in this section will begin by describing the general apparatus used and then discuss the eye tracker in more detail. The apparatus used in the experimental set-up can be seen in Figures 3.2 – 3.9 below. Figure 3.6 has been colour coded for ease of reference to the different parts of apparatus.

On arrival infants and parents were greeted and infants settled down in the reception room (see Figure 3.2) and once the infant was settled and calm they went into the testing room (see Figure 3.3). Once there, infants were seated in the testing cubicle (see Figure 3.4) into an adapted car seat (see Figure 3.5).

Figure 3.2 Reception room

Figure 3.3 Experimental testing room

Figure 3.4 Testing cubicle

Figure 3.5 Infant in the testing cubicle participating in an experimental task (by kind permission of her mother)

3.4.1 General apparatus

Because of their complex nature, the experiments conducted required a number of linked computers and monitors in order to run; Figure 3.6 depicts the equipment used. Its various components and sections are colour coded and each section described. Beginning with the non-coloured section of Figure 3.6, the stimuli for each experiment were presented on a Panasonic 42" plasma screen, to the infant who sat at a distance of 110cm from the screen. The ASL model 504 eye tracking camera was placed protruding 20cm under the plasma screen so that the infant was 90cm away, the optimum distance for eye tracking. Figure 3.5, depicts the modified car seat the infant sat on, the height of which could be adjusted to ensure that the infant's eye line was central to the plasma screen.

Returning to Figure 3.6, the pink colour coded section displays the two stimulus computers, one of which ran the Gaze Tracker eye tracking analysis software. The second stimulus computer displayed movie clips to keep infants' attention whilst different aspects of the experimental task were changed. For instance, the AB switch allowed instantaneous transition from the calibration programme on one computer to the experimental stimulus on the other.

Turning now to the green colour coded section of Figure 3.6, which represents the eye tracking computer and monitors (see also Figure 3.8). The eye tracking computer (ET) contained the eye tracking programme Eyenal, which operated the ASL eye tracking camera situated below the plasma screen. The eye tracking camera has an inbuilt scene camera that allowed an image of the infant to be observed in the scene monitor. The scene monitor also allowed an image of the stimulus to be shown and the operator is able to choose between the two images (participant or stimulus mode) via an A/B switch located on the scene monitor. The location of the participants' gaze is superimposed onto the stimulus as a point of gaze (POG) crosshair from data passed from the eye tracking camera through the ET control box and finally, the scan convertor.

The eye monitor displays an image of the eye with the pupil discrimination (PD) and corneal reflection (CR) thresholds superimposed onto it (see Figure 3.8 below). The

researcher had to keep the image of the eye centrally placed within this monitor (via a remote control device) whilst maintaining the PD and CR thresholds. For a full discussion of the eye tracker and the calibration process, see Section 3.4.2 below. These data were then fed through to the equipment displayed in the blue colour coded section (which was in an adjacent room), where it was time stamped, mixed and video recorded as a backup.

Figure 3.6 Diagram of the experimental setup
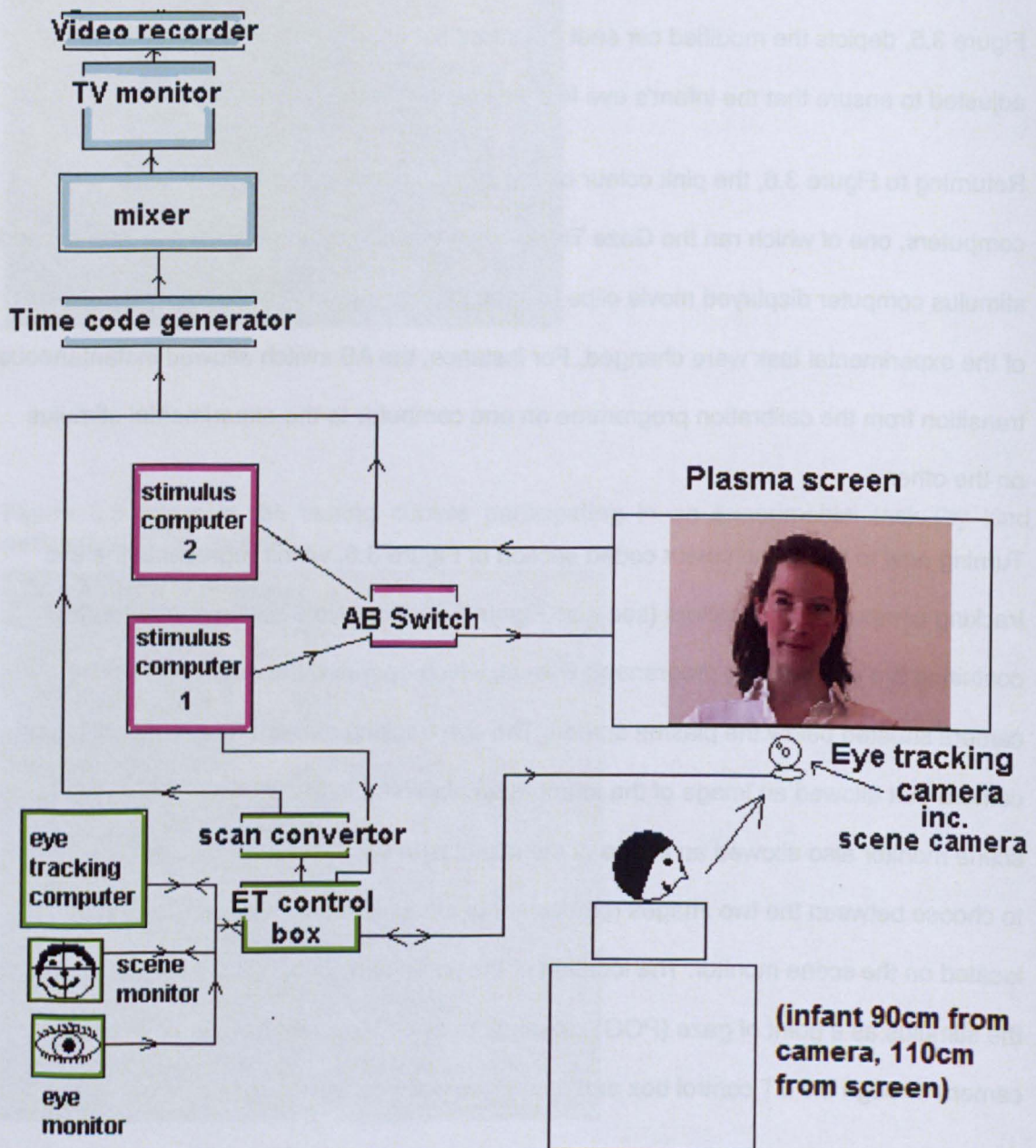
3.4.2 Eye tracking: operation and challenges

3.4.2.1 The eye tracking system

Available evidence suggests that eye tracking is an appropriate method to investigate infant time perception as it can provide precise objective information about infants' eye movements that can be used to infer whether they are sensitive to systematic changes to visual stimuli introduced by an experimenter. Eye movements can also be used to identify if infants have learnt the temporal properties of the ISI and developed the ability to anticipate where a visual stimulus will appear. Eye tracking also eliminates the subjectivity associated with previous methods of eye movement analysis such as coding from video tapes. In addition, as explained previously in Chapter 2, Section 2.2.3 eye tracking addresses the limitations of previous methods used in infant time perception research such as heart rate measures (Colombo and Richman, 2002; Colombo et al., 2005) and EEG/ERPs (Brannon et al., 2004), since eye tracking reveals the focus of infants' attention.

An eye tracking system developed by Applied Science Laboratories (ASL) was used to carry out the experimental investigations reported in this thesis. The ASL Model 504 eye tracking system is a video-based, non-invasive remote optical system designed for use with the Erica Gaze Tracker software. A pan/tilt camera uses infrared light (IR) to measure a participant's line of gaze and eye movements with respect to a stimulus displayed on a single stationary screen. Line of gaze and eye movements are measured by capturing changes in the distance between the corneal reflection of the IR light and the edge of the pupil (known as pupil discrimination). This distance is continually recalculated recording the exact position of the eyes, providing a POG crosshair in relation to the visual stimulus on the screen. The POG is displayed as either a cursor or set of crosshairs that moves about the monitor screen showing which part of the stimulus a participant is looking at. The experiments reported here used the crosshair option. A digital recording of this POG movement is then used for later data analysis. Figure 3.8 illustrates how this system was set up in the laboratory used for the research reported in this thesis.

The ASL Model 504 system was selected as suitable for use with infants for the following reasons. First, it is not a head mounted eye tracker, which infants would not tolerate. The camera is placed in an unobtrusive position in front of the infant (see Figure 3.4, above). Second, the system allows the participant approximately one square foot of head movement which eliminates the need for head restraints, although with infants a head cushion was used to support the head and eliminate any excessive head movements (see Figure 3.7, below). Third, the levels of infrared light required by the system are .04–.06 mwatts per cm². This is much lower than the 10 mwatts per cm² considered the safe level of use by ASL and dramatically lower than normal sunlight (100 mwatts per cm²). Technical and safety information concerning the ASL 504 camera is provided in Appendix 2. Finally, the system can be regarded as non-invasive. At present, no known risks to either infants or adults have been identified in relation to its use. In the experiments reported in this thesis participants have their eye movements recorded for 5–12 minutes.

Figure 3.7 Head cushion which limits an infant's head movements during testing

3.4.2.2 The eye tracking computer and equipment set up

To conduct a successful eye tracking study, the researcher operating the eye tracking system must continually check two monitors (see Figure 3.8, below): the scene or stimulus monitor (A), and the eye monitor (B). The scene monitor indicates where the POG is in relation to the stimulus. By observing this monitor screen, the researcher can immediately see the status of the POG. The eye monitor shows the PD and CR

thresholds. If the POG is lost, this screen enables the researcher to establish which threshold is missing and those levels can be adjusted accordingly via controls located in the eye tracking computer (C). In practice, the levels of these thresholds are continually being adjusted to take account of any head movements and light levels of the stimulus which affect the participant's pupil size. A remote control device allowed manual movement of the pan tilt camera in front of the participant to ensure that the eye was centrally placed in monitor B. The same operation can also be accomplished via controls in the eye tracking computer (C), however, there is a 2s delay between adjusting the controls on the computer and the pan tilt camera moving. The delay makes this system unworkable when trying to keep pace with infants who move their heads quickly (Aslin and McMurray, 2004).

When eye tracking, the camera needs to be focussed on an area of the eye that is the size of a single spectacle lens (see B on Figure 3.8) with the correct PD and CR levels. Although the system will tolerate slow head movement, data are lost until the eye is recovered via the remote control; therefore the quick head movements of infants, represent a problem as they are faster than the movement of the eye tracking camera. And data is lost as the picture of the eye moves out of Monitor B. To counter these problems, the camera could be manually manipulated by the researcher to relocate the picture of the eye within Monitor B. However, because the researcher had to simultaneously monitor the PD and CR levels and make any necessary adjustments, it is important to limit infant head movement as much as possible. This can be accomplished by using a chin rest for the participant's head, but would be impractical with infants.

A simpler practical solution to the infant head movement problem is to place a cushion around the back of the infants' head, (see Figure 3.7 above). The wings either side of the cushion can be expanded so that the infant's head is nestled in the cushion. In this way movement is limited whilst supporting the infant's head and preventing it from dropping down easily. A further advantage of the cushion wings is to limit the infant's peripheral vision, helping to limit distraction during testing.

Figure 3.8 Experimental monitors and computers used during studies to ensure retention of POG and subsequent data collection

A = scene or stimulus monitor displays POG moving around the stimulus scene

B = eye monitor. An image of the eye must be kept centrally in this monitor. The corneal reflection and pupil discrimination thresholds must also be kept stable around the eye in order to keep the POG crosshair.

C = eye tracking computer 1 allows adjustment of CR and PD thresholds

D = eye tracking computer 2 controls stimulus presentation

Key:
= corneal reflection (CR) threshold
= pupil discrimination (PD) threshold
[black and white respectively in reality]

B - schematic drawing

B - photograph

3.4.2.3 Procedural issues in using eye tracking technology with infants

Having reviewed the technical difficulties associated with infant eye tracking, attention will now turn to additional challenges related to physical and cognitive abilities of infants.

Limitations of physical maturity, control over body parts, attention span, and behavioural repertoire (discussed in Chapter 2), impact on the methods that can be used to test young infants' temporal abilities. As previously discussed, infants are unable to follow instructions thus requiring age-appropriate methods of enquiry to be used in order to maintain their

attention. Additionally, infants become easily distressed or fussed or simply get fixated on their hands or feet or a light spot in front of them, resulting in high attrition rates compared to adult studies. Oates (1998) reports that attrition rates of 50% are common in infant studies, a rate which increases depending on task and equipment demands. The technical difficulties associated with eye tracking could result in higher attrition rates. For these reasons, in order to obtain a reasonable sample size, many more infant participants are required than for adult studies.

Some infants were excluded from the final sample in the present research for a number of different reasons. These included failure to complete the task due to distraction (e.g. looking at their hands or feet, or being fixated on a particular part of the testing cubicle), fussiness (e.g. crying), caregiver or sibling interference (e.g. talking to or touching the infant during the task) and technical reasons such as difficulties maintaining the POG and equipment failure. The actual numbers excluded are reported for each experiment later in the thesis.

The next section describes the calibration procedure used that allows the gaze position to be mapped directly onto the stimulus and includes the adaptation of this procedure for use with infants.

3.4.2.4 The calibration procedure

In order to gain a precise registration of participants' eye movements the eye tracking system needs to be calibrated. The calibration procedure requires adults to maintain their gaze at nine points placed at equidistant points in three rows and three columns across the screen. These nine points yield x-y co-ordinates that are entered into a computer giving a Point of Gaze (POG) crosshair reading with accuracy to within .05° visual angle. This is a relatively easy procedure with adults who are simply asked to focus and hold their gaze on nine points on the monitor screen sequentially as the researchers adjust the settings. This procedure is unworkable with infants for several reasons and needs to be adapted.

The first reason is that infants cannot follow instructions to focus and hold their gaze at particular points on a monitor screen. Further, as their interest wanes quickly, the choice of calibration stimulus must maintain their attention. To ensure this, a pulsating chequered ball which loomed in and out with corresponding auditory tones was presented at each calibration point. The centre of the pulsating ball was placed directly onto the location of the calibration point thus drawing the infant's gaze to the correct location. Previous research has established that this stimulus is highly engaging to infants (Johnson, 2000, personal communication), as it allows researchers to adjust PD and CR thresholds to ensure that a clear signal was obtained before entering the x-y coordinates into the eye tracking computer.

The second problem relates to the length of time the calibration procedure takes. The calibration procedure may fail at any one of the nine points; when this happens standard procedure requires re-starting the process. Clearly, this requires concentration on the part of the participant to maintain their gaze in what may become a lengthy calibration process before the experimental task can begin. With infants, this poses a problem as their attention span is short and studies are best limited to between 2-8 minutes (Johnson, 1999) in order to gain useful data. An extended calibration procedure increases the likelihood of infants' attention waning during the experimental task resulting in increased attrition. Therefore, a shorter calibration procedure is required.

Thus for infants, a faster 2-point calibration process was used (Aslin, von Hofsten, Hunnius, Johnson, Mansfield and McMurray, 2002). Although this took under one minute to complete, it has disadvantages. ASL, the manufacturers, estimate that the spatial accuracy of the eye tracker is between 0° and 0.5° error if the eye gaze is in the centre of each calibration point. In other words, it is possible that the resultant POG may have an error of between 0° and 0.5° visual angle when mapped onto the original image. This possible error rate increased to between 0° and 0.75° visual angle when using two calibration points (Aslin et al, 2002), although spatial accuracy was estimated by Johnson, Slemner and Amso (2004) to within 0° and 1° visual angle. For the present studies, the

increase in possible error as a result of only using a two point calibration process was considered to be an acceptable trade-off in order to shorten the calibration procedure and to maximise the likelihood that infants remained attentive during the subsequent experimental task (Aslin et al, 2002). Using this method, the calibration process lasted 15–60 seconds and could be repeated during the experimental procedure to check accuracy as necessary.

The calibration was checked for accuracy by presenting the pulsating ball at random locations on the screen as the POG moves according to the participant's gaze. The researcher judged how close the centre of the POG aligned to the centre of the pulsating ball to determine accuracy. If judged inaccurate, the calibration procedure was repeated.

Finally, in order to collect eye tracking data, a stable POG must be maintained throughout the experiment, it is vital therefore to maintain the PD and CR at all times. The loss of one or both of these thresholds results in losing the POG as the necessary calculations cannot be made by the eye tracking system, and thus data are lost. Factors that destabilise the PD and CR thresholds are head movement; pupil movement, stimulus luminance levels, ambient light levels and the distance of the eye from the camera, but these can be limited by close monitoring via the computer system. In compensating for these factors, the researcher must continually observe Monitor B (see Figure 3.8) and make any necessary adjustments to ensure that the image of the eye is centrally placed and the thresholds are stable. The discussion will now turn to a description of the general experimental procedures used in this thesis.

3.5 General procedure used for empirical studies

An identical general procedure was followed throughout the experimental tasks. Caregivers were offered refreshments when they and their infants arrived at the infant friendly reception room in the Centre (see Figure 3.3). After the equipment, experimental task and procedure had been explained to the caregiver and any questions answered, written informed consent was gained. If infants needed feeding, nappies changing or even a sleep prior to the commencement of the experimental task, this was done. Infants

sleeping on arrival were left to wake up naturally in their own time. Care was taken not to over stimulate infants by playing exciting games such as peek-a-boo in order to reduce the risk of infant fussiness during the experimental task. The caregiver and the infant were taken into the experimental room only when the researcher was satisfied that the infant was in a quiet, alert state. After the experimental tasks were completed, the caregiver and infant returned to the reception room. A small gift, a certificate and information sheets concerning each experiment were given to the caregiver and any further questions answered. All infants were tested individually.

The testing cubicle was enclosed by white screens on three sides with the equipment out of sight and the light was dimmed to ensure infants' attention was directed at the plasma screen before experiments began (see Figures 3.4 and 3.5). All experiments lasted between two and eight minutes, the variation in length being mainly due to differences in the time taken to perform the eye tracking calibration procedures and ensuring the infants were looking towards the plasma screen. This was accomplished by playing noises such as babies laughing (obtained from Microsoft Clip Art) from a speaker just beneath the plasma screen. If infants were wearing potentially distracting footwear such as brightly coloured socks their parents were asked to remove them. In cases where an infant became mesmerised by the movement of his/her own feet or hands, a clean cloth was placed over the lower half of their body.

The majority of infants were tested while sitting on the adapted car seat pictured at Figure 3.5. Caregivers remained with their infants at all times, slightly out of sight during the experiment. Some infants refused to sit in the adapted car seat for the duration of the experiment. In these cases, caregivers usually reported that their infant did not like sitting in their own car seat, finding it too constraining. Accordingly, caregivers were asked to sit in a chair and hold the infant on their lap. Special instructions were given to the caregiver about holding their baby to ensure the infant was kept still during the task. This procedure was demonstrated on a doll to ensure standardisation of holding methods across the infants who sat on their caregiver's lap. This occurred on three occasions, but usually

resulted in little or no data being collected due to the infant becoming easily distracted. The study was terminated if the infant became fussy. Parents were informed that they and their children were free to withdraw from the study at any time. This occurred on one occasion where the mother decided to withdraw after her infant had completed one of two experiments.

In order to keep the infant's attention throughout the testing period either pictures of an infant or video clips of films such as Toy Story, were presented on the plasma screen in front of the infant. The use of an A/B switch allowed the researcher to change over from one stimulus to another, save data and re-calibrate the eye tracker if necessary with a seamless transition from one part of the testing session to the next.

Having reviewed the general procedures used in the experiments reported in this thesis, the general coding procedures will now be discussed.

3.6 Coding methodologies

Similar methods of coding the data were applied to all experiments reported in this thesis. The data were coded in two different ways, first, automatically with the Gaze Tracker analysis software and second manually from the back-up video of each testing session using data from the ASL Eyenal eye tracking programme which generated the offline POG (see Figure 3.6 green and blue sections). The use of both methods maximised data collection as discrepancies in the visibility of the POG during each trial were observed between online (Gaze Tracker) and offline (Eyenal) viewing. The discrepancies arose as the POG production threshold for the Gaze Tracker programme is set higher than the Eyenal programme set by the manufacturers. There were few timing differences in saccade latency between the two analysis systems. A comparison of all the data from Experiments 1-6 that were coded by each method (e.g. the time of each saccade) revealed that intra-rater reliability was 96%. The implications of this are that although the Gaze Tracker output was generally used when differences arose, the Eyenal produced timing was used on the basis that the POG was more consistently visible on the video tapes and the timing between the two methods consistently similar. Utilisation of both

methods acted as an inter-programme cross-check which has been used in other infant research centres (Johnson, 1999). The following section will describe how the experimental data were coded.

3.6.1 Coding protocol

3.6.1.1 Areas of interest

The experiments reported within this thesis fall into two main categories. The first category used inanimate stimuli and the second animate stimuli. To understand the pattern of eye movements observed during the experiments, areas of interest were created on the stimuli. These areas of interest were located where eye movements would show that the infants had processed the spatial information within the sequences. Within the inanimate stimuli category (Experiments 1–4) the areas of interest were located to the right and left of the plasma screen as the stimuli appeared in these locations (see Figure 3.9, below). Within the animate stimuli category (Experiments 5 and 6) the areas of interest were located to the right, left and middle of the plasma screen (see Figure 3.10, below).

As previously mentioned, the design used in the experiments reported here followed the same general principle, that of presenting a predictable stimulus sequence and after a predetermined number of presentations, disrupting the sequence. If infants are keeping time, eye movements should occur in the next location in the sequence at about the time the stimulus was omitted. This was termed the 'correct location' and the area was designated an area of interest (Area 1, Figure 3.9). This area accommodated infants' saccades that either overshoot or undershoot a target (Johnson and Johnson, 2000), that is, those not falling directly into the centre of the target. The second area of interest (Area 2, Figure 3.9) in Experiments 1 to 4 covered the rest of the monitor screen. Eye movements in this area indicated failure to look to the correct location of the omitted stimulus. For Experiments 5 and 6, this was denoted as Area 3 (see Figure 3.10, below) and denoted by the fact that the stimulus woman did not look toward this direction.

Figure 3.9 Areas of interest defined for coding in Experiments 1 to 4
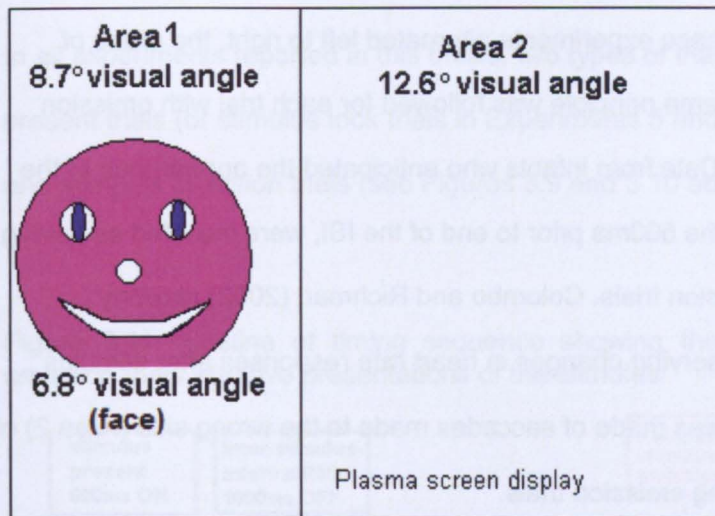
NB: These areas alternate when stimulus appears on opposite side of screen.

Figure 3.10 Areas of interest defined for coding in Experiments 5 and 6
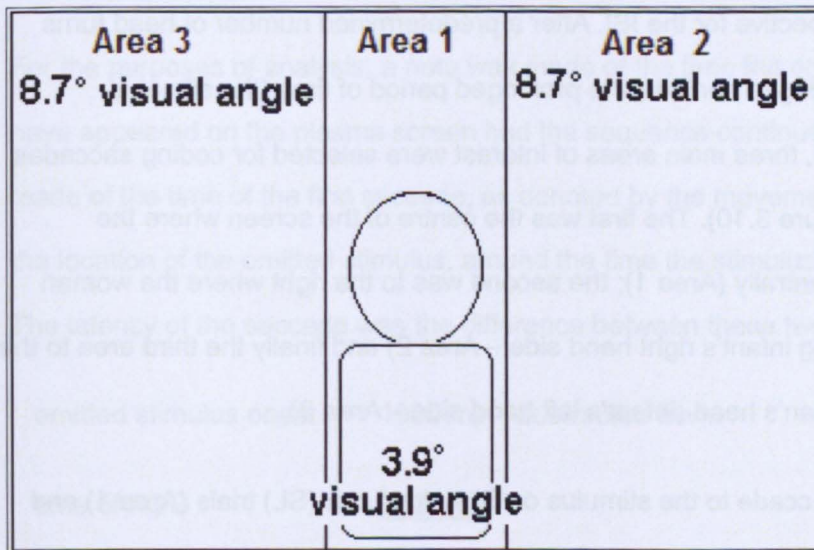
3.6.1.2 Coding

Coding for the experiments using inanimate stimuli (Experiments 1 –4) was carried out in a different way from experiments using animate stimuli, (Experiments 5 and 6) and so these are described separately.

Experiments utilising inanimate stimuli, Experiments 1- 4, were coded as follows. The latency (time) of the first saccade to the stimulus on Stimulus Present (SP) trials (Figure 3.9, Area 1) was recorded. During stimulus omission trials (OM), the latency of the first

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saccade to the correct location of the omitted stimulus in the sequence (Area 1) was recorded. As the sequences in these experiments alternated left to right, the areas of interest changed sides but the same principle was followed for each trial with omission trials following the previous ISI. Data from infants who anticipated the appearance of the stimulus but made saccades in the 500ms prior to end of the ISI, were included as having made saccades during the omission trials. Colombo and Richman (2002) similarly included such a period when observing changes in heart rate responses after stimulus omission. Additionally, a record was made of saccades made to the wrong side (Area 2) of the screen after the ISI and during omission trials.

Unlike Experiments 1–4, the animated stimulus utilised in Experiments 5 and 6 remained visible throughout the sequences. A woman performed a head-turning sequence looking centrally (stimulus look trial) and to her left (stimulus away), that is towards the right from the viewing infant's perspective for the ISI. After a predetermined number of head turns the woman remained facing to her left for a prolonged period of time (the stimulus omission trial). Therefore, three main areas of interest were selected for coding saccades in these studies (see Figure 3.10). The first was the centre of the screen where the stimulus woman faced centrally (Area 1); the second was to the right where the woman looked to her left, (viewing infant's right hand side – Area 2) and finally the third area to the right of the stimulus woman's head (infant's left hand side – Area 3).

The latency of the first saccade to the stimulus on Stimulus Look (SL) trials (Area 1) and the latency of the first saccade to the location of the stimulus woman's gaze on the Stimulus Away (SA) trials (Area 2) on all trials were coded. During stimulus omission trials, the latency of the first saccade to the centre (Area 1) was recorded. Omission trials were taken to start 500ms before the end of the ISI (see Figure 3.11, below). No saccades were made to the wrong side (Area 3) of the screen during the omission trials.

3.7 Analysis

In all experiments reported in this thesis, two types of trial were analysed: stimulus present trials (or stimulus look trials in Experiments 5 and 6) where stimuli were present, and stimulus omission trials (see Figures 3.9 and 3.10 above, and Figure 3.11 below).

Figure 3.11 Timeline of timing sequence showing the stimulus present and stimulus omission trials with five presentations of the stimulus
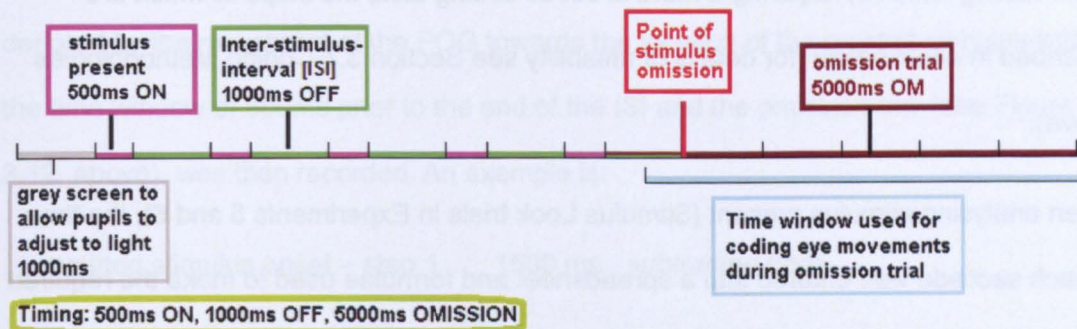
For the purposes of analysis, a note was made of the time the omitted stimulus would have appeared on the plasma screen had the sequence continued. Then a record was made of the time of the first saccade, as denoted by the movement of the POG towards the location of the omitted stimulus, around the time the stimulus would have appeared. The latency of the saccade was the difference between these two scores. For example:

omitted stimulus onset	1000 ms	*subtracted from*
time of POG	2735 ms	
difference score	1735ms	

3.7.1 Gaze tracker analysis for all trials

For stimulus omission trials the time of the first saccade to the correct location was recorded as described above. The previous ISI was also checked and any saccade made within a window of 500ms prior to the end of the ISI was recorded as being an early saccade to the omitted stimulus (see Figure 3.12, above). In Experiments 1-4 this was a

blank screen and in Experiments 5 and 6, the stimulus woman remained faced towards her left (viewing infant's right hand side) away from the viewing infant.

3.7.2 Video analysis

In contrast to analysing the data in Gaze Tracker where the timer in each trial was reset to zero, coding from a time stamped video tape does not allow that facility. Instead, the time code generator (see Figure 3.6, blue section) runs continually until switched off at the end of the testing session, requiring a more arduous coding task, the steps of which are described in detail below (for details of reliability see Section 3.7 Coding Methodologies above).

When analysing stimulus present (Stimulus Look trials in Experiments 5 and 6), the time of each saccade was entered into a spreadsheet and formulae used to make the required calculations. The process by which the times were entered into the spreadsheet had three steps. In step 1, a record was made of the time the stimulus on the monitor screen appeared. In step 2, a record of the time of the first saccade (as denoted by the movement of the POG crosshair towards the stimulus location) was made. In step 3, the time recorded at step 2 was subtracted from the time recorded at step 1 and a difference score obtained for that trial. An example is:

stimulus onset   – step 1   100 ms *subtracted from*

time of POG   – step 2   <u>235 ms</u>

difference score – step 3   <u>135 ms</u>

It was predicted that if infants were aware of the temporal information within each sequence, then difference scores should be minimal as infants would be tracking the stimulus on time. If a saccade was made to the wrong side of the screen no record of the timing was made even if the POG subsequently went to the correct side.

Coding was conducted in line with procedures adopted by other infant research centres such as the Centre for Brain and Cognitive Development, Birkbeck College (Mansfield,

Farroni and Johnson, 2003). The principle used in such research centres is that the time of a saccade is taken from the onset of the gaze shift, that is, the beginning of its trajectory towards the stimulus. This is because the infant has already noted that the stimulus is present but the POG itself takes time to reach the stimulus.

A similar procedure, that is steps 1–3 outlined above, was adopted for coding stimulus omission trials. A record was made of the time the omitted stimulus would have appeared on the monitor screen had the sequence continued. The time of the first saccade, as denoted by the movement of the POG towards the location of the omitted stimulus within the time window of 500ms prior to the end of the ISI and the omission trial (see Figure 3.12, above), was then recorded. An example is:

omitted stimulus onset – step 1   1500 ms *subtracted from*

time of POG   – step 2   <u>3235 ms</u>

difference score   – step 3   <u>1735 ms</u>

3.8 Statistical analysis

In order to ascertain whether infants can keep time the difference scores from the omission trials were compared to the difference scores from the stimulus present trials. If infants are keeping time when tracking the sequence there should be no significant difference between the two scores. This approach is the opposite of the majority of published quantitative psychological studies where variables are manipulated and differences between two or more conditions looked for. Statistical significance is cited if probability values of less than 5% are obtained. For evidence of timing, however, using the approach outlined above, similar scoring in stimulus present and stimulus omission trials which are non-significant rather than a statistically significant difference score is the critical factor. If infants are not aware of the temporal information within the sequences, they will respond randomly and thus statistically significant scores would be predicted.

Most infants completed one or two sequences; however these were not necessarily sequential such as sequences 1 and 2, but 1 and 3 for instance. Only a small proportion of infants completed all the sequences. Since the majority of infants did not provide data at each data point this necessitated the use of non-parametric tests which are distribution free, and do not assume normal distribution of data. For the same reasons, the median and range of the scores are provided as measures of central tendency and dispersion (Brace, Kemp and Snelgar, 2003).

To ascertain whether infants were keeping time within a sequence, that is whether timing was similar in the presence and absence of stimuli, the data were subjected to Wilcoxon tests, the non-parametric equivalent of a paired t-test. To determine whether infants were keeping time over two or more sequences the data were subjected to a Kruksall-Wallis statistical test (nonparametric equivalent of a one-way within participants ANOVA).

3.9 Chapter summary

This chapter has explored the methodological, ethical and procedural issues related to conducting eye tracking experiments with infants. The challenges of recruiting infants to participate in the experiments were discussed as well as the subsequent challenges involved in testing infants. Finally, general methods pertinent to all experiments reported in this thesis were discussed, including data collection, coding and analysis. The following chapters describe the empirical work conducted for this thesis, beginning with the baseline measure used to categorise information processing strategies used by infants when processing a scene that is, long- and short-looking information processing strategies.

Chapter 4
Individual differences in look duration: a baseline measure

4.1 Introduction

One of the key issues raised in Chapters 1 and 2 was that the underlying assumption of many theories including Scalar Expectancy Theory (Gibbon, 1977) and the devSET model (Droit-Volet, 2003) is that all participants make similar responses. There is a large body of literature, however, that discusses individual differences. Of particular relevance to this thesis are individual differences in infant look duration identified by Colombo et al. (1991), which are thought to underpin differences in information processing strategy. Two types of information processing strategies have been identified: long-looking and short-looking. The long-looking category is characterised by fewer but longer looks to selective parts of a scene and posited to be underpinned by local featural processing whilst the short-looking category is characterised by many short looks to a scene and posited to be underpinned by global holistic processing. As individual differences in look duration have been linked to attention (Colombo et al., 2000) and later IQ (Colombo, 1993), it is reasonable to assume that time keeping might be similarly influenced. One of the aims of this thesis is to explore whether individual differences do in fact influence time perception.

Although the influence of individual differences on time keeping was the last research question posed in Chapter 2, this research question is explored in all the following empirical chapters. Within each empirical chapter, the data were analysed to ascertain any effect of the main independent variable under investigation, such as the addition of an auditory cue to visual stimuli (e.g. Experiment 4, Chapter 8). Once the initial analysis was completed, the participants were divided into the two infant looking strategy groups mentioned above and their data re-analysed to ascertain whether individual differences

were evident. Therefore, a discussion of the relevant literature and the procedure by which infants were divided into long- and short- looking groups, (including consideration of whether this is possible), follows. Before embarking on this discussion, the four phases of attention and the proposed link between look duration and attention will be outlined.

As mentioned in Chapter 1, Section 7, four phases of attention – Stimulus Orientation (SO), Sustained Attention (SA), Pre-Attention Termination (PAT) and Attention Termination (AT) – were identified by Richards and Casey (1991) based on HR measures observed in infants between 14 and 26 weeks old. The link between HR measures during SA and AT and look duration was made by Colombo et al. (2001), who found that longer fixations, especially during SA and AT, were negatively correlated with recognition and were thought to be mediated by an inability of long-looking infants to disengage attention. Further, Colombo and Richman (2002) and Colombo et al. (2005) demonstrated more accurate time keeping in infants who showed greater engagement in SA in pre-tests. From this, it could be predicted that long-looking infants may have difficulty terminating attention during stimulus present trials.

This could potentially impair their ability to keep track of temporal information, such as the duration of the ISI. Consequently they would demonstrate less accurate time keeping during omission trials.

Individual differences in fixation duration (variously termed fixation or look duration, by Colombo and colleagues) are explored in research reported in this thesis using eye tracking methodology, to ascertain whether similar results can be obtained for participating infants and if so what influence, if any, these individual differences have on time perception. This chapter outlines how this baseline measure was obtained and further considers the debate concerning the measurement of individual differences in infants' look duration (Colombo et al., 1991; Brown et al., 2005; Courage et al., 2005).

4.2 Individual differences – overview of the literature

4.2.1 Infant categorisation

Early research found that infants aged three months require much longer exposure to a stimulus to process information than 12-month-old infants (Lewis, Goldberg and Campbell, 1969). One reason is the maturation of the memory systems (Kail, 2006). Later, Colombo, Freeseman, Coldren, and Frick (1993) concurred with the Lewis et al. (1969) finding, but proposed an additional reason, namely differences in length of look duration towards a stimulus. Colombo et al. (1995), proposed that by comparison with short-looking infants, long-looking infants had more limited ability to disengage attention from a stimulus due to immaturity of their attentional systems (Posner and Petersen, 1990).

4.2.2 Categorisation of long- and short-looking infants

Evidence to support the categorisation of long- and short-looking infant groups (also called long- and short-lookers by Freeseman, Colombo and Coldren, 1993) has been reported by Colombo and colleagues over many years and samples (Colombo et al., 1987; Frick and Colombo, 1996; Colombo et al., 2001). Whilst some studies have sampled three-month-old infants, the majority have used four-month-olds to investigate many different aspects of individual differences, including disengagement of attention in three-month- (Colombo, Frick, and Ryther, 1993) and four-month-olds (Frick, Colombo and Terrill, 1996), and discrimination and generalisation of abstract figures (Colombo, Freeseman, Mitchell and Coldren, 1990; Freeseman, Colombo and Coldren, 1993). On the basis of their research, Colombo and colleagues have argued that the long- and short-looking dichotomy is robust (Colombo et al., 1988; Colombo et al., 1987). However, Stoecker, Colombo, Frick and Allen (1998, footnote) offer a cautionary note concerning developmental trajectories, stating that individual differences in look duration may only be reliably identified when infants are required to look at 2D static images during the first nine months of life. In the main, however, the findings from the Colombo and colleagues research are consistent. Two groups of infants can indeed be categorised. The question

that now emerges is what procedure should be used to categorise infants into long- or short-looking groups?

4.2.3 Categorisation procedures

The online categorisation procedure adopted by Colombo involved a researcher using a stopwatch to record infants' looks to the stimulus until 20s looking time was accumulated. The length of each look towards the stimulus was recorded. Once the total time that infants looked towards the stimulus reached 20s, the test was terminated. The length of the longest of these looks (calculated offline) was the measure used by DeLoache (1976) and Colombo, Mitchell, Coldren and Atwater (1990) to distinguish between long- and short-looking infants. The longest look is also known as the peak fixation duration or peak look. A bimodal distribution of peak looking times emerged with two clear groups located on either side of the median. Colombo (2004, personal communication) stated that an interval of about 1s separated these two infant groups. Using this procedure, infants engaged in long-looking strategies would take fewer longer looks to the stimulus, accumulating the 20s looking time faster than infants who engaged in short-looking strategies. Consequently, the length of time taken to accumulate the looking time was an inverse function of the length of the longest look.

In the studies conducted by Colombo and colleagues, the stimulus used was a photograph of a female face; however several studies used an additional checkerboard stimulus (Colombo et al., 1987, Colombo, Coldren, Freeseman and Frick, 1996). Longer looking times were accumulated for the face stimulus (20s as opposed to 10s for the checkerboard) as faces are interesting to infants (Fantz, 1961) and as more time is spent looking at them, differences in looking strategies can only be identified over a longer time period. Although Fagan (1978) demonstrated that checkerboard patterns also elicit interest from infants, the majority of studies, however, have used a face stimulus alone.

Over two decades, Colombo and colleagues have examined this phenomenon across many aspects of fixation duration, such as stability of peak fixation (Colombo, Mitchell, O'Brien and Horowitz, 1987), and reliability of looking category over one week (Colombo,

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Mitchell and Horowitz, 1988). Further, short-looking infants show a precedence of global over featural looking strategies as evidenced by scanning the whole scene while long-looking infants show no such predominance of featural looking strategies except after extensive familiarisation (Colombo et al., 1995). Research indicated that for four-month-old infants who had accumulated 20s looking time, the median value of the duration of the longest look for the group was 9s (Colombo, Coldren, Freeseman and Frick, 1996). The median value of the duration of the longest look was found to increase to 14s for a group of three-month-old infants (Colombo et al., 1993), who were required to accumulate 30s looking time, in order to accommodate the longer processing time required by younger infants (Lewis et al., 1969).

Papers from various laboratories (DeLoache, 1976; Colombo et al., 1987; Freeseman et al., 1993) using the standard 20s accumulated looking time procedure usually report a median of 9s for groups of four-month-old infants. That is, when examining measures of central tendency of peak fixation durations for groups of infants, the median is reported as being at 9s. For instance, Colombo et al., (1996) cite data for over 100 four-month-olds when reporting the median as 9s, although the sample size in the studies is normally between 20 to 32 infants. A closer examination of the literature, though, reveals a less clear-cut picture. Colombo et al. (1990) report the median in Study 1 to be at 9.2s, whereas in Study 2 the median was 8.7s. Further, Colombo, Frick, Ryther and Gifford (1996) reported the median peak fixation as 9.03s to face stimuli and 4.31s to concentric squares. Additionally, Orlian and Rose (1997) established median fixation duration at 7.28s. Further evidence was provided by Brown et al. (2005), who identified the median peak fixation time to be 11s, not 9s, based on a sample of 30 four-month-old infants, with the bimodal distribution. Brown et al. (2005) attributed this difference to the increased variance of peak fixations found in their group of infants, which resulted in less evidence of a 'clear-cut' delineation between the two groups. A further suggestion was that using a different face stimulus may have resulted in the difference between this study and the studies conducted by Colombo and colleagues (Colombo et al., 1987). This would

suggest that the finding might be context dependent that is, finding a peak fixation duration of 9s is dependent upon using the stimulus used by Colombo and colleagues.

However, a consistent finding is that a natural break (Colombo et al., 1990) occurs around the median value of approximately 1 second, with the two groups of long- and short-looking infants either side. The implications for the experiments reported within this thesis is that the actual median value does not necessarily have to be 9s, but should show a bimodal distribution with a break in data points at about the median value.

4.2.4 Challenges within the current literature

More recently, the viability of long- and short-looking categories in infants has been called into question. Interestingly, Courage et al. (2005) found data to support evidence for the existence of both long- and short-looking groups but also a third 'inconsistent' group who changed looking category across some stimuli. Their study involved presenting a series of 16 stimuli – either abstract patterns or female faces – to which peak fixation durations were calculated. The median peak fixation durations of approximately 10% of the infants changed with different stimuli, warranting classification as "short-looker" or "long-looker" dependent upon the stimuli. Thus, on the grounds that these infants were regarded as being 'inconsistent' in their original long- or short-looking categorisation, Courage et al. (2005) challenged the reliability of the concept of long- and short-looking information processing strategies and provide further evidence that long-and short-looking categorisation may be context dependent.

To summarise, Colombo and colleagues generally report a median value of 9s for peak fixation durations, in an accumulated looking task to female faces and evidence of long- or short-looking strategies either side of this value. Within the Colombo and colleagues research, however, the 9s median value is not consistent. What is consistent is that a natural break of about 1s occurs within the peak fixation duration data at about the median value, that is, there are no data for about 1s at about the median value providing a clear break between the two groups. More recently however, two challenges have been made to this claim, first Brown et al. (2005) suggest a median value of 11s is more accurate and

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second Courage et al. (2005) challenge the idea that two distinct groups exist by providing evidence of a third inconsistent group who change category dependent on the stimulus. These challenges suggest that long- and short-looking categories may be context dependent.

So, despite the consistent findings published by Colombo and colleagues over many decades, the contrary findings by Courage et al. (2005) suggest that a cautious approach should be taken when considering how to treat individual differences in fixation duration. Nevertheless, it would certainly be premature to entirely dismiss the dichotomy of long-versus short-looking groups without further evidence.

Due to the debate raised above, evidence of these two distinct groups was sought within the infants participating in this research project, using the procedure outlined in Colombo et al. (1987) to categorise the long- and short-looking groups. A female face stimulus will be used in line with Colombo et al. (1987) as well as an abstract checkerboard stimulus employed by Colombo et al. (1987) and Courage et al. (2005) to enable a comparison of peak fixation times to face and abstract stimuli. However, the data obtained in the present research will also give regard to the findings by Courage et al. (2005) and Brown et al. (2005), to ascertain whether peak fixation durations reveal bimodal distributions here. The resultant categorisation, if found to exist, can then be used as a baseline measure and applied to the data obtained from the experimental tasks to ascertain whether either long-or short-looking information processing strategies reveal differences in time keeping in infants.

4.3 Research aims

The purpose of the empirical work reported in this chapter was to ascertain whether long- and short-looking groups exist and, if so, to provide a baseline measure in order to categorise infants into long- and short-lookers (Colombo et al., 1987) in subsequent experiments. Using the procedure outlined in Colombo et al. (1987), individual differences in fixation duration were examined. Visual fixation data were collected by determining the length of peak fixation duration to checkerboard and female face stimuli during an

accumulated looking task. As the infant participants were four months old, 20s looking time was accumulated to the face stimuli, and 10s to the checkerboard, as described by Colombo et al. (1996). Any evidence for individual differences would then be applied to the experiments reported in this thesis to ascertain if differential use of information processing strategy characterised by look length, influences infants' abilities to perceive time.

4.4 Method

4.4.1 Design

To establish this baseline measure, a within-participant repeated measures design was employed, with the dependent variable being the length of peak fixation or look duration of the infant to the stimulus.

The research reported in this thesis was conducted in two phases due to the challenges of infant recruitment (see Figure 3.1). During Phase 1, each infant came into the Centre on one occasion. However, during Phase 2, due to the nature of the repeated measures design of Experiment 6, infants returned to the Centre on a second occasion, three to seven days later. Data for the baseline measure during this phase were therefore collected over both testing occasions. An important benefit of the second visit in Phase 2 was that it allowed test-retest reliability to be measured for 53 of the 63 infants.

4.4.2 Participants

Forty-six four-month-old infants participated in the first testing phase whilst 63 infants took part in the second, with 53 of those infants returning on a second occasion during that phase. The infants' age range was between three months three weeks and four months one week, giving a mean age of four months one day (sd: three days). All infants were between 38–42 weeks gestation, of normal birth weight with no ocular abnormalities and were mainly recruited from the local Milton Keynes area.

4.4.3 Apparatus

Details of the apparatus used in this experiment are described in full in Chapter 3 Section 3.4 and Figures 3.2 – 3.9.

4.4.4 Stimuli

Following the design of Colombo et al. (1987), the stimuli comprised a black and white regular patterned checkerboard and a colour photo of a woman (see Figure 4.1). The stimuli were created in MS Paint and incorporated into a C++ computer programme so that accumulated looking time was calculated automatically by pressing the computer keypad when the infant was looking at the stimulus. The stimulus automatically disappeared from the screen once the accumulated looking time was reached.

Figure 4.1 Baseline measure: Visual pre-test stimuli
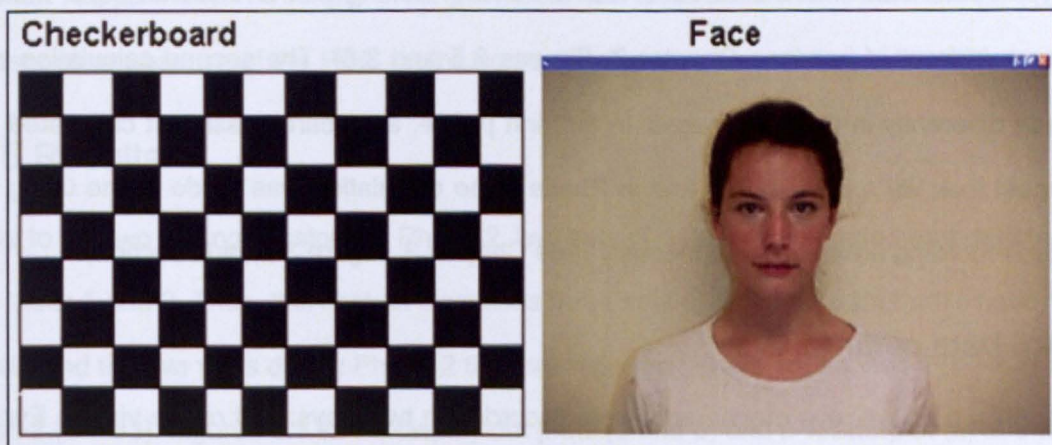
NB: each stimulus filled the whole screen (21°visual angle)

4.4.5 Procedure

The use of a cartoon video clip acted as an attention getter and ensured that infants were attending to the plasma screen in front of them. As soon as the infant was observed to be watching the screen, the stimulus was changed to either the checkerboard or face via an A/B switch (see Chapter 3, Figure 3.6, purple section). The stimuli were not presented until the infants were observed to be looking at the plasma screen in front of them.

Immediately after calibrating the eye tracker as outlined in Chapter 3, Section 3.4.2.4, infants were presented with the baseline measure stimuli to determine long- and short-looking categories. The checkerboard always appeared first and the face second. The stimuli were not counterbalanced as any possible order effects were deemed to be largely negated by the fact that the second stimulus was a face, which is highly salient to infants (Fantz, 1964).

In order to determine the length of the longest look that categorised the two infant looking groups, two calculations were made for the checkerboard and face stimuli. The first was the accumulated looking time, that is, the length of time taken for each infant to accumulate either 10s (checkerboard) or 20s (face) of look duration, and the second was the length of the longest look. The first was calculated automatically online by the Eyenal eye tracking software, and was achieved by the researcher depressing a key on the keypad when the infant was observed to remain looking at the stimulus on a monitor screen in front of her (see Chapter 3, Figures 3.5 and 3.8). The second calculation was made differently in the two phases: in the first phase, a research assistant calculated the longest look via a stop watch, and in Phase 2 the calculation was made offline using the video recording created simultaneously (see Chapter 3, Figure 3.6, blue section).

4.4.6 Data coding

As outlined above, eye movements were recorded in two ways: first online via the Eyenal eye tracking software, which produced a POG crosshair denoting the eye movement data, and the Gaze Tracker software, which superimposed the eye movement data onto the stimulus. The second method was offline, via the time-stamped video recording created during the testing session, or via a stop watch.

A look was defined by the amount of time the POG cross hair remained over the stimulus and calculated from the video time stamp. For each infant, the length of each look was documented in a spreadsheet, so enabling the length of the longest fixation to be revealed, and consequently the long- or short-looking category to be determined. This procedure replicated that adopted by Colombo et al. (1987). When calculating the length

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of longest look, allowance was made for eye blinks by discounting any breaks in the visibility of the POG that were under 60ms, and counting the break within the same look. The median value for the longest looks of all infants for each stimulus for the long- or short-looking category was then calculated.

The total time taken to accumulate the appropriate looking time was also recorded. During Phase 1 testing, in addition to the offline video coding, a research assistant provided offline data using a stopwatch to capture the amount of time that the infant was observed to be looking at the monitor screen. During Phase 2, however, as the researcher worked alone, it became necessary to rely solely on the videotaped recording. To ensure intra-rater reliability between the two methods over the two data collection phases, Phase 1 was double coded from the video backup tape using the same method as used in Phase 2, so that the author had coded all infants herself. Intra-rater reliability was measured at Cohen Kappa =.96. The length of longest look was then calculated offline based on the presence or absence of the POG on the screen during the presentation of the stimulus.

4.5 Results

Due to the two testing sessions in Phase 2, two sets of data were collected and denoted as Visits 1 and 2. Thus, this section discusses three sets of data, the data from Phase 1 (n = 46) and the two visits during Phase 2 that are reported separately as Visit 1 (n = 63) and Visit 2 (n = 53). Figures 4.3 to 4.5 display dot plots (a and b) and a scatterplot (c) of the raw data for the checkerboard and face stimuli for each data collection point. The data represent the length of the longest look to each stimulus, in the dot plot graphs the data are sorted from the smallest to the largest value.

As reported by Colombo et al. (1987), the time taken to accumulate the looking time for each stimulus (checkerboard = 10s, face = 20s) varied as a function of the length of longest look. A common attribute of each plot is that a break in the data occurs around the median value with two groups of long- and short-looking infants either side (see Figure 4.2), replicating findings made by Colombo and colleagues (Colombo et al. 1987; Colombo, 2004). While not commented on by Colombo, the breaks within the data

collected here did not always reach 1s, although a gap was always present. During Phase 1, the median length of longest look to the checkerboard was 6.5s with a natural break of 1s between the groups. The median for the face stimulus was 9s with a break of 1s in look duration at 10s. Durations began again at 11s in line with the findings reported by Colombo et al. (1987). For Phase 2 the median length of longest look was similar across Visits 1 and 2, for the checkerboard 3.66s and 3.76s, and the face 5.13s and 5.8s (see Table 4.1), contrary to the findings of Colombo et al. (1987) and Brown et al. (2005) findings, suggesting that the classification of both long- and short-looking groups is context dependent.

Figure 4.2 Example figure to help the reader follow graphical figures in Figure 4.3 onwards

NB: It should be noted that length of longest look was recorded to the nearest second in Phase 1 but to two decimal points in Phase 2. This accounts for the stepwise arrangement of data points in the left hand graph and the linear arrangement in the right hand graph.
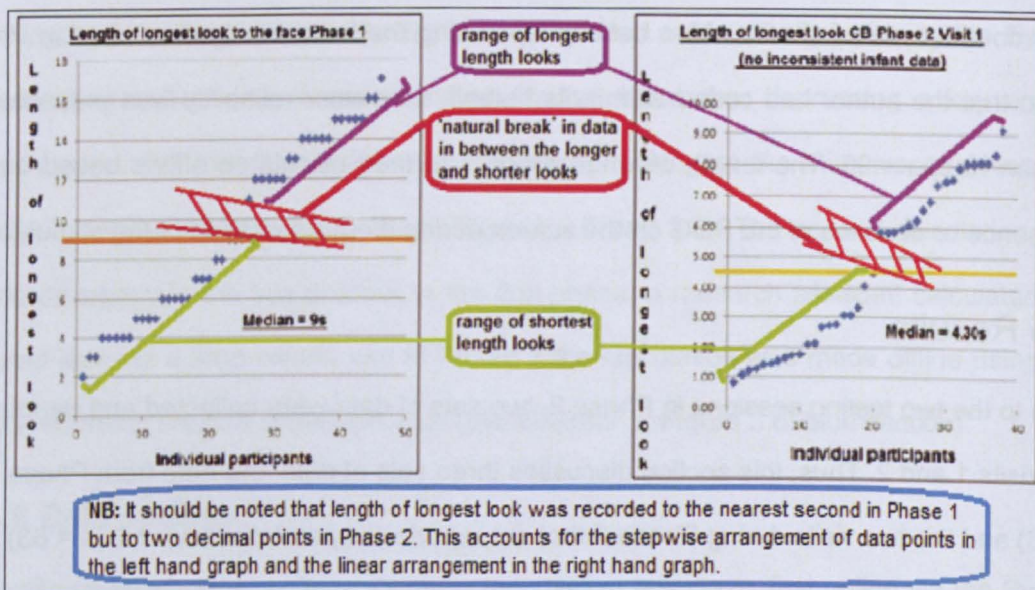
Figure 4.3 Dot plots (a and b) and scatterplot (c) of length of longest look made to checkerboard and face, Phase 1, measured to the nearest second

a) Checkerboard stimulus

b) Face stimulus

c) Dot plot of both checkerboard and face stimuli
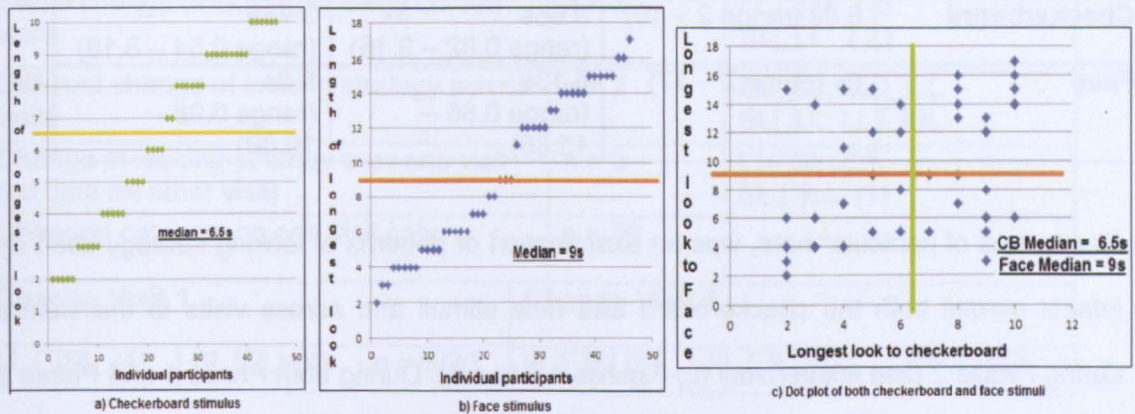
Figure 4.4 Dot plots (a and b) and scatterplot (c) of length of longest look made to checkerboard and face, Phase 2, Visit 1, measured to the nearest second

a) Checkerboard stimulus

b) Face stimulus

c) Scatterplot of checkerboard and face stimuli
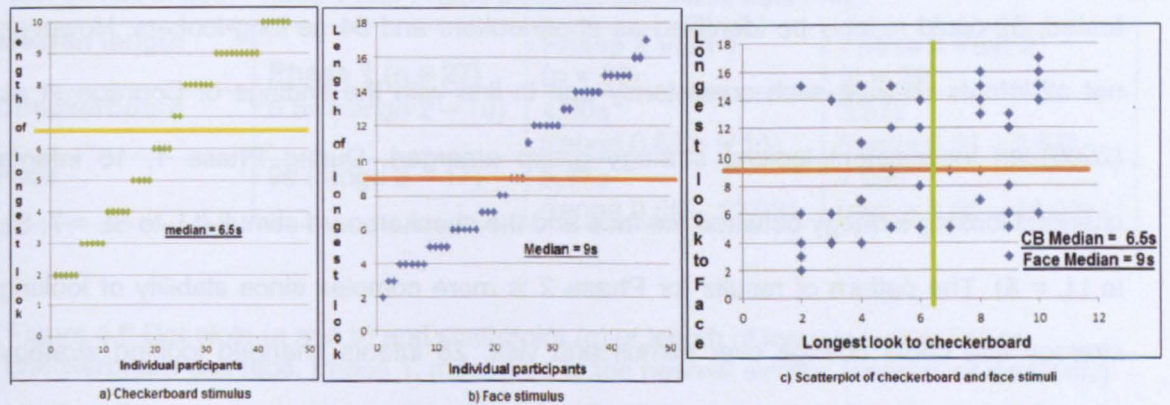
Figure 4.5 Dot plots (a and b) and scatterplot (c) of length of longest look made to checkerboard and face, Phase 2, Visit 2, measured to the nearest second

a) Checkerboard stimulus

b) Face stimulus

c) Scatterplot of checkerboard and face stimuli
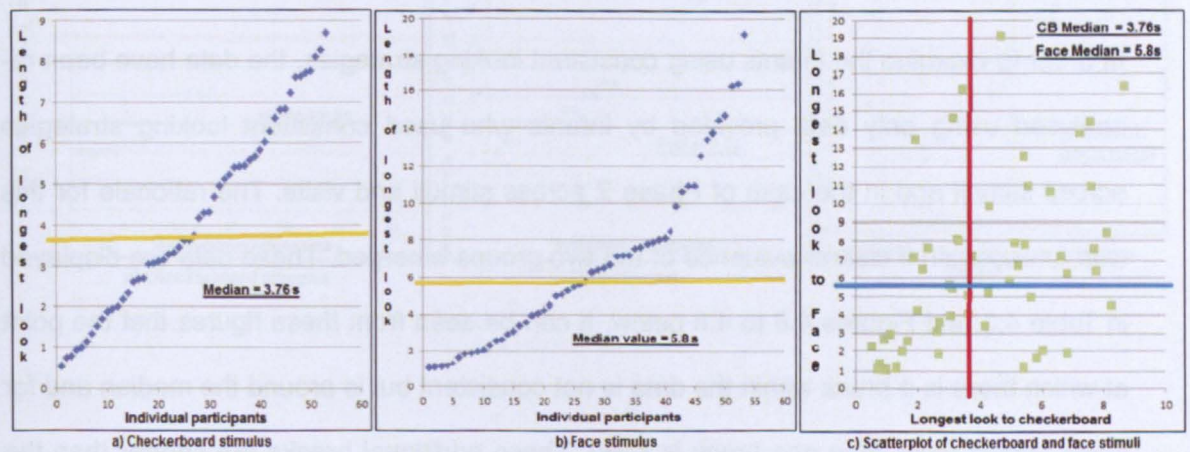
Table 4.1 Median lengths (in seconds) of look duration to the checkerboard and face pre-test stimuli in both Phase 1 and Phase 2

Median length	Phase 1 (n = 46)	Phase 2 Visit 1 (n = 63)	Phase 2 Visit 2 (n = 53)
Checkerboard	6.5s (range 2 – 10)	3.66s (range 0.82 – 9.16)	3.76s (range 0.54 – 8.16)
Face	9s (range 2 – 17)	5.13s (range 0.86 – 15.86)	5.8s (range 0.98 – 19.09)

Finally, and of particular note, was an examination of patterns of looking strategy used by infants across both the checkerboard and face stimuli and across visits to the Centre during Phase 2 (see scatterplots (c) Figures 4.3 to 4.5). During both Phase 1 and Phase 2 many infants were consistent with their use of either long- or short-looking strategies showing stability of looking style as reported by Colombo et al. (1987). Of the infants tested, 30 could reliably be identified as short-lookers and 34 as long-lookers. However, not all infants showed such consistency and in line with the findings of Courage et al. (2005) an inconsistent looking strategy group emerged. During Phase 1, 15 infants changed looking strategy between the face and the checkerboard stimuli (LL to SL = 7; SL to LL = 8). The pattern of results for Phase 2 is more complex since stability of looking strategy use could change over stimuli and visit. 28 infants changed looking strategy either between stimuli or between visits, however, no clear pattern emerges. For clarity, these data are displayed in Table 4.2.

In order to examine the infants using consistent looking strategies, the data have been re-analysed using only data provided by infants who used consistent looking strategies across stimuli and in the case of Phase 2 across stimuli and visits. The rationale for this was to ascertain if clearer evidence of the two groups emerged. These data are displayed in Table 4.3 and Figures 4.6 to 4.8 below. It can be seen from these figures that the point at which there is a break within the data is not consistent but is around the median and for some stimuli more than one break is seen. These additional breaks are shorter than the break around the median value. Furthermore, the scatterplots appear to show four inconsistent lookers, but on examination of the raw data, no infants within this second analysis have changed looking category either between stimuli or within visits.

Table 4.2 Number of infants who changed looking strategies across stimuli and visits in Phase 2

Number of infants in inconsistent group N = 28		
Same change of looking strategy across visits	n = 3	LL→SL (1) SL→LL (2)
Different change of looking strategy across visits	n = 2	LL→SL; SL →LL SL→LL; LL →SL
Change of looking strategy over one visit (no data for other visit)	n = 3	LL→SL (2) SL →LL (1)
Changed category on one visit only	n = 20	
Change Visit 1		**Change Visit 2**

LL →SL (4)	SL →LL(4)	n = 8/20	LL →SL(5)	SL →LL (7)	n = 12/20

Table 4.3 Median length (in seconds) of look duration to the checkerboard and face pre-test stimuli in both Phase 1 and Phase 2 (consistent infant data only)

Median length	Phase 1 (n = 27)	Phase 2 Visit 1 (n = 37)	Phase 2 Visit 2 (n = 29)
Checkerboard	6.5s (range 2 – 10)	4.30s (range 0.82 – 9.16)	3.97s (range 0.54 – 8.63)
Face	9s (range 2 – 17)	5.17s (range 0.86 – 12.93)	4.98s (range 1.02 – 19.09)

Figure 4.6 Dot plots (a and b) and scatterplot (c) of length of longest look made to checkerboard and face, Phase 1, measured to the nearest second (consistent data only)

a) Checkerboard stimulus

b) Face stimulus

c) scatterplot of checkerboard and face stimuli
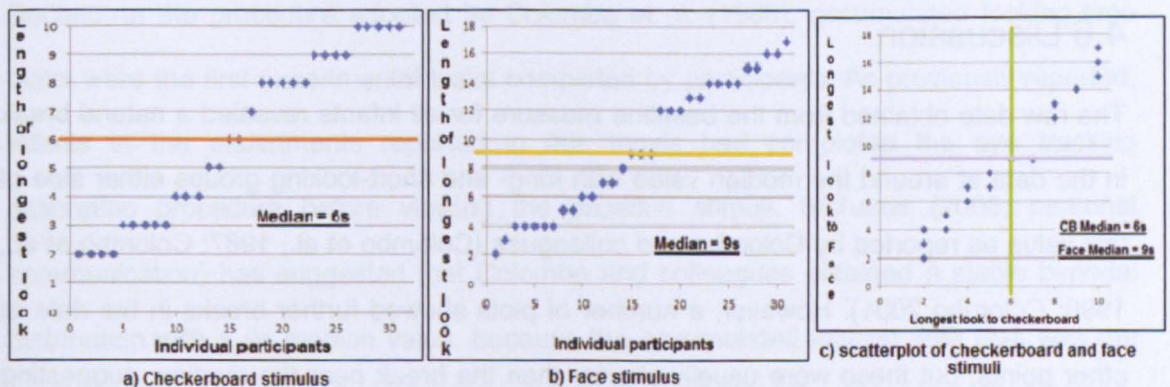
Figure 4.7 Dot plots (a and b) and scatterplot (c) of length of longest look made to checkerboard and face, Phase 2, Visit 1, measured to the nearest second (consistent data only)

a) Checkerboard stimulus

b) Face stimulus

c) scatterplot of checkerboard and face stimuli
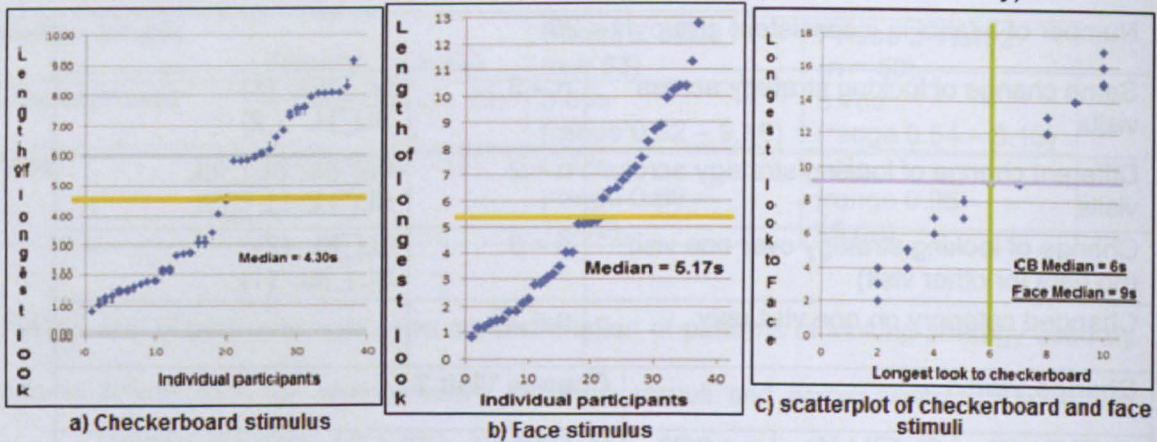
Figure 4.8 Dot plots (a and b) and scatterplot (c) of length of longest look made to checkerboard and face, Phase 2, Visit 2, measured to the nearest second (consistent data only)

a) Checkerboard stimulus

b) Face stimulus

c) scatterplot of checkerboard and face stimuli
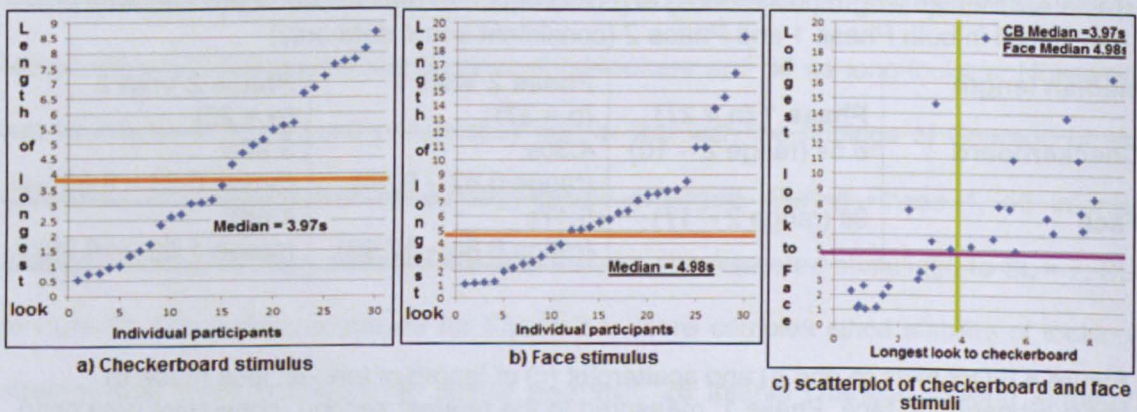
4.6 Discussion

The raw data obtained from the baseline measure for all infants revealed a natural break in the data at around the median value with long- and short-looking groups either side of this value as reported by Colombo and colleagues (Colombo et al., 1987; Colombo et al., 1996; Colombo 2001). However, a number of plots showed further breaks in the data at other points, but these were usually shorter than the break near the median, suggesting that further research may be needed to examine the reasons for this. On examining Colombo's work, no mention is made of additional breaks in the data, so no comparisons can be made. One reason for this could be that the data reported here were collected by an eye tracker, and consequently more objective and reliable than data obtained by coding from video tapes.

Colombo and colleagues (Colombo et al., 1987; Colombo et al., 1996) state that the median length of longest look was approximately 9s to the face stimuli. This value was replicated in Phase 1 but not Phase 2. However, Colombo and colleagues themselves (Colombo et al., 1990; Colombo et al., 1996; Orlian and Rose, 1997) did not always find the median value at 9s. For Phase 2 of the present study, median values were found at 3.76s and 3.88s for the checkerboard and 5.17s and 4.87s for the face. What might account for the different median values, first across Phase 1 and 2 and second between researchers?

These differences could be accounted for in a number of ways, starting with differences in the stimuli themselves. The female face used in the present study had a neutral expression, and whilst no mention of smiling is made in previous papers by Colombo and colleagues, Frick et al. (1999) did use a smiling female face. Hence, the neutral expression on the face stimulus in the present study may have been less positive to infants and possibly influenced looking time. However, a neutral expression was used in the present baseline measure, as a smiling face stimulus would introduce an additional variable of emotion.

Second, in the procedure adopted by Colombo et al. (1999), accumulated looking time tasks were the first experimental tasks completed by participants. As previously reported, infants in the experiments reported in this thesis had completed the eye tracking calibration procedure before viewing the baseline stimuli. Richards (2006, personal communication) has suggested that Colombo and colleagues obtained a stable bimodal distribution with a 9s median value, because the accumulated looking time task was the first task the infant completed when their attentional capacity would have been at its greatest.

In support of Colombo and colleagues (Colombo et al., 1987), a natural break in the data around the median value of length of longest look was found, although as previously mentioned, further breaks emerged elsewhere. However, measures of heart rate and levels of distractibility, or inability to disengage attention, suggest that whilst looking at a

stimulus, infants may not be actively processing the information, especially at the longest length of look.

The findings from the present baseline measure tend to support the view taken by Courage et al. (2005) and Richards (2006, personal communication), that long- and short-looking categorisations should be treated with caution. Using a procedure similar to Richards (2006, personal communication), the eye tracker was calibrated before the test stimuli were presented. Therefore the infants were already into the testing protocol before the checkerboard stimulus appeared, which may have influenced the results, as noted above. Further, the data for both Phases show that some infants changed looking strategy not only between visits but also between stimuli. Thus, similar to Courage et al. (2005) an inconsistent group emerged. This factor should be accounted for within any analysis.

In order to understand the analyses conducted for each of the subsequent experiments reported in this thesis, a brief description of the procedure is provided. The data collected within this thesis were subjected to two analyses. First all the data collected were analysed to ascertain whether infants could keep time. Then, a second analysis was performed using the data from the baseline measure. For the second analysis only data from infants who consistently used either long- or short-looking strategies were used, which meant that fewer infants were included in the second analysis. Data from infants who formed the inconsistent group were discarded for the purposes of the second analysis only.

To conclude, data from this baseline measure show a mixed pattern of results. Whilst evidence has been found for infants using long- and short-looking strategies when encoding information (Colombo et al., 1987), different median values were observed for the length of longest look. Various explanations were offered to account for these variations, including different testing procedures. Evidence was also found for some infants using inconsistent looking strategies across stimuli and time. This evidence suggested that long- and short-looking categories, at least for some infants, are context dependent. To take account of this, the second analyses conducted in the subsequent

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experiments, reported in the following chapters, only used data from infants who were consistent in their use of either long- or short-looking strategy.

4.7 Chapter summary

This chapter reviewed the rationale and procedure outlined by Colombo et al. (1987) to categorise individual differences in fixation duration thought to underpin the differential use of information processing strategies, and thus to determine its existence and usefulness as a baseline measure for the studies reported in this thesis. Previously Colombo and colleagues (Colombo et al., 1987) had found stability of looking patterns within the first year of life, with clear groups emerging either side of the median value of the length of longest look at 9s, and reporting a characteristic natural break of 1s or more around the median value. The findings from the baseline measure reported in this chapter also showed a natural break within the data around the median value, although additional breaks, usually shorter, emerged suggesting a need for further research. The median values of the length of longest look varied across the stimuli. Several reasons were proposed for these variations in median value, first the use of the eye tracker which allowed data collection in an objective manner and second, the differences in testing protocol between the present researcher and Colombo and colleagues (Colombo et al., 1987).

More recent evidence also found inconsistencies in categorising long- and short-looking groups (Courage et al., 2005; Richards, 2006, personal communication). Within the parameters of the present data, distinct groups using long- and short-looking strategies could be identified along with a third inconsistent group, infants who changed looking strategy across stimuli or time or both, suggesting that categorisation into long- and short-looking category is context dependent.

Having outlined individual differences in look duration within this baseline measure, these categories will now be applied to the subsequent timing experiments reported in Chapters 5 –10.

Chapter 5
Experiment 1: Can infants perceive short time intervals?

5.1 Introduction

The aim of the experiment reported in this chapter was to obtain overt behavioural evidence of infant time keeping. Previous time perception research conducted by Colombo and Richman (2002) and Colombo et al. (2005) used heart rate methodology as a measure of attention. Experiment 1 builds on the design used by Colombo and colleagues but uses eye tracking methodology.

5.2 Infant timing – overview of the literature

5.2.1 Overview

As mentioned in Chapters 1 and 2, the initial infant timing study by Colombo and Richman (2002) was replicated and extended by Colombo et al. (2005) using the same design, but with different time intervals. Two intervals were used in the 2002 study, and three were used in the 2005 study: 5s, 10s and 15s. The participants, groups of four- or nine-month-old infants, were presented with predictable light/dark stimulus sequences in a one trial design at one of these intervals and changes in heart rate response were noted during the omission trials when the sequence was disrupted. Infants were divided into high and low SA groups based on their performance during attentional pre-tests. High SA infants were found to be more accurate time keepers in both experiments, but not at the same time intervals. In the 2002 study, high SA infants were better time keepers in both the 5s and 10s intervals. In the 2005 study, they were better time keepers in both 10s and 15s intervals but not the 5s interval. No explanation was provided for this failure to replicate

the previous finding at 5s. It should be noted that there is no confirmed evidence that high and low SA groups are the same as long- and short-looking infants.

5.2.2 Challenges within the existing literature

Several limitations to these two studies have been identified. The first relates to methodology. Stimulus sequences were presented at slow rates in order to accommodate heart rate; consequently the studies were single trial experiments, meaning that time keeping could only be inferred across the different groups of infants and time intervals.

Using eye movements as a measure of attention would overcome this limitation of heart rate methodology and allow the issue to be investigated more fully. As eye movements are faster than heart rate (Aslin and McMurray, 2004) more than one sequence could be presented at different time intervals; a principle that has been employed within this present research design.

Building on the experimental design of Colombo and Richman (2002) and Colombo et al. (2005), raises the issue of what type of stimulus to use. Light/dark stimulus sequences fail to provide a focus of attention, a prerequisite for eye tracking, if meaningful saccadic patterns are to be recorded, rather than just random eye movements or indeed no eye movements at all if the infant is not looking at the stimulus. Unlike eye tracking, heart rate measures allow data to be collected even though the infant may not be looking at the stimulus, so it is possible that some of the data captured in Colombo's studies may not actually be related to the experimental stimulus. This is likely, therefore, to have distorted the research findings.

5.2.3 Influence of current literature on the present research design

In order to compare the results from the Colombo and Richman (2002) and the Colombo et al. (2005) studies with the present research, a gradual change in the appearance of the stimulus was required so that the focus of attention could be seen. To accomplish this, the light screen that filled the entire screen in the Colombo and colleagues studies, was reduced in size so that it became a small white square that allowed infants' eye

movements to be tracked. Initially, the square was located in the centre of a black screen, and in later sequences, on alternate sides of the black screen. Building on the original experimental design, the predictable sequence was disrupted and the subsequent stimulus omitted. It was predicted that eye movement patterns would be qualitatively different during the predictable stimulus sequence than when the stimulus was omitted, when it was predicted that infants might look all around the monitor screen.

To enable eye movements to be observed more easily, the small white square appeared alternately either side of the monitor screen. If infants have kept track of the spatial and temporal information within the sequence, eye movements would be observed to move from the left to the right of the monitor screen, thus providing a clearer pattern of responses. This manipulation extends the work of Colombo and Richman (2002) that simply required infants to keep track of temporal information.

Using eye movements to investigate infant time perception allows for one final manipulation, that of speeding up the presentation of stimulus sequences, allowing additional sequences to be presented. This addresses the single trial design limitation of the original two studies. A further advantage of offering additional sequences within one experiment is that sequences of different ISIs can be presented, for instance 1s compared to 3s. This method should elicit systematic changes in saccadic reaction times according to the difference in time interval, so an ISIs of 3s should elicit longer saccadic reaction times than one of 1s. This design offers a more complete examination of infant time keeping abilities using a within-participant design.

Various manipulations have been proposed to adapt the stimulus to use with eye tracking in the present experiment in order to investigate infants' time perception. However, this may have other consequences. It could be predicted that stimuli presented alternately left and right introduces a spatial component in addition to the temporal information. Moreover, by increasing the speed of stimulus presentation, the information within the sequence has to be processed faster, introducing further cognitive load. Consequently,

these factors may have a detrimental effect on time keeping, although the advantages of this approach are deemed to warrant this method of enquiry.

5.3 Research questions

This experiment compared the saccadic reaction times to omitted stimuli when a predictable sequence was disrupted. The sequences underwent the manipulations discussed above including changing stimulus characteristics and speed of presentation. The aim of this experiment was to investigate whether there are any differences in saccadic reaction times when these manipulations were made.

Consequently, the research questions are as follows:

1   Can overt behavioural evidence of infant time perception be obtained using eye tracking methodology?

2   Do inter-stimulus intervals of 3s elicit longer saccadic reaction times than those of 1s during stimulus omission trials when predictable sequences are disrupted?

3   Are infants able to keep track of the inter-stimulus intervals within each sequence?

5.4 Method

5.4.1 Design

The experiment reported here used a within-participant repeated measures design. The dependent variable was the latency of the first saccade to the correct location in the sequence following stimulus omission. Two independent variables were the speed of the sequence and the number of stimulus presentations. Thus four nine-stimulus sequences were presented, three sequences, with ISIs of 3s, and the fourth with an interval of 1s.

5.4.2 Participants

Thirteen four-month-old infants (range three months three weeks to four months one week, sd = two days) took part in the experiment reported in this chapter. The study was

terminated early for five infants due to distress, and their data discarded. Eight infants remained seated in the car seat for the duration of the study and therefore offered usable data. Of these eight infants, four provided data for 8 omission trial data points out of a possible 32.

Four of the eight infants who completed the task, tracked at least one sequence and looked at the location of the omitted stimulus during the omission trial. These infants provided data in the following trials; one tracked all four sequences and the omission trials; another tracked two sequences and the omission trials; and two tracked one sequence and omission trial. The remaining four kept track of the stimulus during the sequences, but looked away from the screen during omission trials, therefore no relevant data were collected for them and so their data were discarded.

5.4.3 Apparatus

For details of the apparatus used in this experiment, see Chapter 3 Section 3.4 and Figures 3.2 – 3.6.

5.4.4 Stimuli

The stimuli were created in Microsoft Paint and incorporated into the eye tracking Gaze Tracker programme that allowed the sequences to be timed and run continuously through all conditions. Due to the incremental nature of the stimuli, the conditions could not be presented in a counterbalanced order. Data were collected using the Gaze Tracker analysis software.

In order to make the materials more suitable for eye tracking, the stimulus was adapted from the light/dark full screen stimulus used in the two Colombo and colleagues studies to a small white square (see Figure 5.1). Condition 1, however, replicated the design and stimulus used in the 2002 and 2005 studies and the same timings as the 2002 study. The whole screen (21°visual angle) was either black (OFF trial) for 3s or white (ON trial) for 2s while the duration of the omission trial (OM) was 15s. This allowed comparisons to be drawn between the 2002 and 2005 studies and the present experiment in this condition.

The timing of the sequence in Condition 2 was the same as for Condition 1, however, the character of the stimulus for ON trials changed from a whole white screen to a small white square (4° x 4° visual angle) on a black background in the centre of the screen. These were interspersed with a black screen (OFF), and finally the omission trial (OM). The small white square allowed the focus of infants' attention on the screen to be observed and any changes in eye movement patterns to be noted.

Figure 5.1 Stimulus sequences used in Experiment 1
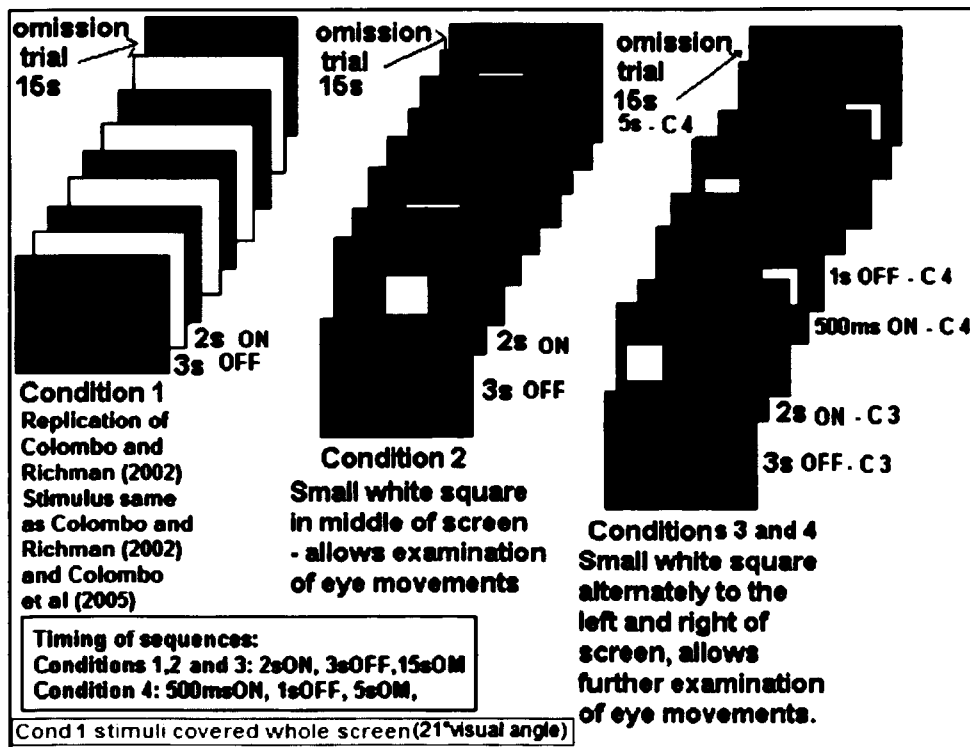
Sequence timings in Condition 3 were the same as for Condition 1, but again the character of the stimulus for ON trials changed. The small white square on the black background (ON trial) now appeared in a regular alternating pattern on either side of the monitor and was interspersed with a black screen (OFF trial). The regular alternating pattern allowed the eye tracking POG crosshair to clearly demonstrate whether infants followed the stimulus sequence.

Finally, Condition 4 replicated Condition 3 and introduced a further difference in the sequence timings: 500msON, 1sOFF, 5sOM. This manipulation was designed to allow any

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time perception abilities to be seen at different time intervals by the same infants within the same testing session.

5.4.5 Procedure

Following calibration and baseline data collection (see Chapter 3 Sections 3.4.2.4 and 3.5) Conditions 1 – 4 were presented automatically through the Gaze Tracker programme with no break between conditions, and in the same order to enable all participants to accommodate the changing nature of the stimuli. Consequently, the stimuli were not counterbalanced, despite the possibility of order effects.

5.4.6 Data analysis

The data for all four conditions were coded and analysed using the same procedure as outlined in Chapter 3, Section 3.6.1 and Figure 3.12. The patterns of saccades were compared across the ON and OFF trials and during omission trials.

Of particular interest, as with the 2002 and 2005 studies were responses made around the time of stimulus omission during the omission trials. During these trials (see Figure 5.2), the time of the first saccade to the correct location of the stimulus after the omission of this predicted stimulus (Region 1) was recorded. Saccades made to Region 2 were deemed to be incorrect.

Figure 5.2 Coding grid used to code saccades made during stimulus omission trials.

Key: Region 1 represents the location where the stimulus would have appeared (the 'correct' location) during omission trials. Region 2 represents the remaining 'incorrect' region.
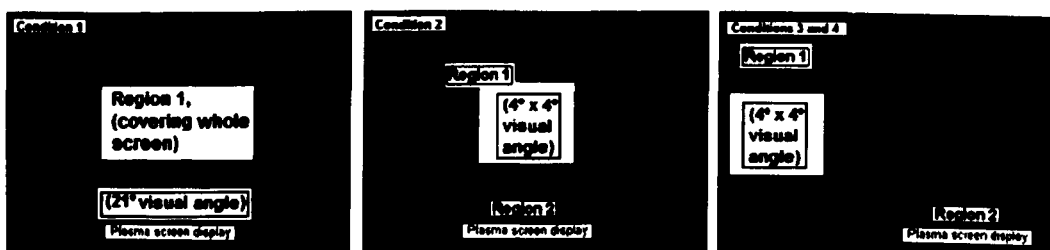
The definition of a saccade in the 'correct' stimulus location differed for each condition. In Condition 1, the 'correct' location was any part of the screen where the omitted stimulus would have appeared if the sequence had not been disrupted. In Condition 2, on the other hand, the 'correct' location was the central part of the screen, whereas in Conditions 3 and 4 it was either to the left or right hand side of the screen, namely the opposite side to where the last stimulus appeared before omission.

Conditions 3 and 4 introduced the need for participants to understand both the spatial and temporal information of the presented sequence. If infants have understood the spatial information, saccades would appear alternately to the left and right of the screen corresponding with the sequence, and would continue after stimulus omission. If the temporal information is also understood, it would be predicted that saccades would be made only after the omitted stimulus would have been presented. So in Conditions 1 to 3, saccades should be made after 3000ms had elapsed, but in Condition 4, after 1000ms. The recording of saccadic latencies began 500ms before stimulus omission.

5.5 Results

Four infants provided data in at least one stimulus sequence, and these data are presented in Table 5.1 below. The data shown represent the time of the first saccade to the correct location after the onset of the omitted stimulus, that is, after the ISI has elapsed.

Table 5.1 Time (ms) of first saccade to the correct location after the onset of the omitted stimulus in each condition

Participant No.	Condition 1 (after onset at 3000ms)	Condition 2 (after onset at 3000ms)	Condition 3 (after onset at 3000ms)	Condition 4 (after onset at 1000ms)
5	296	-	-	-
6	781	5125	5312	1297
7	969	750	-	-
10	-	-	8469	-

It is important to note that the data were collected using the Gaze Tracker software. However, maintaining the eye tracker's POG crosshair was problematic for various reasons that will be discussed in the Discussion section. Due to the paucity of data collected, no statistical tests were conducted on the data presented in Table 5.1. However, it is still possible to make some observations from this exploratory study.

First, four infants tracked at least one of the stimulus sequences and looked to the correct location after the onset of the omitted stimulus, suggesting that they had understood the spatial and temporal information contained in these sequences. More specifically, they may have been attending to the short time intervals in the sequences, and anticipating the presentation of the next stimulus.

Second, Participants 5, 6, and 7 provided data in Condition 1, the first sequence; thus equating to the one trial method used by Colombo and colleagues (2002, 2005), and so they would have been deemed to have completed the whole study. However, because Experiment 1 employed a repeated measures design, Participant 6 completed the study by providing data in all four conditions. Notably, this participant's response latencies were much faster in Condition 4 than in Conditions 2 and 3 (e.g. 1297ms vs 5125/5312ms), suggesting that they may have perceived the shorter time interval in Condition 4.

Referring to the individual differences baseline measure (discussed in Chapter 4), data provided by this infant were categorised as short-looking based on their response to the baseline measure. The remaining infants were categorised as long- (Participants 5 and 7) and short-looking infants (Participant 10). All these infants remained consistently in their categories across both baseline measure stimuli. Differences between the two groups emerged: for instance, long-lookers responded in the first sequence only, whereas the short-lookers responded either on all sequences or later sequences. Although no firm conclusions can be drawn from this small sample size, the results raise the possibility that individual differences may influence time perception and therefore offer relevance for this thesis.

5.6 Discussion

The paucity of data collected signals difficulties with the experimental design, which need to be identified and addressed to enable a more complete investigation of infant time keeping. The main limitation presented was the high levels of participant attrition.

The level of attrition in Experiment 1 was higher than reported in Oates (1998) but similar to those seen in other infant research centres across the world, (e.g. Farroni et al., 2003) and other infant eye tracking studies by Aslin and McMurray (2004) and Johnson, Slemmer and Amso (2004). The high numbers of infants who did not provide data during the omission trials could be accounted for by a number of factors.

First, testing sessions were terminated early for five of the thirteen infants who became distressed during testing and could not be placated. Infants' crying is problematic when using eye tracking methodology as they shut their eyes, thus losing the POG cross hair; consequently tracking cannot continue. However, the infant's wellbeing was always of paramount concern, so infants were removed from the testing environment immediately if they started to cry. A brief session of interaction was usually enough to placate the infant so that testing could resume if all parties were happy. If infants could not be placated the testing session was terminated.

More positively, eight of the thirteen infants completed at least one trial sequence, with four of them providing data in the omission trials, which is within normal attrition limits for infancy research. This is in line with the findings of Colombo and colleagues (2002, 2005) who deliberately only employed the one trial method due to high attrition levels (Colombo, 2005, personal communication). Nevertheless, this implies other contributing factors for the lack of data collected.

A possible reason for the scarcity of data could be the nature of the stimuli used. The fact that many infants looked away after seeing a few stimulus presentations suggests that they may have become bored (Haith, 1993; Lee, Symons, Hains and Miur, 1998): black and white squares may hold little or no interest for infants. However, the stimuli were designed to replicate as far as possible those used by Colombo and Richman (2002), despite the different methodology, so that comparisons could be drawn between the two experiments.

Nevertheless, the main difference between the 2002 and 2005 studies and the present experiment is methodology, with the former using heart rate measures and the latter eye tracking. Heart rate methodology allows data collection despite infant crying. That is, whilst heart rate will increase over baseline levels when an infant is distressed, it can still be measured. On the other hand, eye tracking requires the eyes to remain open and on the stimulus for tracking to take place, and so a crying infant renders this methodology useless. Consequently, this factor heightens the importance of using engaging stimuli to optimise the use of eye tracking.

As noted above, some infants may have become bored. Efforts in future studies to improve the intrinsic appeal of the display might make the stimulus more interesting resulting in lower attrition rates. An examination of the infant literature points to a huge body of evidence dating from Fantz (1963) to more recently authored papers by Humphreys, Gosselin, Schyns and Johnson (2006), which demonstrate that infants prefer faces to more abstract stimuli. Therefore, in order to retain attention, future studies should

contain faces that are more salient for infants than white squares on a black background (Goren, Sarty and Wu, 1975), and hopefully reduce attrition rates.

5.7 Chapter summary

The purpose of Experiment 1 was to ascertain whether overt behavioural evidence could be obtained about infants' perception of short time intervals using eye-tracking methodology. The results showed limited success in achieving this aim and, given the paucity of the data, no firm conclusions could be drawn. Some observations have been offered, however, as eight out of thirteen infants tracked at least part of one sequence, but only four tracked the omission trial. Nevertheless, in the present study, only eight data points from thirty two were collected, thus highlighting the need to address these limitations in the studies reported in the following chapters.

Two explanations were provided for the dearth of data collected. First, the possibility that eye tracking methodology is unsuitable for this research; this was rejected since the levels of infant attrition were comparable to those reported by other researchers who have successfully employed eye tracking methodology (Aslin and McMurray, 2004; Johnson et al., 2004). The second was that the uninteresting nature of the stimulus resulted in infants getting bored (Haith, 1993; Lee, Symons, Hains and Miur, 1998), leading them to look away from the stimulus or to become distressed before the sequences were completed. As similar attrition rates were discussed by Colombo and colleagues (2002, 2005), the use of more salient stimuli will be explored in future experiments. Experiment 2 seeks to address the limitations encountered in Experiment 1.

Chapter 6
Experiment 2: A further examination of infant time perception utilising a face stimulus

6.1 Introduction

Reasoning that the uninteresting nature of the black and white stimuli used in Experiment 1, limited the success of that study, few conclusions could be drawn from the data. Nevertheless, observations from the four infants who did provide useable data showed that tentative comparisons with the Colombo and Richman (2002) and Colombo et al. (2005) studies could be made, in that those infants provided data in at least one omission trial. By addressing the limitations of the stimulus, the question of whether infants perceive short time intervals is examined further in this next experiment.

The stimulus sequences in Experiment 1 ranged from an interchanging black and white stimulus that filled the entire monitor screen (replicating the 2002 and 2005 studies), that decreased to a single centrally placed small white square in Condition 2 to provide a focus for attention, and the same small white square alternating right and left in Conditions 3 and 4 (see Chapter 5, Figure 5.1). However, as few data were collected, it is clear that plain white squares do not appear to keep infants' attention and that this type of stimulus does not successfully test the research question posed. Associated literature will now be reviewed in order to examine how other researchers have attempted to address this limitation.

6.2 Overview of the literature

To address the limitations and inform the design of Experiment 2 this section will examine the saliency of faces and spatial expectancies, as well as revisiting individual differences in look duration.

6.2.1 Saliency of faces

As discussed in detail in Chapter 2, faces are particularly salient to infants (Fantz, 1963) and so could be used to address the limitation discussed above by encouraging attentiveness. There has been a long tradition in the use of schematic faces in infant research (Fantz, 1961; Goren, Sarty and Wu, 1975), showing that face-like configurations gain greatest interest (Johnson, Dziurawiec, Ellis and Morton, 1991; Valenza, Simion, Cassia and Umilta, 1996). The faces used in this experiment were colourful cartoon faces that might be expected to hold an infant's attention.

6.2.2 Spatial expectancies

Evidence that 15-week-old infants learned the spatial relationships of alternating left-right predictable stimulus sequences using the VExP paradigm was demonstrated by Haith et al. (1988) (discussed in detail in Chapter 2, Section 2.5.3.1). These infants showed a decrease in the median saccadic reaction time towards the next stimulus in the sequence (472ms to 327ms) after the fifth trial, suggesting that they had formed expectancies about the location of the next stimulus after only five presentations. However, the authors only discussed the formation of spatial expectancies rather than temporal expectancies, so this further factor will be considered in the present study. The formation of temporal expectancies will be examined by manipulating the number of stimuli in each predictable sequence.

Since completing the experiments reported here, Adler, Wass and Haith (2008) have examined temporal expectancies, but since their findings did not inform the design of these present experiments these will not be discussed until Chapter 11.

6.2.3 Individual differences in look duration

An examination of individual differences in look duration used as a baseline measure within all the empirical work undertaken in this thesis was discussed in detail in Chapter 4. Colombo et al. (2001) correlated look duration and the categorisation of long- and short-looking information processing strategies with HR measures. Further individual

differences in HR measures were linked with increased accuracy in time keeping by Colombo and colleagues (2002 and 2005). To date individual differences in look duration have not been examined in infant time perception research and if found could have several implications. Colombo and colleagues have previously demonstrated that short-looking infants who use global information processing strategies have increased intellectual functioning at age six (Colombo, 1993), better recognition of the contours of shapes (Colombo, Frick, Ryther and Gifford, 1996) and degraded visual forms (Frick and Colombo, 1996).

This benefit of global processing may also extend to performance in time perception. Short-looking infants may gain a more accurate representation of the duration, especially in faster sequences and with fewer referent exemplars than their long-looking counterparts. On the other hand, long-lookers, who are thought to engage in local featural processing, might learn the referent duration (ISI) more accurately as they focus on only one part of the task. However, this possible advantage may be hindered by an inability to disengage attention (Frick et al., 1999), leading to longer durations being perceived and subsequently estimated during omission trials. Thus differences in time perception could be observed between the two groups and forms the basis of one of the research questions below.

6.3 Research questions

The five research questions under examination in the present experiment revisit those posed in Experiment 1.

1. Can overt behavioural evidence of infant time perception be obtained using schematic face stimuli?

2. Would infants be able to keep track of time at more than one time interval?

3. Do infants keep time within a sequence?

4. Do the number of stimuli presented within one sequence influence time perception?

5. Do individual differences in look duration influence time perception?

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These more specific research questions address aspects of the first three major questions posed at the beginning of this thesis.

6.4 Method

6.4.1 Design

The experiment reported here used a within-participant mixed design with three independent variables. The first and second independent within-participant variables were sequence-presentation speed and the number of stimulus presentations. The third between-participant independent variable was looking strategy (short or long). As in Conditions 3 and 4 of Experiment 1, both spatial and temporal factors were under investigation. The dependent variable was the latency of the first saccade to the correct location in the sequence following stimulus omission.

The first independent variable in Experiment 2 examined three stimulus presentation speeds: slow (3s ISI, replicating Colombo and colleagues, 2002, 2005), medium (1s ISI), and fast (750ms ISI). The omission trial was 15s long in the slow sequence (again replicating Colombo and colleagues, 2002, 2005), but 5s duration in the medium and fast sequences. It was predicted that if infants perceived the time intervals, eye movement responses would be slower in the slow sequence than the fast sequences. For labelling purposes, slow sequences are denoted as S, medium sequences as M and fast sequences as F.

The second independent variable was the length of the stimulus sequence. Long sequences comprised eight faces with a ninth being omitted in the omission trial, similar to the procedure adopted by Colombo and colleagues (2002, 2005) so that a slow sequence with nine stimuli (the last one omitted) is denoted as S9. Short sequences comprised of four faces and a fifth being omitted in the omission trial, were denoted as S5 (slow sequence) (see Tables 6.1 and 6.2). Experiment 2 adapted the alternating stimulus pattern of the VExP (Haith et al.,1988) by omitting the last stimulus in the sequence. It was predicted that longer sequences would give infants more opportunity to form a

representation of the ISI than the shorter sequences, thus eliciting more accurate responses within the omission trial. All infants were presented with the three long sequences followed by the three short sequences.

The third independent variable, the baseline measure, was discussed in detail in Chapter 4.

Table 6.1 Experiment 2: Overview of long stimulus sequences

Sequence name	Sequence speed	Sequence description	Sequence timings
S9	Slow	long sequence 8 stimuli in sequence and 1 omitted stimulus	2s ON (stimulus present); 3s OFF (stimulus absent); 15s OM (stimulus omitted)
M9	Medium	long sequence 8 stimuli in sequence and 1 omitted stimulus	500ms ON (stimulus present); 1s OFF (stimulus absent); 5s OM (stimulus omitted)
F9	Fast	long sequence 8 stimuli in sequence and 1 omitted stimulus	500ms ON (stimulus present); 750ms OFF (stimulus absent); 5s OM (stimulus omitted)

Table 6.2 Experiment 2: Overview of short stimulus sequences

Sequence name	Sequence speed	Sequence description	Sequence timings
S5	Slow	short sequence 4 stimuli in sequence and 1 omitted stimulus	2s ON (stimulus present); 3s OFF (stimulus absent); 15s OM (stimulus omitted).
M5	Medium	short sequence 4 stimuli in sequence and 1 omitted stimulus	500ms ON (stimulus present); 1s OFF (stimulus absent); 5s OM (stimulus omitted).
F5	Fast	short sequence 4 stimuli in sequence and 1 omitted stimulus	500ms ON (stimulus present); 750ms OFF (stimulus absent); 5s OM (stimulus omitted)

6.4.2 Participants

Forty-seven four-month-old infants with a mean age of four months, one day (sd: three days; range three months, three weeks to four months, one week) participated in the experiment and were recruited mainly from the local Milton Keynes area. Forty infants completed the study. The seven excluded from the final analysis were due to fussiness (n = 2), looking away from the screen (n = 2) and technical error (n = 3).

6.4.3 Apparatus

Details of the apparatus used in this experiment were described in full in Chapter 3, Section 3.4 and Figures 3.2 – 3.9.

6.4.4 Stimuli

The experimental stimuli comprised sequences of single smiley faces (4°x4° visual angle) on a white background (see Figure 6.1). The images appeared alternately on the left and right of the screen (ON trials) interspersed with a black screen (OFF trials) in three predictable sequences. The timing of each of the three sequences differed, being slow, medium and fast. Different coloured smiley faces were used for each sequence in order to maintain the infant's attention across the experiment.

The smiley face stimuli were created in Microsoft Paint and incorporated into the Gaze Tracker software. This allowed timing and presentation to be seamless throughout all three sequences. The order of presentation of the six sequences was not counterbalanced for two reasons. First, the slow sequence began the experiment in order to replicate Colombo and colleagues (2002, 2005). Second, it was hoped that by completing the slow sequence first, infants' attention would be maintained throughout as subsequent sequences were shorter. It is acknowledged, however, that this might lead to order effects.

Figure 6.1 Experiment 2. Four stimulus sequence presentation (slow condition)
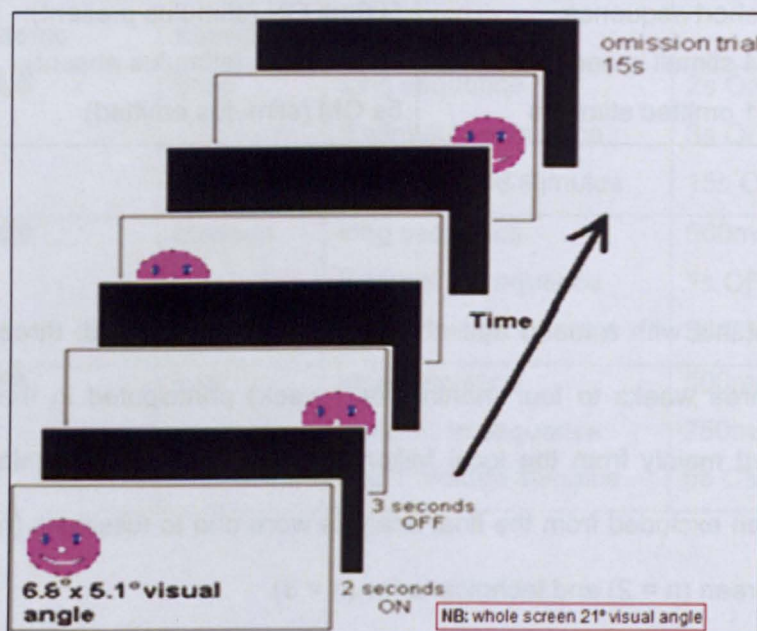
6.4.5 Procedure

Following completion of consent forms, the infants were placed in an adapted car seat and the eye tracking calibration procedure began as described in Chapter 3, Section 4. The main experiment began after obtaining the baseline measure (see Chapter 4). As before, any infants who became distressed were removed from the testing environment.

6.4.6 Data analysis

Data were derived from the Gaze Tracker software and a video backup (see Chapter 3, Figure 3.6) and coding completed using the procedure outlined in Chapter 3, Sections 3.6 and 3.7 and Figures 3.9 and 3.11.

It is predicted that during omission trials, if infants have formed spatial and temporal expectancies about the sequences, their saccades should fall within the omitted stimulus area (Area 1, Figure 3.9) at about the time the stimulus was omitted (i.e. after 3s, 1s or 750ms respectively depending on the presentation speed of the sequence). If infants have perceived the time intervals within each sequence then a comparison of the median latencies of these saccades with saccades made during stimulus present trials should reveal little difference producing non-significant results when subjected to inferential statistical tests. Using the median value of the first saccade made during the last three stimulus present trials for comparison purposes has several advantages such as accommodating differences in response latencies over the trials and any lost data earlier within the sequences due to eye blinks or looking away from the screen.

6.5 Results

Forty of the forty-seven infants who participated in Experiment 2 provided usable data for at least one stimulus sequence. Table 6.3 displays the total number of infants who provided data in each sequence. The data will now be discussed in relation to each research question outlined in Section 6.3.

Table 6.3 Total number of infants providing data in each sequence

Sequence	S9	M9	F9	S5	M5	F5
Number of Participants	13	13	18	22	18	21

In answering question one, can overt behavioural evidence of infant time perception be obtained using schematic face stimuli, the data presented in Table 6.4 show the median and range latencies of saccades made within the omission trial only. The median response latencies in the long sequences (S9,M9,F9) show a corresponding decrease in line with the decrease in ISI duration e.g. 3s, 1s and 750ms. A different pattern is seen in the short sequences (S5, M5, F5) with a corresponding decrease observed between 3s

and 1s, but not 750ms. So these results suggest that infants may have perceived the different time intervals and formed temporal expectancies about them, except in F5. There is also a corresponding decline in the range of response latencies, across all sequences except for sequence F9, suggesting that differential saccades were made within both long and short sequences. The wide range also shows that some infants were very late in making a saccade during the omission trials.

A Kruksall-Wallis test was used to answer question two, which asked whether infants could keep track of more than one time interval. The omission trial data from each sequence within the study were compared to ascertain whether response latencies differed over the three time intervals. That is, did they take longer to respond to a 3s ISI in the Slow sequence compared to the 1s ISI Medium sequence or the 750ms ISI Fast sequence? The data from this test revealed a significant effect of sequence in the long nine-stimulus sequences only (X^2=6.066, df=2, p=.048). Therefore, these results suggest that infants are better able to form spatial and temporal expectancies about the three sequences when provided with additional trials in long sequences, enabling them to become familiar with the referent duration (the ISI). Unfortunately, a Jonckheere trend test could not be applied to these data to establish any trends, as it is essential to have the same number of participants in each group, which was not the case in this analysis.

Table 6.4 Median (and range) latencies (ms) of saccades made to the omitted stimuli on omission trials only. [This refers to all infants who provided data in omission trials]

Response latencies of ALL infants to omission trials only			
Sequence	N	Median (ms)	Range (ms)
S9 Slow:9 (3s ISI: 8 Stimuli)	13	2032	8328
M9 Medium:9 (1s ISI)	13	937	3593
F9 Fast:9 (750ms ISI)	18	836	3657
S5 Slow:5 (Slow 3s ISI: 4 Stimuli)	22	640	6970
M5 Medium:5 (1s ISI)	18	437	3408
F5 Fast:5 (750ms ISI)	21	906	3157

The third question, can infants keep time within a sequence, asked whether saccadic response latencies are similar in the presence or absence of a stimulus, if so, there would be little difference in timing between the two, a non-significant result. To illustrate, during stimulus present trials an infant may make a saccade 100ms after the stimulus has appeared. If the infant then makes a saccade 100ms after the omitted stimulus should have appeared, it could be argued that the infant is sensitive to the temporal parameters of the sequence. Saccades made during the previous 500ms were also recorded as well as any saccades made after stimulus omission.

In Experiment 2, the median latency of the first saccade on the last three stimulus present trials, and the latency of the first saccade to the correct location at the point the stimulus would have appeared, were recorded and these are displayed in Table 6.5. Only sequence S5 was non-significant when the data were subjected to a Wilcoxon test (S5:

Z=-.322, p=.748). In this sequence the response latencies for both the stimulus present and stimulus omission trials were similar, suggesting sensitivity to temporal parameters in this sequence only. This leads us to the next research question that will now considered.

Table 6.5 Table of Median response latencies in stimulus present and omission trials

Sequence	Median Response latencies Stimulus Present trials (ms)	Median Response latencies Omission trials (ms)
S9	515.00	3015.00
M9	141.00	844.00
F9	219.00	1399.00
S5	648.50	282.00
M5	166.67	359..50
F5	336.00	906.00

The fourth question asked whether the number of stimuli presented within a sequence influences time perception. So in essence, is there is a difference in accuracy between long nine-stimulus sequences and the shorter five-stimulus sequences. Differences were observed (see Tables 6.3 to 6.5), but no consistent pattern was found. First, statistical evidence from the Wilcoxon test showed that infants could keep time within one of the short sequences (S5). Second, time keeping was not seen when compared across sequences, the evidence from the Kruksall-Wallis test reached significance only in the long sequences, suggesting that infants kept time better across the longer rather than the shorter sequences. Finally, increased participation was observed in the short five stimulus sequences compared to the longer nine stimulus sequences (S9=13, M9=13, F9=18, S5=22, M5=18, F5=21); a possible reason for this was that infants lost concentration before completing long sequences. To summarise, within sequences, timing advantages are seen in the short five-stimulus sequences, but across sequences, timing advantages are seen in the long nine-stimulus sequences.

The final question asked if individual differences in look duration influence time perception. The categorisation of infants into long- and short-looking information processing strategies was based on the responses to the baseline measures reported in Chapter 4. These infants visited the Research Centre during Phase 1. In the second analysis, data from infants who consistently remained either as long- or short-lookers over

both the baseline stimuli were used. Therefore fewer infants were included within this second analysis (n=26, short-lookers=10, long-lookers=16). The data for these infants were subjected to the same analyses as above and the results are reported below. As in the main experiment, these infants did not provide data consistently across all sequences and so this information is included in the 'n' column of Tables 6.6 and 6.7 below.

In brief, the results revealed some differences between long- and short-lookers. Long-looking, but not short-looking infants, made response latencies during the omission trials of under 200ms in three sequences (S9, F9, M5). For all but one of the sequences (M5) the range of latencies was also shorter for the long-looking infants. The origin of these differences will now be discussed in more detail.

Table 6.6 Short-looking infants only: Table of Median response latencies in stimulus present and omission trials

Sequence	Median Response latencies: Stimulus Present trials (ms)	Range	n	Median Response latencies: Omission trials (ms)	Range	n
S9	953.00	968	3	1078.00	5047	3
M9	164.50	453	6	601.00	1375	6
F9	219.00	454	4	1148.00	2141	3
S5	656.00	258	3	4516.00	5953	3
M5	297.00	423	5	375.00	3161	5
F5	340.00	320	6	851.50	2531	6

Table 6.7 Long-looking infants only: Table of Median response latencies in stimulus present and omission trials

Sequence	Median Response latencies: Stimulus Present trials (ms)	Range	n	Median Response latencies: Omission trials (ms)	Range	n
S9	961.00	1578	2	156.00	251	2
M9	141.00	94	3	594.00	594	3
F9	31.00	0	1	140.00	0	1
S5	403.00	1796	6	429.50	4485	6
M5	119.50	282	6	166.00	3408	6
F5	469.00	273	5	1047.00	1094	5

The pattern of results in Tables 6.6 and 6.7 show that for both groups the omission trial latencies decreased from the slow to the medium sequences suggesting that both groups

may have detected the shorter durations. Latencies increased in the fast sequences for all but F9 (Table 6.7), but this was the latency of only one long-looking infant, suggesting that for most infants the fast sequence may be too fast. Response latencies in the omission trials for long-lookers were smaller than short-lookers for all sequences except F9, as were the range of latencies except sequence M5, suggesting that long-looking infants may show more temporal sensitivity than short-lookers.

Using the procedure adopted for the whole group analysis, the median response latency from the last three stimulus present trials were compared to the response latency of the stimulus omission trial for both long-and short-looking infants (see Tables 6.6 and 6.7). Evidence of time keeping would be seen if the two latencies were similar and so non-significant. The data were subjected to Wilcoxon Tests and the results are displayed in Tables 6.8 and 6.9. In both groups sequences S9 and S5 showed the closest similarity between response times suggesting accurate time keeping. Sequence M5 also suggested accurate time keeping in the long-looking group. Short-looking infants demonstrated no time keeping abilities in F5, whilst the long-lookers showed slightly better abilities. Other sequences in both groups showed accurate time keeping, to a lesser extent, but a different pattern of results than that seen for the sample as a whole, where only S5 showed accuracy in time keeping. To summarise, both long- and short-looking infant groups demonstrated time keeping to differing degrees of accuracy in ten of the twelve sequences, suggesting that both SL and LL infants are better able to keep time. These results also lend support to the notion that examining individual differences may allow a clearer picture of infants' temporal understanding to emerge, which was not possible in the main analysis due to the inclusion of data from inconsistent infants. Nevertheless, caution must be exercised when interpreting these findings due to the paucity of data available for analysis.

Table 6.8 Table of Wilcoxon results for long- and short-looking groups

Sequence	Short-looking infants	Long-looking infants
S9	Z = -.000 p= 1.000, ns	Z = -.477 p= 0.655, ns
M9	Z = 1.572, p = .116, ns	Z = 1.604, p = .109, ns
F9	Z = 1.461, p = .144, ns	Insufficient data *
S5	Z = -.734, p = .463, ns	Z = .314, p = .753, ns
M5	Z = 1.483, p = .138, ns	Z = .943, p = .345, ns
F5	(Z = 2.201, p = .028)	Z = 1.753, p = .080, ns

*Only one infant provided any data for this particular sequence.

Table 6.9 Summary of non-significant results for the whole group, and for long- and short-looking groups separately

Total sample	Long-looking infants	Short-looking infants
S5	S9,M9, F9, S5, M5	S9, M9, S5, M5, F5

6.6 Discussion

The first aim of Experiment 2 was to obtain overt behavioural evidence of infant time perception using schematic face stimuli. The fact that 40 infants provided data in at least one stimulus sequence indicates better maintenance of the eye tracking POG crosshair compared to Experiment 1 suggesting that the use of schematic, smiley faces increases attention to the stimuli, allowing a more reliable method of assessing infants' sensitivity to temporal parameters. Nevertheless, there was considerable variation in infants' ability to maintain attention to the stimuli both within and between sequence presentations, such that relatively few infants provided measurable data across all six sequences.

To address the second aim, the findings demonstrate that infants' saccadic responses on the omission trials in the slow, medium and fast long sequences (S9, M9, F9) and to slow and medium short sequences (S5, M5), corresponded to changes in the ISI (see Table 6.4). This suggests that infants were aware of the temporal information contained in those sequences.

The results displayed in Table 6.8 demonstrated that infants can track alternating stimulus sequences and are sensitive to their temporal parameters. Wilcoxon tests also revealed this to be the case in the slow short sequence data for the whole sample of infants. However, few predictable patterns of responding were evident overall.

An alternative explanation for these findings might be that infants simply learn to move their eyes left and right towards the alternating stimuli when these are present and, as they are unaware that the sequence will be disrupted, continue making eye movements in the same rhythm on the omission trial. This explanation does not imply any time keeping abilities on the part of infants; however, it does suggest that they have formed a spatial expectancy for a forthcoming event at a particular location. Simple motor responses, however, cannot explain why most infants wait until after stimulus omission before responding, suggesting that they may also have formed a temporal expectancy about these events.

Evidence to support the notion that infants are able to estimate three different time intervals (3s, 1s and 750ms) during the same experimental task was seen for the first time. The Kruksall-Wallis test results were significant for the long, nine-stimulus sequences demonstrating differential responding in each of these long sequences. Due to the inability to conduct a Jonckheere Trend test, however, no firm conclusions can be drawn about the direction of the difference, that is, whether longer responses were made during slow sequences compared to the responses made in the medium and fast sequences. However, the median latencies for these sequences would suggest that this was the case. The Kruksall-Wallis test results for the five-stimulus presentation sequences were non-significant, suggesting that to achieve consistent time keeping across sequences, more than four stimulus exemplars are required at each time interval.

No clear answer was found for the fourth research question in Experiment 2, to understand whether the number of stimuli presented within one sequence influences time perception, The data presented in Table 6.5 show consistently faster response latencies within the omission trials of the shorter sequences, suggesting that infants may be better

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able to follow these sequences. This may be due to infants losing concentration by the end of the long eight-stimulus run and suggesting that fewer stimulus presentations may optimise data collection. Nevertheless, four-stimulus presentations may in fact be too few for some infants to form temporal expectancies suggesting that data collection would actually be optimised by an intermediate number of stimuli.

The final research question asked whether individual differences in look duration would influence time perception, and these were indeed found to do so in a number of ways. Long-looking infants were found to have shorter median response times in the fast 750ms sequence, while the short lookers had shorter median response times in the first slow sequence. It is unclear why long-looking infants rather than their short-looking counterparts had these shorter response times when the intervals in these sequences were presented at faster speeds. According to Frick et al. (1996), long-looking infants have difficulty disengaging attention from stimuli and so one would have predicted the opposite outcome. One possible explanation could be that long-looking infants maintain higher levels of attention during these sequences, thus forming a better memory of the duration. Another explanation could be that fast sequences require infants to allocate more attentional resources to the task in order to keep track of it. This link between attention and time keeping was also made by Colombo and colleagues (2002, 2005), thus providing further empirical evidence of the role of attention in time keeping (Boltz, 1998).

Alternatively, it could be argued that the difference between the medium and fast intervals is so short (250ms) that long-looking infants did not notice any difference, and thus treated both sequences the same, estimating the intervals in a similar manner and thus benefiting from practice effects. However, this explanation does not provide an answer for the pattern of results observed in short-looking infants, who performed better in the slower sequences. It is unclear why this should be the case. Also, due to the small numbers involved, no firm conclusions can be drawn on the basis of the secondary analysis comparing short and long-looking infants.

The discussion so far has not situated the findings within the time perception literature and the SET (Gibbon, 1977) and devSET models (McCormack et al., 1999; Droit-Volet, 2002). These issues will now be addressed.

The allocation of attention within timing tasks has not been discussed widely within the devSET model. More variance pro rata was observed in the fastest sequences, that is, in comparison to the duration to be judged the range of response latencies was wider, suggesting that durations of 750ms may be more difficult for infants to keep track of compared to the 1s duration of the medium sequence. This could simply be due to the fact that the infants' ocular motor movements were already working at ceiling capacity. Alternatively, with increased speed, the switch in the SET model is operating at the faster speeds which may increase the variance in switch latency (Lejeune, 1998), or the attentional gate (Zakay and Block, 1995) is opened at its widest to ensure infants attend to the 1s durations and so faster speeds simply result in poorer performance. Additionally, due to the immaturity of infants' ocular motor systems, faster speeds would likely increase any difficulty in disengaging attention (Frick et al., 1996) from fast moving stimulus resulting in increased variance.

Whilst the range of response latencies can be discussed in terms of attention, the role of memory should also be considered. This has been more widely discussed than attention within the devSET model, in particular the role of 'fuzzy' representations (McCormack et al., 1999; Droit-Volet, 2003). Tables 6.4–6.7 reveal that the range of response latencies increases as the ISI durations become shorter and the sequence speeds up, suggesting that infants become more uncertain of the duration of the ISI with increasing speed (although this could result from one or a small number of infants). This could be due to a 'fuzzier', less accurate representation of this duration being stored in memory (McCormack et al., 1999; Droit-Volet, 2003). Another example is the lower median latencies seen in the five-stimulus presentation sequences, suggesting that infants' attention may wane if presented with too many stimuli. One explanation for this could be

that fewer stimuli result in less variance within the representation of the standard referent duration in the memory component of the SET model.

According to SET theory (Gibbon, 1977), examples of the referent duration are not encoded in exactly the same manner due to a variety of reasons such as attention levels or arousal. This means that within STM, representations of the standard duration will vary slightly, although the mean of these representations will be a close approximation of the referent duration.

Likewise, in timing, the mean referent duration of 500ms could be represented by durations of 500ms, 490ms, and 510ms. McCormack (1999) proposed that five-year-old children encode wider variations of the referent duration than older children (eight- and ten-year-olds) and adults, and that this produces a 'fuzzy' duration in short term memory. This in turn results in increased response variability. Young infants too may encode wider variations of the standard resulting in a similarly 'fuzzy' duration. As fewer examples of the referent duration are provided in the short sequence, the infant may form a less 'fuzzy' representation of that duration in memory, which in turn produces a lower median score. On the other hand, the long sequences may be too difficult for infants to keep track of, resulting in higher median latencies. This seems unlikely though as the range of latencies was similar in both short and long sequence conditions meaning that infants may simply be less accurate.

The pattern of results differed when the infants were divided into long- and short-looking groups. The infants who formed these two groups (i.e. infants who remained consistently in their category when responding to the two baseline stimuli) demonstrated much greater accuracy in time keeping (ten out of twelve sequences) than the group as a whole. This suggests that the categorisation did influence time perception. Both long- and short-looking groups benefited from the slower sequences: greater accuracy was obtained for the slow (3s) sequences in both groups. The other sequences showed similar degrees of accuracy across both groups except for M5 where long-lookers were more accurate and F5 where short-lookers did not perform consistently. Infants in both groups benefited most

from the slower rate of stimulus presentation, supporting the idea that presenting stimuli at slower speeds may allow infants to form a less 'fuzzy' representation of the standard duration in memory (McCormack et al., 1999).

An examination of the results shows differential responding across the time intervals. What could account for this? The task involves two components, a temporal and spatial component. To successfully make a saccade at the correct location during the omission trial, both aspects of the task have to be attended to. Therefore, attentional resources are divided between temporal and non-temporal information. At the slowest speed (3s ISI), infants' attention may wane towards the end of the sequence, resulting in increased inaccuracy. At the fastest speed (750ms ISI) attending to non-temporal information may detract from temporal processing, possibly acting as a distracter task resulting in longer time estimations being made. Longer estimates in such conditions are also observed in studies conducted with 6-year-old children (Zakay, 1993) and adults (Zakay and Block, 1997), where the allocation of increased attention was highlighted as a key factor in accurate time keeping.

Finally, whilst a number of the limitations of Experiment 1 were overcome in Experiment 2 by the use of smiley faces, it was found that there were a number of additional methodological issues that needed to be addressed. First, while the stimuli with black and white backgrounds were directly comparable with the Colombo and colleagues (2002, 2005) studies, they were not very suitable for eye tracking. Switching between the two background colours, first white then black, resulted in significant pupil movement. The pupil contracted for the white background and expanded for the black background. Although this happened speedily, the eye tracker could lose the pupil discrimination and corneal reflection thresholds which make up the POG, and be unable to recalculate these as fast as the eye itself. This resulted in the POG being lost while the computer recalculated the thresholds, representing a major issue especially in fast sequences, since no data could be collected on many trials even though the infant was observed to be looking at the screen.

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Second, luminance levels are also affected by the change from black to white and in turn affect the POG. Future studies should utilise stimulus background colours that are at a constant luminance level but at different ends of the same colour spectrum (such as red and green or blue and yellow) to reduce the attention that would otherwise be required to adjust across colour categories.

Finally, attrition rates decreased significantly from the levels observed in Experiment 1 with more data provided by more infants in the five- than in the nine-stimulus sequences. On the other hand, questions were raised in the discussion above as to whether presenting four stimuli (with a fifth being omitted) allowed enough time for the formation of a stable representation of the referent duration in memory. The foregoing suggests that sequences presenting seven stimuli may be beneficial in future studies. This would allow infants sufficient exemplars to form a representation of the standard duration without incurring high attrition rates associated with longer nine-stimulus presentation sequences.

6.7 Chapter summary

Eye movement responses have demonstrated for the first time that four-month-old infants respond differentially to variable time intervals (3s, 1s, and 750ms) within the same experimental task, as revealed by the Kruksall Wallace test for the long sequence. Further evidence was also found of time keeping within sequences and also of individual differences in time perception. These results have been discussed in terms of the devSET model, such as 'fuzzy' representations of the standard referent duration in memory, and also in terms of the competition for attentional resources by both temporal and non-temporal components in the fast sequences. Methodological limitations were discussed and techniques proposed to overcome them. Subsequent experiments therefore adjusted the colour of the stimulus background, the number of stimuli presented within a sequence, and the presentation speed itself.

Chapter 7 Experiment 3: Do number of stimuli and speed of presentation differentially influence time perception in long- and short-looking infants?

7.1 Introduction

As discussed in Chapter 4, individual differences in infant information processing strategies or encoding tasks, as evidenced by length of look duration, have been investigated by Colombo and colleagues for over 20 years (Colombo et al., 1987; Colombo, 1993; Rose et al., 1992; Frick, Colombo and Saxon, 1999; Maikranz et al., 2000). Although Colombo et al. (1987) coined the term 'strategy', this does not imply something purposeful but rather that the infant simply uses that style of processing information. Further, look duration can be interpreted in two key ways: first, in information processing such as stimulus encoding (Colombo et al., 1990), and second, in the ability or otherwise of infants to disengage attention (Frick et al., 1999). The aim of Experiment 3 was to attempt to establish some of the parameters that affect these two aspects of infant time perception, and is supported by a review of the associated literature which now follows.

7.2 Overview of the literature

7.2.1 Stimulus encoding and processing

Chapter 4 identified the two categories of look duration linked to information processing styles (Colombo et al., 1991; Colombo et al., 1993). First, long-looking strategies characterised by fewer but longer looks at a scene are thought to reflect local featural processing. Second, short-looking strategies which are characterised by many short looks at a scene are thought to reflect global holistic processing.

7.2.2 Impact of look duration on attention

Findings from the research conducted by Colombo and colleagues indicate that infants who engaged in short-looking strategies (Colombo et al., 1987) had advantages over their longer-looking counterparts (Colombo et al., 1991). It is thought that long-looking infants may have difficulty disengaging attention, disadvantaging them in areas such as later intellectual functioning (Colombo et al., 1991; Colombo, 1993; Frick et al., 1999). Although it is likely that many cognitive processes influence the development of intellectual functioning, Colombo's own research offers some support for this. He reports a longitudinal study, which showed that four-month-old short-looking infants obtained higher IQ scores than long-lookers at the age of 6 years (Colombo, 1993). Other research by Colombo and colleagues (Colombo et al., 1988; Frick and Colombo, 1996) has demonstrated that manipulating the exposure to a stimulus differentially influences the performance of long- and short-looking infants. For example, keeping exposure to a stimulus relatively short for both groups attenuates the cognitive performance of long-lookers, whereas prolonging exposure equates the performance of both groups (Colombo et al., 1993; Frick and Colombo, 1996), supporting the idea that long- and short-lookers process information in different ways (Colombo, 1993).

The ability of three- and four-month-old infants to disengage attention is also influenced by long- and short-looking strategies (Frick et al., 1999). Long-lookers showed more variability in response latencies when disengaging fixation from a central stimulus to a peripheral target, during trials in which the central stimulus either remained on after the onset of a peripheral target (no gap trials) or disappeared before the peripheral target came on (gap trials). This is to be expected due to the immature ocular motor system, with younger infants generally being slower to look at the peripheral target than older infants (Frick et al., 1999). However, this difficulty in disengaging attention is also hypothesised to be linked to immature attentional systems, being less well developed in long-looking infants compared to those of short-looking infants (Colombo et al., 1999; Frick et al., 1999). This lends weight to the notion that looking strategy may be linked to the development of attentional systems within the brain; namely the Posterior Attention

Network (PAN), which is concerned with visuospatial orienting, including disengagement (Mountcastle, 1978) and the Anterior Attention Network (AAN) (Posner and Petersen, 1990), which processes temporal, semantic and lexical information and maintains sustained attention.

Importantly in relation to this thesis, attention has been shown to underpin time judgements in adults (Zakay and Block, 1996) and infants (Colombo and Richman, 2002; Colombo et al., 2005), therefore any differences in maturity of attentional neural systems may influence the perception of time. Specifically, differences in response latencies may be observed between the infants using long- and short-looking strategies. So the discussion will now turn to how information processing strategies have been seen to influence time perception.

7.2.3 Influence of information processing strategies on time perception

As mentioned in Chapter 4, in order to demonstrate time keeping in the specific tasks reported in this thesis, infants must keep track of both temporal and spatial information in order to make saccades to the correct location at the correct time on sequence disruption. Differential use of information processing strategy could be expected to have several outcomes on saccadic response latencies where the length and speed of sequences were changed. First, that the performance of the long-looking group should be enhanced by prolonged exposure to the stimulus in long six-stimulus sequences (Colombo et al., 1993; Frick and Colombo, 1996), while short-lookers should be able to form accurate representations of all the ISI durations with fewer exemplars. Second, however, that long-looking infants would be disadvantaged in fast sequences (500ms ISI) with few (four) stimulus exemplars, because of their difficulty in disengaging attention (Colombo et al., 1993; Colombo et al., 1999), and thus be unable to form an accurate representation of the referent duration in memory. How might the SET model explain these effects?

7.2.4 Look duration within the SET Model

Difficulty in disengaging attention for long-looking infants (Frick et al., 1999) could pose a number of issues for their ability to perceive time accurately and several predictions could

be made. For instance, difficulty in disengaging attention from the last stimulus presented could lead to less attention being directed to the duration of the following ISI, and consequently misjudging the time interval. Locating this within the SET model (Gibbon, 1977) discussed in Chapter 2, Section 2.3.1, if, during stimulus present trials more pulses are directed from the pacemaker to the accumulator, an infant who fails to disengage attention quickly once the stimulus disappears, will continue to accumulate pulses. Consequently, this will affect the perceived duration of the stimulus.

Another prediction was that long-looking provides an advantage, because these infants have difficulty disengaging attention; they spend longer looking at a stimulus and so they need fewer trials to form a referent duration which is subsequently less 'fuzzy' in LTM (McCormack et al., 1999), resulting in a narrower range of responses. The alternate prediction was that short-lookers, gain a more accurate representation of the duration during the stimulus present trials due to their ability to disengage attention quickly at each stimulus offset (Frick et al., 1999), and subsequently respond more accurately. Hence, shortening the length of stimulus presentation and increasing their presentation rate may allow the influence of information processing strategies to be seen more clearly.

Further, time keeping was more clearly observed in shorter than longer sequences in Experiment 2, possibly due to infants losing concentration in longer sequences. Therefore it was proposed that subsequent studies would benefit from using fewer stimuli per sequence and increasing the presentation rate. Further, to reduce expansion and contraction of pupils with resultant loss of eye tracking data associated with earlier experiments, the background colours of the stimuli were changed from black and white to blue and yellow respectively. In order to increase attention, different cartoon pictures replaced the smiley faces used in the previous experiment.

7.3 Research questions

The two research questions under examination in the present experiment are:

1. Does the number of stimuli presented within one sequence differentially influence time perception in long- and short-looking infants?

2. Does the speed of presentation of stimuli in a sequence differentially influence time perception in long- and short-looking infants?

Experiment 3 also set out to answer the seventh question posed at the beginning of this thesis: Are individual differences in the use of information processing strategies observed, and if so do they influence infants' temporal estimation abilities? Experiment 3 differs from Experiment 2 in that faster rates and fewer stimuli are presented. The results will later be discussed in relation to the devSET model (McCormack et al., 1999; Droit-Volet, 2002).

7.4 Method

7.4.1 Design

This experiment used a within participant repeated measures design. The three independent variables were the length of sequence, either long (six stimuli) or short (four stimuli); the speed of the sequence, either slow (2s ISI) or fast (500ms ISI); and finally the use of either long- or short-looking strategy. The dependent variable was the latency of the first saccade to the correct location in the sequence following stimulus omission.

7.4.2 Participants

Sixty-three four-month-old infants (range three months, three weeks to four months, one week, sd = one day) participated in the experiment. The data from four infants were excluded, as the initial testing protocol was changed due to the inability of the infants to keep pace with the fast speed and limited number of stimuli within the sequences (e.g. three stimuli). Data from a further five were excluded due to fussiness (n=2), looking at feet (n=1) or looking away from the screen (n=2). In total, 54 infants were included in the final sample, having provided usable data in at least one sequence. Based on the

outcome of the baseline face measure (Phase 2) they were divided into long- (n=28) and short-looking (n=26) groups. These data were re-analysed post hoc so that only infants who remained consistent in their category of either long- or short-looking over the two baseline measure stimuli were included in the data set. Since these data were analysed after the completion of the study, it was impossible to ensure that there were equal numbers of infants in each group. Twenty three infants were included in the second analysis: 14 short-lookers and 9 long-lookers.

7.4.3 Apparatus

The details of the apparatus used in this experiment are described in Chapter 3, Section 3.4 and Figures 3.2 – 3.6.

7.4.4 Stimuli

The experimental stimuli consisted of four sequences in which picture stimuli on a yellow background appeared alternately left and right of the screen (stimulus present trials) and interspersed with a blank blue screen (stimulus absent trials) (see Figure 7.1). After either four or six stimuli, a blue screen appeared for an extended period (omission (OM) trial). Hence the sequences are named S5 (four stimuli) and S7 (six stimuli) since the last trial is omitted. The picture stimuli in each sequence were different cartoon toy pictures measuring 4° x 4° visual angle, taken from Microsoft Clip Art. Each stimulus presented a different picture to help infants maintain attention throughout the sequences as previous experiments indicated that attrition rates were high using schematic faces.

Figure 7.1 Experiment 3 stimulus sequence (not to scale)

→
omission
trial 10s

Time

SA (ISI) 2s

SP 500ms

pictures 4° x 4°

Key:
SA = stimulus absent = ISI
SP = stimulus present
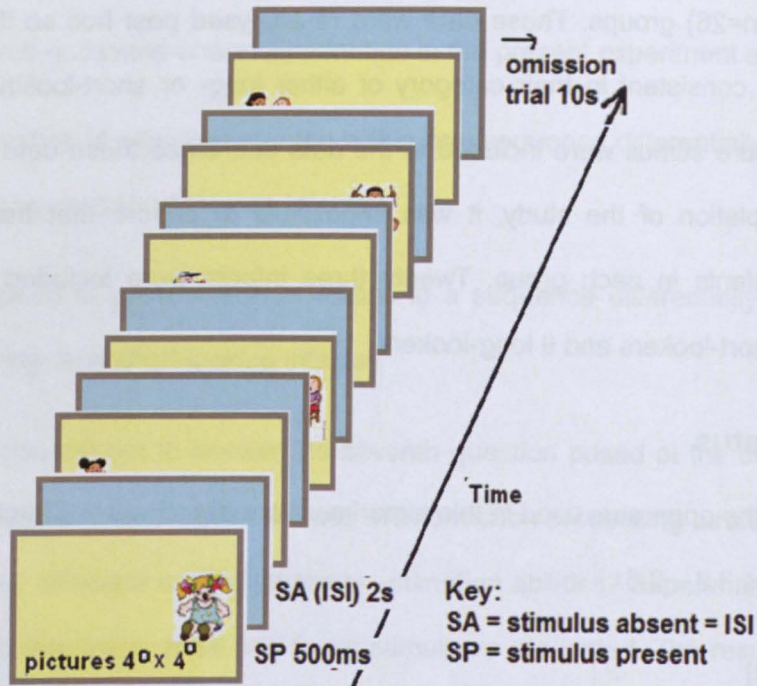
7.4.5 Procedure

Following the experimental procedure outlined in Chapter 3, Section 4, the experiment began after informed consent and the calibration and baseline measure were obtained. Infants were presented with four sequences with either five- or seven-stimulus presentations per sequence plus an omission trial. The sequences were divided into four conditions as displayed in Table 7.1 to control for order of presentation of Slow (S) and Fast (F) sequences. Infants were randomly and equally allocated to one condition, which comprised both fast and slow sequences.

Table 7.1 Table of the presentation of sequences within each condition, Experiment 3

Condition	Presentation of sequence	Timing of sequences
Condition 1	S5, F5, S5, F5	Slow (S) =
Condition 2	F5, S5, F5, S5	500ms Stimulus Present, 2s Stimulus Absent, 10s Omission
Condition 3	S7, F7, S7, F7	Fast (F) =
Condition 4	F7, S7, F7, S7	500ms Stimulus Present, 500ms Stimulus Absent, 10s Omission

7.4.6 Data analysis

The timings of the first saccade made to the location of the stimulus during the stimulus present trials, and of the first saccade made to the location of the omitted stimulus were recorded. Since the stimuli alternated left and right of the screen, these areas of interest are marked as Areas 1 and 2 in Figure 7.2. The areas of interest alternated depending on which side of the screen the stimulus appeared; however, the ratio of the areas remained the same. In order to ascertain whether infants can keep time within a sequence, the median response latencies from the stimulus present trials were compared to the response latency in the omission trial. The data were then subjected to a Wilcoxon non-parametric test, as not every infant provided data in each sequence, thus violating the assumptions of homogeneity of variance.

Figure 7.2 Coding grid used to analyse saccades in Experiment 3 (not to scale)
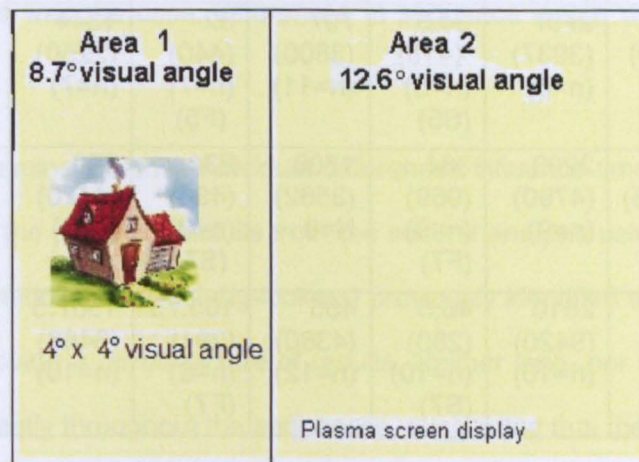
7.5 Results

The aim of Experiment 3 was to ascertain whether the use of long- and short- looking strategies influenced response latencies when infants are presented with sequences of different lengths and at different speeds to those used in Experiment 2. The data were analysed twice, once with all infants (n=54) providing usable data and second with data from those infants (n=23) who consistently remained in the same looking category on the

baseline measure. It should be noted that where 'no data' appears in a cell, that means that the POG was lost and no data collected. Table 7.2 displays the median and range latencies for all participants in the initial sample to the stimulus present and omission trials. No clear response patterns emerge for the whole group.

Table 7.2 All infants: The median (and range) latencies of saccades (in ms) made to the stimulus present and omitted stimuli on omission trials

Condition (n = 9)	Sequence 1		Sequence 2		Sequence 3		Sequence 4	
	SP Median (Range)	OM Median (Range)	SP Median (Range)	OM Median (Range)	SP Median (Range)	OM Median (Range)	SP Median (Range)	OM Median (Range)
Condition 1 S5,F5,S5,F5	42 (168) (n=10) (S5)	3125 (5817) (n=9)	28 (469) (n=9) (F5)	640 (2200) (n=9	40 (485) (n=10) (S5)	356 (5300) (n=11)	38 (460) (n=11) (F5)	169 (1840) (n=10)
Condition 2 F5,S5,F5,S5	47 (3360) (n=7) (F5)	2797 (3937) (n=6)	94.5 (415) (n=6) (S5)	797 (3800) (n=11)	32 (440) (n=7) (F5)	1344 (2250) (n=7)	39.5 (453) (n=5) (S5)	2260 (3060) (n=9)
Condition 3 S7,F7,S7,F7	269.5 (467.5) (n=9) (S7)	2203 (4790) (n=9)	384 (969) (n=9) (F7)	1700 (3562) N=9	234 (490) (n=9) (S7)	940 (4720) (n=9)	188 (453) (n=7) (F7)	860 (3160) (n=8)
Condition 4 F7,S7,F7,S7	128 (280) (n=5) (F7)	2510 (9420) (n=10)	46.5 (280) (n=10) (S7)	455 (4360) (n=12)	105.75 (291) (n=6) (F7)	1567.5 (3468) (n=10)	44 (124) (n=5) (S7)	2058 (4312) (n=12)

The results in Table 7.2 show longer response latencies in the omission trials for slow rather than fast sequences in Conditions 1 and 3 but not in Conditions 2 and 4. That is, when the experiment begins with a slow sequence, infants appear to be able to adapt their responses to the pace of the different sequences (slow, fast, slow, fast), but not vice versa. The responses in Conditions 2 and 4 show that infants initially make longer responses to the first fast sequence and a shorter response to the first slow sequence, but a shorter response to the second fast sequence and longer response to the second slow

sequence. Mixed results emerge for differences between short and long sequences and the large ranges mean that any conclusions must be tentative.

If infants had formed expectations about the temporal properties of the ISIs, then saccades should be made about the time the stimulus appears. During the omission trial this pattern should continue as the infants were expecting a stimulus to appear. Therefore, the difference in latencies when comparing the stimulus present trials with the stimulus omission trials should be non-significant if infants were keeping time. Two non-significant results were found in the Wilcoxon rank tests: Condition 2 sequence 1 (F5), Z=1.069 p=.285; and Condition 4 sequence 1 (F7), Z=1.604 p=.109; both of which were fast sequences. All other sequences were either at or near significance, indicating an inability of these infants to perceive and act on the temporal information contained in them. No sensible patterns emerged from the data to indicate whether the number of stimuli presented in a sequence (5 or 7) had any effect on infants' ability to perceive temporal information. As this was the case, differences in sequence length will not be discussed further.

Turning now to examine whether individual differences influence time perception, Tables 7.3 and 7.4 reveal the pattern of results from the second analysis using the data from the 23 infants (14 short-lookers and 9 long-lookers) previously identified as using a consistent strategy. These provide a mixed picture of results. Neither long- nor short-looking infants responded consistently throughout the sequences, suggesting that the results observed in the whole group was carried by the infants whose data was not included in the present second analysis, but rather by those infants who were inconsistent in their looking strategies across the baseline stimuli. Some patterns emerge, however.

Short-looking infants revealed similar long responses to slow rather than fast sequences in Conditions 3 and 4 in Sequences 1 and 2 in Condition 1 and Sequences 3 and 4 of Condition 2. On the other hand, long-lookers show short and long responses in fast and slow sequences respectively in Condition 4 and Sequences 3 and 4 in Condition 2, and Sequences 3 and 4 in Condition 3, which began with a slow sequence. None of the other

sequences showed such responses, although in some sequences, this may be due to lack of data. No clear pattern of results emerged, however, so more work is required before any conclusions can be drawn.

Table 7.3 Short-looking infants: The median and range latencies of saccades (in ms) made to the location of the stimulus during the stimulus present trials and to that of the omitted stimuli on omission trials

Condition (n = 14)	Sequence 1		Sequence 2		Sequence 3		Sequence 4	
	SP Median (Range)	OM Median (Range)	SP Median (Range)	OM Median (Range)	SP Median (Range)	OM Median (Range)	SP Median (Range)	OM Median (Range)
Condition 1 S5,F5,S5,F5	310 (220) (n=2) (S5)	2870 (1660) (n=2)	305 (170) (n=2) (F5)	2005 (650) (n=2)	310 (357) (n=3) (S5)	140 (0) (n=1)	80 (0) (n=1) (F5)	420 (0) (n=1)
Condition 2 F5,S5,F5,S5	0 (0) (n=0) (F5)	3360 (0) (n=1)	24 (0) (n=1) (S5)	1070 (546) (n=2)	42 (10) (n=2) (F5)	2562.5 (437) (n=2)	47 (0) (n=1) (S5)	4625 (0) (n=1)
Condition 3 S7,F7,S7,F7	193 (266) (n=3) (S7)	1382.5 (1641) (n=2)	446 (664) (n=3) (F7)	899 (3531) (n=4)	259.5 (304) (n=4) (S7)	750 (2212) (n=3)	469 (32) (n=2) (F7)	734.5 (1155) (n=2)
Condition 4 F7,S7,F7,S7	0 (no data) (F7)	2500 (0) (n=1)	65.5 (37) (n=2) (S7)	2656 (562) (n=2)	0 (no data) (F7)	375(0) (n=1)	0 (no data) (S7)	4312 (0) (n=1)

Table 7.4 Long-looking infants: The median and range latencies of saccades (in ms) made to the location of the stimulus during the stimulus present trials and to that of the omitted stimuli on omission trials

Condition (n = 9)	Sequence 1		Sequence 2		Sequence 3		Sequence 4	
	SP Median (Range)	OM Median (Range)	SP Median (Range)	OM Median (Range)	SP Median (Range)	OM Median (Range)	SP Median (Range)	OM Median (Range)
Condition 1 S5,F5,S5,F5	420 (0) (n=1) (S5)	7620 (0) (n=1)	233 (0) (n=1) (F5)	0 (no data)	0 (no data) (S5)	140 (0) (n=1)	80 (0) (n=1) (F5)	420 (0) (n=1)
Condition 2 F5,S5,F5,S5	470 (160) (n=3) (F5)	2234 (0) (n=1)	163 (0) (n=1) (S5)	546 (4219) (n=3)	28 (24) (n=2) (F5)	3203 (94) (n=2)	0 (no data) (S5)	3406 (0) (n=1)
Condition 3 S7,F7,S7,F7	24 (16) (n=2) (S7)	1655.5 (1499) (n=2)	336 (110) (n=3) (F7)	0 (no data)	117 (0) (n=1) (S7)	1507 (203) (n=2)	140 (0) (n=1) (F7)	609 (0) (n=1)
Condition 4 F7,S7,F7,S7	0 (no data) (F7)	2500 (0) (n=1)	65.5 (37) (n=2) (S7)	2656 (562) (n=2)	0 (no data) (F7)	375 (0) (n=1)	0 (no data) (S7)	4312 (0) (n=1)

When the long- and short-looking data were subjected to a Wilcoxon test, which compared the response latencies of stimulus present trials with the stimulus omission trials a different pattern of results emerged (see Tables 7.5 and 7.6). Short-looking infants demonstrated temporal perception (that is a non-significant difference between saccade latencies in the stimulus present and stimulus omission trials) in various sequences in three of the four conditions, whereas temporal perception was shown by long-looking infants in just one sequence in two conditions. The smaller number of participants in this latter group compared to the former may account for this. The infants who provided data for these analyses, however, did appear to show increased temporal sensitivity compared with the sample as a whole, suggesting that differences in information processing strategy may influence time perception. According to the analysis presented here (see Tables 7.5 and 7.6), short-lookers appeared to show more temporal sensitivity than long lookers. However, the lack of cases precludes any firm interpretations.

Table 7.5 Short-looking infants only: Outcomes for Wilcoxon Test results comparing time keeping (as measured by comparing median saccade latencies in the stimulus present and stimulus omission trials) within each sequence

Condition	Wilcoxon test Results
S5,F5,S5,F5 Condition 1	Sequence 1 (S5), Z=1.342 p=.180 Sequence 3 (S5), Z=1.604 p=.109 Sequence 4 (F5), Z=1.069 p=.285
F5,S5,F5,S5 Condition 2	Not enough cases to perform the analysis
S7,F7,S7,F7 Condition 3	Sequence 2 (F7), Z=.000 p=1.000 Sequence 3 (S7), Z=1.069 p=.285 Sequence 4 (F7), Z=-.447, p=.655.
F7,S7,F7,S7 Condition 4	Sequence 2 (S7), Z=1.342 p=.180

Table 7.6 Long-looking infants only: Outcomes for Wilcoxon Test results comparing time keeping within each sequence (as measured by comparing median saccade latencies in the stimulus present and stimulus omission trials)

Condition	Wilcoxon Test Results
S5,F5,S5,F5 Condition 1	Not enough cases to perform the analysis
F5,S5,F5,S5 Condition 2	Sequence 3 (F5), Z = -1.342, p = .180
S7,F7,S7,F7 Condition 3	Sequence 3 (F5), Z = -1.345, p = .180
F7,S7,F7,S7 Condition 4	Not enough cases to perform the analysis

7.6 Discussion

The twofold aim of this experiment was to attempt to establish some of the parameters that may influence infant time perception by asking two research questions: first, do the numbers of stimuli presented within one sequence differentially influence time perception in long- and short-looking infants, and second, does the speed of presentation differentially influence time perception in long- and short-looking infants? In order to examine these questions, the stimulus sequences were presented at slow and fast

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speeds and in long and short sequences of seven and five stimuli. The short fast sequences were designed to test the parameters of infants' perceptual abilities. As no clear patterns emerged, this question remains unanswered; however, some explanations are proposed below.

The data provided by Experiment 3 revealed no clear differences in the response latencies in the main sample between slow and fast sequences. A simple explanation for this could be that the timing used may have been too fast for immature ocular motor systems to keep track of, these speeds being at the upper limit of their processing abilities. The stimuli were presented for 500ms with ISIs of 2s in the slow sequence and 500ms in the fast, with the duration of omission trials being 10s and 5s respectively. It could also be argued that the sequences were not long enough, that is more than seven stimuli may be needed, especially when presented with long and short sequences within the same experiment.

Closer inspection of the data suggested subtle differences emerging when divided into long- and short-looking categories. However, as there were few cases in this analysis, only tentative suggestions can be made. The median response latencies in the omission trials set out in Tables 7.3 and 7.4 showed that slow sequences elicited slow responses and fast sequences, fast responses when conditions began with a slow sequence in both groups. However, the long-looking group also made similar responses in conditions beginning with fast sequences. This lends some support to Colombo et al. (1993) and Frick and Colombo (1996) who suggested that although responses by long-looking infants contain more variability, they are not necessarily consistently slower to process information and thus produce slower response times.

Examining time keeping within sequences was conducted by comparing median response latencies between stimulus present and stimulus omission trials. Results from subjecting the data to Wilcoxon tests suggested that speed of stimulus presentation may mediate time keeping in different ways, but again there were few data points so interpretation can only be tentative.

The simplest explanation for the short-lookers performance would be that global, holistic information processing may be more advantageous for time keeping in changing environments. However, long-looking infants also showed temporal sensitivity in fast sequences, which does not support the notion of having difficulty in disengaging attention from stimuli (Frick et al., 1999) or that they require prolonged exposure to stimuli to enhance performance (Colombo et al.,1993; Frick and Colombo, 1996). Nonetheless, these ideas require further research with increased sample sizes.

Length of stimulus sequence also showed small differences within both groups. The data from short-lookers produced four non-significant Wilcoxon test results within the long sequences and three from the short, whereas long-lookers produced two non-significant result within the short sequences. The results from this experiment do not offer any insights into the number of stimulus presentations needed for four-month-old infants to form reliable internal representations of the stimulus duration and differing ISIs. It is possible that more consistent performances might have been observed with longer sequences, and/or where the rate of presentation did not change between each sequences. Presenting longer sequences, however, may have taxed infants' concentration even more leading to greater attrition.

Notwithstanding the reliability of these findings, if it can be accepted that there is some indication that there appear to be differences between short and long-looking infants in terms of how they process temporal information, what are the implications for the devSET model? As short-lookers performance overall was relatively more reliable, it could be argued that they appear to form more accurate, less 'fuzzy', representations of the standard duration even when provided with fewer exemplars suggesting less variation within the clock component. The finding that long-looking infants also showed temporal sensitivity in fast sequences with fewer stimuli does not support the notion that they have difficulty in disengaging attention, which would influence the switch in the clock component of the SET model (Gibbon, 1977).

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On a technical note, although the POG was retained more easily using the revised yellow and blue backgrounds in the stimulus, changes in pupil size between stimuli still resulted in some lost data, a problem that was compounded by fast presentation speeds. Additionally, difficulties in recruiting infants to participate in the studies meant that the final number in each experimental group was small, so future research would benefit from greater numbers of participants.

7.7 Chapter summary

The aim of this experiment was to attempt to establish some of the parameters of infant time perception by varying both the number of stimuli within a sequence and their presentation speed. Subtle differences in performance were noted in most omission trials, such as longer response latencies in slow sequences and shorter responses in fast sequences observed for long-lookers. The Wilcoxon tests examined timekeeping within sequences showing that short-lookers were better able to track sequences than long-lookers and that the duration of each exemplar, rather than length of the sequence, was the crucial factor in their time keeping.

The change in stimulus background allowed more usable data to be collected as pupil movement was reduced, but not eliminated. Although recognising the limitations presented by Experiment 3, this same design will be carried forward to the next study in order to examine the effects of another influencing factor under investigation, auditory cues. This has been seen to influence time perception in older children (Droit-Volet, 2003), and so will now be considered within the infant population in the following chapter.

Chapter 8
Experiment 4: The influence of auditory cues on infant time perception

8.1 Introduction

A link has been made between attention and infant time keeping (Colombo and Richman, 2002; Colombo et al., 2005) through heart rate measures. Further links have been made by introducing auditory cues, which have been seen to focus attention on a to-be timed duration and thereby optimise the resultant time keeping abilities of children of 3, 5 and 8 years old (Droit-Volet, 2003). Experiment 4 seeks to extend this research, exploring whether the introduction of auditory cues has a similar enhancing effect on infant time perception.

8.2 Overview of the literature

8.2.1 Attention within the SET and devSET models

Within the SET and devSET models (Gibbon, 1977; McCormack et al., 1999; Droit-Volet and Wearden, 2001), attention is thought to mediate the action of the clock component, and more specifically it has been hypothesised to influence the switch (Lejeune, 1998) or the attentional gate (Zakay and Block, 1996). When estimating durations, the switch closes allowing pulses to flow from the pacemaker to the accumulator. However, as the operation of the switch is not instantaneous a slight delay occurs between the onset of the stimulus and the closing of the switch (Meck, 2003), introducing a source of variance within the SET model. Proponents of the switch latency hypothesis (Meck, 1984; Lejeune, 1998; Fortin, 1999; Zakay, 2000) suggest that attention modulates the operation of the switch; increased attention shortens perceived durations (Fortin, 1999), while inattention lengthens them (Allan, 1998) due to increased variance in switch operation. So in

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recognising that attention needs to be directed to temporal information in order for effective switch operation, the discussion now examines how the addition of an auditory cue might facilitate this.

8.2.2 The influence of auditory cues in current literature

The influence of alerting children's attention to time keeping tasks was examined by Droit-Volet (2003) using a TB task in which just presented durations were compared to long and short referent durations. Groups of children aged 3, 5 and 8 years were alerted to the onset of a to-be-timed duration with an auditory click for one of two referent durations (group 1 = 2s vs 0.5s; group 2 = 4s vs 1s). The children were required to make different key press responses to these cues, indicating whether the present comparison duration was similar to the long or short standard duration.

The children were informed that the auditory click would alert them to the appearance of the stimulus, a blue circle appearing in the centre of the monitor screen for the to-be remembered duration. This was the click condition. The click sounded between 3.5s and 4.5s before stimulus onset. Intensive training was provided until each child made no errors in a block of eight trials. Eight-year-olds reached this level in one to two training blocks, 5-year-olds in two to three blocks and 3-year-olds in three to four blocks. Positive or negative feedback was given to their response in each training trial by either a smiling or frowning clown appearing on the computer screen (see Figure 2.5). The results demonstrated that all age groups could discriminate between the long and short standard durations and that alerting children to the stimulus onset enhanced their performance. This was most marked in the three-year-old children, where response variability decreased significantly with the addition of the auditory cue and so their performance looked more like that of older children on these trials.

The significance of these results were discussed in relation to the devSET model, arguing that alerting children to a forthcoming to-be-timed duration reduced random responding, as greater attention was focussed on the task. Increased attention is thought to reduce the variability in switch latency so that the switch closes more promptly (Meck, 1984).

Increased performance variability in the no-click condition for all age groups, but especially in the youngest group (possibly due to possible ceiling effects observed in older children), supports the notion that switch latency is influenced by attentional factors. To date, no studies have been conducted to test whether auditory cues will exert any influence on infant time keeping, and so Experiment 4 sought to examine this.

An additional way that this thesis has sought to examine attention is through look duration and the underlying information processing strategies. The addition of auditory cues is proposed to facilitate disengagement of attention and improve timekeeping especially in the long-looking infant group (Colombo et al., 1993; Frick et al., 1999).

8.3 Research questions

The rationale underlying the present experiment was to examine the influence of concurrent auditory cues on infant timekeeping. Three outcomes may arise from this manipulation: first, auditory cues could enhance timekeeping; second, they could detract from timekeeping or third, make no difference at all. Timekeeping may indeed deteriorate as infants struggle to process different inter-sensory cues and fail to attend to temporal information. Auditory cues may also influence temporal accuracy, as auditory stimuli have been perceived as longer than visual stimuli by adults, in both verbal estimation and key press temporal generalisation tasks (Wearden, Edwards, Fakhri and Percival, 1998). These authors attributed this to operational differences within the pacemaker of the SET model, suggesting that the pacemaker runs faster for auditory than visual stimuli. Durations of auditory stimuli are thus perceived as longer, as larger numbers of pulses are stored in the accumulator.

Therefore, the three research questions under examination in Experiment 4 are:

1. When provided with both auditory and visual cues (stimulus sequences), are infants more accurate at time keeping than when visual cues alone are provided?

2. Do the data support the interpretation that attention modulates the latency of the switch within the SET model at this age?

3. Do differences in long- and short-looking strategies mediate any influence of auditory cue in infant timekeeping?

8.4 Method

8.4.1 Design

A within-participant repeated measures design with one independent variable, the presentation of an auditory cue that coincided with the beginning of each trial (stimuli onset) and the ISI, was used in this experiment. The dependent variable was the latency of the first saccade to the correct location in the predictable alternating sequence following stimulus omission.

Infants were presented with three stimulus sequences in both the auditory and silent conditions, which were counterbalanced to minimise order effects. Each sequence comprised six alternating stimuli interspersed with blank screens, the seventh stimulus was then omitted and the ISI extended. Three sequential sequences were presented in each condition to maximise the likelihood that infants would deliver usable data in at least one sequence.

8.4.2 Participants

Sixty-three four-month-old infants (range three months, three weeks to four months, one week, sd = one day) participated in this experiment. Data from nine infants were excluded from the final analysis due to fussiness and/or looking at feet (n=3), looking away from the screen (n=2) and excessive head movement (n=4). A total of 54 infants were therefore included in the final sample. Based on the categorisation from responses to the baseline measure (Phase 2), the infants were divided into those infants who remained consistent within either the long- or short-looking group across the two stimuli and those who were inconsistent. As in previous experiments, the data from infants who were consistent in their looking categorisation were subjected to a second analysis. 46 infants were included in the second analysis: 27 short-lookers and 19 long-lookers.

8.4.3 Apparatus

Details of the apparatus used in this experiment are described in full in Chapter 3, Section 3.4 and Figures 3.2 – 3.9.

8.4.4 Stimuli

The stimuli used in Experiment 3 (a full description is provided in Chapter 7) were re-used in this study but with the addition of auditory cues. These cues were auditory taps (two drumsticks hit together once) heard at stimulus and ISI onset in each trial in the auditory condition, except for the omission trial which was silent. (The tap was made at the beginning of the ISI, but not at the end of the ISI.). The sound file for the auditory stimulus was created in Sound Forge XP and incorporated into the stimulus. The timing for all three sequences was identical; the stimulus present trial lasted 500ms, the stimulus absent trial 1s, and the omission trial 5s. So the only difference between the two conditions was the addition or absence of sound.

Figure 8.1 Experiment 4 stimulus sequences and timings (not to scale)
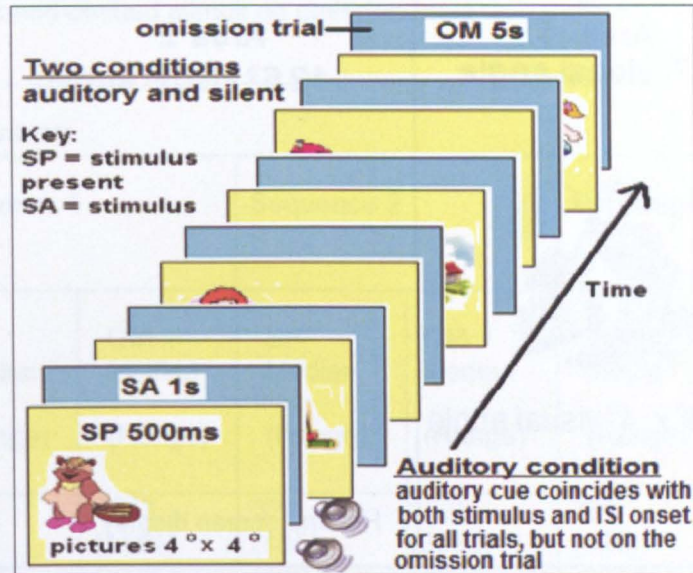
8.4.5 Procedure

Having gained written informed consent from the caregiver, completed the calibration and baseline measures, Experiment 4 began following the same procedure as previous experiments outlined in Chapter 3, Section 4. The experimental conditions were counterbalanced.

8.4.6 Data analysis

The analysis was completed in the same manner as the previous experiments and the areas of interest are marked Area 1 and 2 in Figure 8.2 below. The saccadic response latencies of stimulus present and stimulus absent trials were compared to ascertain whether infants can keep time within a stimulus sequence. The data were subjected to a non-parametric Mann-Whitney U-test, as not every infant provided data in each sequence, violating the assumptions of homogeneity of variance. As in previous experiments reported in this thesis, a second analysis was conducted using the baseline measure data (reported in Chapter 4) to categorise infants into consistent long- and short-looking categories with a smaller group of 46 infants (SL=27, LL=19).

Figure 8.2 Experiment 4 stimulus coding grid

Area 1 8.7° visual angle	Area 2 12.6° visual angle
4° x 4° visual angle	Plasma screen display
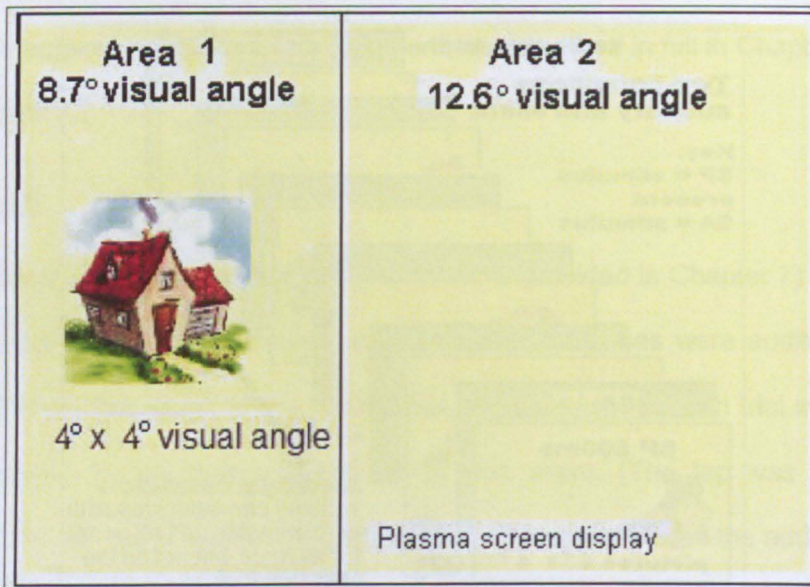
8.5 Results

The aim of Experiment 4 was to examine the influence of concurrent auditory cues on infant timekeeping. As can be seen from Tables 8.1 – 8.3, although the whole sample of 54 infants provided usable data for at least one sequence, the numbers of infants who provided usable data for each individual sequence was between 31 and 38. Attrition rates were therefore still fairly high but within acceptable limits (Johnson, 1999; Oates, 1998).

The median saccadic latencies made during the omission trials displayed in Table 8.1 are lower for the auditory than silent condition, suggesting that auditory cues may help infants to keep track of sequences. Conversely, in the silent condition infants become more accurate at responding as the sequences progress suggesting practice effects, even though this trend is not observed in the auditory condition suggesting that auditory cues also had a muddling effect.

Table 8.1 All infants: Median and range latencies of saccades (in ms) made to stimulus in Stimulus Present and omitted stimuli on omission trials

Condition	ALL infants					
	Sequence 1		Sequence 2		Sequence 3	
	SP Median (Range)	OM Median (Range)	SP Median (Range)	OM Median (Range)	SP Median (Range)	OM Median (Range)
Silent	328 (484) (n=33)	1843 (1181) (n=35)	324 (485) (n=37)	1620 (3953) (n=33)	300 (485) (n=34)	1240 (5542) (n=32)
Auditory	266.75 (476) (n=34)	805 (4672) (n=38)	280 (469) (n=31)	1219 (3885) (n=31)	331.5 (474) (n=34)	836.5 (3797) (n=35)

The results of the second analysis are reported in Tables 8.2 and 8.3 below, and reveal that median latencies were lower in the auditory condition than the silent condition for both groups except in Sequence 1 (silence condition) for short-lookers and Sequence 3 for long-lookers. The range of latencies revealed slightly more consistency across the auditory condition than the silent condition for the whole infant sample, but no consistent patterns emerged when the data were divided into long- and short-looking groups.

In order to answer the first research question of whether auditory cues aid infant time keeping, data from the response latencies to the stimulus omission trials in the silent and auditory conditions were assessed. Unlike the other experiments reported in this thesis, this experiment presents a test of difference: a statistically significant difference between response latencies in the silent and auditory conditions would reveal the effect of an auditory cue. The data for all infants were therefore subjected to a Mann-Whitney U-test, which revealed a significant difference in the first sequence (U=432, N1=35, N2=38,

p<0.01), indicating that auditory cues did influence infant time keeping in that sequence.

No other sequences were significant.

Table 8.2 Short-looking infants only: Median (med) and range latencies of saccades (in ms) made to the stimuli in SP trials and omitted stimuli on omission trials

Condition	SL infants					
	Sequence 1		Sequence 2		Sequence 3	
	SP Median (Range)	OM Median (Range)	SP Median (Range)	OM Median (Range)	SP Median (Range)	OM Median (Range)
Silent	47 (344) (n=9)	1101 (3594) (n=6)	172 (437) (n=9)	1844 (2860) (n=7)	273 (453) (n=9)	1687 (3359) (n=4)
Auditory	31 (336) (n=34)	1250 (3485) (n=5)	109 (453) (n=31)	953 (579) (n=3)	188 (414) (n=9)	1195 (1327) (n=2)

Table 8.3 Long -looking infants only: Median (med) and range latencies of saccades (in ms) made to the stimuli in SP trials and omitted stimuli on omission trials

Condition	LL infants					
	Sequence 1		Sequence 2		Sequence 3	
	SP Median (Range)	OM Median (Range)	SP Median (Range)	OM Median (Range)	SP Median (Range)	OM Median (Range)
Silent	32 (375) (n=5)	2095 (1459) (n=3)	180 (469) (n=5)	3953 (0) (n=1)	304 (422) (n=5)	109 (782) (n=2)
Auditory	351.50 (422) (n=5)	437 (1984) (n=6)	304.5 (469) (n=5)	1164 (3375) (n=4)	31 (235) (n=5)	250 (3234) (n=3)

The second research question sought to discover whether attention modulates the latency of the switch within the SET model at this age. Evidence for this would be demonstrated

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by less variability in response latencies within the auditory condition than in the silent condition. The data in Table 8.4 below show that the range of variability was less within the auditory condition by the whole group. When the data were further divided into long- and short-looking categories, less variability was observed within the short-looking group but not the long-looking group overall. Interestingly, less variability was observed in the auditory condition in long-lookers, but in the silent condition in short-lookers. This pattern of results suggests that long-looking infants benefited most from the inclusion of the auditory cue by reducing switch latency within the SET model.

Table 8.4 Range of response latencies made across the omission trials in the silent and auditory conditions

| Condition | Infant groups | | |
	ALL infants	Short-looking infants	Long-looking infants
Silent	4361ms	734ms	3171ms
Auditory	875ms	2906ms	1391ms

To answer the third research question as to whether long- and short-looking strategies mediated this effect, a second analysis was conducted. The results of the Mann-Whitney U-test revealed a significant difference in only one sequence, Sequence 1 for long-looking infants (U=-2.066, N=3, N2=6, p=.039). These results lend some support to the notion that long- and short-looking strategies may mediate the effect of auditory cue differentially, but more work is necessary to gain a clearer picture.

To ascertain whether infants could keep time within sequences, a test of similarity is required. That is, if infants are keeping time, or tracking on time, there will be little difference between the stimulus present and absent trials. Therefore response latencies to stimulus present and omission trials were compared and the data subjected to Wilcoxon tests. The results from the whole sample revealed no similarity in response latencies within sequences in either condition. In the second analysis, five non-significant

sequences were observed in each group (see Tables 8.5 and 8.6, below). However, in each group, one sequence could not be analysed because of small numbers (n=2): Sequence 3 Auditory (SL), Sequence 2 Silent (LL). Therefore the only conclusion that can be drawn is that when analysed separately, a difference in performance can be seen, but nothing more can be said.

Table 8.5 Short-looking infants only: Outcomes for Wilcoxon Test results comparing time keeping within each sequence

Condition	Wilcoxon test Results
Silent	Sequence 1 Z=1.069 p=.285 Sequence 2 Z=1.753 p=.080 Sequence 3 Z=1.069 p=.285
Auditory	Sequence 1 Z=1.069 p=.285 Sequence 2 Z=1.342 p=.180 Sequence 3 SPSS did not perform test

Table 8.6 Long-looking infants only: Outcomes for Wilcoxon Test results comparing time keeping within each sequence

Condition	Wilcoxon Test Results
Silent	Sequence 1 Z=1.342 p=.180 Sequence 2 SPSS did not perform test Sequence 3 Z=.447 p=.655
Auditory	Sequence 1 Z=-.365 p=.715 Sequence 2 Z=1.342 p=.180 Sequence 3 Z=1.342 p=.180

8.6 Discussion

Three questions were posed in this Chapter. First, do auditory cues facilitate time keeping; second, can evidence be found that switch latency is modulated by attention; third, do auditory cues mediate time keeping in different ways for long- and short-looking infants.

The results reported above reveal that the median response latencies were lower in the auditory condition, and when these data were subjected to a Mann-Whitney U-test, one of the three sequences was significant. Further, an examination of the range of response latencies across the three sequences in each condition revealed a smaller range in the auditory condition than the silent, suggestive of improved time keeping.

Although no evidence that infants kept time within sequences was found for the whole sample, a slightly different picture emerged when the data were divided into long- and short-looking categories. The Mann-Whitney U-tests revealed significant differences between conditions in Sequence 1 in the long-looking group, indicating that, at least for this sequence, auditory cues do enhance time keeping. This could be explained in several ways. Infants could have become tired during the second and third sequences resulting in non-significant results, a factor recognised by Colombo and colleagues (2002, 2005) who presented only one sequence to infants for this very reason (Colombo, 2004, personal communication). The data from the long- and short-looking infant groups were similar for long-looking infants only, suggesting that they had benefited from the auditory cues, which may have lessened their difficulty in disengaging attention from the stimuli (Frick et al., 1999). It could also be argued that, whilst alert at the beginning of the experiment and so better able to disengage attention, performance deteriorated over time as these long-lookers became more fatigued.

This result can also be explained by the devSET model. The results for the whole sample indicate that infants were able to use the auditory cues to aid timekeeping on the first sequence, but not on subsequent sequences. According to the devSET model, when participants are faced with ambiguous stimuli, in this case fast paced stimulus presentations, they will tend to make longer responses. On that basis, long-looking infants may have found the first sequence manageable, being able to keep time. But they found subsequent sequences ambiguous possibly due to difficulty in disengaging attention (Frick et al., 1999), and so difficult to follow, leading to an increasing accumulation of looking delay and subsequent deterioration in time keeping.

The results of the post hoc Wilcoxon tests to examine timekeeping within sequences, found some evidence of temporal sensitivity; however, no clear differences between the groups were observed. This suggests that the inconsistent infants, that is, those who change looking category when responding to different baseline measure stimuli, may be obscuring the picture of infants' temporal abilities.

The question of whether switch latency could be mediated by increasing attention to the ISI with the addition of auditory cues was explored, with the results in Table 8.4 showing that the range of response latencies was smaller in the auditory condition. Proponents of the switch latency hypothesis suggest that attention modulates the closure of the switch. The addition of an auditory cue at the onset of each SP trial and ISI in this experiment allowed attention to be focussed on the task, as infants do not have to look at the monitor screen to keep track of the duration when provided with auditory cues. Long-lookers appeared to benefit more than short-lookers from the auditory cues, which may have acted as distracting influences, paying more attention to non-temporal information resulting in a 'fuzzy representation' being held in memory.

Whilst the results from Experiment 4 are encouraging they are not entirely clear, so a closer look at the task design itself might provide a better explanation of their performance.

As previously seen, the task consisted of three inanimate picture sequences appearing alternately left and right on a screen, presented either in silence or with the addition of an auditory cue. Although the task and stimulus design had been refined throughout the previous experiments, in about 30% of trials, infants continued to look away from the monitor screen, possibly having lost interest, thus not providing any usable data (see Table 8.1). The addition of auditory cues may serve to distract the infants further, being required to process spatial, temporal and auditory information, reducing attention to the temporal aspects of the event. As increasing saliency of the stimulus may increase attention to it, future studies may benefit from using animate stimuli that more closely replicate infants' everyday life experiences, thus resulting in improved data. Additionally,

the use of auditory cues in this type of paradigm may allow the impact of such cues on time keeping to be understood more fully.

A reason for time keeping being observed predominantly in the omission trials rather than within sequences could be that the omission trials did not have an auditory cue. If during the auditory condition, infants were only using the auditory cues to prompt eye movements, then they may have become accustomed to the rhythm of these cues. When the cues were then omitted, this would have alerted them to the disruption of the sequence. This suggests that tracking both visual and auditory cues may divide attention between temporal and spatial information, resulting in improved time-keeping only when attending to one type of information.

8.7 Chapter summary

This chapter has examined the influence of auditory cues on infant time keeping abilities, finding some evidence to support this. The Mann-Whitney U-test result for Sequence 1 (whole sample) harmonised with the notion that alerting infants to durations by means of an auditory cue increased accuracy in timekeeping in that sequence. The smaller range of response latencies in the auditory cue condition were discussed in terms of the Switch Latency Hypothesis (Meck, 1984; Lejeune, 1998; Fortin, 1999; Zakay, 2000) and the devSET model (Droit-Volet and Wearden, 2001). Under ambiguous circumstances, the devSET model posits that response latencies to durations will be longer. Small differences in performance by long- and short-looking infants might be due to stimuli being viewed as ambiguous in different sequences, thus supporting the notion that the two groups process information and attend to temporal stimuli differentially.

This chapter has shown that auditory cues aid time keeping in different ways, and also highlighted the need for socially salient stimuli in order to optimally engage infant participants in research. Hence, the final studies in this thesis will seek to accommodate this principle in further investigations of infant time perception.

Chapter 9
Experiment 5: Influence of socially significant stimuli on infant time perception

9.1 Introduction

Previous research has shown that timing is vital for successful communication and social interaction (Stern, 1974; Isabella and Belsky, 1991; Jaffe et al., 2002). Findings from previous experiments have built an argument for the need in empirical studies to model principles of everyday experiences to create socially salient, animate stimuli that optimally engage infant attention. So Experiment 5 has been designed to test this and will now be described.

9.2 Overview of the literature

9.2.1 Interaction as defined within research

Amongst the many researchers who have examined the development of interactions, Stern, (1974, 1977, 2002) and Jaffe et al. (2001) have explored these with primary caregivers, usually the mother, and in particular have conducted micro-analyses of component parts of the interaction. An interaction is defined by Stern (1977) as a bounded period of time when one or both members focus their attention on each other. The 'duration of a moment' within an ongoing sequence of mother-infant interaction, including both verbal and non-verbal behaviours, has been found to be between 0.3 and 1.0 second (Stern, 1977; Stern and Gibbon, 1979). Stern (1977) further posits that interactions within each period occur at a regular rate and are usually initiated by the mother, bounded by pauses, and often terminated by the infant. An example could be saying 'hello', where each 'hello' would be a 'duration of a moment', bounded by pauses. So micro-analyses itemise each segment of the interaction, whereas in everyday life an interaction would be

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thought of as lasting for more lengthy periods. Stern (2002) also suggests that infants show sensitivity to regular stimulus patterns such as faces as opposed to scrambled faces (Fantz, 1966; Johnson et al., 1991) and temporal patterns as in social interactions, demonstrating that regularity benefits interaction.

9.2.2 The significance of duration in interaction

The duration of social interactions, also called rhythms of dialogue, during mother-infant exchanges with four-month-old infants was investigated by measuring units of vocalisations and pausing within these interactions (Jaffe et al., 2001). The authors identified two types of pausing. First, simple pauses between bursts of vocalisation or gestures, either facial or with the hands etc. Second, pauses after which the active role in the interaction 'switched' between partners, later termed 'switching pauses'. Durations of pauses during vocalisations between mothers and their infants differed by approximately 1s and units of interaction lasted 2–3s, suggesting that these periods were important for infants.

Periods of interaction between 2-3 seconds were suggested by Stern (2001) to reflect the developmental capacity of infants. First, that infant physiology, in particular lung capacity, may limit this duration. Second, that a boundary on this interaction period, namely 2-3 seconds, may be essential in allowing infants to chunk and process the information gained through the exchange. Intervals of 1-3 seconds have also been found to hold importance in infant time keeping by Colombo and colleagues (Colombo and Richman, 2002; Colombo et al., 2005), supporting this view.

9.2.3 The importance of repetition in interaction

The repetition of social behaviours is another crucial part of mother-infant interaction, which Stern calls a 'repetitive run' (Stern, 2002). The function of a repetitive run is to provide an infant with a theme and variations on that theme. For instance, a mother may say "hello" to her infant in several different ways by changing the tempo, pitch etc., with each unit or sound (e.g. "hellooo") falling within the 0.3 to 1.0 second range. This enables

infants to stay alert providing opportunities to learn and categorise behaviours, and learn exemplars of these categories (Stern, 2001).

9.2.4 Use of animate stimuli

Inanimate stimuli were used in Experiments 1–4 of the present research, but infants' attention was found to wane quickly, as observed by only 50-70% of infants providing data in each of those studies (see Table 5.1, Table 6.1, Table 7.1 and Table 8.1 in each respective chapter). Chapter 8 argued that infants may maintain their attention better, increasing their responses to animate objects and people, if provided with a meaningful task. Experiment 5 tested this, using a video clip of a woman performing a head turning task, a type of repetitive run (Stern, 2002).

A socially significant task should hold infants' attention better, decreasing attrition rates and allowing better demonstration of any temporal ability. The task used in Experiment 5, is akin to the game of peek-a-boo that most infants are familiar with and so socially salient. This should allow a more naturalistic exploration of interval timing whilst maintaining experimental rigour. Moreover, the timing of head turning in this experiment reflects important durations found in mother-infant interactions (Stern, 1977; Stern et al., 1977; Jaffe et al., 2001). Two ISIs were used, a long duration of 3s (Jaffe et al., 2001) and a short duration of 1s (Stern, 1977).

It was predicted that increased attention to the animated stimulus task should produce shorter response latencies in the omission trials since the task is less ambiguous and so more attention is directed to temporal information. In turn this has several implications for interpreting mechanisms of the devSET model (Droit-Volet and Wearden, 2001). First, switch latency (Lejeune, 1998), discussed in Chapter 8, Section 2, should be minimised resulting in a more accurate representation of the standard duration. Second, increased attention to the task should result in a less 'fuzzy' representation of the standard duration being stored in memory, as fewer variations would be formed (McCormack et al.,1999). Third, the duration may be perceived as longer due to increased attentional resources

being allocated, resonating with the 'watched pot' effect proposed by Block, George and Reed (1980).

9.2.5 Head turning and gaze following

The introduction of head turning in this experiment allowed observation of the emergence of gaze following in infants, not examined to date with an eye tracker. Importantly, gaze following is a component of an infant's subsequent ability to engage in joint attention (Scaife and Bruner, 1975). Collis (1977) posited that an ability to follow gaze has emerged by the age of 8 months, while Trevarthen (1993) and Butterworth (2001) argued that dyadic eye-to-eye contact emerges at 3 months, but extends to objects outside the dyad from 6 months. Conversely, Corkum and Moore (1998) argued that it does not reliably appear before 10 months, while Churcher and Scaife (1982) pointed out that infants begin to follow head turns at 3 months but not consistently until 40 weeks or 9 months.

Gaze following has also been linked with the onset of gaze shift and joint attention beginning at 6 months old (Morales, Mundy, Delgado, Yale, Messinger, Neal and Schwartz, 2000), which has been thought to influence later vocabulary development at 10 months (Baldwin, 1995; Rollins, Marchman and Mehta, 1998; Morales et al., 2000). This view has been supported more recently by DeGroot, Roeyers and Striano (2007), who found that gaze following becomes more robust at 6 and 9 months compared to 3 months. Kuroki (2007) further showed that 12-month-old infants will engage in increased joint gaze with people who show a positive expression, in contrast to 6- and 9-month-olds who will not. At present there is no clear consensus as to when the ability to follow gaze emerges, but it is clear that joint attention and social interaction are vital factors in its emergence. Eye tracking may provide behavioural evidence of gaze following by employing this methodology with 4-month-old infants.

9.3 Research questions

Three research questions emerge from the literature and are investigated in the present study.

1. Can overt behavioural evidence of timekeeping be seen in a social context? (This is the sixth primary research question set out in Chapter 2).

2. Do individual differences in look duration influence temporal accuracy in a socially salient task?

3. Does the use of a socially salient task using eye tracking methodology allow gaze following to be observed at four months?

9.4 Method

9.4.1 Design

Experiment 5 employed a within-participant repeated measures design with two independent variables, namely the speed of the sequence and the number of stimulus presentations. The dependent variable was the latency of the first saccade to the correct location in the sequence following stimulus omission.

The animated stimulus sequences used in this experiment comprised a video clip of a woman performing a head turning task in which she faced towards and then turned away from the viewing infant, remaining visible to the participant at all times. This design should largely overcome the methodological limitations reported in Experiments 2-4 whereby fluctuating pupil size resulted in a loss of the POG. Stability of the POG was enhanced in Experiment 5 by retaining the same background and stimulus throughout the sequences thus stabilising light and luminance levels and ensuring stable pupil discrimination and corneal reflection thresholds.

9.4.2 Participants

Thirty-seven infants, aged three months, three weeks to four months, one week, (mean age four months, sd: three days) participated in the experiment. Twenty-three infants completed at least one sequence of the task, with insufficient data from 14 others. This

was for several reasons, mainly infant inattentiveness such as looking at their feet, crying or being distracted by their mother (n=4), and experimenter error (n=2). A further 8 infants became fussy during the initial piloting stage of the experiment due to a prolonged interval before testing could begin and so provided no data. As a result the stimulus was changed (see Section 9.4.4 below).

9.4.3 Apparatus

Details of the apparatus used in this experiment, are described in full in Chapter 3, Section 3.4 and Figures 3.2 – 3.9.

9.4.4 Stimuli

The original version of the experiment involved asking mothers to perform the head turning sequences while maintaining a neutral looking face, with auditory guides being provided via earpieces after some training. The mothers performed the head turn sequences before a camera in an adjoining testing room which had a live feed to the plasma screen in front of the infant. This method was originally adopted as it was thought that the study would be more appealing if infants saw their own mother. However, it was discontinued for three reasons. First, mothers were unable to perform the task at the correct time intervals despite a training period. Second, they were unable to complete a full 90° head turn, often only turning their heads 45° – 50°, especially during the fast sequences. This caused problems as mothers were partially facing their infants all the time. Third, infants often became fussy whilst their mothers were 'training'; resulting in neither mother nor infant wanting to continue with the task and consequently, eight infants provided no data. Therefore, a video clip of the task was created to automate the stimulus process.

The revised stimulus sequences comprised a continuous video clip of a woman performing four head turning sequences that differed in the length of ISI and the number of head turns in a sequence as outlined below (see Figure 9.1). A female face was used as infants are more attracted to female faces (Quinn, Yahr, Khun, Slater and Pascalis, 2002; Quinn, Uttley, Lee, Gibson, Smith, Slater, Pascalis, 2008) and therefore attention to

the stimulus should be maximised. The woman in each stimulus sequence was positioned in the centre of the screen looking straight ahead at the viewing infant (stimulus look (StL) trial) then turned her head to her left at an angle of 90° so that she faced the right (viewer's) side of the monitor screen (stimulus away (StA) trial). The sequence continued as the woman returned her gaze towards the viewing infant and subsequently towards her left hand side and so on for the required number of head turns. After either eight (long sequences) or four (short sequences) head turns the sequence was disrupted and the omission trial began, during which the stimulus woman remained facing towards the side for an extended period of time.

Figure 9.1 Experiment 5: Stimulus sequences and timings for four stimulus sequence.
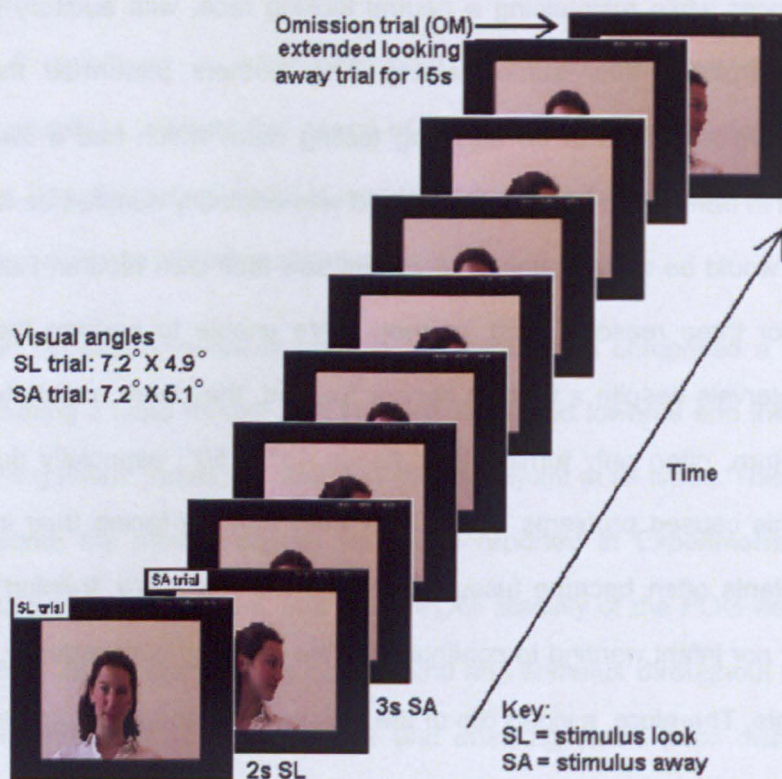
Each of the four stimulus sequences had different timings and a different number of head turns presented within the sequences. All sequences began with the stimulus woman facing the viewing infant as initial mutual gaze has been shown to be important in early infancy in modulating face recognition (Farroni, Massaccesi, Menon and Johnson, 2007).

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Table 9.1 displays sequence order and timings. Despite the possibility of order and practice effects, sequences were not counterbalanced.

Table 9.1 Sequence timings for Experiment 5

Key: S = slow, F = fast; 9 = 8 head turns within the sequence, 9th omitted; 5 = 4 head turns within the sequence, 5th omitted; StL = stimulus look; StA = stimulus away; OM = omission trial

Sequence	Timings
S9	2 seconds StL, 3 seconds StA, 15 seconds OM
F9	500 milliseconds StL, 1 second StA, 5 seconds OM
S5	2 seconds StL, 3 seconds StA, 15 seconds OM
F5	500 milliseconds StL, 1 second StA, 5 seconds OM

When creating the stimulus, sound files were first produced using the software programme Sound Forge XP to provide auditory tones as a guide to ensure the exact timing of each sequence. The final stimulus video presented to infants was completely silent.

To ensure preciseness of head movement with respect to timing and completeness of head turns to 90°, a professional ballet dancer performed the head turning sequences, undergoing a training period with the auditory guides to ensure accuracy. Once filmed, the video was edited using iMovie software to remove the auditory guides and later incorporated into the Gaze Tracker analysis programme.

The stimulus sequences were continuous, that is with no pausing between them, so at the end of the stimulus omission trial in Sequence 1, the woman turned her head towards the viewing infant, thus commencing Sequence 2 and so on through all four sequences. At the end of Sequence 4, the woman turned towards the centre of the screen and smiled at the viewing infant signalling the end of the task. Throughout the sequences she maintained a straight neutral looking face. The first central gaze in each sequence was longer at 1s

instead of 500ms to ensure that the infant's attention was engaged after the long period of looking away.

The infants' eye movements were tracked using an ASL model 504 eye tracker, and the stimulus presented on a plasma screen. Data were collected via the Gaze Tracker software and also via a video link. Full details can be found in Chapter 3, Section 4 and Figures 3.2 to 3.9.

9.4.5 Procedure

After gaining informed consent from the caregiver, calibrating the eye tracker and obtaining the baseline measure data, the present experiment began. Infants saw four experimental conditions in a fixed order (S9, F9, S5, F5).

9.4.6 Data analysis

Three areas of interest for analysis were identified on the screen for coding and are shown in Figure 9.2: first, the centre of the screen where the stimulus woman faced towards the centre; second, the right hand side where the woman looked to the side; third, the left of the woman's head from the viewing infant's perspective. Inspection of the data showed that infants did not look to Area 3, which was an empty space with no activity throughout the experiment.

Figure 9.2 Areas for coding eye movements in Experiment 5
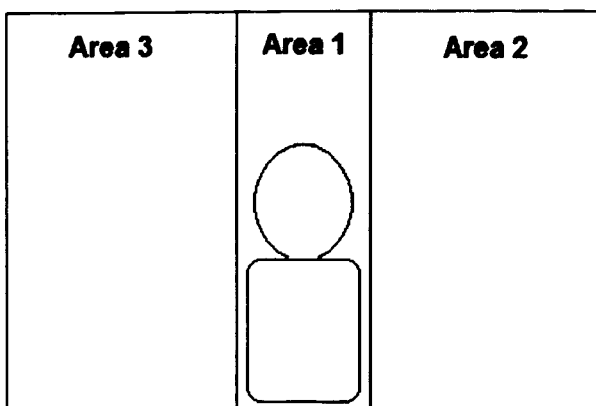
Eye movement data were recorded in the following way. The first saccade to the stimulus on StL trials (Area 1) and the first saccade to the location of the woman's gaze on the StA

trials (Area 2) were recorded. Omission trials were judged as starting at the end of the previous ISI, that is, after 3 seconds in the slow sequence and after 1 second in the fast sequence. During stimulus omission trials, the first saccade to Area 1 and any saccades made early to the correct location during the last 500ms of the previous ISI were recorded, to capture any anticipatory saccades and the first subsequent saccade to the correct location after the point of omission (see Figure 3.12).

Once collated, the data were subjected to non-parametric Wilcoxon tests due to the assumptions of homogeneity of variance being violated. As with all previous studies, a second analysis was conducted using data from consistent long- and short-lookers as identified from baseline measure responses.

9.5 Results

One aim of the experiment was to ascertain if socially significant stimulus sequences produced overt behavioural evidence of infant time keeping. Data from some infants were excluded from the sample because they failed to make saccades either during the last three stimulus present trials or during the omission trial. Therefore the total number of infants who successfully participated in each sequence was as follows: S9=23; F9=17, S5=22; F5=16; this represented a decrease in attrition rates compared to Experiments 1–4 (Exp1=8/13, Exp2=40/47, Exp3=54/63, Exp4=54/63, Exp5=23/29). Only one infant looked to the centre of the screen before the ISI on the omission trial had elapsed (1.37s before), and consequently their data for this sequence were omitted from the analysis. These results will now be examined in response to the research questions outlined earlier.

The first research question asked whether overt behavioural evidence of timekeeping can be seen using social stimuli. The data reported in Table 9.2 below show the median and range response latencies of infants who made saccades to the location of the omitted stimulus (i.e. to the centre of the screen for the next StL trial, had the sequence continued) within the OM trial. The median response latencies indicate that infants produced shorter saccadic latencies to the faster sequences with shorter ISIs, indicating that they perceived the temporal information within these sequences. The median and range for Sequence 3

(S5) were uncharacteristically large across all tables for all infants, indicating that participants were inaccurate in their temporal estimations of this sequence. However, better levels of accuracy returned in the fourth sequence.

Table 9.2 All infants: Median and range of response latencies in milliseconds (ms) of saccades made to stimuli in StL trials and the omitted stimulus on omission trials only. Timing of sequences (Tables 9.2 – 9.4): S=2s StL, 3s StA, 15s OM. F=500ms StL, 1s StA, 5s OM

Sequence (ISI)	N	StL Median (Range)	N	OM (Range)
S9 (3s)	23	441 (1735)	23	400 (7749)
F9 (1s)	19	60 (527)	17	77 (2141)
S5 (3s)	22	741.5 (1907)	22	1152 (10484)
F5 (1s)	17	49.5 (301)	16	78 (3652)

If infants were tracking the sequences on time, response latencies to StL trials should be similar to the response latencies observed during OM trial. To ascertain this, the data from the last three StL trials and the OM trials were subjected to a Wilcoxon test, and non-significant results predicted. These results can be seen in Table 9.3 below.

Table 9.3 All infants: Outcomes for Wilcoxon Test results comparing time keeping within each sequence

Sequence	Wilcoxon test Results
Sequence 1 (S9)	Z= -1.118, p=.236
Sequence 2 (F9)	Z= -1.539, p=.124
Sequence 3 (S5)	Z= -2.906, p=.004
Sequence 4 (F5)	Z= -1.189, p=.234

Although non-significance was clear across three of the trials indicating timekeeping, the significant result seen in Sequence 3 (S5) presented an intriguing anomaly, which will be discussed in Section 9.5.

Regarding the second research question, which asked whether individual differences in look duration influenced temporal accuracy in socially salient tasks, comparisons between the consistently long- (n=8) and short-looking (n=7) groups were made and the results re-analysed. Tables 9.4 and 9.5 below show that short-looking infants do not show the same temporal accuracy as long-lookers, as both the median response latencies were greater in three of the four sequences.

Table 9.4 Short-looking infants: Median and range of response latencies in milliseconds (ms) of saccades made to stimuli in StL trials and omitted stimulus on omission trials only

Sequence (ISI)	N	StL Median (Range)	N	OM (Range)
S9 (3s)	7	284.5 (1025)	7	400 (7749)
F9 (1s)	7	44.75 (466)	7	500 (2141)
S5 (3s)	7	425.5 ((1532)	7	378 (2406)
F5 (1s)	6	40.5 (117)	6	28 (200)

Table 9.5 Long-looking infants: Median and range of response latencies in milliseconds (ms) of saccades made to stimuli in StL trials and the omitted stimulus on omission trials only

Sequence (ISI)	N	StL Median (Range)	N	OM Range
S9 (3s)	8	671 (1710)	8	517.5 (4797)
F9 (1s)	7	77 (527)	7	93 (1531)
8	11	815.5 (1907)	8	4495 (10469)
F5 (1s)	6	87(92.25)	5	135 (287)

Following the procedure undertaken for the whole sample, evidence of time keeping was again sought by subjecting the data to a Wilcoxon test, with temporal awareness being demonstrated by non-significant results. Once again, Sequence 3 (S5) proved anomalous but only for the long-looking group, indicating a lack of time keeping in this group, but not

in short-lookers who demonstrated very accurate time keeping. These data are reported in Tables 9.6 and 9.7 below.

Table 9.6 Short-looking infants: Wilcoxon Test results comparing time keeping within each sequence for short-looking infants

Sequence	Wilcoxon test Results
Sequence 1 (S9)	Z=1.183, p=.237
Sequence 2 (F9)	Z=1.859, p=.063
Sequence 3 (S5)	Z=.169, p=.866
Sequence 4 (F5)	Z=.943, p=.345

Table 9.7 Long-looking infants: Wilcoxon Test results comparing time keeping within each sequence

Condition	Wilcoxon test Results
Sequence 1 (S9)	Z=.420, p=.674
Sequence 2 (F9)	Z=1.402, p=.161
Sequence 3 (S5)	Z=2.100, p=.036
Sequence 3 (F5)	Z=-.405, p=.686

9.6 Discussion

The present study has three research questions. First, evidence was sought that socially significant stimuli would allow infant time keeping to be observed; second, that the use of long- and short-looking strategies may influence infant time keeping; and lastly, those socially significant stimuli would facilitate gaze following in four-month-old infants. The first and second will be discussed together, with the third treated later in this section.

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Interval timing was explored in a more natural manner by using animated head turning sequences, akin to a game of 'peek-a-boo'. Regarding the first research question, response latencies during OM trials showed that infants responded quicker in the fast (1s ISI) than the slow sequences (3s ISI), suggesting that they were in fact responding differentially to the different time intervals (see Table 9.2). Time keeping within sequences was observed from the Wilcoxon test data, which produced non-significant results in three out of the four sequences, showing similar responses in both StL and OM trials. Sequence S5 showed no evidence of timekeeping (see Table 9.3).

The influence of individual differences in long- and short-looking on temporal accuracy, raised by the second research question, was found to be mixed. This second analysis used the data from infants who were consistent within the category of their baseline measure responses, and the results are reported in Tables 9.4 to 9.7 above, indicating that long-looking infants responded pro-rata to the length of the ISI, that is longer in the slow (3s) sequences and earlier in the fast sequences (e.g. S9=517.5ms, F9=93ms, S5=4435ms, F5=135ms). Short-lookers responded in a pro-rata manner in three sequences (e.g. S9=400ms, S5=378ms, F5=28ms). The 42ms difference in long-lookers responses in the fast sequences (F9=93ms, F5=135ms) suggests increased temporal sensitivity in the 9-stimulus presentation sequences. This finding lends some support to Frick et al. (1996), who demonstrated that prolonged exposure to a stimulus allows long-looking infants time to equate their performance to that of short-lookers (but seen only in Sequence 4 of the present experiment).

The Wilcoxon Test results produced a clear difference between the two groups. Short-looking infants showed a degree of temporal sensitivity in each sequence, particularly Sequence 3 (Z=.169, p=.866). Conversely, whilst long-looking infants showed a degree of temporal sensitivity in three sequences, in Sequence 3 there was no evidence (Z=2.100, p=.036). This suggests that these two groups processed the temporal information contained in these sequences differentially. Interestingly, long-lookers returned to temporal accuracy in the following sequence (Z=-.405, p=.686).

Other key findings from this experiment related to the maintenance of infant attention levels and technical issues. First, infant attention levels were maintained by presenting socially significant animated stimuli, thus increasing attention and decreasing attrition compared to previous experiments. In the final sample of 29 infants, 23 participants provided data at many more data points than in previous experiments ($\geq$80%), demonstrating the engaging nature of the stimuli. Second, that technical difficulties caused by the contraction and dilation of pupils encountered in previous experiments were largely overcome by maintaining a constant background. Both of these additional points will now be discussed in further detail.

Socially significant stimulus sequences provided overt behavioural evidence of infant time keeping in three of the four head turning presentations, the stimulus woman retaining infants' attention by remaining visible throughout. Consequently, infants made saccades and provided usable data in most trials resulting in greater power to the analysis. A further observation is that increased attentional resources focussed on temporal aspects of the task, resulting in more accurate representations of the standard duration being formed within the 'training period' i.e. StL trials. This in turn allowed the infants to make a more accurate estimate of the time interval in omission trials. Discussed in terms of the FSM and AGM versions of the SET model respectively (Gibbon, 1977; Lejeune, 1998; Zakay, 2000), switch latency was reduced or the attentional gate opened wider for a socially significant stimulus, accounting for increased accuracy. However, the data reported in the present experiment do not allow judgements to be made about which of these two attentional mechanisms has the most explanatory power, and indeed it must be remembered that only three sequences revealed supporting evidence of timekeeping.

The anomalous result for long-looking infants in S5, indicating a lack of infant time keeping, warrants more detailed discussion as it could be accounted for in several ways. First, infants could simply have become bored or tired by the time S5 was presented as the experimental task had been running for 118.5 seconds at that point. However this is not satisfactory since the following sequence F5, showed evidence of time keeping.

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Alternatively, infants could have been confused by S5 since the stimulus presentation changed in two ways between Sequences 2 and 3 (F9 and S5). First, the time interval of the ISI changed from fast (1s) to slow (3s), and second, the number of exemplars decreased from nine to five, meaning that there were less exemplars of the duration from which to form an accurate representation of the standard. This view is supported by the devSET model, which posits that in conditions of uncertainty, durations will be estimated as longer. But although this explanation is plausible it raises the question of why accurate time keeping returned in Sequence 4 for this group. Sequence 4 (F5) was identical to Sequence 2 except shorter, and could be predicted to create conditions of uncertainty and consequently long responses, but this was not the case. Further, timekeeping was observed throughout the sequences for the short-looking group.

Therefore a third explanation for this outcome could be due to the habituation–dishabituation phenomenon. This is an effect which is exploited in novelty preference tasks where participants are habituated to one stimulus, for example two photographs of the same woman's face presented side by side. One of these photographs is then paired with a photograph of a different woman, and if participants remember the previous photograph longer looks will be made to the new photograph in recognition of this difference. In the present study, infants had been habituated to stimulus sequences with eight head turns for the first two sequences (S9, F9), but in Sequence 3 (S5) only four head turns were presented. Therefore a novel presentation could be said to have occurred, in that the sequence finished sooner than before, which may influence infant responses. Again though, this is not a very satisfactory explanation as the infants were shown to return to time keeping in Sequence 4 (F5) and the main difference between the sequences only occurs at omission, which simply occurs earlier.

The novelty effect discussed above could lead to increased levels of attention to the OM trial. In turn, increased attention could produce longer duration estimates (Block et al., 1980), which could serve as a fourth explanation for the results in S5. The effect of increased attention to temporal information due to the changes between the second and

third sequence would result in switch latency decreasing (Lejeune, 1998) or the attentional gate (Zakay, 2000) being held wide open, both of which would lead to the duration being estimated as longer, as seen in S5. The results in Sequence 4, however, show evidence of timekeeping, indicating that responses are made based on temporal information, which draws this explanation into question.

Yet another explanation could be stimulus unpredictability which produced longer reaction times in 3.5-month-old infants, in studies using the VExP (Haith, Adler and Wass, 1996; Adler and Haith, 1998). The Adler and Haith (1998) study demonstrated that when both the spatial and temporal aspects of a stimulus were unpredictable within a sequence, infants produced longer reaction times than when only one aspect was unpredictable. Their results were discussed in terms of infants forming expectations based on encoding the average flow of information presented to them over a sequence. Temporal expectations were formed about the relationship between individual events, in this case the flow of the alternating stimulus pattern. These findings were not discussed in terms of the timing literature.

Whilst these studies are interesting, it must be remembered that the VExP examines infant anticipatory and reactive saccades made towards a visible stimulus within a sequence, whereas it is the predictability of the speed and location of a stimulus within a sequence that is manipulated in the present experiment (see Chapter 2, Section 2.7 for full discussion). The paradigm used in the current series of experiments presents a predictable sequence, examining eye movements when the sequence is disrupted and the stimulus omitted in Experiments 1–4 (i.e. in the absence of any stimuli). However, in the present experiment, two specific changes are introduced between Sequence 2 and 3, namely the number of stimulus presentations and presentation rate. Therefore, in introducing both temporal and spatial changes, levels of unpredictability increased, resulting in longer look durations and less accurate time keeping, lending support to the findings of Haith, Adler and Wass (1996) and Adler and Haith (1998).

A final explanation could arise from the Contextual Change Hypothesis (CCH) of time perception proposed by Block and Reed (1978), which posits that the numbers of changes encoded within a duration influence the perceived length of that duration. In the example of the novel car journey used in Chapter 2, the outward journey was perceived as longer than the return journey, as unfamiliar roads, landmarks etc. were seen and had to be remembered. The return journey along the same road was perceived as being shorter as the road was now more familiar and subsequently only salient landmarks were looked for. Block and Reed (1978) discuss these changes as being environmental, but they could be internal, such as levels of arousal etc.

In the present experiment, changes in presentation rate and stimulus length occurred between Sequence 2 (F9) and Sequence 3 (S5). The CCH would predict that in conditions of greater change, for instance rate and number rather than rate or number, longer durations would be perceived, thus providing a possible explanation for the data from long-looking infants in this experiment. Future research could examine the explanatory power of CCH by presenting infants with a similar experimental task in two conditions: Condition 1 with no changes, that is, sequences remain the same such as F9, F9; and Condition 2 with two changes such as S5, F9. CCH would predict that long-looking infants would be able to keep time in Condition 1 with no changes, but not in Condition 2 with two changes. On the other hand, short-looking infants should continue to keep time throughout the sequences regardless of the number of changes that occur. The CCH explanation would seem to carry greatest weight and will be tested in the final experiment reported in Chapter 10.

Turning now to the third research question of whether gaze following could be observed using a socially salient task and eye tracking, an inspection of the data revealed an interesting phenomenon seen for the first time within the field. The POG superimposed over the video recording of the head turning task showed the direction of gaze, allowing inferences about the focus of attention to be made. The POG followed the same pattern as the stimuli, moving from the centre of the screen to the left and then back to the centre

and so on, following the woman's head turns and thus the direction of gaze in real time over most of the length of the sequences. This phenomenon was observed on at least four head turns by 23 infants and often throughout the whole sequence of up to eight head turns.

Gaze following is usually attributed to older infants of between 6-18 months, with Churcher and Scaife (1982) proposing that gaze following only emerges reliably at 10 months. In their longitudinal study with infants from 3 months-old, reliable gaze following emerged at 10 months in half of the infants, with younger children looking mainly at the experimenter. These studies have typically involved a mother sitting opposite her infant and turning her head towards an object to the side of the pair, although in some cases, for instance Corkum and Moore (1998), the target location was an empty space, so there was nothing interesting for the mother or infant to look at.

The ability to follow another person's gaze in cued-attention studies has been demonstrated in neonates of two to five days old (Farroni, Csibra, Simion and Johnson, 2002), four-month-old infants (Farroni and colleagues, 2000, 2003, 2004), and five-month-olds (Hood, Willen and Driver, 1998). In these studies, which all utilise the Posner cueing paradigm (Posner, 1980), infants were presented with a woman's face that blinked and then looked to the left or right of the screen. A target appeared at locations that were either congruent or incongruent with the stimulus woman's gaze, with response latencies being 40ms faster to congruent targets. Importantly, these studies showed that infants up to five months old reliably followed another's gaze. Within each trial, the stimulus woman initially engaged in mutual gaze with the viewing infant, and only when the infant was looking at the woman did the trial begin. Interestingly, gaze following only occurred after a period of mutual gaze, as shown by Farroni and colleagues (2003, 2006, 2007), and not if the gaze was averted at the start of the trial (Farroni et al., 2003). Therefore an initial period of mutual gaze was vital for subsequent gaze following. The authors of these cued attention studies also suggested that movement itself was an influencing factor in gaze following in young infants (Farroni et al., 2000; Farroni et al., 2007).

There is a qualitative difference between the gaze following in the experiment reported in this chapter and the studies conducted by Farroni and colleagues (2003, 2006, 2007) and Hood et al. (1998). In the present experiment, the stimulus was a continuous video clip of a head turning task. The only time the stimulus woman was not actively engaged in the sequence was during the omission trials when she remained facing the side of the screen. This means that to follow the woman's gaze, infants had to look from the centre to the right hand side and back to the centre and so on in real time. Consistent gaze following was observed in this experiment, whereby the POG moved from the centre of the screen (engaging in mutual gaze), to the right of the screen in real-time with the stimulus woman's head turns. It could be argued that the gaze following demonstrated by these infant participants was triggered by movement alone. However, whilst the influences of movement as well as the period of mutual gaze with every central look are undoubtedly mediating factors in this phenomenon, it is not the case for the omission trials so cannot fully account for this.

It is harder to argue that there was an influence of movement in the omission trial in each sequence of this experiment. The POG movement made by the infant back to the centre during omission trials was not influenced by the movement of the stimulus woman, as she remained facing 90° to her left for a prolonged period of time, suggesting that it was based on the expectation that the woman would return her gaze towards the viewer. An alternative explanation for this is that it is merely a conditioned ocular motor response. However, neither of these explanations seems plausible since there was evidence that infants waited until about the time that the stimulus woman would have returned her gaze towards the centre before making a response, suggesting time perception or at least an awareness of the temporal parameters of the sequences. Notably, the use of the eye tracker providing a precise registration of eye movements has enabled this phenomenon to be revealed for the first time.

9.7 Chapter summary

The aim of this chapter was to examine whether using a socially salient head turning task would influence time keeping. The results revealed that infants showed temporal accuracy in three out of four sequences under these conditions with some differences in responding between long- and short-looking groups. Several explanations as to why time keeping was not observed in Sequence 3 were explored. One explanation was the CCH (Zakay and Block, 1978) and this will be examined in more detail in the following chapter.

Behavioural evidence of gaze following at four months old was obtained for the first time with the eye tracker, revealing that these infants can consistently follow the gaze of another person throughout a sequence after a period of mutual gaze. This is significant as this ability had previously been thought to emerge at eight months of age (Collis, 1977; Corkum and Moore, 1998). Further, this is qualitatively different to gaze following observed in cued attention studies, which is triggered by an event such as movement.

The role of contextual changes was discussed above within the framework of the CCH, whereby increased numbers of environmental changes lead to a longer estimation of durations. As this would appear to hold more explanatory power for the anomalous result observed in S5 of Experiment 5, it will be tested in the final experiment within Chapter 10.

Chapter 10
Experiment 6: Influence of contextual changes on infant time perception

10.1 Introduction

Experiment 5 demonstrated evidence of timekeeping using stimulus and timings that were socially significant to infants; that is, a video of a woman performing sequences of head turning similar to a game of 'peek-a-boo'. The experiment comprised four sequences with time keeping being demonstrated by all infants in three of these (S9, F9, F5) but not the third (S5). The third sequence involved a change in presentation speed from fast to slow, and number of head turns from nine to five, whereas between all the other sequences either speed *or* number of head turns changed but not both. In Sequence 3, long-looking infants demonstrated a lack of timekeeping. Several explanations were offered for this in Chapter 9, and the Contextual Change Hypothesis (CCH) (Block and Reed, 1978), which discusses the effect of contextual change, appeared to have the most explanatory power. Experiment 6 seeks to understand the impact of contextual change on time perception.

10.2 Overview of the literature

10.2.1 Stimulus predictability and complexity

Using the VExP, Haith and colleagues (Haith, 1989; Haith, Adler and Wass, 1996) found that under conditions where both spatial and temporal aspects of a sequence were unpredictable, infant reaction times were longer than when only one aspect was unpredictable. Further, the CCH (Block and Reed, 1978) provided a possible explanation in that a remembered duration is judged longer if increased environmental changes occur at the time the duration was encoded.

So the first aim of Experiment 6 was to explore whether contextual change (e.g. change in number and presentation rate) do influence time perception as proposed by the CCH (Block and Reed, 1978; Block 1982). (Contextual changes are referred to as environmental changes by Block and Reed, 1978.) In conditions where no contextual changes occur between two sequences, that is the speed and number of head turns does not change, durations should be estimated as being shorter compared to sequences that are preceded by two environmental changes. Accordingly, the present experiment involved exposing infants to two conditions, a 'no change' condition and a 'two changes' condition. Specifically, it was hypothesised that in the no change condition, infants' ability to keep time should remain stable in both the long- and short-looking groups. In the two changes condition, timekeeping by long-lookers should be less accurate in the second sequence due to contextual changes that occurred between the sequences. It would be predicted, based on their performance in Experiment 5 that short-lookers would be able to maintain timekeeping regardless of any changes occurring.

The present experiment utilised the same socially significant stimuli as Experiment 5, namely the head turning task, in order to replicate the conditions that decreased infants' ability to keep time in Sequence 3 (S5). Further, as the animate stimulus was more appealing to infants as evidenced by the number of infants contributing usable data – Exp1=8/13, Exp2=40/47, Exp3=54/63, Exp4=54/63, Exp5=23/29 – the video clip of the head turning task was adapted to include two instead of four sequence video clips for the current experiment.

10.2.2 Internal clock speed

A second aim of Experiment 6 was to examine whether evidence could be found for a change in the speed of the internal clock, within the clock component of the SET model (Gibbon, 1977). According to the SET model, clock speed is concerned with the rate of emission of pulses from the pacemaker to the accumulator (see Figure 10.1) and determines whether the pulse emission rate changes under different conditions (Meck, 1983; 1998). Research exploring clock speed has involved animals (Maricq et al., 1981)

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or humans (Meck and Church, 1987) being trained to recognise a standard or referent duration in one state, for example under amphetamines, then being tested under a different condition, for example saline, which does not influence performance. Clock speeds differed depending upon which condition the participant was tested under; for example, the clock speed of an animal trained under amphetamines would increase, resulting in the animal perceiving durations as shorter than when tested under saline when the durations would be perceived as longer (Meck, 1983).

Figure 10.1 A typical SET model after Allan (1998) and Wearden (1999)
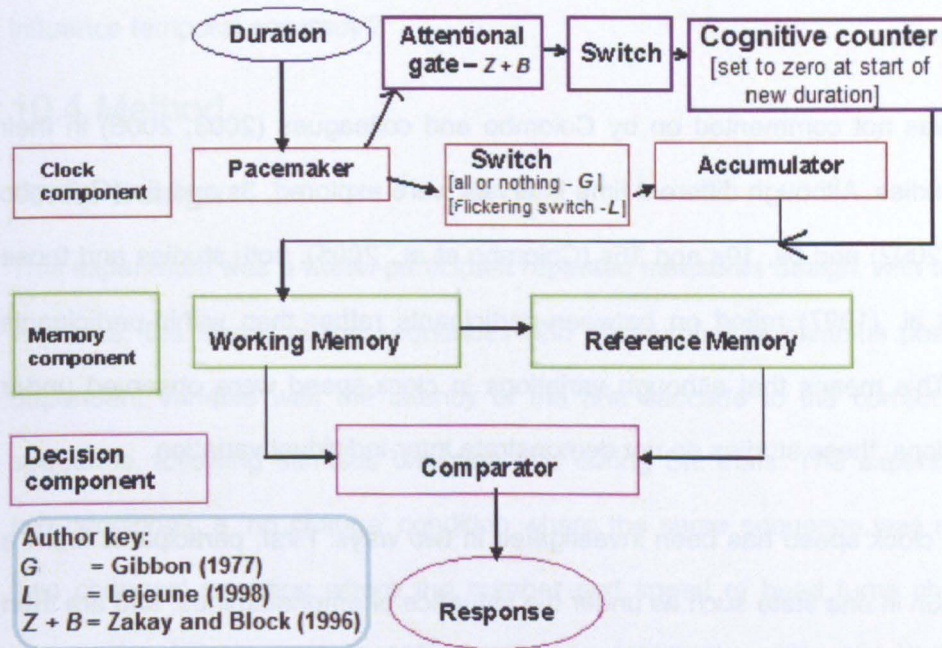
One of the limitations of the clock speed studies is that the animal participants were in a different state or condition at the time of testing than at the time of training (e.g. trained on saline, tested on amphetamines or vice versa, Meck, 1983). Under these conditions the clock component of the SET model would have been recalibrated in the testing condition as the participant was in a different state and thus produced a different duration. As suggested by Wearden (2001) and others, a more conclusive test of clock speed would be if the same participants were tested in two conditions e.g. two different durations of 3s and 1s within the same testing session, and performance compared across the two durations in the same study. This has been called state change without recalibration (Wearden, 2001). That is, the condition under which timing is to be estimated changes without the

opportunity for the participant to recalibrate their internal clock in between one testing session and the next, or to use the previous example, being under the influence of amphetamines and then saline.

Developmental differences in the variability of the internal clock were demonstrated by Wearden, Wearden and Rabbitt (1997). In comparison with younger adults, increase variability was observed in an elderly group (60yrs +) indicating that the internal clock might slow down with increased age. This suggests that the clock component is susceptible to developmental change and that increased variability might be observed for very young groups.

Clock speed was not commented on by Colombo and colleagues (2003, 2005) in their infant timing studies. Although different time intervals were explored, 3s and 5s (Colombo and Richman, 2002) and 5s, 10s and 15s (Colombo et al., 2005), both studies and those of Wearden et al. (1997) relied on between-participants rather than within-participants comparisons. This means that although variations in clock-speed were observed under different conditions, these studies do not demonstrate inter-individual variation.

To summarise, clock speed has been investigated in two ways. First, participants learn a standard duration in one state such as under the influence of amphetamines, and are then tested in a different testing session under different conditions such as saline, which should have no influence on timing (Meck, 1983; 1998). Clearly such procedures cannot be used with infants. Second, change in clock speed has also been observed between different groups of participants trained to estimate a standard duration (Wearden et al.,1997) or different standard durations (Colombo and Richman, 2002; Colombo et al., 2005). But no study has explored changes in clock speed over several changes of duration within the same testing session, with the same participants. The current experiment therefore aims to explore this gap in the research.

10.3 Research questions

Three research questions pertain to the present experiment, the first being the fifth core research question outlined in Chapter 1.

1. Is there evidence to suggest that contextual changes such as stimulus change affect infant time keeping?'

2. Do infants adjust the timing of their eye movements to account for coinciding changes in stimulus presentation speed?

3. When contextual changes are increased, do individual differences in look duration influence temporal accuracy'?

10.4 Method

10.4.1 Design

This experiment was a within-participant repeated measures design, with two independent variables; the speed of the sequences and the number of stimulus presentations. The dependent variable was the latency of the first saccade to the correct location in the sequence, following stimulus omission and during StL trials. The experiment comprised two conditions: a 'no change' condition where the same sequence was repeated; and a 'two changes' condition where the number and speed of head turns changed between sequences. Infants were presented with one continuous video clip that contained two head turning sequences.

After discussion about the challenge of recruiting participants, it was decided that infants should attend the Centre on two occasions to complete this experiment. During Visit 1 the 'no change' condition was presented and during Visit 2 the 'two changes' condition was presented as the experimental condition. As these conditions were not counterbalanced, age and practice effects might have influenced the results. By scheduling Visit 2 within a few days of Visit 1 age effects were hopefully minimised.

In the 'two changes' condition consecutive stimulus sequences with ISIs of different durations were presented to ascertain if there was any evidence that infants can adjust

their internal clock speed to different time intervals. An examination of eye movements after a change in timing between stimulus sequences would provide evidence from which to infer whether infants have an internal clock and whether they are able to recalibrate the clock in line with different time intervals presented to them. This aspect of timing was not calculated in previous experiments reported in this thesis due to difficulties with maintaining the POG.

10.4.2 Participants

Seventy-two infants between the ages of three months, three weeks and four months, one week (mean age four months, sd: three days) were mainly recruited from the local neighbourhood to take part in this study during the second testing phase. Of these, 12 infants were withdrawn by their parents for varying reasons (work commitments n=4, illness in family n=6, disinterest in research n=2), leaving 60 participants. The two conditions ('no change' and 'two changes') were completed on two separate visits to the Centre and parents were asked to attend at least one testing session, preferably both. Sixty infants participated on Visit 1 and 54 infants participated on Visit 2. There were several reasons for the decrease in numbers over the two visits; some parents felt unable to attend the Centre for two sessions either due to work or family commitments (n=4), but were willing to attend the Centre once. Additionally, two parents lived many miles away (e.g. Bristol, but grandparents worked for University) and could only attend once.

Data from eleven infants were excluded from the final sample because of fussiness or tiredness (n=9) or due to technical difficulties associated with a failure to calibrate the eye tracker (n=2). The final sample therefore involved 47 infants who provided usable data in at least one condition.

10.4.3 Apparatus

For a full description of the apparatus used in this experiment, please see Chapter 3, Section 3.4 and Figures 3.2 – 3.9.

10.4.4 Stimuli

The stimulus comprised dynamic video clips of a woman performing sequences of head turns similar to a game of 'peek-a-boo', as used in Experiment 5. There were two conditions. In the 'no change' condition', the speed and number of head turns remained constant. In the 'two changes' condition, infants were presented with two different stimulus sequences, that is the speed and the number of head turns changed between the sequence cycles. This condition replicated the changes between Sequence 2 (F9) and Sequence 3 (S5) in Experiment 5. The order of presentation was not counterbalanced due to challenges in infant recruitment, so the 'no change' condition was the control condition providing baseline data for the experiment. A description and order of the sequences are presented in Table 10.1.

During the testing phase, infants were randomly allocated to one of the four 'no change' conditions on Visit 1. On their second visit, infants were assigned to a corresponding 'two changes' condition (see Table 10.1), so that an infant assigned to Sequence (S5,S5) in Visit 1 would be tested on either (F9,S5) or (S5,F9) in Visit 2. This meant that the groups were only partially randomised.

Table 10.1 Description and order of sequences in the 'no change' condition and 'two changes' condition.
Key: Slow speed (S) 2sStL, 3sStA, 15s OM; Fast speed (F) 500mstStL, 1sStA, 5sOM.
Either 9 or 5 head turns per set

'No change' condition	'Two changes' condition
S9,S9	S9, F5
F9,F9	F9,S5
S5,S5	S5,F9
F5,F5	F5,S9

Figure 10.2 Experiment 6: Stimulus sequence for Sequence S5
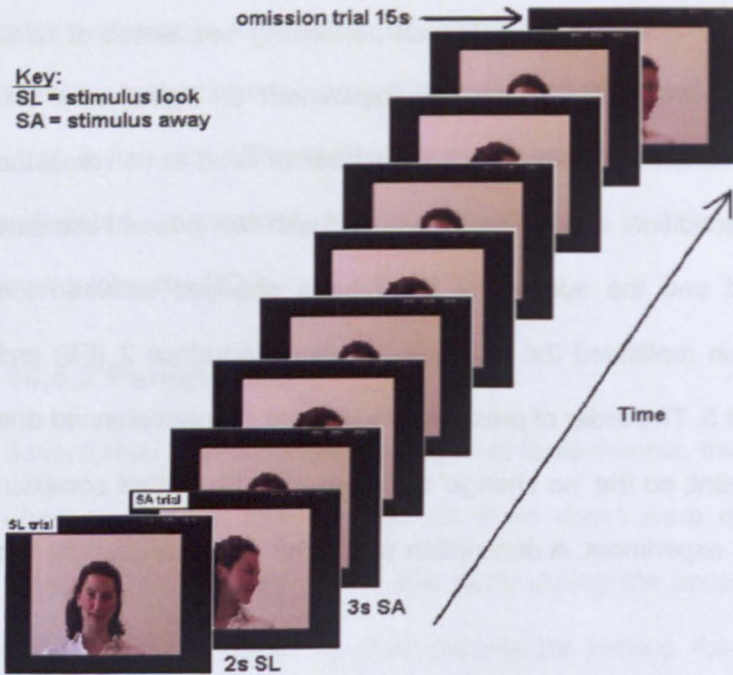
10.4.5 Procedure

As testing in this experiment was conducted over two visits, the procedure was the same for each visit, but with changed stimulus (see Table 10.1). As in previous experiments, informed consent, eye tracking calibration and baseline measure procedures were completed before commencing each testing phase.

10.4.6 Data analysis

In line with previous experiments reported here, the first saccade to the location of the stimulus in the stimulus present trials, and the first saccade to the location of the omitted stimulus in the omission trials were recorded. These areas of interest are marked as Areas 1 and 2 in Figure 10.3.below, and were the same as for Experiment 5. A visual inspection of the data showed that no infants looked to Area 3, the blank region of the screen.

Figure 10.3: Experiment 6 Areas of interest for coding eye movements
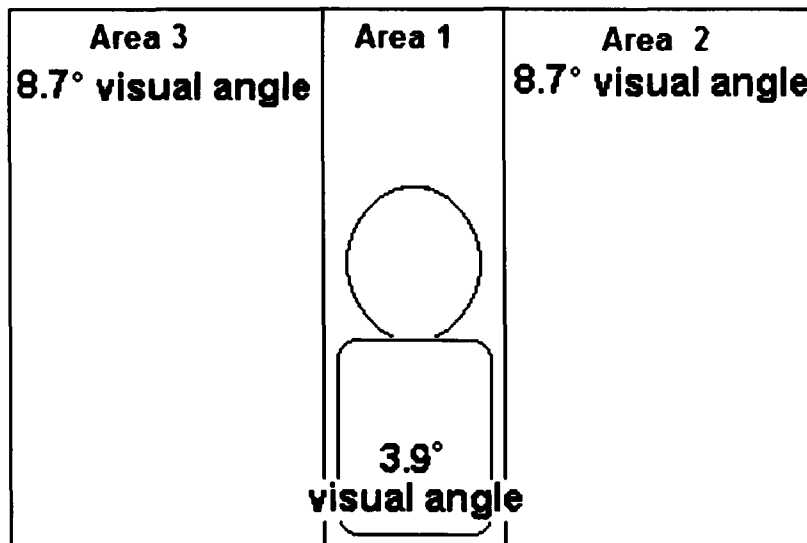
Eye movement patterns were examined and three timings were recorded. First, the first saccade to the stimulus on StL trials (Area 1). Second, the first saccade to the location of the stimulus woman's gaze on the StA trials (Area 2). Third, the first saccade to Area 1 during OM trials, and any saccades made early to the correct side during the last 500ms of the ISI preceding the OM trial. Omission trials were taken to start at the end of the previous ISI, that is, after 3 seconds in the slow sequence and after 1 second in the fast sequence.

10.5 Results

The data were used to ascertain whether changes in the speed and length of presentation within a stimulus sequence influenced infants' time keeping abilities. Two outcomes were expected. First, it was hypothesised that when the number and speed of head turns were held constant over two sequences ('no change' condition), infants' timekeeping performance should remain stable. Second, it was predicted that when two changes occurred between two sequences ('two changes' condition), infants would be unable to keep time in the second sequence. Table 10.2 below provides an overview of the data, presenting the median response times for the last three StL trials in each sequence and

the OM trials. Data for the 'no change' condition collected on Visit 1 are at the top of the table, and data for the 'two changes' condition from Visit 2 are at the bottom.

The first research question asked if contextual changes would influence infant time keeping within the 'two changes' condition. The data in Table 10.2 reveal that within the 'no change' condition, longer median response latencies were made for the slow than for the fast sequences and that a similar pattern was seen across Sequences 1 and 2. No clear pattern emerges in the 'two changes' condition, however, suggesting that contextual changes detrimentally affect infant time keeping.

Table 10.2 All Infants: Median and range (ms) of response latencies for the last three StL trials and the OM trials

Condition	permutationSequence	Sequence 1					Sequence 2				
		Stimulus look			Omission		Stimulus look			Omission	
		n	median	range	median	range	n	median	range	median	range
'No Change' condition	S9,S9	11	43	86	136	730	12	62	127	154	716
	F9,F9	13	28	92	124	168	14	19	79	29	138
	S5,S5	13	59	103	114	426	14	44	91	135	398
	F5,F5	12	17	40	62	222	9	28	62	44	316
'Two Changes' condition	S9,F5	14	43	108	83	683	13	21	22	111	357
	F9,S5	9	20	33	82	246	9	50	79	60	262
	S5,F9	11	58	90	16	34	9	16	34	64	300
	F5,S9	10	31	60	48	148	9	67	146	64	204

To ascertain whether infants are able to keep time within a sequence, the median latencies of saccades towards the stimulus during the last three StL trials were compared to the latency of the first saccade to the centre of the screen in the OM trial. These were subjected to a non-parametric Wilcoxon test as not all infants provided data for the data points in each sequence within a condition, that is, they may have provided data for Sequence 1 but not Sequence 2 and vice versa. If they were sensitive to the temporal components of each trial, the latencies for the stimulus present and omission trials should be similar, resulting in a non-significant Wilcoxon score. If contextual changes affect infant time keeping then it would be predicted that timekeeping may be evident in both sequences in the 'no change' condition, but only Sequence 1 in the 'two changes' condition. The analysis was conducted with the whole sample first (see Table 10.3). A second analysis divided the data into long- and short-looking categories based on infants' responses to the baseline measure.

No clear overall pattern emerges from these results except that infants only appear to keep time in some sequences. In the 'no change' condition where time keeping would be predicted in both sequences, this is observed only in Sequences 1 and 2 of (S9,S9). However, time keeping is also observed in Sequence 2 of both (F9,F9) and (F5,F5) which are fast sequences. In the 'two changes' condition where time keeping would be predicted in the first but not the second sequence, timekeeping was observed in both sequences in (S5,F9) and Sequence 1 of (S5,F9) but not Sequence 2 of (F9,S5). Sequence (F9,S5) replicates Sequences 2 and 3 of Experiment 5, but here the opposite pattern of results was observed: infants kept time in the second, but not the first sequence, thus failing to replicate the findings of Experiment 5. There is some indication, however, that time keeping is observed more often in slower rather than faster sequences suggesting that infants may be sensitised to the temporal parameters in these sequences.

Table 10.3 Wilcoxon tests results to ascertain whether infants can keep time within a sequence. Key √ = timekeeping, × = no timekeeping

Condition	Sequence permutation	Sequence 1	Sequence 2
'No Change' condition	(S9,S9)	Z = 1.334, p = .182 √	Z = 1.120, p = .263 √
	(F9,F9)	Z = 2.091, p = .037 ×	Z = 1.179, p = .239 √
	(S5,S5)	Z = 2.402, p = .016 ×	Z = 1.915, p = .056 ×
	(F5,F5)	Z = 2.580, p = .010 ×	Z = .980, p = .327 √
'Two Changes' condition	(S9,F5)	Z = 2.103, p =.035 ×	Z = 2.667, p = .008 ×
	(F9,S5)	Z = 2.547, p = .011 ×	Z = .980, p = .327 √
	(S5,F9)	Z = .889, p = .374 √	Z = 2.547, p = .011 ×
	(F5,S9)	Z = 1.244, p = .214 √	Z = .178, p = .859 √

The second research question relates to whether infants adjust the timing of their eye movements to coincide with changes in stimulus presentation speed. If so, it could be inferred that infants adjust the speed of their internal clocks to different time intervals. This would be seen if the pace of infants' eye movements at the beginning of a sequence are different from those seen at the end of the sequence, and a comparison of these latencies would reveal the number of trials required to recalibrate the clock. The mean latency of the first saccade to the first two stimuli was compared with the first saccade to the last two stimuli, over the two sequences. If infants adjusted the speed of their saccades, there should be a difference between these two latencies. The mean latencies of two trials at the beginning and end of each set were selected to ensure that the same criterion could be applied to both the four- and eight-stimulus presentation sequences. The mean response latencies to the first and last two stimuli within each sequence are reported Table 10.4 below.

Table 10.4 Comparison of the mean (ms) response latencies of the first and last two stimuli in each sequence.

Condition	permutationSequence	First 2 stimuli Sequence 1			Last 2 stimuli Sequence 1			First 2 stimuli Sequence 2			Last 2 stimuli Sequence 2		
		n	mean	sd	n	mean	sd	n	mean	sd	n	mean	sd
'No Change' condition	S9,S9	11	105	77	12	55	34	10	62	24	9	74	43
	F9,F9	10	61	41	10	43	46	10	39	25	13	39	39
	S5,S5	11	72	52	15	52	36	15	43	34	14	71	43
	F5,F5	5	28	17	7	19	13	9	30	20	8	29	16
'Two Changes' condition	S9,F5	16	88	55	16	59	40	12	30	15	14	23	12
	F9,S5	8	27	17	9	26	14	11	57	28	11	67	43
	S5,F9	13	65	31	12	88	42	8	36	17	6	16	06
	F5,S9	7	40	21	7	19	13	12	58	52	12	70	33

In the 'No Change' condition, responses in the slow sequences get slower whilst the speed is maintained in the fast sequences, but in the 'Two Changes' condition, they fluctuate in line with the change of stimulus presentation. Tables10.4 and 10.5 suggest that there was a change in clock speed in all sequences in the 'two changes' condition, as response latencies decrease in fast sequences and increase in slow sequences. The data from saccades made during the first and last two StL trials were again subjected to a Wilcoxon test to ascertain if the infants adjusted the pace of their eye movements to account for the change in the rate of stimulus presentation. The results, reported in Table 10.6 below, did not reach statistical significance.

Table 10.5 Differences between response latencies at the beginning and end of sequences to evaluate evidence for change in clock speed.

Condition	Sequence permutation	Sequence 1			Sequence 2		
		Beginning vs end		Difference (ms)	Beginning vs end		Difference (ms)
'No Change' condition	(S9,S9)	S9	105 - 55	-50	S9	64-74	+10
	(F9,F9)	F9	61 - 43	28	F9	39 - 39	0
	(S5,S5)	S5	72 - 52	20	S5	43 - 71	+28
	(F5,F5)	F5	28 - 19	9	F5	30 - 29	-1
'Two Changes' condition	(S9, F5)	S9	88 - 59	-29	F5	30 - 23	-7
	(F9, S5)	F9	27 - 26	-1	S5	57 - 67	+10
	(S5, F9)	S5	65 - 88	+23	F9	36 - 16	- 20
	(F5, S9)	F5	40 - 19	-21	S9	58 - 70	+ 12

Table 10.6 Table of Wilcoxon test scores to examine clock speed

Sequence	First vs Last Sequence 1	First vs Last Sequence 2
(S5,F9)	Z = .674, p = .179	Z = 1.412, p =.158
(F9,S5)	Z = .365, p = .715	Z = .756, p = .450
(S5,F9)	Z = .890, p = .374	Z = 1.095, p = .273
(F5, S9)	Z= .674, p = .500	Z = 1.511, p = .131

The discussion will now turn to examining the results from the second analysis, which addresses the third research question, 'When contextual changes are increased, do individual differences in look duration influence temporal accuracy'? The median and range response data displayed in Table 10.7 and Table 10.8, show that infants identified as consistent long-lookers have lower response times than consistent short-lookers for all

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but Sequence 2 of Condition 3 in the 'No Change' condition. In the 'Two Changes' condition, short-lookers had lower response rates in Condition 9, but not in conditions 10-12. This pattern of results suggests that long-lookers were more accurate on the whole at judging the time intervals.

Table 10.7 Median response latencies (in seconds) for the last three Stimulus look (StL) trials and the stimulus omission (OM) trials in the 'No Change', conditions 1-4 for consistent long- and short-looking infants (SL, LL)

Infant categorisation	No Change Condition															
	Cond 1 (S9,S9)				Cond 2 (F9,F9)				Cond 3 (S5,S5)				Cond 4 (F5,F5)			
	Seq 1		Seq 2		Seq 1		Seq 2		Seq 1		Seq 2		Seq 1		Seq 2	
	StL	OM	StL	OM	StL	OM	StL	OM	StL	OM	StL	OM	StL	OM	StL	OM
SL	3.25	4.37	.92	5.41	1.02	1.36	.11	.07	.44	1.26	.34	1.88	.31	.88	.20	.89
LL	.92	1.37	.74	1.66	.22	.84	.16	.78	.61	.69	.86	1.10	.10	.62	.41	.31

Table 10.8 Median response latencies (in seconds) for the last three Stimulus look (StL) trials and the stimulus omission (OM) trials in the 'Two Changes', conditions 9-12 for consistent long- and short-looking infants (SL, LL)

Infant categorisation	Two Changes Condition															
	Cond 9 (S9, F5)				Cond 10 (F9,S5)				Cond 11 (S5,F9)				Cond 12 (F5.S9)			
	Seq 1		Seq 2		Seq 1		Seq 2		Seq 1		Seq 2		Seq 1		Seq 2	
	StL	OM	StL	OM	StL	OM	StL	OM	StL	OM	StL	OM	StL	OM	StL	OM
SL	.30	.62	.41	.31	.23	2.20	.53	1.00	.57	.64	.34	2.07	.12	1.60	.87	.35
LL	.50	.65	.22	1.11	.18	.82	.75	.60	.73	.88	.09	.90	.36	.28	.36	1.11

Tables 10.9 and 10.10 give the Wilcoxon test data, which examined whether SL and LL infants were keeping time within a sequence. To demonstrate timekeeping, similar response times should be observed within the stimulus present trials and stimulus omission trials, thus producing non-significant Wilcoxon test results. The results suggest that during the nine stimulus sequences in the 'No Change' condition (Table 10.9) infants kept time in both sequences, as the response latencies are non-significant. Infants kept time in all the sequences except Condition 3, Sequence 2 for the short-lookers only, suggesting that five stimuli are adequate for forming a representation of the to-be judged interval and that long-lookers are more able to do this than short-lookers. Practice effects cannot account for these results, as infants only looked at one condition.

Table 10.9 Wilcoxon tests results to ascertain whether infants can keep time within a sequence, 'No Change', Conditions 1-4. Consistent long- and short-looking infants (LL, SL)

| Infant categorisation | No Change Condition | | | | | | | |
| | Cond 1 (S9,S9) | | Cond 2 (F9,F9) | | Cond 3 (S5,S5) | | Cond 4 (F5,F5) | |
	Sequence 1	Sequence 2	Sequence 1	Sequence 2	Sequence 1	Sequence 2	Sequence 1	Sequence 2
SL	Z=1.342 P=.180	Z=1.342 P=.180	No data – lost POG	Z=-1.000 P=.317	Z=1.604, p=.109	Z=2.023, p =.043	Z=1.461, p = .144	Z =1.069 p = .285
LL	Z=1.461, P=.144	Z=1.604, P=.109	Z=1.826, p = .068	Z=1.826, p =.068	Z = .365, p = .715	Z = .730, p = .465	Z =1.604 p = .109	Z = .477, p = .655

The results presented for the 'Two Changes' condition in Table 10.10 below reveal that infants are able to keep time within the two sequences which change both the number and speed of the head turns. Condition 10, which replicated Experiment 5 (Sequence 3) where evidence of timing was not found, did reveal evidence of timing here. So the initial finding in Experiment 5 was not replicated in this experiment. No clear differences emerged between the long- and short- looking groups.

Table 10.10 Wilcoxon tests results to ascertain whether infants can keep time within a sequence, 'Two Changes Condition' Conditions 9-12. Consistent long- and short-looking infants (LL, SL)

Infant categorisation	Two Change Condition							
	Cond 9 (S9, F5)		Cond 10 (F9,S5)		Cond 11 (S5,F9)		Cond 12 (F5.S9)	
	Sequence 1	Sequence 2	Sequence 1	Sequence 2	Sequence 1	Sequence 2	Sequence 1	Sequence 2
SL	Z = .405, p = .686	Z = 1.483, p = .138	Z = 1.00, p = .317	Z = -1.00 p = .317	Z = .000, p = 1.000	Z = 1.00, p = .317	Z = 1.00, p = .317	No data lost POG
LL	Z = 1.483, p = .138	Z=1.461, p = .144	Z = 1.826, p = .068	Z = .944, p = .345	Z = .000, p = 1.000	Z = 1.604, p = .109	Z = .000, p= 1.000	Z=.447, p = .655

10.6 Discussion

The present experiment investigated three questions. First, 'Is there evidence to suggest that contextual changes influence infant time keeping?' Second, 'Do infants adjust the timing of their eye movements to account for changes in stimulus presentation speed?' Third, 'When contextual changes are increased, do individual differences in look duration influence temporal accuracy'?

In order to ascertain whether contextual changes influenced infants' time keeping abilities, the number and speed of head turns across sequences remained the same in the 'no

change' condition but varied in the 'two changes' condition. It was hypothesised that changes within the 'two changes' condition would have a detrimental effect on infant time keeping in the second sequence. The OM trial data reported in Table 10.2 revealed that in the 'no change' condition, the median response latencies were longer for the slower sequences than the faster sequences, suggesting that infants' sensitivity to temporal information is inversely related to the degree of change within an event or sequence. No clear pattern emerged in the 'two changes' condition, suggesting that infants become insensitive to the temporal component of these sequences when multiple changes are introduced.

Any evidence of timekeeping should also be observed if infants track on time within a sequence, that is, during StL and OM trials. Wilcoxon test results compared the median response latencies of the first saccade towards Area 1 (Figure 10.3), during the last three StL trials to the response latencies of the first saccade towards Area 1 in the OM trial. It would be predicted that if contextual changes influenced infant timekeeping detrimentally, then the Wilcoxon tests should produce non-significant results in the 'two changes' condition. However, the findings were mixed. In the 'no change' condition where the sequences were identical, only infants participating in Sequence (S9,S9), were able to keep time over the two-stimuli sequences. This suggests that infants may require slower presentation speeds with more exemplars to perceive time intervals. The results for the faster sequences, however, showed that although infants were unable to keep time during Sequence 1, they could in Sequence 2. An explanation for this could be that they became accustomed to the speed of the sequence in Sequence 1, similar to a practice sequence, and need more exemplars. In terms of the SET model of timing, it would appear that in the fast presentation sequences two-stimulus presentations were needed for infants to form a representation of the referent duration to be used in the comparator of the decision component.

The inability to keep time in Sequence (S5,S5) suggested that it was the number of exemplars presented rather than the speed of presentation which had the greater impact

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on time perception, as time keeping was observed in Sequence (S9,S9). These results suggest that infants require more than five examples of the referent duration to form a representation. A review of the literature shows that between five (Droit-Volet, 2003, Friedman, 2003) and eight (McCormack et al., 1999) trials are presented in practice sessions for children of between 3.5 to 6.5 years old respectively. In adults, the training phase usually consists of approximately three practice trials (Franssen and Vandierendonck, 2002), whereas considerably longer training sessions are afforded to animals and birds, such as 143 sessions (Aum, Brown and Hemmes, 2004; 2007). Animals and birds, in common with infants, are unable to understand direction, and so are not provided with instructions in the same way as children and adults in human timing studies. Additionally, in the present experiment an intensive training period was not provided, other than the limited number of StL trials preceding the stimulus omission trial where time keeping was expected to be observed. Nevertheless infant time keeping was observed in some sequences.

The present experiment sought to explore further the findings reported in Experiment 5 (see Chapter 9), which revealed an inability of infants to keep time when the speed and length of a stimulus sequence changed. The 'two changes' condition, in particular Sequence (F9,S5), are identical to Sequences 2 and 3 of Experiment 5 where no time keeping was observed. Interestingly though, the present experiment reveals a different pattern of results for these sequences. Although infants were unable to keep time in Sequence 1 (F9) they did demonstrate evidence of time keeping in Sequence 2 (S5). In both occurrences where fast sequences were followed by slow sequences (F9,S5) and (F5,S9), evidence of timekeeping was observed in Sequence 2 but not Sequence 1. One reason for this could be that infants find longer durations easier to remember.

Of note is the finding for Sequence (F5,S9) in which nine stimuli are presented at the slow speed in Sequence 2 and where time keeping is very accurate. This suggests that although infants were unable to adjust to the fast speed of Sequence 1, completion of F5 (which could loosely be called 'training') facilitated infants' timekeeping in the slow

sequence S9, thus producing an accurate estimate of that duration. Sequence (S5,F9) again demonstrated infants' ability to keep track of slow sequences but not fast sequences, indicating that for these participants a slower presentation rate allowed for optimal time keeping. The results for this experiment are therefore mixed, providing no clear evidence for the Contextual Change Hypothesis (Block and Reed, 1978), although this seemed to account for the findings reported earlier (in Chapter 9) that seemed to indicate that increasing contextual changes influences time perception.

Attention now turns to the second research question: whether infants adjust the timing of their eye movements to coincide with changes in stimulus presentation speed. It was not possible to provide evidence of infants tracking at different speeds in previous experiments due to a lack of usable eye tracking data for some of the trials. Failure to capture infants' attention and data was thought to be due to the inanimate nature of the stimulus sequences in Experiments 1-4. The present experiment, on the other hand, captured data from most infants at each data point. The results reported for the 'two changes' condition in Tables 10.5 and 10.6 appear to suggest that infants did adjust their eye movements to accommodate changes in presentation speed. However, as the Wilcoxon Test results did not reach significance, no evidence was found to support the notion that infants recalibrate their internal clocks to coincide with changes in stimulus presentation speed.

The results from the analysis that examined individual differences in looking strategy and the third research question were equivocal, producing mixed results. On the whole, infants were able to keep time, suggesting that in this task, looking strategy did not influence time keeping, although increasing contextual changes did. The small numbers of infants included in this analysis, however, means that these findings would need to be replicated with a larger sample.

The analysis conducted in this thesis has set out to ascertain whether time keeping can be observed according to three different levels of evidence. First by examining response latencies in the omission trials; second, by investigating if infants' response latencies for

StL trials and OM trials are similar; and lastly by determining whether differential responding occurs across sequences with different ISIs. This approach has revealed mixed findings allowing no firm conclusions to be drawn from the data. A likely explanation for these inconsistencies could be that the methodological and technical difficulties encountered in testing infants preclude stable performance and reliable measurements.

10.7 Chapter summary

The experiment reported in this chapter set out to explore two aspects of timing. First, whether the Contextual Change Hypothesis proposed by Block and Reed (1978) could account for an inability of infants to keep time when presenting sequences with increased contextual changes within a stimulus sequences. The results were inconclusive, showing that infants provided evidence of time keeping in 50% of the trials in both the 'no change' and 'two changes' conditions. The second aim sought to explore whether infants adjust the timing of their eye movements to coincide with changes in stimulus presentation speed. Differences in response latencies were observed in the 'two changes' condition, but as these results did not reach statistical significance the notion that infants recalibrate their clock speed with different durations in order to keep time is unsupported and therefore requires further attention within future research. No clear differences between long- and short-looking infants' responses were observed in the second analysis providing no answer to the third research question. On a positive note, the stimulus used in this Experiment continued to keep the infants' attention and allowed data to be obtained from the majority of infants, showing that animated stimulus sequences should be considered in future research.

Chapter 11
General discussion and final conclusions

11.1 Introduction

Whilst interval timing has been studied extensively in animals and human adults and more recently in children as young as 3 years of age, to date there has been little research with infants. The dominant framework within which the research has been discussed is Gibbon's (1977) Scalar Timing Theory, otherwise known as Scalar Expectancy Theory (SET), and the SET model. More recently, this model has been extended by Droit-Volet and Wearden (2001) and Droit-Volet (2003), and termed 'devSET' by the current author to account for developmental trends in children of 3 years of age and upwards. This chapter discusses how the results of the experiments reported in this thesis can be accommodated within the devSET model. It is claimed in this thesis that the evidence presented suggests that the model should be extended to account for time perception in infants as young as 4 months of age. As the study of interval timing in infants is nascent, many research questions arise, only some of which have been addressed in this thesis. These questions address key issues that include whether overt behaviours such as eye movements can provide measurable evidence of infants' temporal estimation abilities as well as a consideration of some of the factors which may influence this ability.

The first part of this chapter will focus on a discussion of how the infant findings can be accounted for within the framework of the devSET model. Following this discussion, alternative explanations for the findings will be discussed. Finally methodological and other issues are discussed before outlining future areas of research.

11.2 Review of the main outcomes from studies

Seven main research questions emerged from a review of the timing literature, each of which has been addressed in at least one of the experiments reported in this thesis. These questions will now be examined and briefly answered before the implications of these findings are explored in more detail.

The answer to the first research question "Can infants keep time and how might this be accounted for within the devSET model (Droit-Volet and Wearden, 2001), Droit-Volet, 2003)" is equivocal, that is, there is some indication within the data reported here that this may be the case; however, there are limitations. Evidence of infant time keeping was demonstrated to differing degrees throughout the reported experiments. However, due to technical difficulties and notwithstanding infant limitations, timekeeping was only demonstrated clearly in Experiment 6 which used socially significant animated stimulus sequences.

As with research question one, the second research question – whether overt behaviours such as eye movements can provide evidence of infants' temporal estimation abilities – can be answered with a 'qualified yes'. The experiments reported here have explored several stimulus designs with mixed results. The findings suggest that the optimal method to obtain such data is to use animated stimulus sequences where the background remains unchanged throughout the experiment.
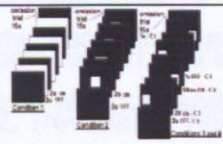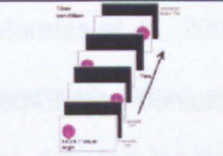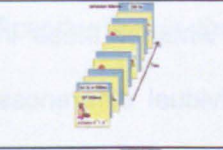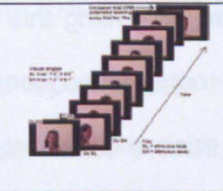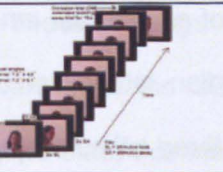
Closely linked to the second research question, the third question asked whether overt behaviours such as eye movements provide evidence of infants' temporal estimation abilities over more than one time interval. For ease of reference, Table 11.1 shows the stimuli used and the time intervals explored in each experiment. The data reported in Experiments 1, 2, 3, 5 and 6 provided evidence to varying degrees of infant time keeping over more than one interval. Notably, Experiment 1 reported one infant who kept time over three different time intervals (3s, 1s and 750ms). This experiment used black and white stimulus sequences in an effort to replicate the findings of Colombo and Richman (2002), who found evidence of time keeping in infants using heart rate measures. The black and

white stimuli used in Experiment 1, however, appeared uninteresting to many infants, resulting in little reliable data. Therefore the stimulus was changed for Experiment 2 to a smiley face. With this adjustment it was demonstrated that some infants could keep time over the same three time intervals as Experiment 1. Furthermore it was found that the three ISIs resulted in differentiated responses by infants, suggesting that they were aware of the temporal properties of those ISIs. The stimulus sequence, however, was not conducive to effective data collection using eye tracking technology, as the black and white stimulus background made infants' pupils expand and contract, affecting the maintenance of the POG cross hair.

In an attempt to overcome this, the background colour of the stimuli was changed for Experiments 3 and 4. These experiments explored infants' abilities to track fast sequences of 2s and 500ms durations. Time keeping was observed over all three sequences, although again there was considerable within and between infant variability. The data generated by Experiments 3 and 4 were more reliable but still subject to technical difficulties due to the changing background colours of the stimuli. Finally for Experiments 5 and 6, the stimulus was changed to an animated video clip with a consistent background. This modification appeared to offer a more reliable method for measuring infant time keeping at two time intervals (3s and 500ms). Having obtained overt behavioural evidence over a range of intervals (500ms, 750ms, 1s, 2s and 3s) the question of what might influence infant time keeping was then explored.

The role of attention in time keeping was explored in the fourth research question by signalling the onset and offset of a time interval by an auditory cue. The ranges of response latencies decreased in the auditory condition. It was posited that the auditory cue influenced the switch mechanism in the SET model by focussing attention on the to-be-timed duration. However, as time keeping was not demonstrated in all auditory sequences, it was suggested that these cues may have confused infants, making the stimuli ambiguous and resulting in longer response latencies.

Table 11.1 Table of stimuli and time intervals explored in each experiment conducted for this thesis

Experiment	Stimuli	Inanimate/Animate Stimuli	Time interval explored
1		Inanimate stimuli	Conditions 1,2, and 3 = 3s, Condition 4 = 1s
2		Inanimate stimuli	Slow = 3s Medium = 1s Fast = 750ms
3		Inanimate stimuli	Slow = 2s Fast = 500ms
4		Inanimate stimuli	500ms [Auditory and silent conditions]
5		Animate stimuli	Slow = 3s Fast = 500ms
6		Animate stimuli	Slow = 3s Fast = 500ms

The fifth and sixth research questions were answered by Experiment 5, which examined the influence of social saliency, and Experiment 6 investigating contextual changes. Increased social saliency using animate video clips of a head turning task overcame previous limitations with inanimate stimuli and increased data collection. Evidence of time keeping was demonstrated in Experiment 5 in all sequences except one, Sequence 3. One possible explanation for this was explored in the fifth research question: "Is there evidence to suggest that contextual changes affect infant time keeping?" Contextual changes were proposed by Block and Reed (1978) to explain the lengthened durations

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perceived using Retrospective Timing. As the speed and length of the sequences changed between Sequences 2 and 3 of Experiment 5, Experiment 6 set out to explore whether the CCH could provide a satisfactory explanation for infants' apparent inability to keep time in Experiment 5, Sequence 3. Although Experiment 6 failed to replicate the results of Experiment 5, it demonstrated that timekeeping was enhanced when infants were presented with a change in the number and speed of head turns in each sequence, thus failing to support the CCH (Block and Reed, 1978).

Evidence relating to the final research question was obtained from Experiments 1–6. The question asked whether individual differences in the information processing strategies employed by infants would be observed, and if so whether these influenced infants' temporal estimation abilities. Some evidence for individual differences was found, but again this was equivocal. Notwithstanding, using the same procedure as Colombo (1987) as a baseline measure, two groups of infants emerged. Infants were categorised as either long- or short-lookers based on the length of the longest look to each of two stimuli, a face and a checkerboard, so that two data points were obtained. Using this categorisation, a second analysis restricted to those infants who were categorised consistently on both baseline measures, was conducted on the data for each experiment to examine the influence on infant timekeeping. The tentative pattern of results that emerged suggested subtle differences between the two groups. The median latency of the first saccade towards the stimulus made during each of the last three stimulus present trials was compared to the latency of the first saccade to the position of the omitted 'stimulus' during the omission trial. Long-looking infants appeared to track the stimulus present trials and then reproduce a saccade at a similar interval in the stimulus omission trials. This resulted in a reduction of variance within latencies. Long-lookers also appeared to benefit more from the addition of auditory cues than short-lookers in that response latencies were generally shorter for the former group. Statistically significant differences between the auditory and silent conditions were found for Sequence 1 in long-lookers and Sequence 3 in short-lookers in Experiment 4. However, as the numbers in the second analysis were small, the results have to be treated with caution. There also emerged a group of infants,

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termed inconsistent, who changed looking category either across baseline stimuli or visits; these are discussed later.

Experiments 5 and 6 also provided behavioural evidence of gaze following in four-month-old infants. At present there is no consensus as to when the ability to follow gaze emerges, with some researchers suggesting that this emerges by three months (Churcher and Scaife, 1982; Trevarthen, 1993; Butterworth, 2001) and others that it emerges by six to ten months (Morales et al., 2000; DeGroot, Roeyers and Striano, 2007; Kuroki, 2007). In the present research, when presented with socially significant stimulus sequences, gaze following as denoted by the movement of the eye tracker's POG cross hair was observed. Significantly, this is the first time this has been observed in four-month-old infants.

Having summarised the main findings, the discussion will now turn to how these findings may be explained by the devSET model (Droit-Volet and Wearden, 2001).

11.3 Implications for the devSET model

The experiments reported here have extended our knowledge of infant time perception abilities, and provided evidence of timekeeping in some infants under certain circumstances. These findings can be explained within the devSET model, the developmental version of the SET model (Gibbon 1977), proposed by Droit-Volet and Wearden (2001). To date, this model has been used to explain timing data obtained from participants ranging from 3 to 99 years of age. So this is the first time that the devSET model has been applied to infants of four-months old.

Before embarking on a discussion of the implications of the devSET model however, it is important to state that due to methodological reasons (see Chapter 3, Section 3), the experimental tasks reported in this thesis were not designed to test SET or devSET directly as they are not timing tasks per se and only have up to 4 data points per study, that is up to 4 omission trials. In other timing studies, participants will have 30+ experimental trials. As mentioned in Chapter 2, the temporal generalisation (TG) and

temporal bisection (TB) tasks are specifically designed to test the SET and devSET models being used to date, with animals and humans but not infants. Timing tasks involve participants making decisions about a just-presented duration, compared to a standard duration, and such tasks are inappropriate for infants. Therefore, the infant data reported in this thesis could not produce TG or TB gradients that can be compared directly to previous research. TG and TB tasks also require lengthy training periods before the participant, especially animals and children, can make appropriate responses, which would be impossible with infants due to their much shorter attention span. Moreover, the responses required were either 'yes' or 'no' and many trials were completed per participant in each study to obtain the reported results, again impossible requirements for infants. Further, the current experimental tasks require that infants respond to the interval of the ISI rather than whether the just presented interval is the same as (TG task), or either longer or shorter than (TB task), the standard duration previously learned. Therefore, the current empirical research merely allows for hypotheses and suggestions regarding infants' abilities. Further empirical work building on these hypotheses may in time allow for more concrete proposals to be made regarding infants abilities. However, and notwithstanding this caveat, implications for the devSET model can still be drawn. As originally outlined in Chapter 2, Section 2.3.2, the four main tenets of the devSET model are as follows.

First, according to the paradigm employed by Droit-Volet and Wearden (2001), there is variability in the representation of the standard duration within long term memory. That is, many experiments designed to investigate time perception use a standard duration which is a time interval (such as 3s) to be learned and later estimated as in the TG task or compared as in the TB task. Second, children employ a conservative decision rule when deciding whether to make a 'yes' or 'no' response in temporal tasks. Third, random responding in children decreases from the age of 3 to 8 years old with no random responding observed by 8 years. Fourth, memory of the standard duration is distorted within long term memory. Each tenet will be considered in turn with respect to the data from the infant studies reported in this thesis.

The first tenet relates to the variability in the representation of the standard duration within long term memory. According to the devSET model, each time the participant is exposed to the standard duration the duration is encoded slightly differently. For example, in adults a 4s standard duration may be encoded as 3.9s, 4.0s or 4.1s; the mean of these durations is the standard, in this case 4s. As can be seen from Figure 11.1, this variability is greater with children than adults as evidenced by less steep temporal generalisation plots (McCormack et al., 1999; Droit-Volet et al., 2001) and flatter temporal bisection plots (Droit-Volet and Wearden, 2001). Variance could stem from encoding the standard duration during the 'training' period as participants have greater exposure to the standard, which is encoded slightly differently each time it is encountered thus increasing variability within each representation. In the McCormack and Droit-Volet studies, children underwent extended training periods until each child individually learned the standard. In contrast, infants in the experiments reported here received between four and eight 'training' (stimulus present) trials in which to learn the standard duration. This presents a limitation to the comparability of the results between these experiments; however, as very young infants will not tolerate long 'training' periods consisting of many trials it was not possible to conduct similar extended training phases as outlined in the McCormack and Droit-Volet studies, thus limiting variability in response latencies.

Figure 11.1 Temporal Generalisation and Temporal Bisection plots for children and adults

(after McCormack et al., 1999)
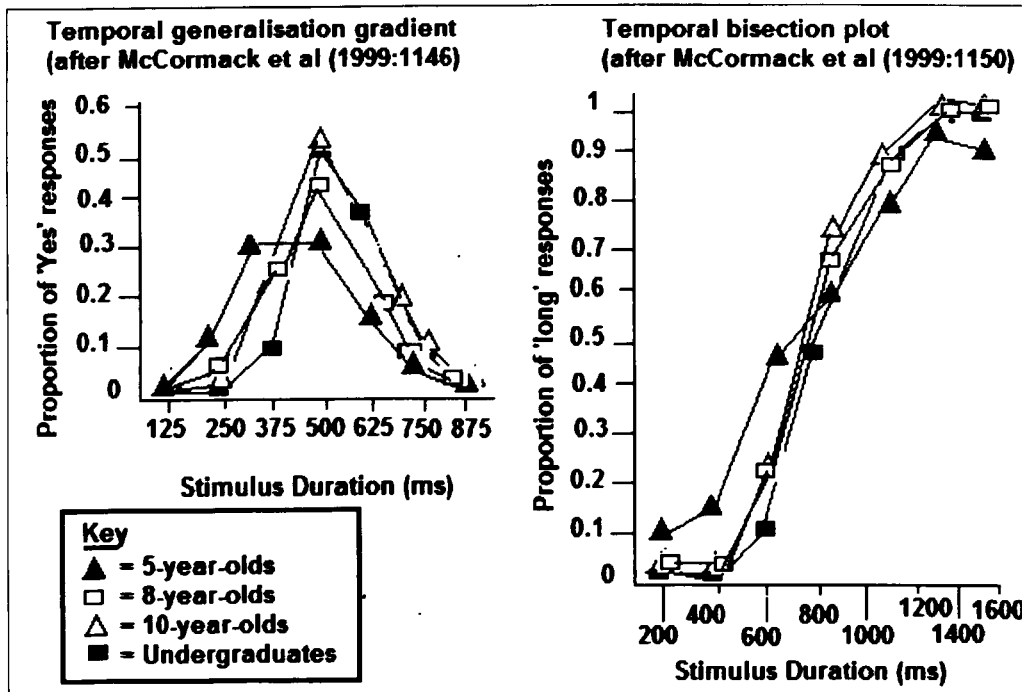
The second tenet stated that children employ conservative decision rules when choosing whether to make 'yes' or 'no' responses in temporal tasks. In temporal generalisation tasks participants learned a standard duration and were subsequently presented with a range of comparison durations spaced evenly (e.g. every 150ms) either side of the standard. Participants indicated whether the just presented duration was the standard or not. McCormack et al. (1999) and Droit-Volet and Wearden (2001) argue that when young children were unsure of whether the just presented duration was similar to the standard, they made shorter responses resulting in a leftward shift in the temporal generalisation gradient (see Figure 11.1), indicating that these children judged the comparison duration immediately adjacent to the standard as being the same as the standard. The leftward shift effect was observed in five- and ten- year-old children in the McCormack et al. study, and in three- and five-year-olds in the Droit-Volet study. A notable difference emerged between the developmental transition point where the gradient became adult-like with a rightward shift, with McCormack stating it occurred at young adulthood (20 years approximately), whereas Droit-Volet argued it at eight years old. Regardless of the debate

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about the timing of the developmental transition, it is clear that young children make shorter responses. As the devSET model has only been applied to data from children of three years and upwards, questions remain about the quality of infants' responding and whether additional developmental transitions occur during infancy. Notwithstanding, it could be hypothesised, based on the data obtained in the present series of experiments, that infants would make longer responses as responses were made in the omission trials after the onset of the omitted stimuli.

The experimental tasks described within this thesis follow the same method of interrupting a predictable stimulus sequence. Eye movement patterns were observed to establish whether infants delay their responses until after the ISI has elapsed in the interrupted (or omission) trial. If infants are consistently anticipating the arrival of the next stimuli, their responses will be shorter and so may be made during the previous ISI, or near to the point of stimulus omission, using a conservative decision rule. If they wait until after the ISI has elapsed, then they will make longer responses. In Experiment 2, two infants responded within 500ms of the ISI elapsing but to the 'incorrect' location (e.g. the location of the last stimulus presented) so their data were discarded. However, approximately 10% of infants in Experiment 5 responded within 150ms of the time when the stimulus should have appeared, suggesting that they may have learned the duration of the ISI during the previous SP trials. Infants responded after the duration had elapsed (although not making decisions about the duration as in temporal tasks), so the data, if plotted on a temporal generalisation gradient, would result in a shift of the gradient to the right. Thus four-month-old infants make longer, not shorter responses, which is opposite to what the devSET model would predict (see Figure 11.2). The simplest explanations for this are that either the data from the different experimental tasks cannot be compared, or that the ISI is just too short, explaining the late responding.

Figure 11.2 Possible location of temporal generalisation plot for infants

Temporal generalisation gradient (after McCormack et al (1999:1146)

NB: Red stars indicate possible location of infant data if using comparable TG task

Key
▲ = 5-year-olds
□ = 8-year-olds
△ = 10-year-olds
■ = Undergraduates
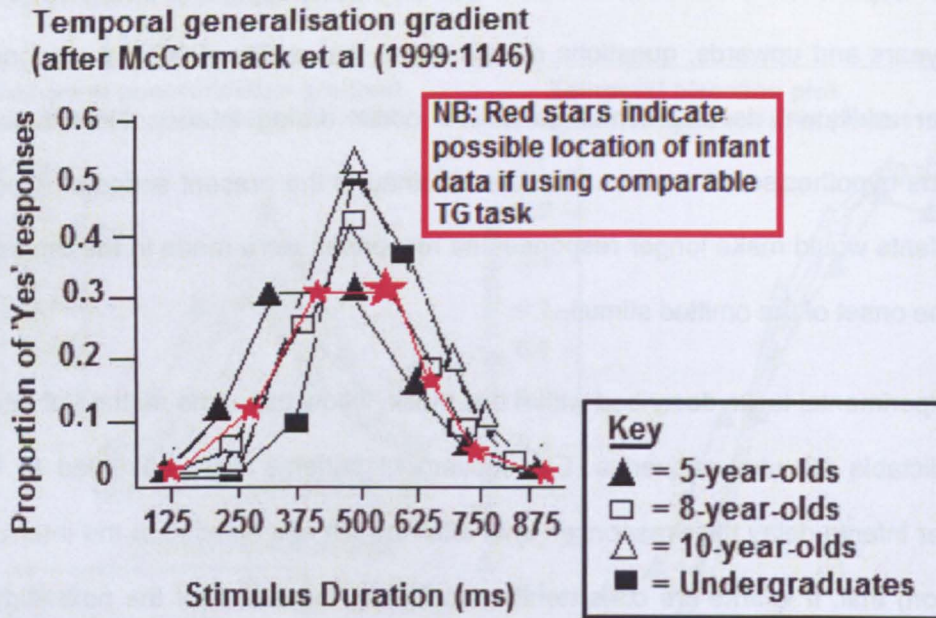
A further explanation for the longer responses made by infants in these experiments, as opposed to the young children in the McCormack and Droit-Volet studies, comes from the developmental model described by McCormack et al. (1999). This model added a distortion parameter (k) to the SET model to represent noise. The noise located in this model is not in long term memory as described by Wearden et al. (1997), but in the just presented duration. If k<1, participants make shorter estimations than the standard duration producing a leftward shift in the generalisation gradient. If k=1, participants make accurate estimations of the standard duration producing a symmetrical generalisation gradient. If k>1, longer estimations are made producing a rightward shift. Using the noise parameter k to explain the infant data, noise could distort the estimation of the duration within the omission trial as no stimulus appears, resulting in a longer estimation than the standard being made. If this explanation holds true using this paradigm, it would mean that infants were reacting to the appearance of the stimulus rather than being sensitive to temporal parameters. However, one might expect to see wider variation in responses if infants were merely attending to the appearance of the stimulus which failed to appear in the omission trials. Although there was wide variation in some of the experiments reported, e.g. Experiment 4, these results were argued not to be due to timing factors but rather other experimental factors such as the auditory cue. In experiments where clearer

evidence of time keeping was obtained, e.g. Experiment 5, the data revealed a wide variation in response times for some but not all infants. Of course, the responses for the present research do not involve decision making as in timing tasks.

Finally, the data could be interpreted as infants having 'learned' that a stimulus simply appears, rather than a stimulus appearing after a particular time interval. According to this idea, infants look back to the screen again only when some time has passed and they have not been prompted by a stimulus appearing to look for it (in other words they are not actually estimating anything, except in a very general sense). However, this is not a very satisfactory interpretation since responses were usually made after the ISI had elapsed, and few anticipatory saccades (n=2) were made.

The third tenet of the devSET model proposes that young children's responses are more random in relation to older, 8-year-old participants. According to Droit-Volet and Wearden (2001), random responding occurs as younger children are unsure whether the just-presented duration is the same as the standard, especially at short durations, resulting in an increase of random responding. This counteracts the short response bias seen in young children producing a leftward shift in the generalisation gradient reported in some studies. Random responding is reduced by the age of 8 years, as older children become more competent at the task resulting in a shift of the generalisation gradient towards the right as in adult gradients. Interestingly, no random responding is observed in adult data. The range of response latencies observed within omission trials in the experiments reported in this thesis show that for very young infants some random responding occurred pro-rata for the different intervals. That is, saccades very early (e.g. 1+s before ISI terminated) or very late (5s+ after stimulus omission) could be classed as random responses as they are not controlled by stimulus duration. Random responses were classified by Church and Gibbon (1982) as a high rate of 'yes' responding at short durations, that is responses not controlled by the signal duration. They found that rats made random responses about 20% of the time, whilst Droit-Volet et al. (2001) found random responding in over 10% of the trials made by 3- and 5-year-old children. The data

reported here would suggest random responding by some four-month-old infants as evidenced by the wide range of response latencies, supporting the notion that random responding is observed in very young infants as well as younger children. Indeed, it might be plausible to suggest that there would be an inverse relationship between age and random response rate.

The devSET model also posits that random responding will increase under conditions of uncertainty and that durations will be estimated as longer. Data from the alternating picture sequence experiments (Experiments 1 – 4) supports this, reporting more variance as the changing location introduced an element of uncertainty, but less variance was observed in Experiments 5 and 6. The main difference between the two sets of experiments was that the stimulus used in the latter experiments was a video clip of a head turning task that was judged to be more socially significant to the viewing infant. If so, social significance could be argued as a factor that would result in decreased uncertainty and concomitant increase in temporal accuracy.

If the task was judged to be more socially significant by infants it could be argued that this would result in decreased uncertainty and concomitant increase in temporal accuracy. Fewer very late responses (e.g. 5+s after stimulus omission) were observed under these conditions, suggesting that infants were better able to understand the task. A further explanation could be that increased understanding resulted in increased attention to the stimulus sequences. Consequently, infants formed a more accurate representation of the standard duration or in these experiments the ISI, making fewer very long responses. In terms of the SET and devSET models (see Figure 11.3), this would mean that more consistently accurate representations of the standard duration with less variation were accumulated within the clock component and subsequently stored within the memory component during the 'training' period of the SP trials in Experiments 5 and 6. Thus, during the omission trial, a more accurate response could be made within the decision component when comparing the current time or duration elapsed to the standard. The difference between saccadic latencies in Experiments 1 to 4 and Experiments 5 and 6

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lends support to the notion that random responding originates from the decision making component of the SET and devSET models (Wearden, 1999).

The fourth tenet of the devSET model postulates that the memory of the standard duration is distorted within long term or reference memory. Wearden (1992) proposed that in older children the representation of the standard duration is less prone to decay in long term memory, due to the fact that working memory capacity increases with age (Case, 1992; Kail 1990). For younger children the increased decay, combined with the fact that they produce more variation in their estimations within the clock component, as previously mentioned, results in a 'fuzzy' (or unclear) representation of the standard duration, which in turn produces a longer estimation in time perception tasks. Conversely, McCormack et al. (1999) argued that the variation does not arise in long term memory but rather in the just presented comparison duration, which was where the noise parameter (k) was located. Experiment 3 of the current research presented infants with short durations resulting in increased variance, especially when sequences were presented at fast speeds with few exemplars. It could be argued that having fewer exemplars could also result in 'fuzzy' representations of the standard duration. A further contributing factor to this could be the inclusion of additional stimuli such as auditory cues in Experiment 4. Responses in this experiment showed even more variance in the auditory condition, suggesting random responding. This was possibly due to the auditory cues confusing the infants, again resulting in 'fuzzy' representations of the standard duration being stored in long term memory.

Figure 11.3 A typical SET type model after Allan (1998) and Wearden (1999)
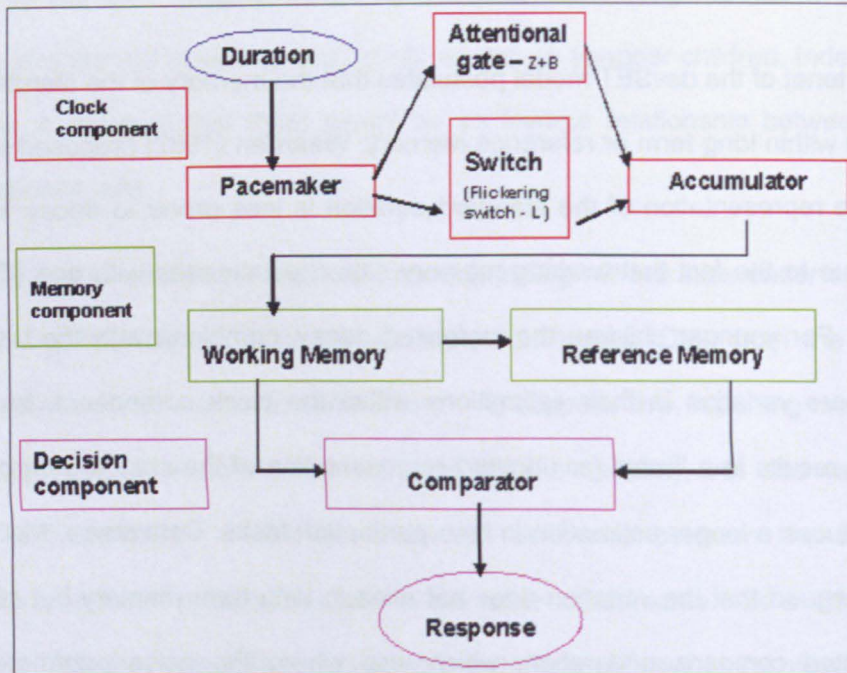
A further explanation for differences in duration estimation was the Contextual Change Hypothesis (CCH) (Block and Reed, 1978). Experiment 6 examined the role of stimulus change to ascertain whether environmental changes, such as stimulus speed or number of presentations, encoded automatically or unconsciously throughout durations, influenced the later estimation of those durations. According to CCH, the remembered duration of a time period lengthens as a function of the amount of contextual changes stored in memory. For instance, when driving to a new destination, the initial outward journey is perceived as longer than the return journey due to the number of landmarks noticed; however, only salient landmarks are remembered on the return journey and this has the effect of making the journey seem shorter. Data supporting this notion were observed in Sequence 3 of Experiment 5 where a change in both speed and number of stimulus presentations within the sequence resulted in longer durations being estimated for that sequence only. Experiment 6 examined this further, finding that infants produced more accurate temporal estimations when both stimulus sequences remained the same ('no change' condition) rather than when both the number of stimuli and presentation speed changed within the sequences ('two changes' condition). However, the results for the 'two

changes' condition were mixed. When slow sequences were followed by fast sequences more accurate time keeping was observed in the second sequence than vice versa. These results could also be accounted for by the devSET model, which would propose that longer estimations are made in conditions of uncertainty. Further, unpredictability, which is similar to uncertainty, was proposed by Haith, Adler and Wass (1996) to account for longer reaction times observed using the VExP paradigm.

From the infant data presented here it is difficult to draw any conclusions about this, inasmuch as longer estimations than the standard, (e.g. longer than 3s if that was the standard duration or ISI) were made by infants during omission trials. This can be accounted for in several ways. First, 'fuzzy' representations of the standard duration may arise within reference memory, especially at high speeds and with few exemplar durations from which to form the referent, resulting in increased variance. Second, the fact that response latencies were usually longer in OM trials than SP trials could also indicate that one source of variance is located in the clock component, as proposed by McCormack et al. (1999). Within the clock component of the SET model (see Figure 11.2), factors such as understanding the task and attentional resources allocated to the task during encoding influence the amount of information collected in the accumulator about the duration.

To summarise thus far, this thesis represents the first attempt to extend the devSET model to infant time keeping tasks. The infant data reported can be explained by three of the four tenets of the devSET model: first, increased variance; second, increased random responding; and third, making long responses under uncertain conditions. However, the debate regarding developmental trajectories of time perception have dealt more with memory and decision making components rather than the clock component, which has received little attention. Factors that can influence the clock component are attentional factors during encoding, which in turn influence clock speed, and switch latency. So can the infant data reported here inform us about one or more of these factors?

11.3.1 Attentional Factors

The attentional resources required by a four-month-old infant simply to complete any task should not be underestimated. Remaining in a state of alertness is difficult for infants who are very distractible (Oates 1998). Posner (1980) argues that over childhood, the ability to remain alert and attentive increases and distractibility decreases. In the experimental tasks reported here infants have to be in an alert state and looking at the monitor screen prior to and during a stimulus sequence being presented so that they can process the duration of the ISI. Posner and Peterson (1990) call this state 'alertness', suggesting alertness develops from three months of age, with infants of six months and older remaining alert for longer durations (Vecera, Rothbart and Posner, 1991). Within the experiments reported in this thesis, infants were required to remain alert for a lengthy period, in order to calibrate the eye tracker and complete the baseline measure task before the timing experiments could commence. Although all the experiments lasted between two to eight minutes (reported by Johnson (1999) to be the optimal duration of infant studies) this pre-experimental calibration phase may, unintentionally, have had an adverse effect on infants' ability to remain alert and attentive during the experimental phase.

The research reported in this thesis attempted to manipulate attentional resources by changing the presentation rate of the stimulus sequences. A change in presentation speed, either decreasing or increasing should result in a corresponding change in attentional load. As expected, the results show that infants can keep time at intervals of 3s and 1s but have greater difficulty at 500ms. Short intervals of 500ms produce a wider range of response latencies than longer intervals, suggesting that the shorter intervals require infants to maintain an alert state and/or to pay increased attention in order to keep track of the stimuli. This supports the notion proposed by Colombo & Richman (2002) that attention mediates infant time keeping.

In order to test the role of attention in adult time perception, dual task paradigms have been employed to divide attentional resources (Thomas and Weaver, 1975). In such

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paradigms participants are required to attend to both temporal and non-temporal information. An increase in attentional resources to one type of information results in a corresponding decrease of resources to the other. It could be argued that the experimental paradigm employed in the tasks reported here require infants to divide their attention between temporal information (the duration of the ISI) and non-temporal information (the spatial location of each stimulus within the sequence). If thought of in this manner, the tasks can be separated into high and low attentional load tasks.

The low attentional load tasks were Experiments 5 and 6 where the stimulus is judged to be salient to infants, and related to their everyday experience. The data from these studies showed increased temporal sensitivity with response latencies being closer to the time of stimulus omission, supporting the suggestion that more attention could be directed to the temporal information. The high attentional load tasks were Experiments 1 – 4, the alternating inanimate picture stimulus sequences. In order to demonstrate temporal awareness here, infants would have to remember the sequential spatial information that spanned both their visual fields as well as temporal information in a task that may not have been immediately meaningful to them. The data from these experiments showed reduced sensitivity to temporal parameters, as evidenced by response latencies being farther away from the time of stimulus omission, which could be accounted for by the increase in attentional load. Task difficulty is increased still further by increasing the speed of stimulus presentation and decreasing the number of exemplars presented, and in Experiment 4, the addition of auditory information. Again the same pattern of results is seen with Experiments 1 – 4 revealing an increase in long responding, suggesting decreased temporal accuracy compared to Experiments 5 and 6. This supports the notion that increasing attentional resources to non-temporal information has a detrimental effect on time perception – the first time this has been shown in infant time perception. These findings are compatible with previous studies (Droit-Volet, 2003; Zakay, 1992; 1993), demonstrating that attentional factors influence the clock component of the SET model. An additional source of variance within the clock component is switch latency, and will now be discussed.

11.3.2 Switch latency

A further source of variance in the SET model (Gibbon, 1977) is thought to be located in the operation of the switch, which lies within the clock component, comprising a pacemaker, a switch and an accumulator (see Figure 11.2). The onset of a to-be timed event, in this case the ISI, closes the switch, allowing pulses from the pacemaker to flow to the accumulator where they are stored, until the event stops and the switch is opened, thus terminating the flow of pulses. This store of pulses then transfers to the working memory store representing that duration. The number of pulses for any given duration should be consistent, thus allowing for accurate estimation. However, there is a slight delay in the opening and closing of the switch, called switch latency. The operation of the switch is influenced by the amount of attentional resources allocated to the temporal nature of the stimulus. This results in variability in the latency, which in turn affects to a greater or lesser degree the number of pulses that flow to the accumulator. Lejeune (1998) favours the idea that the switch flickers on and off depending on the level of attention directed to the task (FSM), whereas Zakay and colleagues (Zakay and Block 1995; Zakay 2000) favour the inclusion of an attentional gate in addition to the switch (AGM). High levels of attention result in the attentional gate being open wide, while low levels of attention result in the gate being only narrowly opened. However, the attentional gate introduces a second source of variance (in addition to the switch) within the clock component, but as yet there is insufficient evidence to argue for the existence or not of an internal clock.

A consideration of response latencies between the inanimate and animate stimuli used in the infant experiments reported in this thesis makes a start at examining switch latency in infants. The data reported here reveal an increase in long responding, suggesting decreased temporal accuracy to the inanimate picture sequences (Experiments 1–4) compared to the animate experiments (Experiments 5 and 6). One explanation of this is that the infants were more attentive in Experiments 5 and 6 as the stimulus was more salient to them, which in turn resulted in less variation in the representation of the standard duration being encoded, whereas more variance arose with the less salient

picture sequences. One tentative interpretation is that salient sequences produce a more consistent flow of pulses to the accumulator, resulting in a more accurate estimation of the standard duration. It could be speculated that the increased attentional resources directed to the animate sequences reduces the latency of the switch to close so that a more accurate number of pulses pass through to the accumulator forming the representation of the standard duration. No conclusions, however, can be drawn from these data as to the impact of the inclusion, or otherwise, of an attentional gate within the model.

Attention is clearly a major source of developmental change influencing timekeeping in young infants. Infants have limited attentional resources that increase with age (Posner 1980), making the clock component of the SET model, which is underpinned by attention, a fruitful area of enquiry for future time perception research. Finally, one can ask the question whether the experiments reported here inform us about other aspects of the SET model.

The idea that animals and humans possess an internal clock which aids time perception comes from studies where the speed of the pacemaker within the clock has been manipulated. In animals this has been accomplished by administering drugs such as amphetamines during the training phase and testing with no drugs (e.g. saline), which has revealed a speeding up of the clock (Meck 1996; Meck 1998). With human adults, speeding up the pacemaker has been accomplished by providing auditory clicks to increase the participant's arousal levels, speeding up the clock by approximately 10% (Penton-Voak et al., 1996). Using a similar paradigm but with visual flicker, Droit-Volet and Wearden (2002) found similar effects in children of three, five and eight years old.

Whilst the infant experiments reported in this thesis did not specifically set out to explore clock speed, they do shed some light on whether infants possess an internal clock. In the time perception experiments conducted to date, adult and child participants have been presented with one or two time intervals to be learned and these are later either produced or compared with comparison durations. The tasks reported within this thesis present infants with a series of time intervals that have to be 'learned' and 'estimated' using eye

movements, meaning that the saccadic response latencies are used to infer whether infants have taken any account of the time intervals. Some of these intervals within an experimental task have been the same as in Experiments 4 and 6 ('no change' condition), whereas others have changed from sequence to sequence with the experimental task as in Experiments 1, 2, 3, 5 and 6 ('two changes' condition). As previously discussed, the durations have been estimated by infants with varying levels of success. Nevertheless, despite the limitations of the different experimental tasks some infants have successfully kept time in all conditions within an experiment and overall infants have kept time in at least one condition, or more commonly two or more conditions (see Table 11.2 below). During each experimental task, infants were required to estimate several time intervals (some the same and some different) within a period of between 1 – 2 minutes. Being pre-verbal, infants cannot use counting as a strategy to help them keep time. This suggests that infants do possess an internal clock, but that it may not be as reliable or well calibrated as those of older children and adults.

Table 11.2 Number of infants tracking sequences in experimental tasks

Experiment	Infants tracking at least one sequence (n/N)		Infants tracking all sequences (n/N)	
1	4/8		1/8	
2	40/47		10/47	
3	54/63		24/63	
4	54/63		21/63	
5	23/37		21/37	
6	Visit 1: 60/72	Visit 2:54/72	Visit 1: 11/72	Visit 2: 9/72

The rate that pacemakers run at has been discussed by Droit-Volet (2003) who proposed that pacemakers run slower in children than in adults. Evidence for this comes from the fact that children show more variance in their time estimates. As infants too show

increased variance in temporal estimates, it would follow that their pacemakers run at a similarly slow pace.

In summarising this section of the discussion, despite the variations in infant responding, which can be accounted for by various attentional factors such as competition between temporal and non-temporal information, the findings discussed here indicate that at least some four-month-old infants possess a functional internal clock enabling them to keep time under a variety of intervals and conditions. Various aspects of the clock component of the original SET model (Gibbon 1977) have been discussed in this section from the latency of the switch to the speed of the pacemaker. Clearly, to enable further tests of both the SET and the devSET models, more research needs to be conducted in order to replicate and extend the findings discussed in this section.

Whilst the data presented here can be accounted for by three of the four tenets of the devSET model (McCormack et al., 1999; Droit-Volet and Wearden, 2001) there are other models of infant cognition that may also provide an equally good account of the data. These will be examined next.

11.4 Alternative explanations of infant timekeeping within the infant literature

The data reported in this thesis suggest that some infants can keep time over a variety of intervals between 500ms and 3s and that this ability is mediated by factors such as attention, and rate and length of stimulus sequence presentation. The design of the experiments reported here presented infants with alternating stimulus sequences while their eye movements were tracked with an eye tracker. The aim of this section is to discuss alternative explanations and models that may account for the findings observed in the research presented in this thesis.

11.4.1 Alternating saccade strategy explanation

The simplest explanation for the findings reported in this thesis is that infants were merely using an alternating saccade strategy, whereby they simply move their eyes to the right and then to the left of the plasma screen in a conditioned ocular motor response. This explanation is not satisfactory for several reasons. First, the infants did not randomly move their eyes across the plasma screen; the data show that they appeared to form an expectation about where and when the stimulus would next appear in the omission trials. That is, although in a conditioned response one would expect to see a left then right eye movement, one might not expect to see these movements occur approximately on time. There should be a high number of random responses made. Second, a visual inspection of the eye tracking data (the POG superimposed onto the stimuli) reveals that whilst some eye movements were made to both sides of the monitor screen in experiments using the left-right picture sequences, saccades and fixations mainly fell on the target side of the screen during omission trials. That is saccades fell in the correct location, but when the stimulus did not appear after 5+ seconds about 25% of infants would look to the opposite side of the monitor screen and then return their gaze to the correct side. For instance in Experiment 5 no saccades were made to the non-target side. This would not be the case with random responding where saccades on the omission trials would be predicted to be made at both sides of the screen (but not in alternating saccade strategies). It could be speculated that infants looked to the opposite side to see whether the stimulus appeared there and when it did not returned their gaze to where they had originally thought it would appear.

11.4.2 Task meaningfulness explanation

The animated head turning sequence design used in Experiments 5 and 6 showed increased temporal accuracy. An alternative explanation for this that does not need recourse to a timing mechanism, is that the task was more meaningful to infants who were likely to be familiar with the game of 'peek-a-boo', whereas the inanimate picture sequence tasks presented in Experiments 1–4 may have appeared more abstract, thus

making these tasks harder for infants. As Donaldson (1978) demonstrated, when a task makes sense to a child, appropriate responses will be given by most children. When an analogous, but more abstract version of the same task is presented, however, children will tend to make errors. In the timing tasks reported in this thesis, there was a similar contrast between abstract and meaningful tasks; whereas some timing has been noted in all tasks, the best evidence of timing has been found in Experiment 5 where infants were likely familiar with the task. Future studies should bear this point in mind and utilise stimuli that are more salient to infants.

Levels of accuracy in time keeping have been discussed by McCormack (1999) and Droit-Volet (2001) who observed less accurate time keeping in younger children (three and five years old) than older children (eight and ten years old), who in turn were less accurate than adults. The findings reported by McCormack (1999) and Droit-Volet (2001) suggest that as time keeping ability increases in accuracy as children grow up this suggests that time keeping in infants and very young children may be absent or immature. The research reported in this thesis, however, indicates that some infants are fairly accurate time keepers when the task is salient to them, as in Experiment 6. A plausible explanation for this could be that the development of time-keeping follows a U-shaped trajectory. Several theorists have developed ideas concerning how the processes underlying children's development occurs and will be examined in the following paragraphs.

The Representational Re-description model (RR model) proposed by Karmiloff-Smith (1992) accounts for similar U-shaped developmental trajectories observed in many aspects of cognitive development. (The U-shaped pattern of development shows that children are initially successful at a task, followed by a period of being unsuccessful, with a subsequent improvement of performance.) The model suggests that perceptual knowledge is encoded and stored as procedural information that is not necessarily accessible to consciousness. In order to be able to think consciously about the perceptual knowledge, this information has to be re-described and the concept analysed and categorised. In other words, the RR model seeks to explain the process by which children

progress from having implicit knowledge about a task and being successful at it, usually by trial and error, but are unable to access this knowledge consciously and verbalise it, through to having explicit knowledge that is both accessible to consciousness and capable of verbalisation. According to Karmiloff-Smith, the original perceptual information may remain as implicit procedural information for many years before being transformed into explicit conceptual knowledge.

The RR model consists of 3 phases: procedural, meta-procedural and conceptual. First, the implicit or procedural phase, whereby children are successful at tasks but cannot verbally describe the process by which they accomplished them as the thought processes are not available to consciousness. Second, during the meta-procedural phase (called the abstraction phase by Messer et al., 1998; 2006), children have a coherent strategy for a task but this is not always effective; the thought processes are still not accessible to consciousness and so they cannot verbalise their strategies. Finally, during the conceptual or explicit phase, children successfully complete tasks and can also verbalise the concepts and strategies used. The RR model is not a stage model as children can be operating at different phases for different tasks.

Applying the RR model to time perception, the data from the experiments (e.g. long responses to the durations) reported in this thesis, if plotted onto temporal generalisation plots would produce a right asymmetry gradient (see Figure 11.2). This is an adult-like response. In contrast, the Droit-Volet (2001) and the McCormack study (1999) studies revealed a left asymmetry gradient for three- and five-year old children but a right asymmetry gradient for eight-year-old children and adults. Taken together with the findings from the current experiments, this suggests a U-shaped developmental curve. This pattern of results can be explained by the RR model. According to this model, the performance of three to five-year-old children suggests that they can distinguish the time intervals implicitly but that they are unable to re-define them in explicit terms that are accessible to consciousness. Thus children at this intermediate age make more inaccurate responses than either infants or adults. While this explanation seems plausible, it would need to be

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tested using eye tracking timing tasks with children of different ages as well as with infants and adults.

In Droit-Volet's (2003) study, enhanced performance of the eight-year-olds compared to the younger children was attributed to their better understanding of the task and the concept of time. The RR model (Karmiloff-Smith, 1992), would suggest that eight-year-old children are at the explicit conceptual phase and so can perform temporal estimation tasks at similar levels to adults. Five-year-old children, on the other hand, could be at the abstraction phase, having a better understanding of the task than the three-year-olds but unable to perform it correctly, in this case estimating shorter durations as the standard resulting in a left asymmetrical generalisation gradient.

In addition to the RR model, development in children has been explained in other ways, for instance Seigler (1987) when examining development, sought to find an explanation for the variations in individual responses observed in many tasks across different domains such as physical and cognitive. Seigler (1987) devised two models, the Staircase model which is similar to the domain-general step/stage model proposed by Piaget (1969) and the domain-specific Overlapping Waves Model (OWM) (see Figure 11.4) to account for individual differences in responding. In the OWM, a number of strategies are available to infants at any one time, and the use of one strategy will overlap with other strategies. Variance, according to Seigler in this model, is due to infants and children using different strategies to solve problems.

How do infants and children devise strategies? According to Seigler, strategies are chosen for speed and accuracy and also to take into account task demands. Some strategies are chosen because they were successful for previous tasks, whilst others are optional back-up plans. If found to be ineffective, strategies are not necessarily discarded, but they simply become a less used strategy, which may later become a back-up or default strategy. Effective strategy use is dependent on a number of factors such as prior experience and memory capacity, both of which are limited in infants resulting in fewer available strategies. Furthermore, individual differences in prior experience mean that

each set of strategies is highly individualised and so, within a sample of infants, an infant may use any one of a number of strategies, and different infants will use different strategies. Consequently, a considerable variation in responses is likely to be observed. Siegler (1995) makes an interesting point about variance, stating that training periods are provided to eliminate variance in a participant sample as it is seen as a limitation of the study; however, according to Siegler, variance facilitates learning as it provides many examples of the to-be-learned variable. An example of this has already been provided by Stern (1977) who discussed how the variability in pitch and pace of speech directed to infants such as saying 'hello' facilitated learning of that word within an interaction.

Figure 11.4 The Overlapping Waves Model (Shrager and Seigler, 1998; page 406)
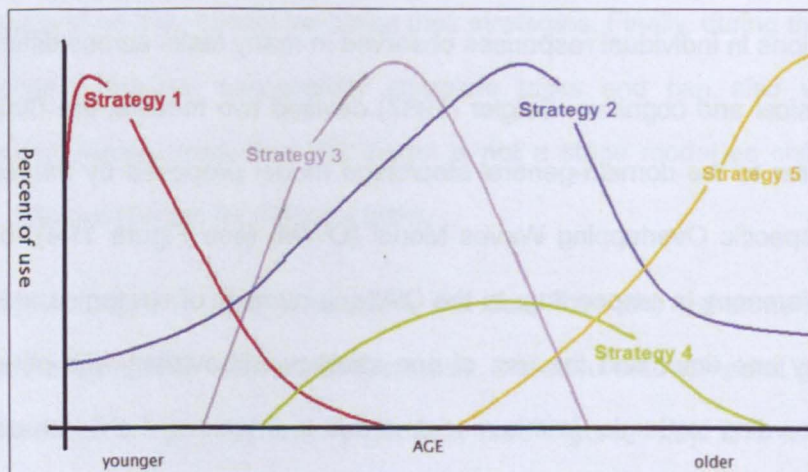
The second possible explanation for the variability in responding observed was again based on the long- and short-looking strategies identified from baseline measures. Data from these measures revealed that a number of infants changed from using either a long- or short-looking strategy across baseline stimuli and could change again across visits to the Centre; the infants' data could therefore be divided into different groups. That is, one group with those who used consistent looking strategies for each stimulus or visit and another group for those who were inconsistent. An additional analysis comparing the data

from consistent and inconsistent infants was conducted, but revealed equivocal results, and hence was not included within the results and cannot be used to explain the variations observed in infant responding. Thus, although the data show some consistency with the predictions of the OWM, further research would be needed before adopting this as an explanation of the reported findings.

A further theory which attempts to explain individual differences in development is the Dynamic Systems Theory (DST) proposed by Thelen and Smith (1996) and others. DST originally emerged from work conducted on physical development and social interaction, and seeks to explain how the accumulation of small qualitative changes within the environment brings about large changes in development. Two types of dynamic systems have been proposed, linear systems, which explain smooth proportional changes in development, and non-linear systems, which seek to explain abrupt changes in development. The former is concerned with physical systems such as gravity, the latter with biological systems.

Two types of knowledge are described within the non-linear systems, explicit declarative knowledge involving verbal communication, so not relevant to the discussion here, and implicit procedural knowledge relating to the relationships and interactional processes occurring within them. New information learned from changes in the environment triggers the re-organisation of existing knowledge thus affecting thoughts and behaviour. Increasing knowledge results in more elaborate systems emerging, in turn, developmental changes occur as a consequence of system expansion. This is similar to the re-organisation of neuronal connections when new knowledge is acquired triggering the creation of new connections in the brain.

The non-linear model also proposes that using existing knowledge, infants form expectations about future events and also generalise to other relationships. One example of this comes from Bowlby's (1969) theory of attachment where internal working models of how relationships work are formed and used to anticipate future interactions with significant others and then generalised to other people. With regard to the experimental

tasks undertaken here, procedural knowledge about the relationships of the appearance of stimuli are organised and stored throughout the trials of the sequence. This information is incorporated into the infant's timing system and predictions are formed about the next appearance of the stimulus within that sequence. During the omission trials, these predictions are acted upon and saccades made at the time the infant predicts the stimulus would appear. Across the different sequences presented to infants in each experiment, generalisations about stimulus appearances are made.

In accounting for the wide variation in responses and strategies used by infants across development, the DST posits that there is no typical developmental trajectory as argued by theorists such as Piaget (1969). Rather, each infant's experience of development is unique and so DST predicts a wide variation of responses. Given the timing tasks conducted in this thesis, the DST would predict the existence of an inconsistent looking strategy group that would show a wide range of response latencies. Infants may use one strategy at first and then once a task is more familiar to them, use another, thus by using different strategies to complete the task they gain a better understanding of it and thus facilitate learning. So both the OWM and the DST predict similar experimental outcomes which are observed in the present experiments. But how does this relate to the devSET model?

The devSET model also acknowledges variance and predicts a wider range of variance in responses from young children of 3- and 5- years old, than 8-year-olds, stating that variance increases under conditions of ambiguity. Random responding is seen as being unrelated to time under devSET, but under OWM and DST would not be classed as random responding, simply different strategy use.

As previously mentioned, if the present data are combined with those of McCormack et al. (1999) and Droit-Volet and Wearden (2001) with older children, a U-shaped developmental curve is seen. These curves can be explained by the DST. For instance, the apparent disappearance and later re-emergence of the neonate stepping reflex ability has been argued by Thelen (1984) not to disappear at all, but simply that there is a

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continuity of that ability throughout life, it is merely that their legs have to gain enough strength during the first year of life to be able to crawl and later walk. The ability to perceive and act on temporal parameters in an implicit manner may be innate allowing infants to use this knowledge to facilitate abilities such as motor actions, attachment behaviours, language acquisition and timing itself. The ability appears to disappear in early childhood because it has to become explicit and meaningful requiring further processing and re-organisation of the timing system. Once this has taken place and the timing system expands, becoming more elaborate, timing can be explicitly stated and explained and accurately estimated. This has similarities to the explanation of the RR model (Karmiloff-Smith, 1992).

The models described in this section predict individual variability in strategy use and developmental trajectories and offer plausible post-hoc accounts of the findings reported in this thesis. Further research would be needed to establish whether the development of time keeping conforms to these models. The discussion within this section shows that development is a complex process and suggests that a different methodological approach might be of benefit in future infant timing research. The method used in this thesis has been the snapshot approach common to all experiments, whereby the researcher seeks to get a snapshot of abilities at a particular moment in time, the experimental session. However, due to the complexities of development, a longitudinal or microgenetic approach might be more conducive to unpacking these complexities. These approaches might elucidate the factors involved in the change of looking strategy used by some infants over tasks and visits to the research centre. Nevertheless there are limitations to this method, for example participant dropout rates over the course of a longitudinal study. This is a major concern in light of the challenges faced by the present author in recruiting infants for the experiments reported here (see Chapter 3, Section 3.3.4 for a full discussion).

11.4.3 Implicit mechanisms – implicit knowledge

The models described above do not suggest that younger children in the initial phases consciously understand a task just because they perform it correctly. Infants do not have

to 'understand' the task nor the concept of time to be able to perform the task. For instance, according to the RR model, conceptualising and re-describing internal representations is linked to language competence, whereas the initial success at a task is linked to implicit knowledge. In the case of sensitivity to temporal parameters this knowledge may be innate or at least learnt within hours of birth. For example, temporal conditioning of neonate heart rate responses was demonstrated by Stamps (1977) within 48 hours from birth. In the womb, infants are exposed to the rhythm of heart rate, their own and their mother's, and later in pregnancy hear the rhythm of music (Hepper, 1991) and speech sounds (Querleu, Renard, Versyp, Paris-Delrue, and Crepin, 1988) despite the noisy environment of the womb. This exposure may result in foetal learning of temporal regularities within the intrauterine world, and at the very least they may become sensitive to rhythm and other temporal parameters.

Implicit knowledge is observed in many different areas of cognitive development; one such area is 'core or initial knowledge' proposed by Spelke (1994). Core knowledge is defined as the knowledge infants possess about the fundamental properties in the world about them. Fundamental properties, such as gravitational force, are regularities in the world that are easily learned by the child. It is plausible to suggest that another such fundamental property is that of temporal parameters. This ability to extract regularities from the infants' world may be either innate or emerge soon after birth. The most compelling example of the ability to extract information soon after birth comes from studies of face processing. Goren, Sarty and Wu (1975) demonstrated that newborn infants will track a face-like stimulus. Johnson, Dziurawiec, Ellis and Morton (1991) expanded this research and demonstrated that whilst tracking occurs in newborns and three-month-olds, it declines during the second month of life. Johnson and Morton (1991) explained this U-shaped developmental curve in their CONSPEC and CONLERN model of face processing. CONSPEC is an innate predisposition to look at face-like objects that is sub-cortically mediated. This ability declines between four- and six-weeks old, when CONLERN, a cortically mediated process becomes dominant. Interaction with faces in the environment allows infants to become highly specialised at face recognition by one year of

age. The interaction between existing neural pathways and the infant's interaction with her environment, Johnson (1993) called the Interaction Specialisation approach. The U-shaped developmental trajectory observed in face processing is thought to occur through the change from subcortical to cortically mediated processes and has been examined by Johnson and colleagues using EEG/ERP methodology (Johnson, 1999; 2005; de Haan, Humphreys and Johnson, 2002; de Haan, Johnson and Halit, 2003). Future research into infant time perception could utilise ERP methodology to ascertain whether there is a similar shift from subcortical to cortically mediated processes in time perception.

11.4.4 Development of attentional mechanisms

Research into the field of visual attention, for example Posner and Petersen (1990), indicates that the attentional system comprises two fairly independent systems, the Posterior Attention Network (PAN) and the Anterior Attention Network (AAN). PAN is concerned with visuospatial orienting (Mountcastle, 1978) which has three main functions: engagement, involving the lateral pulvinar of the thalamus (Posner, Walker, Friedrich and Rafal, 1987), disengagement, involving the posterior parietal lobe (Posner et al.,1987), and the movement of focus, involving the superior colliculus (Posner and Petersen,1990). The AAN, on the other hand, is connected between the frontal cortex, the hippocampus and the limbic system, processing temporal, semantic and lexical information and appears to maintain sustained attention (Posner and Petersen, 1990). The PAN is reported by Haith, Hazan and Goodman (1988) and others to begin functioning at about 3.5 months of age when infants begin to engage in anticipatory fixations, whilst the AAN does not mature until the second year of life (Vecera, Rothbart and Posner, 1991). This has implications for temporal processing as it would suggest that infants should not be sensitive to temporal information until they are over one year old, although they can anticipate where a stimulus is likely to appear (Johnson and Johnson, 2000). The data reported here, however, suggest that infants are sensitive to temporal information much earlier, suggesting that other attentional systems might be involved in early temporal processing. However, this explanation of anticipatory saccades does not explain why infants wait before making a saccade. Anticipatory saccades were demonstrated in the Johnson and Johnson (2000)

eye tracking study where four-month-old infants were observed to make anticipatory saccades towards the exiting point of a partly occluded rod emerging from a box immediately after the rod partially disappeared. If anticipatory saccades explained the findings reported in this thesis, based on the findings of Johnson and Johnson, (2000) saccades would be made immediately to the next location. However, the pattern of results show those infants did wait before making a saccade to the location of the omitted stimulus at the end of sequence suggesting that these saccades were not anticipatory in nature.

The onset of functioning of the PAN at 3 to 6 months (Johnson, Posner and Rothbart, 1991; Hood and Atkinson, 1993; Johnson, 1993) coincides with developmental changes in fixation found by Colombo, Harlan and Mitchell (1999). Colombo et al. hypothesised that long-looking infants appear to be slower to encode visual information because either they have an immature PAN, or the functions of PAN are depressed. This is seen in their apparent inability to disengage attention from one object and attend to another. Two competing models accounting for disengagement of attention have been proposed. Johnson (1990) holds that input from stimuli produces diffuse cortical activity which inhibits activity in the superior collicular pathway that triggers eye movement to peripheral targets, therefore resulting in fixations remaining on the central stimulus and difficulty in disengaging attention. The second model, proposed by Hood (1995), states that difficulty in disengaging attention is due to the immaturity of the Parietal Lobe which is implicated with the disengagement of attention in adults. Within infant time perception the use of different information processing strategies (e.g. long- and short-looking) has been tentatively observed to benefit infants in different ways. The next section discusses this in more detail; however, before doing so a brief discussion on visual attention and spatial certainty is relevant here.

Cued attention experiments (Posner, 1980), which use spatial cues to test endogenous attention, have provided evidence showing that in trials of spatial uncertainty, performance is inversely affected (Foley, 1998). Moreover, this effect was more pronounced when

performance was low (Eckstein & Whiting, 1996; Pelli, 1985). The data reported in this thesis also show a similar pattern. For instance, in experiments using animated stimuli where the stimulus woman was constantly visible, infant performance increased in both the number of data points collected and the spatial accuracy of those responses during stimulus omission trials. On the other hand, experiments using inanimate stimuli in which the ISIs and the omission trials were a blank screen showed a decrease in the number of data points collected and spatial accuracy of those responses. Foley (1998) suggests that such responses are observed because spatial uncertainty is introduced and the participants may become confused as to the position of the target. In contrast, the experiments by Haith and colleagues (Haith,1989; Adler et al., 2008) using inanimate stimuli in the VExP found that four-month-old infants gain knowledge of long predictable alternating sequences (as opposed to the short alternating sequences used in the experiments reported in this thesis) which included blank ISIs, and respond accurately. This suggests that further evidence is required to elucidate the relevant factors relating to spatial certainty and visual attention. The discussion will now turn to infants' use of different information processing strategies.

11.5 Infants' use of different information processing strategies

Throughout the empirical work presented within this thesis infants' use of different information processing strategies, long- and short-looking, has been employed to examine attentional effects on time keeping. The results from this empirical work revealed some differences between the two groups of infants that may suggest different patterns of time keeping, although more work is needed to explore these differences further.

Some evidence was observed for differences in information processing strategies between the long- and short-looking infants, showing that long-lookers benefited more in Experiment 4 from the addition of auditory cues than short-lookers. Furthermore, evidence from this experiment showed significant results for Sequence 1 for the long-looking group whereas the short-looking group had more success with Sequence 3. One suggestion made to account for this was that short-lookers may have benefited from practice effects.

The general pattern of results revealed that short-looking infants showed shorter response latencies but wider variance during omission trials, whilst long-looking infants showed longer response latencies but a narrower range of variance. Further, the latter group responded at a similar rate during stimulus present and omission trials indicating that they keep better time within a sequence and track the stimuli on time. Methodological limitations may have influenced the results, however, and further studies will be needed to replicate and clarify these observations.

Nevertheless, it can be proposed that long-looking infants are able to keep better time within a sequence, even though their demonstration of longer response latencies during the omission trial could be due to their difficulty in disengaging attention. Frick et al. (1999) found that long-looking infants have difficulty disengaging attention from a central stimulus towards a peripheral stimulus when the central stimulus remained present. Using a combination of look duration and heart rate, Colombo et al., (2001) linked the difficulty of disengaging attention to the fourth phase of attention as defined by heart rate (Richards and Casey, 1991), attention termination. Colombo et al. (2001) posit that during attention termination, infants continue looking at a stimulus but do not process information about it and that this is more pronounced in long-looking infants. Hence, an argument could be made that long-looking infants in the studies reported here are simply following the sequence pattern and when the sequence is disrupted, they take longer to disengage attention and make a saccade to the omitted stimulus location. On the other hand, they could just be moving their eyes alternately, simply continuing when the sequence ends but at a slower rate than their short-looking counterparts.

Other evidence that suggests differences in information processing for long-looking and short-looking infants is as follows. First, Colombo et al. (2001) have proposed that long-looking infants process information throughout the longer look durations. Second, how quickly a stimulus is processed has been linked to the length of fixation duration; for example Lewis, Goldberg and Campbell (1969) demonstrated that very young infants require longer exposure to a stimulus to process visual information than do older infants.

These findings suggest that long-lookers process information slower than short-lookers (Rose and Feldman, 1995; Rose et al., 2002) and indicate a more immature information processing style. The implication for time perception is that short-looking infants would be better able to perceive and act on time intervals within their environment which may have benefits for later cognitive abilities (Rose et al., 1992). For instance, poor rhythm perception (Wood and Terrell, 1998) and speech processing during synchronous social interaction (Kuhl, 2007) have been linked to poor reading ability in older children (Wood and Terrell, 1998). Further research is required though to clarify and expand the findings of long- and short-looking reported in this thesis and the existence of an inconsistent group.

The existence of an inconsistent group, that is, a group of infants who change information processing strategy from one baseline stimulus to another supports the findings of Courage et al., (2005), but not Colombo et al. (1988) and Colombo and Fagen (1990), who posit that looking strategy remains stable for up to 3 months. Richards (2006, personal communication) states that the effect can only be seen using the stimuli and the exact procedure set out by Colombo (1988). Any variation, according to Richards, de-stabilises the categorisations. However individual differences are discussed as a necessary part of development by Siegler (1989) and Thelen and Smith (1994) whereby individual differences lead to the development of knowledge about the world. Both of these explanations for the variations in responses can be applied to the data reported here. First, that the baseline measure used in this thesis, was presented after calibrating the eye tracker, and thus not the first stimulus seen by the infant, thereby not following the exact procedure used by Colombo and colleagues. Second, that individual differences in strategy use are explained by the OWM (Shrager and Siegler, 1998), showing that infants use different strategies for different tasks and over time, this could apply to the infants participating in the experiments here. Finally, individual differences account for the dynamic systems (Thelen and Smith, 1996) that make up an individual's knowledge set. As each infant's learning system is individually tailored, the wide variability within response latencies observed within the data reported here can be explained.

11.6 Further implications for the devSET model

Can any of the results for the long- and short-looking groups be explained by the devSET model? As discussed above, long-looking infants appeared to be more accurate at time keeping on slow sequences with many exemplars, whereas short-looking infants fared better with faster sequences with fewer exemplars, although variance was greater for short-looking infants. This pattern of results suggests that short-looking infants may be engaging in more random responding than the long-looking infants who have a bias for making long responses but make fewer random responses. Random responses are linked to increased uncertainty suggesting that short-looking infants may be less certain of the duration to be estimated. This implies that a slow and steady method of processing information appears to equip an infant with better time keeping abilities, at least in optimal conditions. By engaging in local featural processing, long-looking infants appear to form a more reliable representation of the standard duration in reference memory that is less vulnerable to distortion. This processing style may be to the infant's disadvantage in everyday life, however, where the need to keep track of temporal information may change rapidly from minute to minute or second to second, as for instance within social interactions. In everyday life, short-looking infants who are better at coping with changes in the environment whilst keeping track of temporal information may be more advantaged.

A further explanation for longer response latencies being observed in long-looking infants could be attributed to their difficulty in disengaging attention (Frick et al., 1999), which could affect the operation of the switch within the clock component of the SET model (see Figure 11.2) by increasing switch latency for long-looking infants. When engaged in a timing task, the processing systems of long-lookers might have difficulty opening the switch in order to stop the pulses flowing into the accumulator. In this case, the response latency for long-looking infants would be longer than for short-looking infants as seen in the results for the experiments reported here. Interpretations should be made cautiously, however, as the results from the present experiments are not conclusive due to the small

numbers included in the second analyses. A limitation of this line of enquiry is that infants' categorisation as either long- or short-looking may not be stable over time or task.

Richards (personal communication, 2006) points to an explanation for the lack of clarity in the findings between the long- and short-looking infant data. Unpublished studies conducted in his lab examined the stability of long- and short-looking categorisations using 16 different stimuli, one was the face used by Colombo and colleagues, the other stimuli varied. These stimuli were presented at various points throughout a sequence of pictures, and durations of looks were recorded. Richards reported that the results showed that infants did not make the same response to each of the target stimuli. For some stimuli, infants even changed information processing groups. Therefore, as previously mentioned, Richards suggests that in order to replicate the long- and short-looking categories found by Colombo and colleagues, tests must be conducted using exactly the same procedure as those authors. That is, the face stimuli must be the first stimuli that infants see in the testing session.

Further, Richards suggests that heart rate is a better measure of attention than look duration. However, for the reasons discussed in Chapter 2, Section 2, heart rate was not considered a suitable methodology for extending the study of infant time perception. For instance, accommodating heart rate only allows one stimulus sequence to be presented to infants (Colombo and Richman 2002). The stability or otherwise of long- and short-looking categories may account for the results reported here.

To summarise, the use of information processing strategies used by infants in the experiments reported here was found to have a small influence on time keeping. It was shown that long-looking infants are able to keep time when stimuli remain the same, but short-looking infants are better able to keep track of time under changing conditions. The existence of an inconsistent group of infants was discussed and several explanations examined. Finally, individual differences in relation to the SET and devSET models (Gibbon, 1977; Droit-Volet, 2003) were explained by increased random responding by

younger children and also in ambiguous tasks, both of which apply to the data reported here. Discussion will now turn to methodological issues arising in this thesis.

11.7 Methodological issues

Eye tracking has proved to be a useful tool for investigating cognitive development in infants as eye movements are automatic and have been shown to reflect cognitive processing at different stages of development (Morison and Slater, 1985; Hunnius and Geuze, 2004) with tasks such as scanning (Hunnius and Geuze, 2004) or reading (Andreu, Sanz-Torrent and Guardia-Olmos, 2011). Whilst infant time keeping requires further investigation to replicate and clarify the findings reported in this thesis, a valuable contribution has been made as to how future infant time perception research using eye tracking methodologies may be conducted more effectively.

Eye movements made in everyday life are complex; the eye movements measured in the experiments reported here, however, are single saccades towards the omitted stimuli so are not necessarily a good representation of how infants may account for temporal factors within their environment. Whilst the tasks reported in this thesis are not complex, they still engage many cognitive processes such as attention, memory etc., although Aslin and Fiser (2005) have suggested that eye trackers may not be able to capture the subtleties of these processes; a limitation that should be borne in mind for future research.

The experiments reported here reveal several limitations that result from using a standalone pan tilt eye tracker. The first limitation concerns the loss of the POG cross hair used to calibrate infants' gaze, and the second is infant head movement.

The loss of the POG cross hair occurs because the threshold levels of the pupil discrimination (PD) and corneal reflection (CR) can fluctuate due to several influences. A major influence is changes in the background colour and luminance levels that can produce movement of the pupils. In Experiments 1 and 2, the stimuli had black and white backgrounds that created large movements of the pupils and subsequent loss of the POG and diminished data collection. This situation was remedied to a degree by using stimuli

with colour backgrounds from the same colour category, such as blue and yellow as proposed by Hering (1964) in his Opponent Process theory of colour. Using the extremes of the same colour category limited pupil movement and increased the amount of data collected in Experiments 3 and 4. However, this did not completely solve the problems associated with data collection as the stimulus disappeared during the alternating sequences and a screen of a different colour (blue), but the same luminance, appeared. The animated video sequence used in Experiments 5 and 6 meant that the background colour and luminance remained constant as the stimulus woman remained centrally placed, turning her head to the right of the viewing infant and returning to face them. This allowed infants simply to move their eyes to follow the stimulus sequence rather than having to move their heads even slightly to keep track of a stimulus appearing on the right and the left of the plasma screen. This modification of the original experimental procedure and stimulus resulted in a more reliable and consistent data collection procedure. This should be of interest to other researchers using eye tracking measures with infants.

The second problem was head movement, which was associated mainly with Experiments 1 – 4. One factor affecting head movement was the content of the stimuli in maintaining the interest of infants in the experiments. This was important because if interest waned, infants moved their heads and looked away from the stimulus display and no data could be collected until the image of the eye and the threshold levels were regained. Since the image of the eye was required to be the size of an over large spectacle lens (see Figure 11.5, below) any head movement required adjustments to be made in order for eye image to be central in the monitor screen which was optimal for keeping the CR and PD thresholds. Hence continual adjustments were necessary throughout each testing session, and show the importance of minimising head movement. Although the magnetic head tracker could have been used to counter head movement, the author's previous experience had shown that this method was less effective than the head cushion which gently keeps the infant's head still (see Chapter 2, Figure 2.1). Using a foam head rest within the infant car seat, infants' heads are held gently in place, facing forward, limiting the infants' peripheral vision thus helping to maintain infant's attention onto the screen.

Figure 11.5 Image of eye in eye tracking monitor screen

B - photograph

B - schematic drawing

Key:
═ = corneal reflection (CR) threshold

— = pupil discrimination (PD) threshold
[black and white respectively in reality]
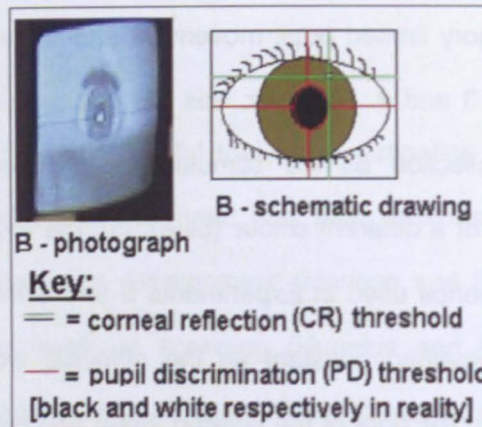
Head movement is also influenced by the immaturity of infant neck muscles. Each testing session lasted between two to eight minutes, which is within the optimum length of experiments according to Johnson, (2003) but 10 – 15 minutes according to Aslin and Fiser (2005:92). However infants would find it difficult to keep their heads still and upright for that amount of time. Therefore, the head cushion also acts as an aid to help keep infants heads raised and facing squarely onto the plasma screen in order to detect and maintain the POG. Sometimes infants would not remain seated in the car seat and so after training, were held on their parents' laps with their chin supported in order to maintain the neck and eye position at their optimal positions.

Further recommendations to reduce head movement are as follows. Attention-getting sounds such as animal sounds can draw infants' attention back to the monitor screen. Covering brightly coloured footwear with a clean neutral coloured cloth can limit distraction from foot movement. Hand movement is a more difficult problem, but if particularly bad, parents could be asked to gently hold their child's hand whilst remaining seated to the back of them to avoid distraction.

Before leaving the discussion of methodological limitations and the impact on data collection some interesting work has been discussed in the literature recently concerning the number of data points that one can expect to collect during experiments with infants. Aslin and Fiser (2005:93) discuss the number of data points that can be collected from

infants during any test stating that infants will provide between 2 to 12 data points per study which equates to 1 to 4 data points per condition. This was the experience found in the experiments reported in this thesis. More recently, individual differences were reported by Stets and Reid (2011) in the number of trials needed to collect data in EEG/ERP studies: some four-month-old infants took under 60s to provide the appropriate data in each condition whereas other infants took 150s for the same data to be collected. Thus Stets and Reid's study showed similar variance in infant responses to that obtained for the experimental data reported in this thesis.

To conclude the discussion, the research reported in this thesis has established that the most successful stimuli for reducing head movement and thereby increasing the accuracy of the eye tracking measure was the animated video sequences used in Experiments 5 and 6. Suitable tasks are ones that are understandable and salient to infants. Therefore the optimum method would be to utilise animated video footage where the target stimulus remains visible and the background colours and luminance remains constant. This suggests that this type of stimulus should be employed by researchers wishing to use eye tracking as a measure.

Future researchers would also benefit from using eye trackers which incorporate infrared light sources within the stimulus computer, that is along the top and bottom panels of the screen. There are two advantages to this type of system, first that infrared light is reflected off a wider area and so the CR and PD thresholds required to create the POG are more stable and not so prone to disruption with increased eye movements. Second, these systems, being one computer, are easily transportable and so can be used outside of the laboratory which is useful for conducting research in real life settings.

Finally, eye tracking is a difficult methodology to use in research, especially with infant participants, but the benefits of measuring eye movements objectively outweigh the disadvantages, especially when using appropriate stimuli. Eye tracking has allowed infants' abilities to be revealed that would not be possible with video analysis alone. The

final section will discuss the final conclusions and applications to be drawn from these studies and also outline future research.

11.8 Final conclusions and future directions

The use of eye tracking technology has provided overt behavioural evidence for the first time that four-month-old infants can keep time when methodological conditions are designed to optimise their performance. Time keeping was enhanced when the sequences were salient and meaningful to infants, such as the head turning task which was similar to a game of 'peek-a-boo' that infants would likely be familiar with. Auditory cues were also shown to facilitate timekeeping for some whereas contextual changes were not. Little evidence for timekeeping was evident in the remaining studies, which could have been for a number of reasons such as infants looking away or fussing because of lack of interest in the stimuli thereby not providing usable data to allow a more detailed examination of time keeping.

The empirical studies reported in this thesis indicate that infants can keep time and that the data can be explained by three of the four tenets of the devSET model. This is the first time that this model has been applied to four-month-old infants; previously the youngest age was three years old. In line with the devSET model the infant data reported here revealed that their response latencies showed wider variation, and that infants make longer responses similar to older children and adults. Random responding is proposed by McCormack et al. (1999) and Droit-Volet (2001) to increase in ambiguous or uncertain conditions and this was observed in studies using stimuli which were not salient and meaningful to infants such as the inanimate picture sequences. The third tenet of the devSET model that could account for the long response latencies seen in the present findings was that infants have a bias towards long responding.

The enhanced ability to keep time in the socially meaningful head turning studies are opposite to the predictions that would be made by the devSET model, which would predict that young infants of four months should not be accurate timekeepers. McCormack et al. (1999) and Droit-Volet (2001) found that accuracy in timekeeping increased in older

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children of between eight and ten years old; this finding suggests a U-shaped developmental trajectory. Explanations for this were discussed in terms of several developmental theories. The Representational Re-description model (RR model) proposed by Karmiloff-Smith (1992) and the Dynamic Systems approach (Thelen and Smith, 1996) both state that many cognitive and perceptual abilities undergo a similar U-shaped developmental curve during early childhood. The Dynamic systems approach suggests that immature cognitive and physical abilities may hinder the expression of that implicit knowledge becoming explicit knowledge. Finally, the Overlapping Waves model proposed by Seigler (1986) suggested that infants may be using different strategies to understand and respond appropriately to the timing tasks and thereby introducing variation into their responding. Variation within age-groups was predicted by both the Overlapping Waves model and the Dynamic Systems approach as learning is unique for each infant and typical developmental trajectories do not exist. Further the emergence of an inconsistent looking group would also be predicted by these models as different strategies are employed at different times and over different tasks. This suggests that a longer term microgenetic approach rather than the snapshot approach taken by the experimental work reported here might be a better method to capture the influences on infant time keeping. Whilst these models account for the developmental U-shaped curve found in the child data, the models can only explain the process by which performance is enhanced with maturity, it cannot provide an account of infant time keeping per se.

The fact that infants appear, on the whole, sensitive to the temporal parameters of sequences presented at speeds of between 3s and 750ms within the same experimental task, suggests flexibility and adroitness in timing from an early age. Clock speed can be changed quickly and adapted to new stimuli, which is an important ability in everyday life. The data reported here suggest that infants can glean temporal information about tasks without much training suggesting that further research may elucidate the factors influencing clock speed.

Furthermore, the use of an eye tracker revealed sustained gaze following, which had not been observed in infants of four months old to date. The data from Experiment 5 showed that young infants consistently follow the gaze of another person for four or more head turns. Previously it was thought that this ability only emerged later in infancy at around eight months (Corkum and Moore, 1998).

In evaluating the experiments presented in this thesis it is apparent that time keeping could only really be examined after much adjustment to the stimulus sequences. The use of inanimate black and white stimuli in Experiments 1 and 2, whilst similar to the foundation study of Colombo and Richman (2002), did not produce much usable eye tracking data. The situation improved slightly with the use of stimuli with blue and yellow backgrounds in Experiments 3 and 4. However, the breakthrough in stimulus design came in Experiments 5 and 6 where infants' attention was maintained and more usable eye tracking data produced. These two experiments provide the most useful insights into infants' abilities to keep time and suggest that the use of video sequences should continue to be used. Notwithstanding, even under sub-optimal conditions infants were able to reveal sensitivities to temporal parameters in some of the present experiments, indicating that future research may benefit from re-visiting these areas with different stimuli, for example, incorporating auditory cues into the animated head turning task to investigate the influence of such cues on timekeeping.

Research into infant time perception is nascent with many remaining questions to be examined. Future research should continue to examine the influencing factors within infant time perception developing new timing tasks to ascertain whether these abilities are present at birth or whether they are learned soon afterwards. A further line of enquiry would be to adapt existing standard timing tasks for use with infant populations, to enable a direct comparison of temporal generalisation and bisection gradients and further develop the SET and devSET models. The data from this and other studies suggest a U-shaped developmental trajectory in relation to time perception, so future research could examine whether these findings correspond with the maturation of different attentional and memory

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systems within the brain. In order to understand the neural correlates of infant timing, these studies would benefit from the use of eye tracking and brain imaging methods such as EEG/ERP, or Near Infrared Spectroscopy (NIRS), which is more conducive to infant research. Further work would benefit from combining eye tracking and brain imaging or heart rate methodologies to understand systematically the factors influencing time perception in infants.

In conclusion, writing well over a hundred years ago, Judd (1899:210) noted that "the investigations of time perception are [still] among the most difficult undertaken in experimental psychology". Since that time, a few steps have been taken in developing our understanding of time perception, and the research reported in this thesis has taken a significant step forward in recognising that infants as young as four-months-old are capable of time perception. Whilst the difficulties evident within this thesis testify to Judd's statement, the author would like to add that they are also some of the most fascinating investigations to undertake.

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Appendices

Appendix A.1 Glossary of terms

Term/ Abbreviation	Definition
AAN	Anterior Attention Network
AGM	Attentional Gate Model
AT	Attention termination, fourth phase of Richards and Casey's phases of attention
CCH	Contextual Change Hypothesis of timing
CR	Corneal reflection, threshold used by eye tracker whereby the location of the corneal reflection is calculated. This coordinated together with the coordinate of the edge of the pupil enables the eye tracker to calculate the precise location of the participant's eye gaze.
devSET	Developmental version of SET model discussed by McCormack et al. (1999) and Droit-Volet (2003). Abbreviation made by the current author.
DST	Dynamic Systems Theory
EEG/ERP	Electroencephalogram /event related potential, sometimes known as HDERP, high density event related potentials due to the high number of electrodes placed on the skull to measure the brain potentials such as 64/128 sensors for infants.
Eyenal	Eye tracking programme developed by Applied Science Laboratories (ASL), when Eyenal data put through a scan convertor it appears as a POG on a monitor screen.
F9	Fast sequence, 8 stimuli presented, 9th omitted, F5 similar, fast sequence, 4 stimuli presented, 5th omitted
Fixation	Focus of the eye on a particular part of the scene

FSM	Flickering Switch Model
Gaze Tracker	Eye tracking analysis programme developed by Eye Response Inc. which produces an online POG.
LL	Long-looking infant, thought to use featural processing methods by looking at scene with fewer longer looks.
LTM	Long Term Memory
M9	Medium sequence, 8 stimuli presented, 9th omitted, M5 similar, medium sequence, 4 stimuli presented, 5th omitted
MCM	Mode Control Model, similar to SET model but counts number and time.
MMN	Mismatch negativity, a negative ERP component.
OFF	Inter-stimulus interval either the presentation of a blank screen in the inanimate studies (Experiment 3,4 and 5) or the stimulus woman turning to face the right hand side of the viewing infant in the animate studies (Experiment 6 and 7).
OM	Omission trial, this occurs at the end of the predictable stimulus sequence, during which time eye movement patterns are examined to determine whether infants look to the location of the omitted stimulus at the time it should appear.
ON	Stimulus present trial either the presentation of a picture in the inanimate studies (Experiment 3,4 and 5) or the stimulus woman facing towards the viewing infant in the animate studies (Experiment 6 and 7).
OWM	Overlapping Waves Model
PAN	Posterior Attention Network
PAT	Pre Attention Termination, third phase of Richards and Casey's phases of attention
POG	Point of Gaze cross hair created by eye tracker to show where the participant is looking.
PD	Pupil discrimination, threshold used by eye tracker whereby the edge of the pupil is discriminated from the iris, and its location calculated. This coordinate, together with the coordinates of the corneal reflection, enables the eye tracker to calculate the precise location of the participant's eye gaze
S9	Slow sequence, 8 stimuli presented, 9th omitted, S5 similar, slow sequence, 4 stimuli presented, 5th omitted
SA	Sustained attention, second phase of Richards and Casey's phases of attention
Saccade	Ballistic eye movements.

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Scan path	A sequence of fixations and saccades.
SET Theory	Scalar Expectancy Theory (Gibbon, 1977), accounts for timing of intervals in the range of seconds and minutes, also known as Scalar Timing Theory.
SET Model	The Model which seeks to explain the process by which intervals are timed.
SL	Short-looking infant, thought to use global processing methods by scanning the whole scene with brief looks.
SO	*Stimulus* Orientation, first phase of Richards and Casey's phases of attention
SP	Stimulus present trial
StA	Stimulus Away trials
StL	Stimulus Look trials
STM	Short Term Memory
Stimulus present trial	During these trials the stimulus appears.
Stimulus omission trial	During these trials no stimulus appears, the latency of saccades made to the correct location at about the time the omitted stimuli should appear were recorded.
TB	Temporal Bisection Task
TG	Temporal Generalisation task
VExP	Visual Expectancy Paradigm

Appendix A.2 Ethical permission

Appendix A.2.1 University ethics committee permission

A.2.1.1 Consent for initial studies

TheOpen University

MEMORANDUM

HUMAN PARTICIPANTS AND MATERIALS ETHICAL

COMMITTEE

FROM:	**John Oates, Chair, HPMEC**	Email:	j.m.oates@open.ac.uk
To:	Eileen Mansfield, ChDL, FELS	TEL:	**52395**
CC:		DATE:	**22 July 2003**

SUBJECT:	**Ethics application:** *"Infants' Understanding of Time: The role of attention".*	Ref:	HPMEC/03/#44/1

This memorandum is to confirm that the research protocol for the above-named research project, as submitted on 21st July 2003, is <u>approved</u> by the Open University Human Participants and Materials Ethical Committee.

You are asked to take the following points into consideration:

1) It is recommended that you give some further justification for the research in the information sheet for parents, for example by suggesting the contribution that the results might make to science and human well-being.

2) It is recommended that further consideration be given to restrictions on the use of still and moving images of participant children and parents, both in the manner and time-frame of use. If commercial use were to be envisaged, then proper payment and rights arrangements should be negotiated with the participant(s) concerned.

In due course, the Committee would like to receive an update on the progress of this project, any ethical issues that have arisen and how they have been dealt with.

John Oates

Chair, OU HPMEC

A.2.1.2 Extension of consent for further studies

From: J.M.Oates
Sent: 22 June 2005 14:42
To: E.Mansfield
Cc: C.Collins
Subject: RE: Chairs Action Ethics approval reference HPMEC/03/#44/1

Dear Eileen,

I can confirm that this extension to your project falls within the protocol already approved by the Human Participants and Materials Ethics Committee and hence has full ethical approval to proceed.

John Oates,
Chair HPMEC

-----Original Message-----
From: E.Mansfield
Sent: 01 June 2005 14:36
To: J.M.Oates
Subject: Chairs Action Ethics approval reference HPMEC/03/#44/1

Dear John,

Ethics approval reference HPMEC/03/#44/1

I am writing to ask you to approve further eye tracking studies via Chairs Action.

The studies I propose running are with the same population, 4 month old infants, using the eye tracker and the same protocol but with different stimulus. I expect to have another 60+ babies in to participate in the studies for two sessions, on the first session they will receive a bib and on the second a T shirt as a token of our appreciation for their time etc.

If you would like detailed information about the studies please let me know.

Regards,
Eileen

Eileen Mansfield
FELS / CHDL
240D Briggs Building
Open University
Walton Hall
Milton Keynes
MK 7 6AA

Tel: +44 (0)1908 858824
Fax:+44 (0)1908 858868
email: e.mansfield@open.ac.uk

The Open University Centre for Childhood Development and Learning,
Open University,
Walton Hall,
Milton Keynes, MK7 6AA.
Tel. 01908-858824, Fax: 01908 654111
Email: e.mansfield@open.ac.uk

TIME PERCEPTION IN INFANTS

Consent Form

Dear

We are asking for your consent for your baby to take part in our studies into what infants understand about time. This work is part of a doctoral thesis and is supervised by Professor Vicky Lewis and Dr Sarah Norgate of the Open University and has ethical approval from The Open University Human Ethics Committee.

The studies are designed to be fun for babies and involve watching a computer display for a few minutes and/or playing with toys. You will be with your baby all the time, either standing behind him/her, having him/her sit on your lap or playing with him/her.

Before the study begins, the researchers will explain the purpose of the study and all the procedures to you and will be pleased to answer any questions you may have. If at any time you decide you do not want to continue you are free to withdraw from the study.

Your baby will be video-taped whilst participating in the study, this is done so that we can later analyse where your baby was looking when we show him/her different things. This video is normally kept for data analysis purposes but may also be used at scientific meetings or conferences for the purposes of explaining a particular procedure or piece of research.

Thank you very much for taking the time to come in and help us with our research. If you agree to participate, please complete the consent form below, you will be given a copy to take home with you.

Yours sincerely,

Eileen Mansfield, Dr Sarah Norgate & Prof Vicky Lewis

....

I, ... agree to participant in the studies investigating what babies understand about time with my baby .... I understand that I am free to withdraw from the study at any time. I also agree that the video tape of the testing session can be shown at scientific meetings and conferences.

Signature.................................... Name....................................

Date.................................... Baby's Name....................................

Address..

Centre for Childhood Development and Learning,
Open University,
Walton Hall,
Milton Keynes,
MK76AA.
Tel. 01908-858824, Fax: 01908 654111
Email: e.mansfield@open.ac.uk

TIME PERCEPTION IN INFANTS

Photo and Video Consent Form

Dear

This form is asking for your consent to take some photographs and or video of your baby. We are collecting pictures of babies who come into the Open University (OU) to help us with our research. The pictures will be used in the parent newsletter and information letter for new parents. They may also appear on the OU web site or in other publicity material produced by the OU. If, at any time, you do not wish us to continue to using these photos for such a purpose, the pictures would be withdrawn. Your consent will always be sought before giving any pictures of your child to another organisation such as book publishers etc.

Thank you very much for your help with our research

Yours sincerely,

Eileen Mansfield

....

I, ... agree to pictures of my baby .... being taken for OU publicity purposes, such as parental newsletter, information sheets or the web site. I understand that my consent will always be sought before any pictures of my child are given to any other organisation.

Signature................................... Name...................................

Date..

Baby's name......................................

Address..

....

Applied Science Laboratories
An Applied Science Group Company
175 Middlesex Turnpike
Bedford, MA 01730 USA
Tel: (781) 275-4000
Fax: (781) 275-3388
Email: asl@a-s-l.com
Web site: http://www.a-s-l.com
September 2, 1998
Safe Levels of Infrared Illumination

One of the most comprehensive and authoritative sources on the subject of light source safety is a handbook entitled *Safety with Lasers and Other Optical Sources*, by David Sliney and Myron Wolbarsht, first published in 1980 by Plenum Press. Quoting from page 147 of this book, " However, safe chronic ocular exposure values, particularly to IR-A, probably are of the order of 10 mW/cm² or below". "IR-A" refers to the spectral band between 760 and 1400 nanometers, the range in which the ASL remote module operates.

We are aware of no data, made available since the book was published, that would challenge this conclusion. Most people might wish to be more conservative than the figure cited above, and ASL's eye tracker optics modules operate at least an order of magnitude below this level.

The power of the LED's used varies somewhat from sample to sample. The largest irradiance value that we have ever measured with either the Head Mounted Optics or pan/tilt optics module is 0.75 - 0.80 mW/cm², at the plane of the eye. Under normal use, eye irradiance will be between 0.1 and 0.3 mW/cm².

Joshua Borah
Vice President, Engineering

Appendix 4 Forms

Appendix A.4.1 Letter to Parents

The Open University

Centre for Childhood, Development and Learning,
Open University,
Walton Hall,
Milton Keynes, MK7 6AA.
Tel. 01908-858824, Fax: 01908 858568
Email: e.mansfield@open.ac.uk

7th February 2006

Bletchley
Milton Keynes

Dear [parent's name],

Thank you very much for agreeing to bring young [child's name] in to visit us on **Tuesday 7th February 2006** at **4pm** and **Wednesday 8th February 2006** at **3pm**. The aim of the project is to determine what babies understand about time and whether this influences the everyday interactions between mothers (primary carers) and their infants.

I enclose the 2 questionnaires that we spoke about. These questionnaires have been used around the world for many years now to investigate mother/infant interactions. The very short one looks at how you have felt in the last couple of weeks and the second one is about your baby's behaviour in the last week. All information is strictly confidential and will be anonymous. I also enclose as promised a map showing the parking space (which is marked with a signpost by the space). I will be outside the building to meet you for your appointment and as mentioned there is a lift to the second floor so we can bring the pram/buggy up in it.

Each visit will last approximately 45mins – 1 hour. I will discuss the project with you in full before we begin, please feel free to ask any questions you wish at any time. Each testing session lasts approximately 12 mins and is broken up into 2 sections, one of which involves a 2 minute interaction session with you and [child's name].

Many thanks for your help, it is greatly appreciated.

Yours sincerely,

Eileen Mansfield

**Centre for Childhood, Development and
Learning,**
Open University,
Walton Hall,
Milton Keynes, MK7 6AA.
Tel. 01908-858824, Fax: 01908 858568
Email: e.mansfield@open.ac.uk

26th July 2005

Sue Weeks
Health Visitor
Cobbs Garden Surgery
West Street
Olney
MK45 5QG

Dear Sue,

Time perception in infants

Last July you kindly displayed a poster and some leaflets for me letting parents know
about my PhD research project. I need 15 more 3-4-month-old babies to help me out with
my last studies and then I can finish my PhD. I have taken the liberty of enclosing another
poster and some leaflets and newsletters about my work and would be very grateful if you
could display them for me again

I was also wondering whether I might be able to pop along to your Post natal group and
come and see the Mums as I find that if they can see a face behind the poster they often
come along with their babies to help me.

Many thanks in advance for your help, as always I really do appreciate your efforts to
recruit babies on my behalf.

Yours sincerely,

Eileen M. Mansfield

Do babies understand time?

Thank you for coming in to help us with our research. Today your baby participated in a study with three parts.

In the first part we were looking to see whether babies can learn a predictable sequence of smiley faces. We are looking at their eye movements to help us understand what they learn. This is the first time that studies about babies understanding of time has been conducted with an eye tracker. We expect to see eye movements patterns change if the predictable sequence is disrupted. If this is so, we will be able to use eye movement patterns to examine children's understanding of time in the future.

In the second part of the study your baby will be watching a dancing cartoon on the monitor screen which will periodically stop dancing and remain still. We are interested in whether baby's eye movement patterns change when they look at dynamic and static pictures.

In the final part of the study which looks at social interaction, you are asked to participate in the study by interacting with your baby via a video and then to look towards and then away from your baby in a timed sequence, with similar time periods to the smiley faces your baby saw earlier. In this part of the study we are looking to see how long it takes for babies to catch on to the game of when Mum is looking at me and whether they look to the centre when we disrupt the 'game' and *you* remain looking to the side.

When the study is complete we will be sending out an information sheet so you can see how Milton Keynes babies understand time.

Thank you very much for coming to see us today.

Eileen Mansfield

FELS/ CHDL Open University

240 Briggs Building,

Walton Hall, Milton Keynes MK 7 6AA

Phone: 01908 858824; **Fax:** 01908 858868

Email: e.mansfield@open.ac.uk

2nd June 2005

Dear parents,

Infant time perception research at the Open University

Thank you very much for your support in my research. I am enclosing a newsletter to let everyone know the findings of my research so far. I have sent you the short version but have a longer version, which covers the background to the research in greater detail. If you would like a copy please contact me.

I am about to start the final testing phase in my PhD research and would appreciate your help once again. Approximately 60 babies came in to see me during the first two studies and I need another 60 babies to participate in the next studies. That is a lot of babies. I am asking parents if they have had a second baby or whether they know anyone who has a baby under 4 months old? If you / they would be interested in coming in to participate in my studies please contact me. I am asking parents if they can come in for one hour or if possible for one hour on two occasions, a week apart, whichever is convenient for them. As you may remember, the studies themselves only take about 10 minutes, but I like to discuss what we are going to do with parents beforehand so that they are completely happy. This also gives us time to have a cup of tea!

Thank you once again for your support, I have really appreciated it.

Yours sincerely,

Eileen Mansfield

PhD Research Student.
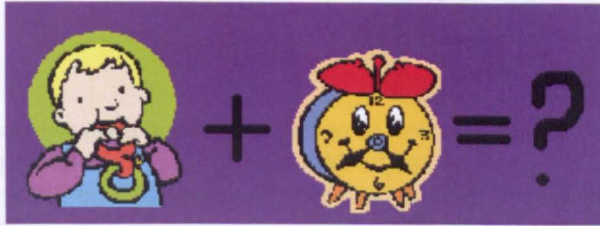
Baby research newsletter
Eileen M. Mansfield
Centre for Childhood, Development and Learning,
The Open University.
May 2005

Thank you

I hope that you and your babies are well. I would like to say a very big thank you for your help with my research. Over 60 babies and parents have come into the Centre to participate. Without you, I couldn't do my research.
I really do appreciate your participation.

More baby volunteers needed!

I am about to start my last studies for my PhD and need another 60 three- to four-month-old babies to come in to visit me between now and the beginning of September. If you have had second baby, or know someone who has a baby under four-months-old who would be interested in coming in to help me with my research, please could they/ you contact me on 01908 858824 or email e.mansfield@open.ac.uk and I can give you/ them further information. Thank you in advance.

Babies perception of time

When you came into the Centre, we did three studies. I will tell you the results of two of those studies in this newsletter.


Background to the studies

The aim of my studies is to understand whether babies can estimate time. You may say, isn't asking whether babies can estimate time like asking them what they know about quantum physics or philosophy? On the face of it, time perception does not seem very relevant to the life of a four-month-old, baby. However, if you think about it, the ability to estimate time is the basis for many things for example when reaching for a toy, babies need to know when to stop reaching and begin to grasp the toy. When children get a little older, and begin eating on their own, they need to time how long they should raise a spoon to their mouths and successfully eat some yoghurt. An instance of using time perception as adults is when driving our cars and we want to negotiate a roundabout or entry onto a motorway safely.

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In addition, when talking, if the timing of the interaction is not synchronous then we notice that something is wrong. For example, if someone keeps interrupting us or fails to respond on time, we think that they are rude or have something to hide. The easiest way to think about this is if you are on the phone to somebody. Although you cannot see them (unless you have a video phone!), you can tell whether they are paying attention to what you are saying if their responses are appropriately timed.

Young babies are learning about how to 'converse' very early on in life. They begin with smiling and then making sounds, which later become words. If you listen to your four-month old, he/she will actually be 'conversing' with you. They will begin a conversation with a smile or sound and then take their turn in the conversation by replying to what you say. Over 25 years ago a psychologist named Daniel Stern realised that 'bursts' or parts of "conversations" between adults and four-month-old babies last between 2 and 7 seconds. Each burst of conversation contains vocalisations or sounds, pauses and turn-taking between the partners. Daniel Stern thought these bursts were short because babies lungs are small, so they run out of breath quickly. A further study by Jaffe and colleagues in 2001 found that babies of four months old have a more relaxed style of 'conversing' with their mothers than with strangers. In addition, those bursts of 'conversation' are on average one second shorter between infants and adults than between two adults. Their work suggests that perceiving intervals of between 1s and 3s are important for babies.
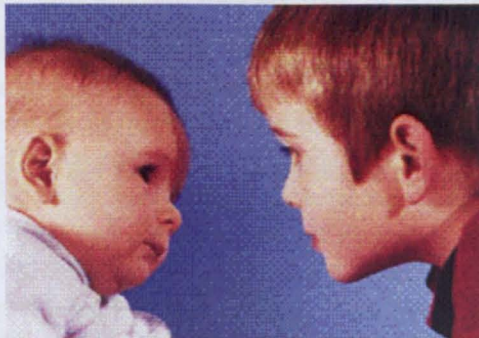
 The next question is, how can you test babies' perception of time, after all you can't ask them how long something lasted for?

In 2002, Colombo and Richman published a study examining babies time perception. They showed babies a predictable dark/light sequence and measured their heart rate while they were watching it.

Colombo and Richman 2002 stimulus sequence

omission trial 15s

3s OFF
dark screen

2s ON
light screen
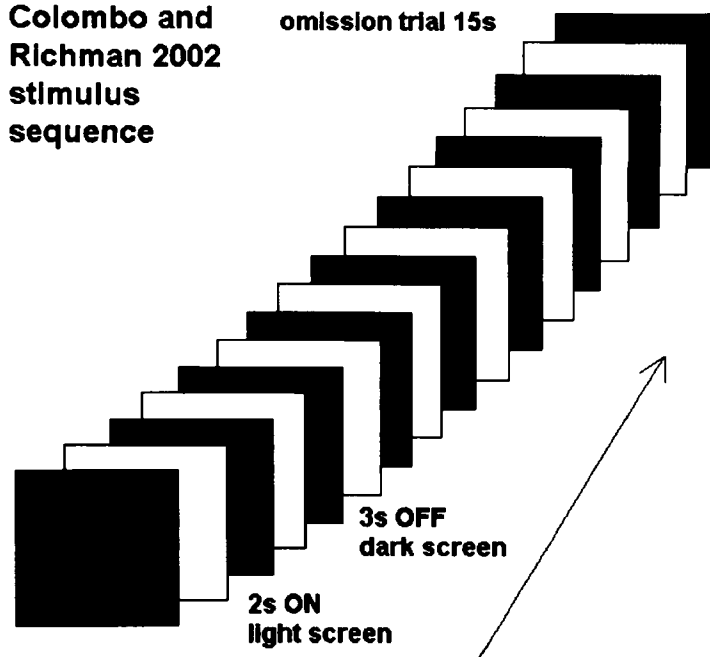
Recording babies' heart rate is one of the ways we can measure their levels of attention. If heart rate drops this indicates that babies' attention levels have increased. Colombo and Richman found that if you stop the predictable sequence and just show a dark screen babies heart rate decreases about the time the light screen should have re-appeared indicating that they are paying more attention at this time. Because two groups of babies made the same heart rate responses, both with a different time interval, the researchers suggested that babies of this age can estimate time. This was an important study as it was the first time anyone had ever looked at whether babies could understand time.

Although measuring heart rate tells us about changes in babies' attention levels, it does not tell us exactly where babies are looking. To be able to do this we need to examine their eye movements. Eye movements are very useful when researching the abilities of babies as we do not have to wait until they have developed physically such as being able to speak, before we can see what sorts of things they notice.

The studies that your babies have been participating in use a similar method to Colombo and Richman showing a predictable sequence, which is then disrupted. We are using an eye tracker, which shows us exactly where babies are looking, before and after the sequence is disrupted.

The eye tracker bathes the room in a very low level of infra red light (about 100th of sunlight) and enables the camera to measure the distance between the corneal reflection (the reflection of light on your eye) and the edge of the pupil. By continually recalculating this distance the exact position of the eye is recorded as a small cross that moves about showing which part of a picture the person is looking at. Many infant researchers around the world are now using eye tracking to understand the way that babies learn.
We have conducted two studies so far, the first one involves sequences of smiley faces and the second involved a game like that of 'peek-a-boo.

The smiley face study
In this study we showed sequences of different coloured smiley faces interspersed with a black screen. We showed babies three sequences which had different time intervals, fast, medium and slow. After the baby had seen a number of smiley faces, the sequence was disrupted and a black screen appeared for an extended period of time. We look to see if any patterns of eye movements emerged at this time.

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Smiley face study

sequence
disrupted
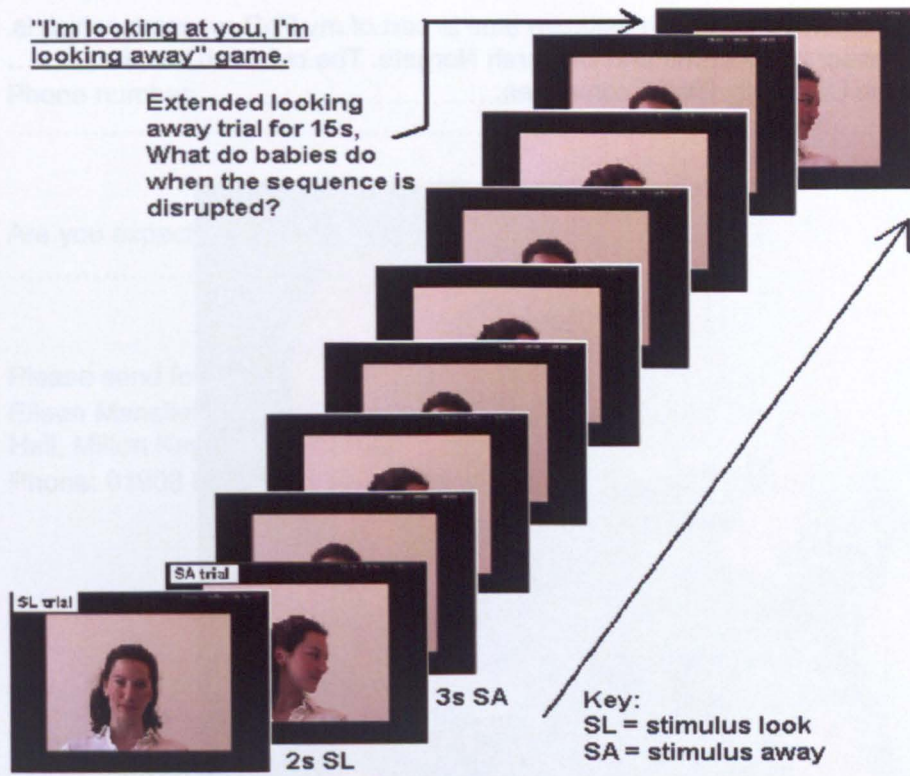for 15s.
What do
babies
do now?

3 seconds
OFF

2 seconds
ON
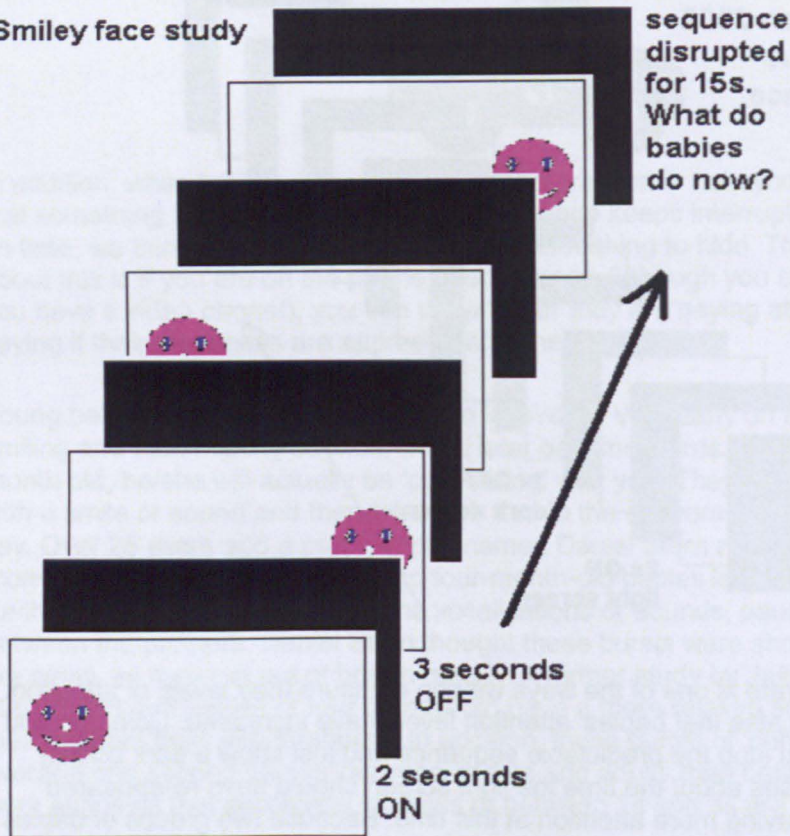
What did we find?

When the sequence was disrupted, babies looked to the next smiley face location about the time it should appear again. If you compare the time it takes babies to look at the smiley faces when there is a smiley face, to the time that they take to look at the black screen during the disrupted part of the sequence, there is not much difference. This suggests that babies are estimating the time that the next smiley face should arrive. Babies were able to do this in the slow and the medium time intervals but some were not very good with the fast sequence. It was just a bit too fast for them.

The 'peek-a-boo' game.

The second study used a video clip of a lady playing a game of "I'm looking at you, I'm looking away", rather like a game of 'peek-a-boo'. The length of time of the lady looks away in each sequence uses the intervals that are important for social interactions (conversations) that we talked about earlier, intervals of 1 second and 3 seconds.

Most babies liked this study and smiled and tried to talk to the lady on the screen, but some babies appeared to think that she was very rude as despite their best efforts to 'converse' the lady never responded to them. They simply looked away in disgust and played with their feet! In a future study, I intend to have the lady on the screen say something to the babies.

"I'm looking at you, I'm looking away" game.

Extended looking away trial for 15s, What do babies do when the sequence is disrupted?

SL trial

SA trial

2s SL

3s SA

Key:
SL = stimulus look
SA = stimulus away

What did we find?

When the sequence was disrupted and the lady looked away for an extended period of time (15s), babies looked to the where the lady would look at the centre of the screen, at about the time the game should have continued. This shows us that they were "playing the game". If you compare the time it took babies to look at the lady's face when she looked to the front, to the time that they looked at the centre screen during the disrupted part of the sequence when the lady continued looking to the side, there is not much difference. This suggests that infants are estimating the time that the lady will look at them again. Babies seem to be able to use this ability when looking at both fast and slow sequences. That is babies seem to be able to estimate intervals of 1 and 3 seconds.

These two studies suggest that most babies are able to estimate two different time intervals, those of 1 second and 3 seconds, and that some babies can estimate intervals of 750 milliseconds. This may not seem very long but as we saw earlier these intervals are important for social interaction.

Conference presentations

I have presented this information at two developmental psychology conferences where other infant researchers were very interested in my findings. After I have written the thesis, I will write some articles for scientific journals

.

Future studies

We want to examine this ability further to see whether babies are more accurate at time keeping when they are given sounds and well as pictures to look at. This is also more like every day social interaction that uses both sound and vision. This is the aim of the remaining studies for my PhD research.

To be able to understand this ability more and its implications for social interactions we need lots of babies (about 60 babies) to come in to see us. We are asking parents if they will visit us for one hour on one occasion or if possible for one hour on two separate occasions. If you would like to participate in these studies with your baby please contact me, **Eileen Mansfield**, on **01908 858 824** or email me at e.mansfield@open.ac.uk.

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This research into whether babies can estimate time is part of my PhD research, which is supervised by Professor Vicky Lewis and Dr Sarah Norgate. The research has the approval of the Open University Ethics committee.

Thank you again to all our babies; this is Beth modelling her T shirt!

Have your details changed?

At the end of my PhD when I have written up my thesis I will be writing a second newsletter to tell parents the results of all the studies in which their children participated in. In order to make sure that every parent gets a newsletter I need to keep my records up to date. If you have you changed address in the past year, or are about to, please complete the form below and send it to me at the address at the bottom of the form. Also let me know if are you expecting another baby. Many thanks.

****

Name: .... Baby's name:

....

Address:...

....

....
....
Phone number: .... email:
....

Are you expecting another baby, if so when?
....

Please send form to:
Eileen Mansfield, Rm240D Briggs Building, FELS/CHDL, The Open University, Walton
Hall, Milton Keynes, MK7 6AA
Phone: 01908 858 824;   Email: e.mansfield@open.ac.uk .