THE DEVELOPMENT OF INFANTS' EXPECTATIONS FOR EVENT TIMING

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Abstract

The ability to process and incorporate temporal information into behaviour is necessary for functioning in our environment. While previous research has extended adults' temporal processing capacity onto infants, little research has examined young infants' capacity to incorporate temporal information into their behaviours. The present study examined 3- and 6-month-old infants' ability to process temporal durations of 700 and 1200 milliseconds by means of an eye tracking cueing task. If 3- and 6-month-old infants can discriminate centrally-presented temporal cues, then they should be able to correctly make anticipatory eye movements to the location of succeeding targets at a rate above chance. The results indicated that 6-, but not 3-month-old infants were able to successfully discriminate and incorporate temporal information into their visual expectations of predictable temporal events. Brain maturation and the emergence of functional significance for processing temporal events on the scale of hundreds of milliseconds may account for these findings.

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Table of Contents

List of Figures

The Development of Infants' Expectations for Event Timing

The perception of time is a capacity necessary for functioning in our environment. For example, the information one gains from detecting the passage of time is a necessary component of speech production and comprehension (Rosen, 1992; Poeppel, 2003; Van Wassenhove, Grant, & Poeppel, 2007), reasoning (Van Beek, 1992), episodic memory (Tulving, 2002), goal planning (Janicik & Bartel, 2003), and expecting future events (Caruso, Gilbert, & Wilson, 2008). Although research has suggested adults have the capacity to detect, process, and modulate behavior on the basis of the temporal parameters of events (Jones, Rosenkranz, Rothwell, & Jahanshahi, 2004; Wild-Wall, Willemssen, & Falkenstein, 2009; Wittmann & Paulus, 2008), adults seem to lack a precise stopwatch-like mechanism (Hass & Herrmann, 2012). Nevertheless, the capacity to perceive the passage of time is functional in adults and extensively used by their cognitive processes. As cognitive processes develop and become available to the individual, theoretically, so should the capacity to perceive the passage of time become more evident in support of those increasing cognitive processes (Lewkowicz, 1989; Rovee-Collier, 1995). In early infancy, consequently, the capacity to perceive time would facilitate the cognitive constructs that allow them to better understand their complex environment. One particularly important cognitive construct that increases processing efficiency, even in infancy, is future oriented thinking that enables the allocation of resources prior to the occurrence of regular events (Haith, 1994). If infants have the ability to process time, therefore, then they should be able to use time information when trying to make predictions about temporally predictable events in their environment. The ability to understand and create expectations about temporally predictable events is important because it allows individuals to plan and prepare for the future occurrence of these events, so they can act optimally in their environment.

Time perception studies typically investigate an individual's awareness of subjective time. Subjective time can be thought of as the amount of physical time one believes they have experienced from the initiation to termination of a specific event. The information about events one receives regarding their subjective time is important when planning for the future. For example, students' attitudes towards studying for an upcoming test will be different when they perceive themselves as having a little versus a lot of time to do so (Nussbaum, Liberman, & Trope, 2006). While subjective time can theoretically be studied with respect to any magnitude of time (e.g., milliseconds, minutes, hours, etc.), researchers typically study subjective time perception with respect to a restricted range.

Time perception studies typically involve the ability to judge, contrast, and produce events' time durations or the time between events, which last from 500 milliseconds to a few minutes (Grondin, 2008; Zakay & Block, 1997). The ability to perceive and process temporal events of small magnitude has led to the emergence of the idea that humans may possess a temporal cognitive mechanism similar to an internal clock (Church, 1984). Since the internal clock is a mechanism that keeps track of the temporal parameter of events, subjective time is the temporal information one obtains from their internal clock.

Internal Clock Theory

One of the earliest, if not the earliest, bit of evidence in favour of an internal clock for processing time can be traced back to the work of Hudson Hoagland in the early 1930s. Hoagland (1933) noted that his wife would complain how slowly time passed as she was ill with a fever. While recording her body temperature, Hoagland asked his wife to count to 60 seconds. He observed an inverse relationship between her body temperature and the time it took her to count to 60 seconds. As her body temperature increased, the amount of physical time required for her to subjectively experience 60 seconds decreased. Hoagland concluded that the human body possesses a chemical clock that can either be sped up or slowed down by changes in temperature—similar to a chemical reaction. The chemical clock, as Hoagland concluded, was what allows humans to perceive the passage of time.

Around the same time of the assertion of humans possessing an internal, or chemical, clock was made, psychophysicists were trying to understand subjective timing in humans themselves. The psychophysicists were particularly concerned with understanding subjective timing as a prospective, rather than retrospective, judgement. Prospective time judgements involve tasks that require the participant to have a present awareness of time since the information is necessary for the completion of the task (Eisler, Eisler, & Hellström, 2008; Hicks, 1992). In contrast, retrospective time judgements involve judgements about time after the task is completed (e.g., "how long did it take you to complete that test?"). So the time perception tasks being used required participants to discriminate, verbally estimate, produce, or reproduce the time values of viewed visual and auditory stimuli. In discrimination tasks, participants were asked if a given stimulus had the same duration as a previously viewed stimulus (Henry, 1948). In verbal estimation studies, participants verbally stated for how long they believed a stimulus was displayed (Gilliland & Humphreys, 1943). In tasks requiring production and reproduction, participants were asked to generate or mimic, respectively, a temporal event usually by tapping or pressing and holding a button down (Gilliland & Humphreys, 1943; Woodrow, 1930). Regardless of the type of task used, researchers observed a common pattern in the way humans process and subjectively perceive time.

The pattern of results obtained from decades of psychophysical work on subjective timing was difficult to explain and interpret from a theoretical perspective. When an individual was asked to estimate how long a temporal event lasted, the variability in their replies increased as the temporal event's duration increased. When the variability associated to the replies was defined as a proportion relative to the magnitude of the estimated temporal event, however, the coefficient of the variability in the replies was relatively constant (Treisman, 1963). Furthermore, this pattern of results conformed to Weber's Law (Laming, 1986)—the variation of estimation around a given mean is proportional to variation around other means of different magnitudes. Such a pattern of results suggested a mechanism of constant sensitivity towards subjective timing in humans.

To combine the idea of humans possessing a chemical clock with the psychophysical data on subjective timing in humans, Treisman (1963) theorized that Hoagland's (1933) chemical clock could be thought of as an internal clock composed of three distinct stages that operate together. The first stage is the pacemaker-accumulator center, in which arousal causes the pacemaker to emit pulses. When arousal is constant, as in being exposed to a temporal event of a set magnitude, the pulses emitted by the center are emitted at a constant rate as well. When an experienced event is over, the number of emitted pulses are tabulated by the accumulator and then stored into memory (i.e., the second component of the model). The memory of the event can later be retrieved by the third component of the model, the comparator. The comparator enables the individual to compare the number of pulses for a recently attended event with the number of pulses for a similar event represented in one's memory, and determine if both events had similar temporal parameters or not (as indicated by the number of accumulated pulses). Since the pacemaker-accumulator must open and close to tabulate the number of pulses emitted during a given temporal event, temporal events with the same temporal duration may have a different total number of pulses attributed to it. This is due to there being systematic variability associated with how long it takes to open and close the pacemaker-accumulator. As well, the degree of variability in opening and closing the pacemaker-accumulator increases for larger temporal parameters that are being measured by the internal clock. Finally, Tresiman (1963) postulated that the memory residuals of past timed events may contain sources of error as the timed events may be remembered for occurring longer or less than what was actually experienced. Together, the internal clock model provided a theoretical explanation as to how individuals process time and why subjective timing does not precisely encapsulate the amount of physical time of a specific event's duration.

Though Treisman's (1963) theory advanced the idea of humans possessing an internal clock for processing and making judgements related to the temporal parameter of events, it did not create immense interest in human time perception as a field of study (Wearden, 2005). Interestingly enough, a theory quite similar to the internal clock theory emerged from a different area of scrutiny, animal learning behaviour (Allan, 1998). This alternate theory proved to become the foundation for explaining subjective timing in animals and, subsequently, humans.

Scalar Expectancy Theory

Operant conditioning as a phenomenon and paradigm was first extrapolated through animal learning studies. A typical operant conditioning experiment consisted of an animal (e.g., a rat) learning to perform a specific behaviour (e.g., push a lever downward) through the reinforcement of receiving a reward (e.g., a food pellet). Typically, hundreds, or even thousands, of trials were required until the behavioural action was successfully learned. Skinner (1990) designed a specific form of operant conditioning that released rewards to the animal on a fixed-interval schedule. Only behavioural actions emitted after a specific amount of time had elapsed were rewarded. As a result, the animal learned to temporally regulate their responses such that responses were emitted in higher proportion as the amount of elapsed time neared the onset of the reward being available (Dews, 1970; Ferster & Skinner, 1957; Lowe & Harzem, 1977; Schneider, 1969). Along with the rat, animal species such as cats, birds, fish, and turtles have been observed to temporally regulate their actions (Lejeune & Wearden, 1991). The ability of animals to temporally regulate their behaviours puzzled learning behaviourists as they could not theoretically explain the pattern of results through a mechanism like reward-based learning.

Eventually, through mounting consistent evidence, the initial inability for learning behaviourists to explain animals' ability to temporally regulate their actions was replaced by the formation of Scalar Expectancy Theory (SET). A closer look at the fixed-interval operant conditioning studies revealed that the temporally regulated behaviours of the animals conformed to Weber's Law (Gibbon, 1977). With evidence from multiple studies, most notably the work by Dews (1970) which investigated fixed-interval learning with pigeons, Gibbon (1977) concluded that animals possess a scalar timing mechanism that allows them to encode the temporal parameter of events. Animals were able to recognize and encode the critical amount of time that had to elapse before their behaviour would be rewarded. This was observed as: (1) the animals increased the frequency of executing the learned behaviour as the elapsed time since their last reward increased and mounted closer to the magnitude of time that had to elapse before the learned behaviour could be rewarded again, (2) the animals were more accurate at executing the learned behaviour at the appropriate time for shorter reward schedules than longer ones, and (3) the likelihood of the animal performing the learned behaviour was a function of a ratio rather than an absolute difference between the onset of when the learned behaviour was executed and the magnitude of time that had to elapse before the learned behaviour could be rewarded again—a property of Weber's Law. For example, the probability of a rat executing a learned behaviour will be the same when 30 seconds has elapsed in a experimental condition where the rat is rewarded for executing the learned behaviour every 60 seconds, and when 60 seconds has elapsed in a experimental condition where the rat is rewarded for executing the learned behaviour every 120 seconds (LaBarbera & Church, 1974). As an outcome of SET, researchers postulated that animals contain a non-random capacity that allows them to temporally regulate their behaviours. An exact model of this temporal capacity was established a few years later (Gibbon, Church, & Meck, 1984).

What is most notable about the SET model proposed by Gibbon, Church, and Meck (1984) is its resemblance to Treisman's (1963) internal clock theory. SET contains clock, memory, and decision processes that operate quite similarly to the components proposed by Treisman (1963). Like internal clock theory's pacemaker-accumulator, the pacemaker-switch—the clock process of the SET model—offers a source of variability within the SET model that accounts for the scalar property (i.e., conformity to Weber's Law) in animals' capacity to temporally regulate their behaviour. Similar to the explanation proposed by Treisman (1963), the pacemaker-switch tabulates the temporal parameter of an event by emitting and recording pulses throughout the duration of the event. There is systematic variability associated with the speed of opening and closing of the pacemaker-switch. The variability in the speed of opening and closing the pacemaker-switch increases for events with longer durations. The variability associated with the opening and closing of the pacemaker-switch provides a mechanism for why subjective timing is not a perfectly precise approximation of physical time. That said, however, the SET model does differ from internal clock theory by placing a greater emphasis on the memory process associated with the model. Gibbon et al. (1984) postulated that the memory representations of events' temporal parameter provide a source of the scalar variance in animal's capacity to process time information since the regular variability in the temporal component of representations for events increases as the magnitude of the event's temporal parameter increases. While SET and internal clock theory have some differences in the structure of their associated models and as to which component of the model provides the greatest source for the scalar property in animal's capacity to process temporal information, the theories are remarkably similar. Perhaps what distinguishes SET and internal clock theory the most is not the theories themselves, rather their field of origin and application (Wearden, 2005). While both theories promoted the notion of the existence of an internal clock, SET became the dominant theory in the study of time perception.

As SET explained temporally regulated behaviours in animal learning studies, researchers began to investigate if SET could explain time perception in adults as well. Wearden and McShane (1988) provided one of the earliest accounts of SET being applied to adults on a time production task. Participants were asked to produce temporal events that mimicked a temporal parameter that ranged between 500 and 1300 milliseconds in duration. Results from the study indicated that adults were able to produce temporal events that centered the temporal parameter they were supposed to mimic. As well, the variability of the produced temporal events increased as the temporal parameter that was to be mimicked increased in magnitude. The real interesting finding, however was that the variability of the produced temporal events for each temporal parameter that was mimicked was proportional to one another—the hallmark of SET. Furthermore, the non-random pattern of results could not be explained by participants relying on chronometric counting (i.e., the ability to explicitly "count-out" how much time has elapsed) since the studied durations were too short to do so (Zeiler, Scott, & Hoyert, 1987). The conclusion drawn from the results suggested the presence of an involuntary internal time-keeping mechanism. As SET provided a possible theoretical foundation for the results of Wearden and McShane (1988) in addressing their findings of subjective timing in adults, methods similar to those used in animal studies were developed for further adult testing.

Two commonly used tasks for measuring temporal processing in animals are temporal generalization and temporal bisection. In temporal generalization, the animal (e.g., rat) learns through reward to press a lever when a light is turned on for a standard duration (e.g., 4 seconds) (Church & Gibbon, 1982). Once the animal successfully learns to temporally regulate their behaviour so they only execute the learned behaviour when they are exposed to the standard duration, the test phase of the experiment begins. In the test phase, the light is turned on for an amount of time that is either the same, greater, or smaller than the standard duration by a fixed, linear value (e.g., 0.8 seconds). For trials where the light was turned on for an amount of time that was unequal to the learned standard duration, the animal is not rewarded for pressing the lever. The animal, therefore, is motivated to only press the lever when exposed to the standard duration. The researcher then records the proportion of lever presses made by the animal when exposed to the standard and non-standard time durations. The results from such a task reveal the animal's decision-making criteria when determining if two durations are equal in magnitude or not. This is evident as the proportion of lever presses is highest for when the animal was exposed to the standard duration, and then decreases as the degree of separation in magnitude increases between the standard duration and the non-standard durations used in the experiment. The effectiveness of this task for exposing the decision-making behind animal time judgements led to the development of a variant for human testing (Wearden, 1991a, 1992).

Adult participants are shown a stimulus that is presented for a specific duration of time. After multiple trials of being exposed to the standard duration, the participants enter the test phase. In the test phase the participants are exposed to the same stimulus as before, but this time the stimulus is displayed for durations that are either the same or different from the standard duration. For the durations that are different, the values are scaled to be greater and less than the standard duration by a fixed amount. Across trials, the participants view the stimuli and push one of two buttons that corresponds to them either agreeing or disagreeing that the most recent viewed stimulus was displayed for an amount of time that was the same or different to that of the standard duration. After every submitted response, feedback is given to the participant. Just like the variant used with animals, this task reveals the decision-making criteria adults use when determining if time durations are equal to one another or not.

Another commonly used test for measuring temporal processing in animals is temporal bisection. In this task, the animal (e.g., rat) learns to press a lever (e.g., left lever) when it is exposed to a signal of short duration (e.g., 2 seconds) and another lever (e.g., right lever) when it is exposed to a signal of long duration (e.g., 8 seconds) (Church & Deluty, 1977). After learning this discriminatory behaviour, the animal is exposed to stimuli (displayed individually) for durations that are intermittent of the short and long durations. The animal must push one of the two levers to indicate whether they perceive the stimulus’ duration as being similar to either the short or long duration. The responses of the animal are then typically recorded as a proportion of hitting the lever corresponding to the long duration as a function of the stimulus’s duration. Use of such a task reveals the animal’s ability to categorize intermittent times as being similar or dissimilar to the standard durations, while showing at approximately what time duration the animal is unable to consistently categorize the intermittent duration as being similar to either the short or long duration. As a result, this type of task has been used to exhibit the criteria that animals use when discriminating time durations as being distinct from one another. A variant of this task was later developed to determine the decision-making criterion process in humans (Allan & Gibbon, 1991; Wearden, 1991b).

Adult participants are shown a stimulus that is presented for either one of two specific durations of time. The participants learn to push one button for when the stimulus is displayed for the duration of time that is the shorter of the two standard durations of time, and another button for when the stimulus is displayed for the longer of the two standard durations of time. After successful practice trials where the participant is able to view the stimulus and push the correct button that corresponds to the duration that it was displayed for, the participants enter the test phase. In the test phase the participants are exposed to the same stimulus as before, but this time the stimulus is displayed for durations that are either the same or different from the standard durations. For the durations that are different, the values are scaled by a fixed amount to be between the two standard durations in magnitude. Across trials, the participants view the stimuli and push one of two buttons that corresponds to them either believing that the most recent viewed stimulus was displayed for a time duration that most closely resembled the short or long standard duration. Just like the variant used with animals, this task reveals the decision-making criteria adults use when determining the threshold of what classifies two time durations as being distinct from one another.

The use of temporal generalization and temporal bisection tasks has consequently provided evidence for scalar timing properties in adults' estimation of time durations. Though animal performance on temporal generalization tasks indicated animals show no bias for shorter or longer time durations when determining if time durations are similar or not to one another (Church & Gibbon, 1982), the same was not entirely true for adults. Unlike animals, adult performance on temporal generalization tasks revealed adults to preferentially select longer times to be the same as the standard duration versus shorter durations that differed from the standard duration by equal magnitude (McCormack, Brown, Maylor, Darby, & Green, 1999; Wearden, 1991a; Wearden, Denovan, & Haworth, 1997; Wearden & Towse, 1994). With respect to adult performance on temporal bisection tasks, Allan and Gibbon (1991) found the bisectional point to be the geometric mean—similar to animal performance—of the short and long durations, whereas other adult studies found the bisection point to be just below the arithmetic mean (Wearden, 1991b; Wearden & Ferrara, 1995; Wearden & Thomas, 1997). Reasoning to explain the latter result could be that adults show a bias to indicate that an intermittent duration is similar to the long duration. Whereas it is likely that adults and animals have different decision-making criteria when classifying time durations as being similar or dissimilar, as indicated by adults' bias toward long durations, adults (like animals) still show non-random, scalar properties (i.e., conformity to Weber's Law) in their representations of time durations.

To better understand the capacity to perceive differences in time, time processing abilities were assessed in children to see how functional and refined this capacity is in the early years of life. Since temporal generalization and bisection tasks were able to investigate temporal processing in adults under the rubric of SET, these same tasks were applied to young children. Droit-Volet, Clément, and Wearden (2001) tested 3-, 5-, and 8-year-old children using temporal generalization tasks with standard durations of either 4 or 8 seconds. Though the performances of the 3- and 5-year-old children were similar to one another, they were not similar to the performance of adults from earlier studies. That is, the 3- and 5-year-old children showed no bias towards shorter or longer durations when comparing them to the standard duration. Eight-year-old children however showed a bias, like adults, towards choosing longer durations to be similar to the standard duration but not short durations that differed from the standard duration by the same magnitude of time. Chronometric counting by the 8-year-old children could not have influenced these results, as the results were later replicated using standard durations of 0.4 and 4 seconds (Droit-Volet, 2002). Nevertheless, while age seemed to impact the decision-making criteria for discriminating time durations from one another, age did not influence young children's use of scalar timing when comparing various time durations to a standard.

Using a temporal bisection task this time, Droit-Volet and Wearden (2001) investigated the performance of 3-, 5-, and 8-year-old children with a short and long duration combination of either 1 and 4 seconds or 2 and 8 seconds. Regardless of the age and standard durations used, the researchers calculated the bisectional point to be just below the arithmetic mean, suggesting a selection bias for overestimating time durations when classifying time durations as being relatively long from short. These findings generated from young children completing temporal generalization and temporal bisection tasks suggest non-random, scalar timing is consistent across development. It is therefore possible that the capacity to perceive differences in time is even present in infancy. If so, then infants may have the capacity necessary to process time and use temporal information when constructing a knowledge base about events that occur in their environment.

Time Perception in Infancy

Studying time perception in infants has been quite limited since infants lack the language skills and motor precision to follow instructions and make manual responses. Non-traditional timing tasks, therefore, are required to address any temporal processing question down the developmental timeline to infants. A commonly used paradigm for investigating infants' ability to detect changes in temporal sequences has been a variant of the familiarity/novelty-preference paradigm (Fagan, 1970; Fantz, 1964; Saayman, Ames, & Moffett, 1964) known as the violation-of-expectation paradigm (Baillargeon, Spelke, & Wasserman, 1985). In this paradigm, infants are exposed to a sequence of stimuli depicting a particular event. After multiple trials where the particular event is presumably learned by the infant, there is a novel (sometimes called impossible) trial. The novel trial is unique because it contains a stimulus event that does not conform to an assumed "expectation" that the infant would have due to their knowledge of their world. Researchers infer that any change in the infant's looking behaviour during the novel trial is indicative of the infant being able to detect the apparent impossible change in the perceptual nature of the event sequence. Needham and Baillargeon (1993), for example, used the violation-of-expectation paradigm to investigate 4.5-month-old infants' knowledge about support events (i.e., understanding that items cannot be suspended in mid-air, rather must be resting on something). In this experiment, infants sat in front of an apparatus that contained a platform and screen. From behind the screen, a gloved hand emerged carrying a box. As the infants saw the gloved hand carrying the box over the platform, one of two events occurred. In the control condition, the gloved hand placed the box onto the platform. In the experimental condition, a novel (or impossible) event occurred; the glove hand released the box beyond the platform, leaving the box suspended in mid-air with no apparent source of support. The looking times of the infants in each condition were measured. The infants in the experimental condition looked longer at the novel (impossible) event than the infants in the control condition who looked at the probable event. The researchers concluded that the looking time of infants was greater in the experimental condition than in the control condition because 4.5-month-old infants have knowledge about support and were more surprised to see a box suspended in mid-air than a box supported by a platform.

Use of the violation-of-expectation paradigm has subsequently been used by researchers by using measures other than looking time to investigate infants' ability to detect changes in temporal sequences. Colombo and Richman (2002), for example, had 4-month-old infants view a light stimulus on a screen that would be on for 2 seconds and then turn off for 3 (or 5, depending on the condition) seconds, only to reappear and be on for 2 seconds again. This alternating sequence continued for eight trials until on the ninth trial when the light stimulus did not reappear on screen. The researchers measured the infants' heart rates and noted a deceleration in heart rate on the ninth trial at the time when the light stimulus was to reappear. The deceleration in heart rate was interpreted by the researchers to depict the state of surprise the infants were in due to the light stimulus not reappearing on screen. The researchers, therefore, concluded that infants as young as 4-months of age were able to detect temporal values of 3 and 5 seconds. In a similar study, Boswell, Garner, and Berg (1994) observed that 2-month-old infants show a similar deceleration in heart rate in response to an omitted temporal event.

With yet another different measure, Addyman, Rocha, and Mareschal (2014) recorded the onset of eye fixations to an omitted event in infants with ages of 4, 6, 10, and 14 months. The task involved infants viewing a sequence of events on a screen as the onset of their eye fixations toward these events was recorded by an eye tracker. The sequence of events involved a stimulus predictably appearing in the same location on a screen. After multiple trials that provided the infants with the opportunity to form an expectation for where and when the stimulus was to appear, the stimulus was not displayed at all. When the stimulus did not appear in its expected location, the researchers observed that the infants fixated their eyes onto the area of the screen and around the expected time that the stimulus was to appear. The eye fixation data revealed the onset of fixations to be normalized around the onset of the expected omitted event (i.e., at either

3 (or 5, depending on the condition) seconds after the previously viewed stimulus' offset) and the variability of the fixations to be proportional to the time interval themselves—suggesting yet again that temporal processing consists of a scalar component in infants as young as 4 months of age.

Finally, another measure in the form of physiological data form of event-related potentials (ERPs) has provided further evidence that 10-month-old infants, like adults, show similar scalar timing properties in brain responses to omitted temporal events (Brannon, Libertus, Meck, & Woldorff, 2008). Ten-month-old infants and adults were exposed to auditory stimuli that were separated by an interstimulus interval of 1500 milliseconds. After successive trials where the participants heard the auditory stimuli being presented in a predictable, timed sequence, the magnitude of the interstimulus interval for a given trial differed. Measurement of the mismatch negativity (MMN) waveform can suggest if the change in the predictable timed sequence of auditory stimuli was perceived. Analysis of the MMN waveform revealed that 10-month-old infants, like adults, not only detected the change in the timing of the predictable sequence of the presented auditory stimuli, but the amplitude of the waveform was greatest by the proportional difference between the standard interstimulus interval (i.e., 1500 milliseconds) and the deviant interstimulus interval, and not by the absolute difference between their magnitudes. While the methods used to study time perception in infants have been different to those used in animals, adults, and even studies with young children, the results produced by these infant time perception studies have revealed a non-random, scalar time processing capacity in infants.

Inspired by SET, studies have shown that adults, children, and even infants possess the capacity necessary to discriminate temporal parameters from one another. While the scalar timing properties observed in humans were predicted by SET, additional theories have emerged trying to account for these results as well (see Grondin, 2010, for review). For instance, while the pacemaker of the pacemaker-switch component is believed to emit pulses at a fixed, linear rate, other theorists believe the pulses are emitted as an oscillation in response to perceived timed events (Jones & Boltz, 1989). Conversely, there are some theorists that believe a central timekeeping mechanism does not exist and, therefore, particular systems and processes within organisms have their own capacity to process time (Ivry & Schlerf, 2008; Jantzen, Steinberg, & Kelso, 2005). As the purpose of the current study is not to test different theories or models, I will not be discussing them further. The important issue to address, however, is while humans of varying ages have a non-random capacity to perceive differences in time, what is the development of this capacity in early infancy?

Timing in Infants' Visual Expectations

As previously pointed out, the ability to perceive differences in time can be thought of as a necessary capacity for human cognition (e.g., language comprehension). Whereas much research has been conducted to investigate time processing in adults and what mechanism may account for that processing, it is important to question whether individuals actually use their perception of time to their advantage. In particular, there has been very little research that has investigated the development of time processing in early infants and if infants actually use time information when trying to make sense of the novel environment in which they live. For instance, one way infants can use temporal information when trying to make sense of their environment is to encode the temporal regularities of nearby events and use that information when forming expectations about those events. By being able to cognitively index the temporal regularity of events and formulate expectations, infants will be able to make predictions about these events, anticipate them, and thereby have more time to spend on processing all the information regarding those events. Having more time to process an event leads to more efficient information processing and better comprehension (Haith, Benson, Roberts, & Pennington, 1994).

First developed in 1988, the Visual Expectation Paradigm (VExP) investigated 3.5-month-old infants' ability to visually anticipate the location of images on screen (Haith, Hazan, & Goodman, 1988). A classic example of the VExP involved infants viewing images presented with fixed duration (e.g., 700 milliseconds) in a simple, left-to-right alternating sequence on a screen. Between the presentations of successive images, there is a fixed interstimulus interval (e.g., 1000 milliseconds). As infants learn the predictable sequence of images appearing on screen, they begin to correctly look towards the side of the screen before the image appears (i.e., anticipate). Successive studies using the VExP have revealed that infants' anticipatory looking patterns occur even when the sequence of images was more complex (Canfield & Haith, 1991) and the content predictability of the images (Adler & Haith, 2003; Wentworth & Haith, 1992) were manipulated. Anticipations were used as an index for observing expectations because while expectations are predictions held by the individual, anticipatory eye movements are behavioural responses that are guided by expectations. If an infant creates an expectation of where and when an image should appear on screen, then the ability to look to a particular area on the screen before any stimulus is presented is a behavioural response (i.e., anticipation) that was guided by an internal understanding (i.e., expectation) of the predictable sequence of events.

To this end, Adler, Haith, Arehart, and Lanthier (2008) attempted to see if 3-month-old infants encode the temporal parameter of events and use this information when formulating visual expectations. While the researchers failed to observe infants encode the exact timing of a temporal event, they did observe 3-month-old infants encode the overall temporal flow rate of a given event. That is, the 3-month-old infants were observed to encode the overall timing of a repeating set of stimulus events. This set of stimulus events consisted of an image being presented on one side of the screen, followed by an interstimulus interval, then the presentation of a second image on the other side of the screen, and finally the occurrence of another interstimulus interval. The overall flow rate for any set of events—which the 3-month-old infants were able to encode—lasted for either 2600, 3400, or 4200 milliseconds. Infants first experienced a flow rate of 2600 or 4200 milliseconds and were then shifted to a 3400 millisecond flow rate. Infants changed the frequency of their anticipatory eye movements as a function of whether they experienced a shift to a shorter or longer flow rate. These findings further support previous findings that young infants do not show a bias toward longer durations, having initially shown equivalent anticipation regardless of the magnitude of the flow rate. As already stated, however, the study by Adler et al. (2008) did not show evidence that infants were able to encode the exact timing of individual stimulus events and then use that information to guide their behaviour.

The Present Study

The current study is designed to further investigate the capacity of infants to encode the temporal parameter of events and if they use that information when interacting with their environment by forming expectations for temporally predictable events. Unlike previous research that investigated young infants’ capacity to perceive differences in time with use of the violation-of-expectation paradigm, this study will use a variation of the VExP for methodological and potentially theoretical short comings of the violation-of-expectation paradigm. First of all, previous studies on infant time perception have measured infants’ ability to perceive differences in time on the second-scale. If the capacity to perceive time and temporal differences is important for higher-order cognitive processes, then infants should contain a temporal capacity that is sensitive to even small differences of time, such as on the scale of hundreds of milliseconds. Secondly, whereas previous studies on infant time perception suggest infants can perceive differences in time, the researchers never investigated if infants actually use temporal information to their advantage. By investigating infants' ability to encode temporal information and use it when forming expectations in their environment and making anticipations to those expected events will not only address infants' ability to perceive differences in time—a foundational capacity necessary for the functioning of higher-order cognitive processes—but, also, that they can use temporal information when making predictions about events in their environment. Finally, perhaps counterintuitive to what the name suggests, the violation-of-expectation procedure does not actually measure expectations. An expectation is a prediction an individual may have involving something they predict will happen in the future. Considering that an expectation is a prediction about an event that has not happened yet, any observation of an expectation should, therefore, occur before the event has happened. Thus, observing changes in behaviour after an expected event has occurred—like what is done in studies using the violation-of-expectation paradigm—may not actually be indicative of a violated expectation, but of something else. Research suggests that use of violation-of-expectation paradigms can lead to infants developing a preference for the familiar rather than the novel information (Cashon & Cohen, 2000; Cohen, 2004; Schilling, 2000). Since there are aspects of test events that are familiar, infants may be responding to that familiarity rather than to any novelty in timing. As a consequence, interpreting findings from violation-of-expectation paradigms are inherently difficult. A study that can address these three positions of discussion will not only advance the current understanding of infant time perception, but will exhibit a capacity sensitive to temporal information on the scale of hundreds of milliseconds, which can aid infants in understanding their complex environment.

The Visual Expectation Cueing Paradigm (VExCP) is a variant of the VExP that assesses perceptual discrimination. Unlike the VExP, the VExCP uses central cues to predict the spatial location of target stimuli (Baker, Tse, Gerhardstein, & Adler, 2008). In this paradigm, in order for infants to adequately anticipate the location of the target stimuli above chance performance they must be able to discriminate the perceptual parameter that distinguishes the central cues. In Baker et al. (2008) 6-month-old infants viewed stimuli on a screen while an eye tracker recorded their eye movements. At the start of every trial, a cue was presented at the center of the screen for 2000 milliseconds. The presented cue was either an image of a circle or square contour made up of Gabor patches. After cue offset, an interstimulus interval of 500 milliseconds occurred. After the 500 milliseconds, a target stimulus appeared on the left or right side of the screen for 1500 milliseconds. At target offset, the screen remained empty for 250 milliseconds and it was after this period when the cue reappeared marking the onset of the subsequent trial. In the experimental condition of the study, the cue predicted the spatial location of the subsequent target. If 6-month-old infants are able to perceptually discriminate circle and square contours from one another and use this information when formulating visual expectations, then they should be able to correctly anticipate the spatial location of the target stimuli above chance performance. The researchers observed this as 6-month-old infants were able to correctly anticipate the location of the target stimuli above chance performance regardless of whether the cue was the circle or square contour. The infants in the control condition, where there was no predictable cue–target location relation, anticipated the location of the target stimuli at chance performance. The researchers concluded that 6-month-old infants can perceptually discriminate circle and square contour images from one another and use this content-specific information about the cue when forming expectations in their visual environment.

The purpose of the current study, therefore, is to investigate whether young infants possess a capacity for detecting differences in time on the scale of hundreds of milliseconds and if such information can be used to formulate expectations. Such a finding will not only suggest that the capacity to perceive differences in time is functional early in life, but that this capacity has a functional purpose as it enables infants to better understand their environment by being able to formulate expectations on relevant, temporally predictable events. In order to investigate such a capacity and its development, the present study will use the VExCP as its paradigm with 6- and 3-month-old infants. Infants will be exposed to a variant of the VExCP that contains cues that perceptually deviate from one another by the duration they are displayed for. Thus, as a consequence of this paradigm and manipulation, a direct measure of infants' ability to formulate expectations based on temporal information can be achieved. If infants are able to use temporal information as a distinguishing factor when forming expectations, then they will be able to correctly anticipate the spatial location of cued targets at a rate above chance when there is a predictable cue duration–target location relation.

Experiment 1 – Temporal Cueing in 6-Month-Old Infants

Methods

Participants. Forty-four 6- to 7-month-old infants, recruited from a mailing list supplied by a Toronto-area marketing company (Z Retail Marketing Company Inc., Toronto, Canada), participated in this study. The data from 20 infants were excluded from this study due to crying and general fussiness (*n* = 12), inattentiveness (i.e., provided data on less than 65% of the trials;

n = 5), and experimental error (*n* = 3). As a result, 24 infants (11 males, 13 females) who ranged in age from 168 to 201 days (*M* = 180.9, *SD* = 8.8) and came from middle social economic status (SES) were included in the final sample for analysis. The infants were of Caucasian (*n* = 13), Asian *(n* = 2), African (*n* = 1), Hispanic (*n* = 2), and Other (*n* = 6) ethnic backgrounds. Infants were all born at full-term, in good health, and with no apparent visual, neurological, or other abnormalities as documented by parental recording. Informed consent was given by the parent of each infant.

Stimuli and apparatus. The cue and target stimuli were computer-generated images. The cue was a pink and grey checkerboard image, whereas the target stimuli were images of vertical stripes, concentric circles, and diamond shapes in various colour combinations of red, green, blue, and yellow (see Figure 1). The stimuli were approximately 4.5° degrees in diameter.

The infants were laid supine in a specialized crib and viewed the images on a 19-inch LCD colour monitor with 1024 x 768 pixel resolution that was mounted 48 centimeters overhead. There was a 30 x 30 centimeter infrared-reflecting, visible-transmitting mirror between the infant and monitor. A remote, pan-tilt infrared eye tracking camera (Model 504, Applied Science Laboratories [www.a-s-l.com], Bedford, MA) emitted infrared light that was reflected off the mirror and into the infant's eye (see Figure 2). The reflection of the infrared light coming back from the infant and off the mirror was recorded by the camera at a temporal resolution of 60 Hz. To minimize outside light entry into the crib, black felt curtains were drawn over and around the crib.

Infrared light emitted from the diodes on the camera, reflected from the mirror into the infants' eye, and then reflected back from the infants' retina through the pupil, produced a backlit white pupil. In addition, the infrared light produced a point of reflection on the cornea of

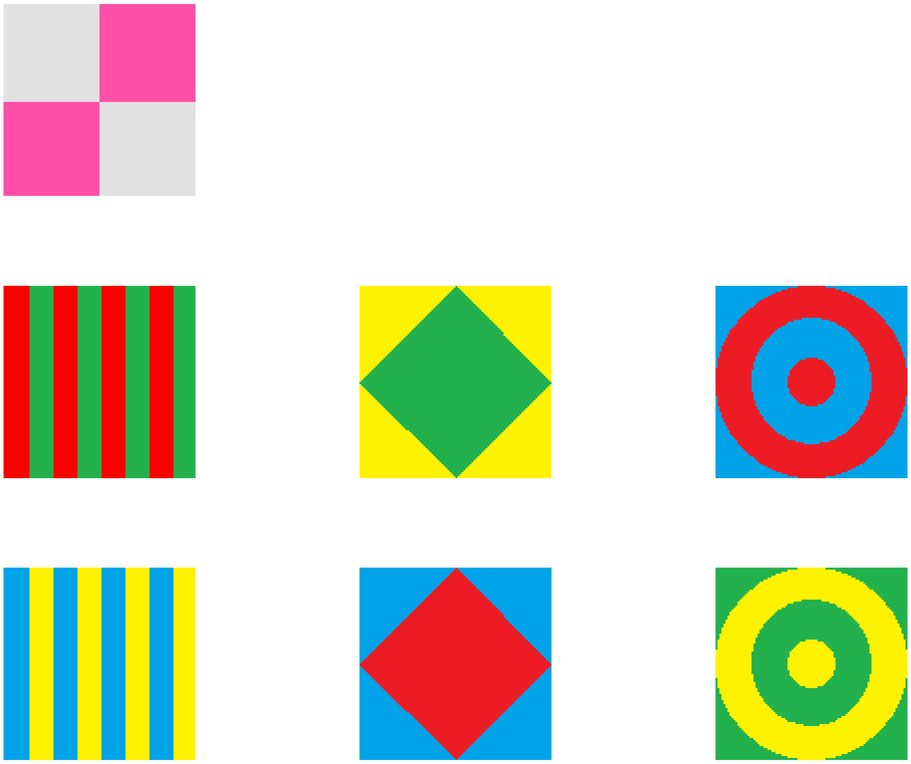

Figure 1. Stimuli used in Experiments 1 and 2. The image in the top row was the cue, while the remaining six images in the middle and bottom rows were the targets.

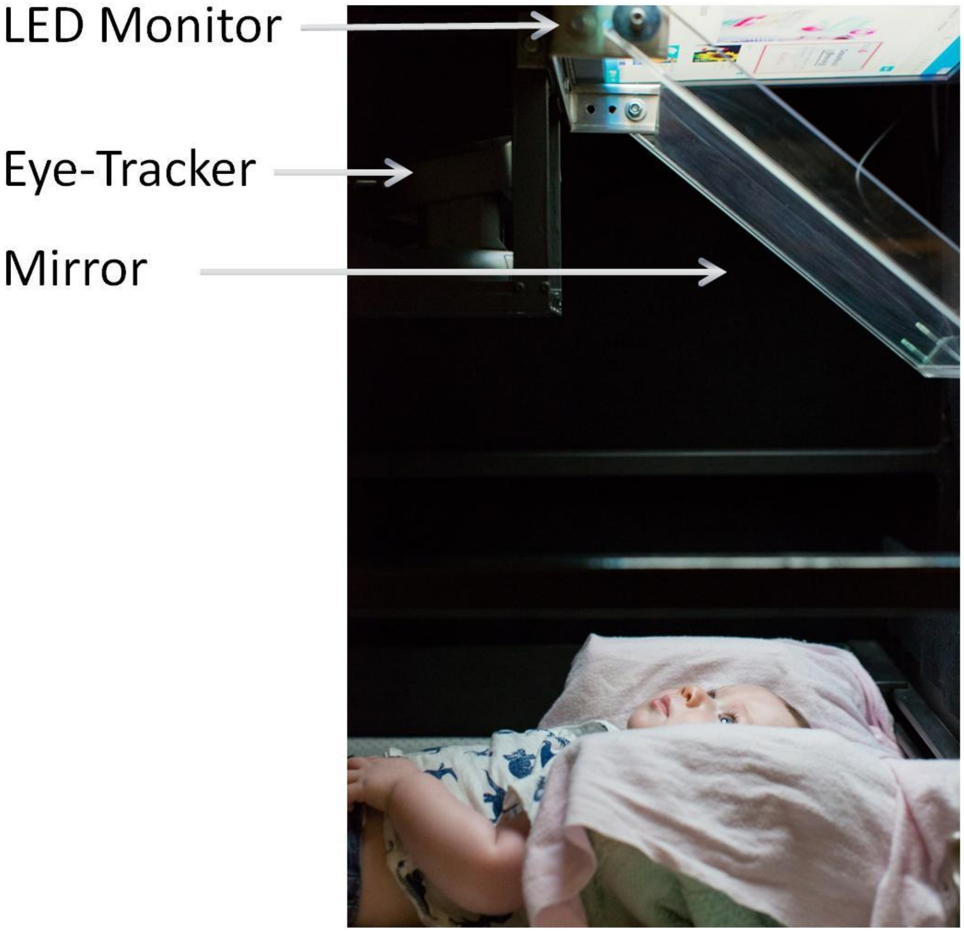

Figure 2. Testing crib apparatus.

the infants' eye. Using proprietary software (Applied Sciences Laboratories), the eye fixation position was calculated as the relation between the centroid of the backlit pupil and the corneal reflection. The eye tracker was calibrated by having each infant view a continuous loop of varying shapes and colours at two known locations on the screen. All future recorded eye tracker fixation values were filtered through the calibration file to produce measures of eye position data.

Throughout the experimental session, two Dell computers were used. One computer generated and presented the stimuli using the program Direct RT (Empirisoft Inc., New York; www.empirisoft.com/DirectRT.aspx). The stimuli generated and displayed onto this computer were relayed to the LCD monitor that was above the crib. This allowed the experimenter to simultaneously view what the infant was viewing. The second Dell computer was used to control the eye tracker and record the data collected from it. The stimulus-generating computer sent a unique, time-stamped numerical code, indicating the onset and type of trial, through a parallel port to the data-collecting computer. Synchronization of the unique code with the eye movement data in the data file allowed coordination of the eye movement sequences to specific stimuli and their onsets.

Procedure. Each infant was exposed to 60 experimental trials. Each experimental trial started with the cue being displayed at the center of a greyscale screen for a duration of either 700 or 1200 milliseconds. The magnitude of the cue's duration on any given trial was selected at random, but every infant was exposed to 30 trials of each of the two cue durations. After cue offset, an interstimulus interval (ISI) of 1000 milliseconds followed during which the screen was empty. After the ISI, one of six target stimuli were randomly selected and presented either on the left or right side of the screen with a visual angle of 5.5° from the center of the screen. The target remained fixed on the screen for 1000 milliseconds. At target offset, the screen remained empty for an intertrial interval of 500 milliseconds. After the 500 milliseconds passed, the cue reappeared at the center of the screen signalling the onset of the next trial (see Figure 3).

Infants were randomly assigned to one of two conditions. In the experimental condition, there was a predictable cue duration–target location relation. That is, the cue's duration predicted the location of the target stimulus with 100% validity. For example, if the cue was presented for 700 milliseconds then the target would be presented on the left side of the screen, while the target would be presented on the right side of the screen if the cue was presented for 1200 milliseconds. The cue–side relation was counterbalanced between participants. In the control condition, there was no predictable cue duration–target location relation. This meant that the duration of the cue provided no reliable prediction as to which side of the screen the target stimulus was to appear on (see Figure 3). The control condition served as a baseline measurement for infants' chance eye movement performance when there was no predictable relation upon which to form an expectation. In total, 12 infants were assigned to each condition.

Data reduction and analysis. The raw digital data recorded by the eye tracker were imported into a MATLAB toolbox called ILAB (Gitelman, 2002) for analysis. ILAB separated individual eye movements into its horizontal and vertical components while displaying the components on a trial-by-trial basis. ILAB also displayed the scan path of the eye, which allowed eye movements to be analyzed based on its timing, direction, and distance relative to the stimuli shown on screen.

For an eye movement to be included in the final data sample, it had to meet a number of criteria. First, as the critical question is whether infants use temporal information when forming expectations, the infants had to fixate on the cue for any trial to be considered valid. Second, in

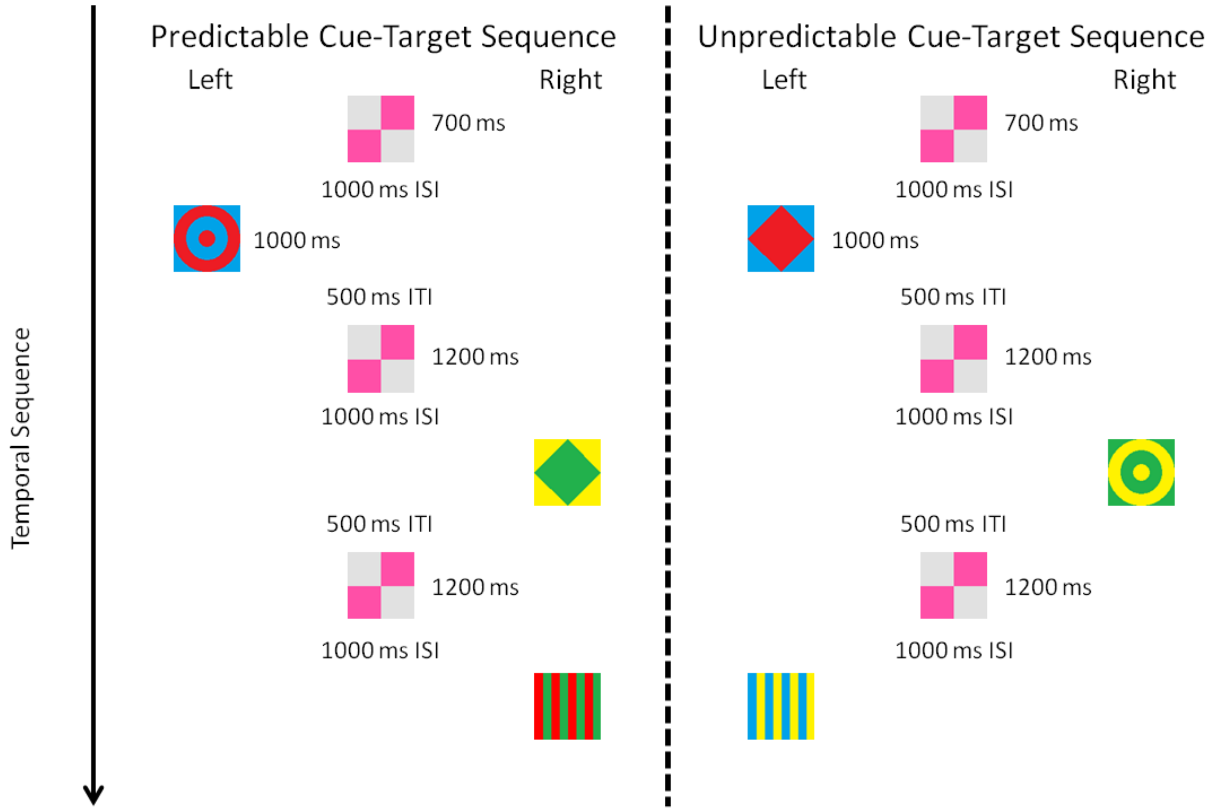

Figure 3. Example schematic of experimental conditions that had either a predictable or unpredictable cue duration–target location relation. Each infant was assigned to one of the two condition types. The cue was either presented for 700 or 1200 milliseconds. An interstimulus interval (ISI) of 1000 milliseconds followed the offset of the cue. Then, one of six target stimuli appeared at random for 1000 milliseconds either on the left or right side of the screen. At target stimulus offset, an intertrial interval (ITI) of 500 milliseconds occurred. In the predictable condition the cue's duration predicted the location of the target, but no such relation existed in the unpredictable condition—the target stimuli appeared on the left and right side of the screen at random.

order for an eye movement to be counted as anticipatory it needed to occur between 133 milliseconds after cue offset and 133 milliseconds after target onset. This latency value was chosen as the anticipation cut-off because it has been previously determined that 6-month-old infants cannot make eye movements in reaction to the onset of a stimulus faster than 133 milliseconds (Canfield, Smith, Brezsnyak, & Snow, 1997). If the eye movement occurred between 133 milliseconds after target onset and 133 milliseconds after target offset, it was considered reactive in nature (see Figure 4). Third, in order for an infant's data to be included in the final sample, they must have looked at the stimuli on a minimum of 65% of the trials (e.g., Adler & Haith, 2003; Adler & Orprecio, 2006). Finally, the eye movement to the target had to trace a path that is more than 50% of the distance between the cue and the target. The 50% criterion has been used in previous studies using infants' eye movements (e.g., Adler & Haith, 2003; Adler & Orprecio, 2006) and is typically taken as an indication that the eye movement was intentional and not random.

Infants' eye movement data were analyzed in terms of three dependent measures. First, a total anticipation measure was calculated by taking the percentage of all valid eye movements that were made to the targets that were anticipations (correct and incorrect). Second, a correct anticipation measure was calculated in terms of the percent of all anticipations that correctly localized target locations. Finally, the median reactive latencies of all eye movements towards the target after its onset and that were not anticipatory in nature were calculated. The latter has been chosen to be a dependent measure because though some past studies have shown a dissociation between anticipatory and reactive eye movements (e.g., Adler and Haith, 2003), the dissociation is not entirely exclusive (Haith, Hazan, & Goodman, 1988; Haith & McCarty, 1990; Haith, Wentworth, & Canfield, 1993). It can be interpreted that the facilitation of reactive eye

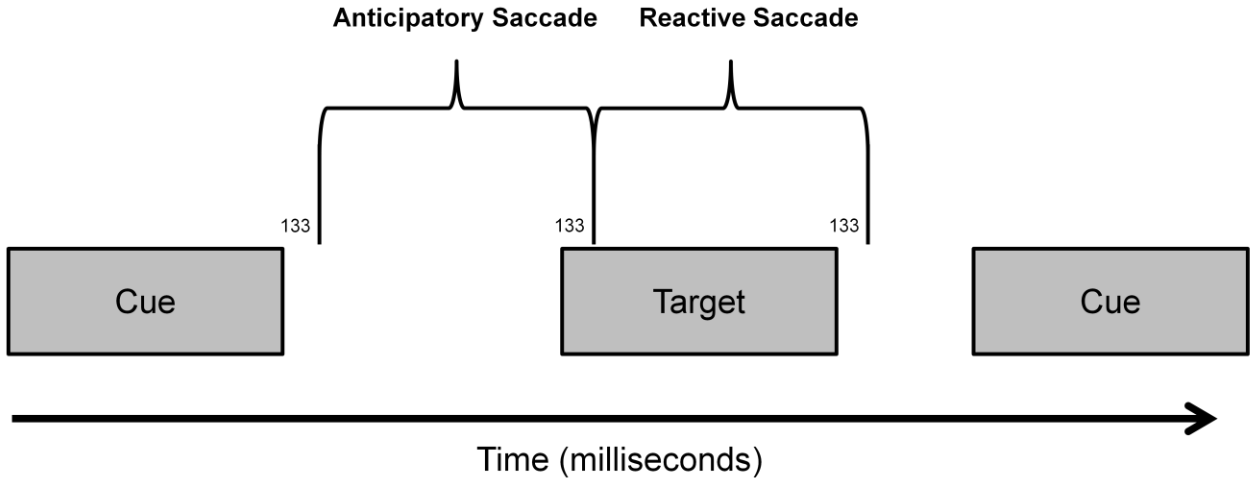

Figure 4. Criteria for classifying eye movements as anticipatory or reactive. Since the quickest eye movement a 6-month-old infant can make in response to a stimulus' onset or offset is 133 milliseconds, an anticipatory eye movement had to occur between 133 milliseconds after cue offset and before 133 milliseconds after target onset. A reactive eye movement had to occur between 133 milliseconds after target onset and before 133 milliseconds after target offset.

movement latencies toward stimuli is an index of an underlying expectation. Finally, considering that majority of the valid eye movements exhibited by infants are reactive and not anticipatory, it is important to include them.

Results and Discussion

Total Anticipations. Though correct anticipations are the primary measure of interest, prior to analyzing that measure it is necessary to insure that any possible differences between conditions are not due to the total number of anticipations made. A 2 x 2 mixed-design analysis of variance (ANOVA) was performed on the percent of total anticipations, with Condition (predictable, unpredictable) as a between-participant factor and Cue Duration (700, 1200) as a within-participant factor. The analysis revealed a significant main effect of Cue Duration, $F(1,44) = 4.69$, $p < .05$, $d = .54$, indicating that 6-month-old infants made more anticipations when the cue was displayed for 1200 milliseconds ($M = 44.54\%$, $SE = 5.19$) than when it was displayed for 700 milliseconds ($M = 35.63\%$, $SE = 4.25$). Neither the main effect of Condition, $F(1,44) = 0.74$, *ns*, or the interaction between Condition and Cue Duration, $F(1,44) = 1.71$, *ns*, were significant (see Table 1 of the Appendix for mean responses across Condition and Cue Duration). The results from this analysis suggest that the number of anticipations, regardless if correct or not, were not determined by the cue duration–target location relation. That said, cue duration did influence the total number of anticipations made (see Figure 5). Since neither condition elicited a difference in the total number of anticipations, any difference subsequently observed in correct anticipations by condition type cannot be attributed to differences in total anticipations.

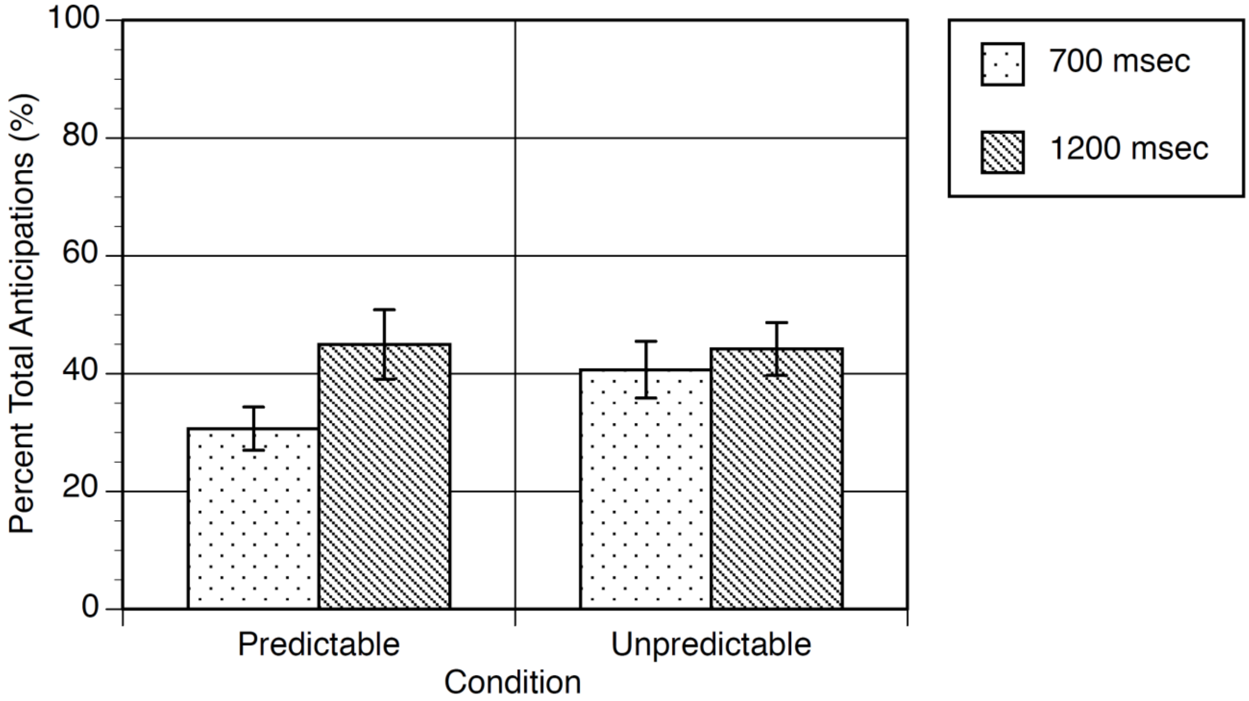

Figure 5. This figure represents the mean percent of total anticipations that 6-month-old infants made to the targets based on the cue durations in both the predictable and unpredictable conditions. Error bars represent +/- 1 standard error of the mean. There was a significant main effect of cue duration, as more anticipations were made after the cue was displayed for 1200 rather than 700 milliseconds.

Correct Anticipations. To determine if 6-month-old infants can discriminate and use distinct temporal information when forming expectations, the percentage of anticipations that correctly predicted the target's location was assessed. If 6-month-old infants are able to discriminate and use temporal information in their expectations then they should have made correct anticipations in the predictable condition at a rate greater than 50% (chance performance). If, however, the infants could not discriminate between the temporal values of the cues then they would not be able to form a cue duration–target location expectation and would consequently anticipate the correct target location only by chance, or at a rate not different than 50% correct. Conversely, for 6-month-old infants in the unpredictable condition, where there is no predictable cue duration–target location relation and hence no expectation to form, they should have made correct anticipations at a rate equal to 50%.

A 2 x 2 mixed-design ANOVA was performed on the percent of correct anticipations with Condition (predictable, random) as a between-participant factor and Cue Duration (700, 1200) as a within-participant factor. The analysis revealed a significant main effect of Condition, $F(1,44) = 10.44$, $p < .01$, $d = .94$, indicating that 6-month-old infants made more correct anticipations in the predictable condition ($M = 70.49\%$, $SE = 5.25$) than in the unpredictable condition ($M = 48.05\%$, $SE = 4.49$). This finding suggests 6-month-old infants were able to discriminate the cues' durations and successfully use the temporal information when the cue duration–target location relation was predictable (see Figure 6). There was no main effect of Cue Duration, $F(1,44) = 1.53$, *ns*, nor a significant interaction between Condition and Cue Duration, $F(1,44) = 0.85$, *ns*, however, indicating infants exhibited a similar percentage of correct anticipations for each cue duration in both the predictable and unpredictable conditions (see Table 1 of the Appendix for mean responses across Condition and Cue Duration).

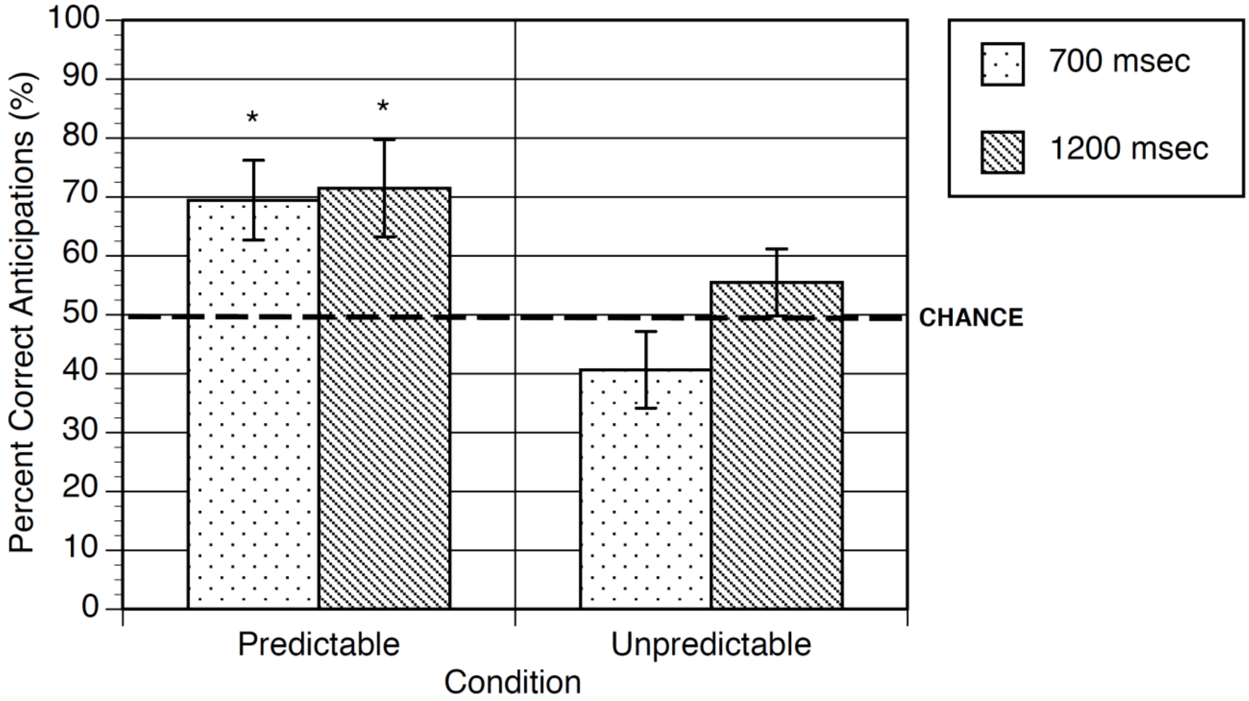

Figure 6. This figure represents the mean percent of correct anticipations that 6-month-old infants made to the targets based on the cue durations in both the predictable and unpredictable conditions. The dashed line represents performance at chance (50%). Asterisks symbolize performance that was significantly greater than chance performance. Error bars represent +/- 1 standard error of the mean.

While the previous analysis exhibited a difference in percentage of correct anticipations due to condition type, it did not take into account if the 6-month-old infants made correct anticipations at a rate that was significantly greater than chance or 50%. With cue duration collapsed, due to no main effect of Cue Duration, a one-tailed, one-sample *t*-test indicated that 6-month-old infants in the predictable condition made correct anticipations at a rate greater than chance, $t(23) = 3.82$, $p < .001$, $d = .80$, whereas the infants in the unpredictable condition did not, $t(23) = 0.43$, *ns*. Additional one-tailed, one-sample *t*-tests revealed that 6-month old infants in the predictable condition made correct anticipations at a rate greater than 50% when the cue was displayed for 700 milliseconds, $t(11) = 2.76$, $p < .05$, $d = .83$, and for 1200 milliseconds, $t(11) = 2.59$, $p < .05$, $d = .75$. Six-month-old infants in the unpredictable condition, however, made correct anticipations at a rate not significantly different than chance when the cue was displayed for either 700 milliseconds, $t(11) = 1.44$, *ns*, or 1200 milliseconds, $t(11) = 0.97$, *ns*. These findings indicate that 6-month-old infants were able to discriminate the two cue durations and make correct anticipations at a rate greater than chance when the cue duration–target location relation was predictable but not when it was unpredictable.

Reactive Latencies. In order to assess the effect of condition and cue duration on reactive latencies, a 2 x 2 mixed-design ANOVA was performed on median reactive latencies, with Condition (predictable, random) as a between-participant factor and Cue Duration (700, 1200) as a within-participant factor. This analysis did not reveal a significant main effect of Condition, $F(1,44) = 3.06$, *ns*, of Cue Duration, $F(1,44) = 1.65$, *ns*, or a significant interaction between Condition and Cue Duration, $F(1,44) = 0.37$, *ns* (see Table 1 of the Appendix for mean responses across Condition and Cue Duration). The results from this analysis suggest that the predictability of the cue duration–target location relation and the cue duration did not influence

6-month-old infants' reactive latencies towards the targets (see Figure 7). Though the percent of correct anticipations and reactive latencies revealed a dissociation in their influence by infants' visual expectations, consistent with Adler et al. (2008), the correct anticipations clearly demonstrate that 6-month-old infants encoded the temporal information of events to form an expectation and used such information when making behavioural decisions.

Experiment 2 – Temporal Cueing in 3-Month-Old Infants

Considering the findings from the previous experiment, it seems possible that the use of temporal information in infants' visual expectations may be present earlier in life. The purpose of this experiment was to attempt to determine a developmental timeline for the capacity to detect differences in time on the scale of hundreds of milliseconds and if such information can be used to formulate expectations. This was made possible by conducting the same experiment as before but with 3-month-old infants as the age of interest instead of 6-month-old infants. Whereas previous research has suggested that infants as young as 3-months of age can perceive differences in time (e.g., Adler et al., 2008; Boswell et al., 1994; Clifton, 1974), none have investigated if infants of this age can perceive differences in individual events' timing on the scale of hundreds of milliseconds for the purpose of moderating active behaviour. As well, 3-month-old infants have been observed to encode and incorporate the spatial (Canfield & Haith, 1991) and content information (Adler & Haith, 2003; Wentworth & Haith, 1992) of individual events into their visual expectations. This experiment, therefore, has the potential of exposing another event-specific parameter that 3-month-old infants may use when forming visual expectations. If the capacity to perceive differences in time on the scale of hundreds of milliseconds is present in early infancy, then 3-month-old infants should be able to incorporate

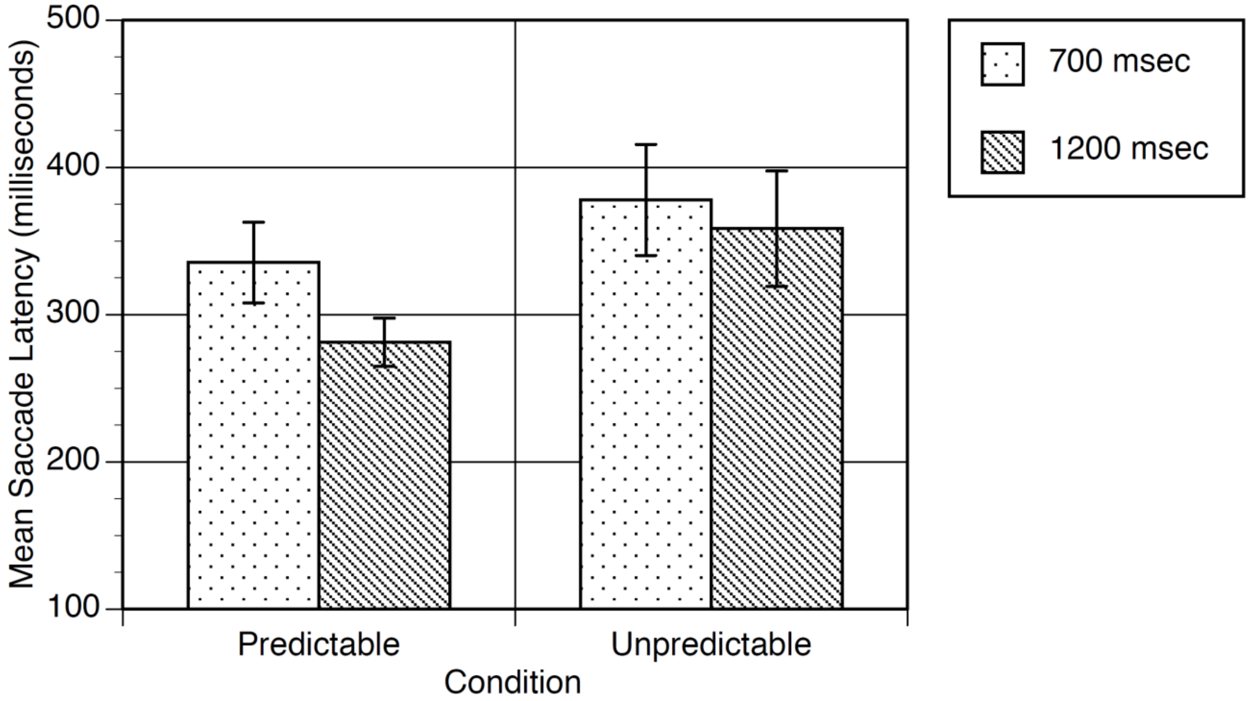

Figure 7. This figure represents the mean reactive latencies that 6-month-old infants made to the targets based on the cue durations in both the predictable and unpredictable conditions. Error bars represent +/- 1 standard error of the mean.

temporal information when formulating visual expectations in their environment. Findings from this study, therefore, may reveal just how early in human development the individual becomes informed of the relevant temporal information present in their environment.

Methods

Participants. Forty 3- to 4-month-old infants, recruited from a mailing list supplied by a Toronto-area marketing company (Z Retail Marketing Company Inc., Toronto, Canada), participated in this study. The data from 16 infants had to be excluded from this study due to crying and general fussiness (*n* = 5) and inattentiveness (i.e., provided data on less than 65% of the trials; *n* = 11). As a result, 24 infants (15 males, 9 females) who ranged in age from 91 to 127 days (*M* = 104.2, *SD* = 9.0) and came from middle (*n* = 20) and high (*n* = 4) social economic status (SES) were included in the final sample for analysis. The infants were of Caucasian (*n* = 13), Asian (*n* = 3), African (*n* = 2), Hispanic (*n* = 1), and Other (*n* = 5) ethnic backgrounds. Infants were all born at full term, in good health, and with no apparent visual, neurological, or other abnormalities as documented by parental recording. Informed consent was given by the parent of each infant.

Stimuli and apparatus. The stimuli and apparatus used for Experiment 2 were identical to those used in Experiment 1.

Procedure. The procedure, including durations, interstimulus and intertrial intervals, and study conditions used for Experiment 2 were identical to those used in Experiment 1.

Data reduction and analysis. Data reduction and analysis for Experiment 2 was identical to that for Experiment 1 with one major exception. In order for an eye movement to be counted as anticipatory it needed to occur between 167 milliseconds after cue offset and 167 milliseconds after target onset. This latency value was chosen as the anticipation cut-off because it has been previously determined that 3-month-old infants cannot make eye movements in reaction to the onset of a stimulus faster than 167 milliseconds (Canfield et al., 1997). If the eye movement occurred between 167 milliseconds after target onset and 167 milliseconds after target offset, it was considered reactive in nature (see Figure 8).

Results and Discussion

Total Anticipations. As in Experiment 1, prior to analyzing the primary measure of correct anticipations, an analysis had to be done to insure that any possible differences between conditions are not due to the total number of anticipations made. A 2 x 2 mixed-design ANOVA was performed on the percent of total anticipations with Condition (predictable, random) as a between-participant factor and Cue Duration (700, 1200) as a within-participant factor. The analysis did not reveal a significant main effect of Condition, *F*(1,44) = 0.31, *ns*, of Cue Duration, *F*(1,44) = 0.55, *ns*, or an interaction between the two, *F*(1,44) = 0.11, *ns* (see Table 2 of the Appendix for mean responses across Condition and Cue Duration). The results from this analysis suggest the number of anticipations, regardless if correct or not, were not determined by the cue duration–target location relation (see Figure 9). Since neither condition elicited a difference in the total number of anticipations made, any difference observed in correct anticipations by condition type could not be attributed to a difference in total anticipations.

Correct Anticipations. To determine if 3-month-old infants can discriminate and use distinct temporal information when forming expectations, the percentage of anticipations that correctly predicted the target's location was assessed. If 3-month-old infants, like the 6-month-

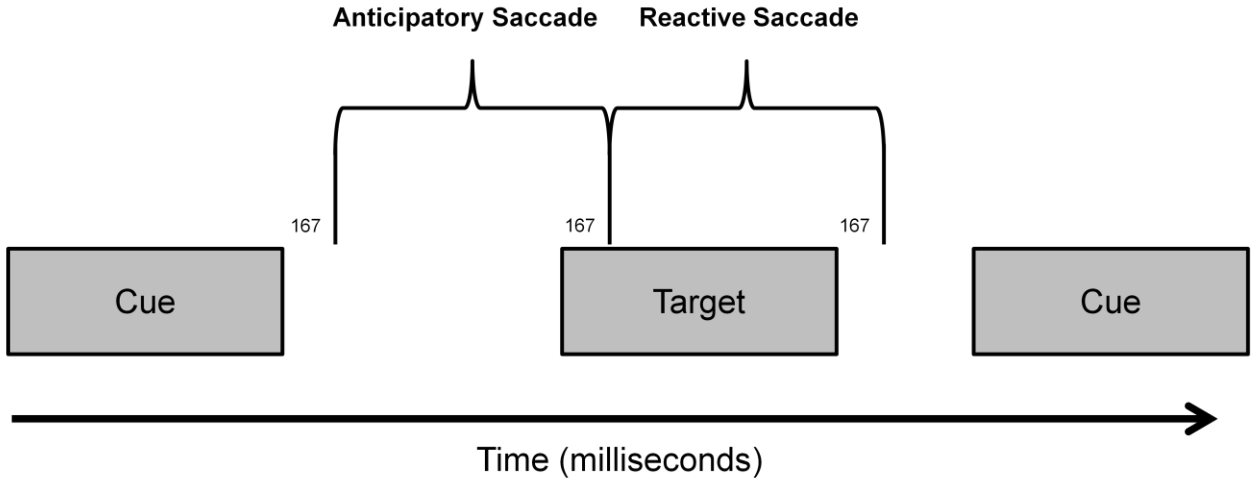

Figure 8. Criteria for classifying eye movements as anticipatory or reactive. Since the quickest eye movement a 3-month-old infant can make in response to a stimulus' onset or offset is 167 milliseconds, an anticipatory eye movement had to occur between 167 milliseconds after cue offset and before 167 milliseconds after target onset. A reactive eye movement had to occur between 167 milliseconds after target onset and before 167 milliseconds after target offset.

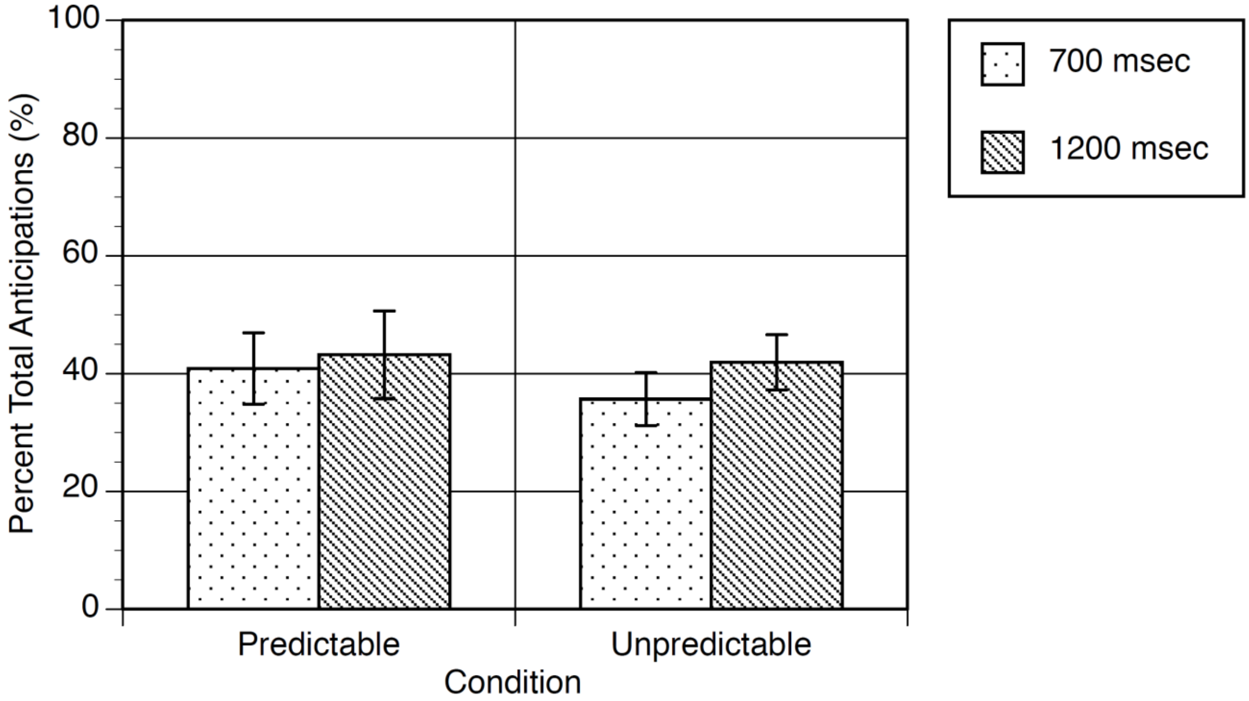

Figure 9. This figure represents the mean percent of total anticipations that 3-month-old infants made to the targets based on the cue durations in both the predictable and unpredictable conditions. Error bars represent +/- 1 standard error of the mean.

old infants in Experiment 1, are able to discriminate and use temporal information when formulating expectations then they should have made correct anticipations in the predictable condition at a rate greater than 50% (chance performance). If, however, the infants could not discriminate between the temporal values of the cues then they would not be able to form a cue duration–target location expectation and would consequently anticipate the correct target location only by chance, or at a rate not different than 50% correct. Conversely, 3-month-old infants in the unpredictable condition, like the 6-month-old infants, where there is no predictable cue duration–target location relation and hence no expectation to form, should have made correct anticipations at a rate equal to 50%.

A 2 x 2 mixed-design ANOVA was performed on the percent of correct anticipations with Condition (predictable, random) as a between-participant factor and Cue Duration (700, 1200) as a within-participant factor. The analysis did not reveal a significant main effect of Condition, *F*(1,44) = 1.29, *ns*, indicating that 3-month-old infants in the predictable condition (*M* = 59.32%, *SE* = 6.95) did not make more correct anticipations than infants in the unpredictable condition (*M* = 48.61%, *SE* = 5.88). This finding suggests 3-month-old infants were not able to discriminate the cues' durations and successfully use the temporal information when the cue duration–target location relation was predictable (see Figure 10). There was no main effect of Cue Duration, *F*(1,44) = 0.02, *ns*, nor a significant interaction between Condition and Cue Duration, *F*(1,44) = 0.63, *ns* (see Table 2 of the Appendix for mean responses across Condition and Cue Duration).

While the previous analysis failed to exhibit a difference in percentage of correct anticipations due to condition type, it did not take into account if the 3-month-old infants made

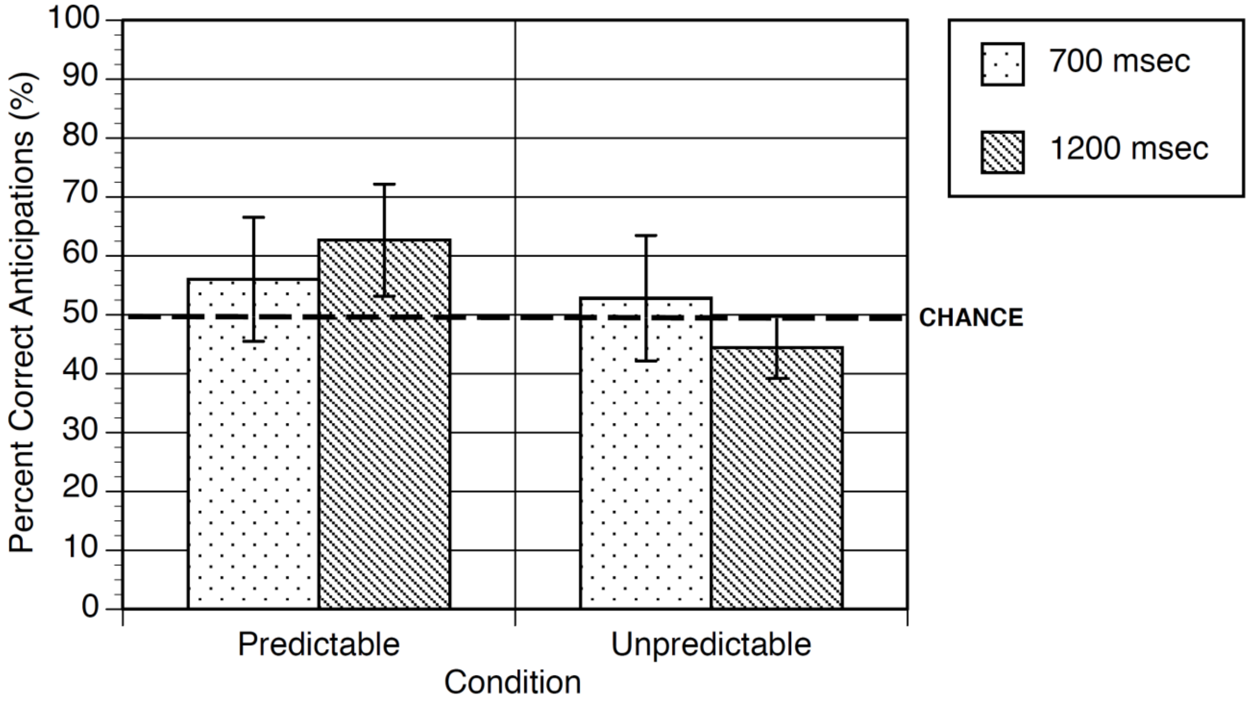

Figure 10. This figure represents the mean percent of correct anticipations that 3-month-old infants made to the targets based on the cue durations in both the predictable and unpredictable conditions. The dashed line represents performance at chance (50%). Error bars represent +/- 1 standard error of the mean.

correct anticipations at a rate that was greater than chance or 50%. Collapsing across cue durations, as the previous analysis did not reveal a difference between the different cue durations, a one-tail, one-sample *t*-test indicated that 3-month-old infants in the predictable condition did not make correct anticipations at a rate greater than chance, *t*(23) = 1.28, *ns*, as neither did 3-month-old infants in the unpredictable condition, *t*(23) = 0.24, *ns*. Additional one-tail, one-sample *t*-tests revealed that 3-month old infants in the predictable condition did not make correct anticipations at a rate greater than 50% when the cue was displayed for 700 milliseconds, *t*(11) = 0.54, *ns*, nor when the cue was displayed for 1200 milliseconds, *t*(11) = 1.27, *ns*. As expected, 3-month-old infants in the unpredictable condition made correct anticipations at a rate no different than chance when the cue was displayed for either 700 milliseconds, *t*(11) = 0.26, *ns*, or 1200 milliseconds, *t*(11) = 1.06, *ns*. These findings seem to strongly indicate that 3-month-old infants were not able to discriminate the two cue durations, thereby forming a cue duration–target location expectation and make correct anticipations at a rate greater than chance when the cue duration–target location relation was predictable.

Reactive Latencies. As in Experiment 1, the majority of valid eye movements were not anticipatory in nature but were reactive after target onset. In order to assess the effect of condition and cue duration on the latencies of these reactive eye movements, a 2 x 2 mixed-design ANOVA was performed on median reactive latencies, with Condition (predictable, random) as a between-participant factor and Cue Duration (700, 1200) as a within-participant factor. Consistent with Experiment 1 and Adler et al. (2008), this analysis did not reveal a significant main effect of Condition, *F*(1,44) = 1.66, *ns*, of Cue Duration, *F*(1,44) = 0.04, *ns*, or a significant interaction between Condition and Cue Duration, *F*(1,44) = 0.08, *ns* (see Table 2 of the Appendix for mean responses across Condition and Cue Duration). The results from this analysis suggest that the predictability of the cue duration–target location relation did not influence 3-month-old infants' reactive latencies towards the targets differently (see Figure 11).

Together, these findings reveal that 3-month-old infants, unlike the 6-month-old infants in Experiment 1, were not sensitive to temporal differences in the cue duration and, consequently, were not able to detect the predictability of cue duration–target location relation. Without the capacity to detect that predictability, 3-month-old infants could not form an expectation and thereby exhibited anticipations at chance performance when the cue durations predicted a target's location. The findings from Experiment 2, therefore, demonstrate that 3-month-old infants are unable to detect differences in time on the scale of hundreds of milliseconds and use such information when moderating their behavioural responses.

General Discussion

The purpose of the current study was to investigate if young infants possess a capacity for processing time information and if they use time information when trying to form a knowledge base for events in their environment. Findings from these experiments suggest that as young as 6 months, but not 3 months of age infants can detect differences among the temporal parameters of events on the scale of hundreds of milliseconds and can then use this information when formulating expectations in their environment. Evidence of this comes from 6-month-old infants being able to make anticipations above chance performance when there was a predictable cue duration–target location relation, but failed to do so when the cue duration–target location relation was unpredictable. Three-month-old infants, in contrast, failed to discriminate the temporal parameters of the cues from one another and were thus unable to successfully use this information when formulating expectations. As a consequence, 3-month-old infants were unable

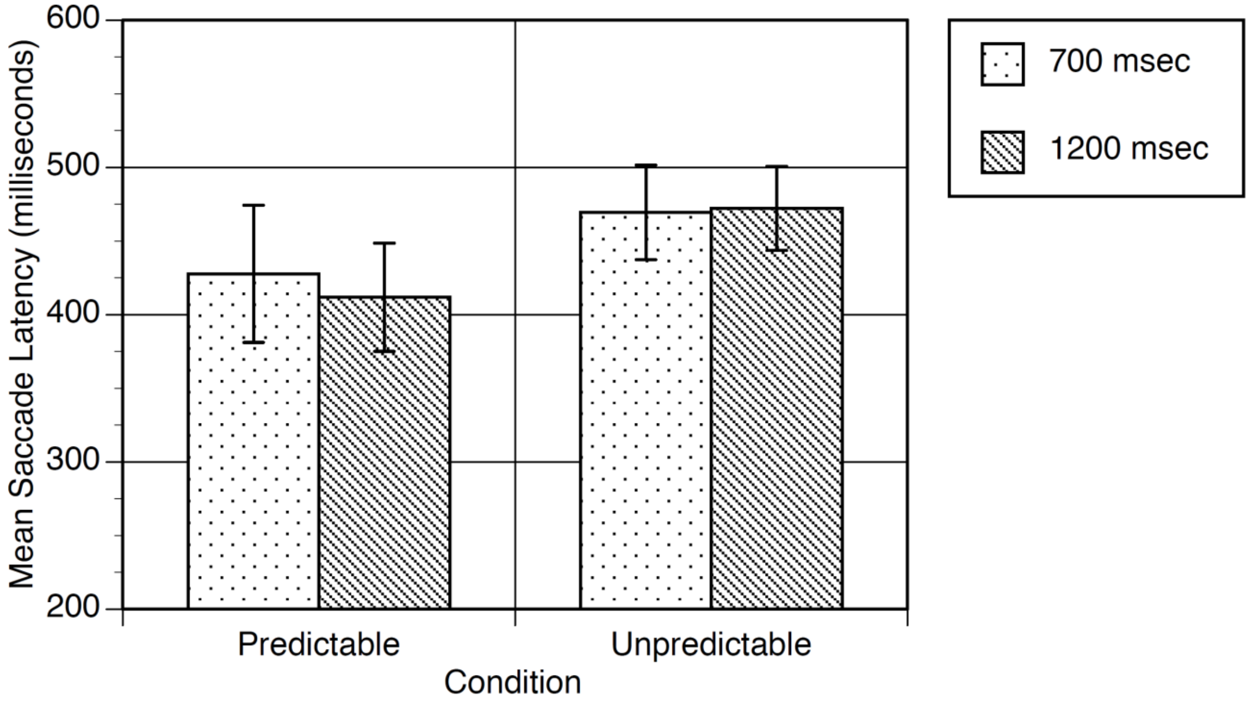

Figure 11. This figure represents the mean reactive latencies that 3-month-old infants made to the targets based on the cue durations in both the predictable and unpredictable conditions. Error bars represent +/- 1 standard error of the mean.

to make anticipations above chance performance even when the cue duration–target location relation was predictable. In fact, the performance of the 3-month-old infants in the condition with a predictable cue duration–target location relation mirrored the performance of the 3-month-old infants in the condition with an unpredictable cue duration–target location relation. These findings may suggest that there is a developmental transition point between 3 months and 6 months of age in sensitivity to time differences on the scale of hundreds of milliseconds and the ability to use this temporal information when moderating behavioural responses.

The capacity to process time information and use it when moderating behavioural responses is a capacity that allows individuals to potentially function more efficiently in their environment (Buhusi & Meck, 2005). For this reason, therefore, a number of studies have been devoted to understanding the developmental trajectory of the capacity to perceive time. Though similar methodological paradigms were used to study temporal processing in adults and young children, unique paradigms had to be designed and used for the studying of infant time perception due to methodological-related and behavioural limitations (e.g., infants lack the ability to press buttons and, therefore, cannot complete a temporal generalization task similar to those used on adults and young children). As a consequence, studies investigating infant time perception have defaulted to using a version of the familiarity/novelty-preference paradigm, called the violation-of-expectation paradigm. Though studies using the violation-of-expectation paradigm have suggested infants can perceive seconds-long temporal differences between the timing of events time (Addyman et al., 2014; Boswell et al., 1994; Brannon et al., 2008; Colombo & Richman), as discussed earlier, the nature of the paradigm makes clear interpretation difficult. First, the violation-of-expectation paradigm does not measure expectations, as expectations are predictions that occur before a particular event has occurred. In studies that use the violation-of-expectation paradigm, the dependent variable, which is used to provide evidence for infants' having expectations, is measured after the "expected" event has occurred. This criticism is merely not one of semantics either, as there is empirical evidence that suggests that the conclusions generated from violation-of-expectation studies may explained by means other than a violated "expectation." Hunter, Ames, and Koopman (1983) investigated how young infants' preference for looking at novel stimuli after familiarization to other stimuli is influenced by the amount of time infants were given to become familiarized to the stimuli, the age of the infants, and the difference in perceptual complexity between the familiarized and novel stimuli. With respect to studies using violation-of-expectation paradigms, it is, therefore, possible that the explanation behind the findings were not due to infants having the novelty of their "expectations" violated, but rather infants choosing to continue looking at those perceptual characteristics that were perceptually familiar to them. The present study was designed, therefore, to overcome this (and other) limitation and to better address whether young infants can process the temporal parameter of events and use such temporal information when formulating expectations, and the development of these abilities. If infants are able to process the timing of events and use this information when formulating expectations, then they will be able to moderate their behavioural responses (i.e., anticipatory eye movements) so that they are matched with the timing of temporally predictable events. The VExCP, therefore unlike the violation-of-expectation paradigm, provides a methodology that measures behavioural responses that cannot lead to an interpretability issue as the only way infants can correctly anticipate the location of the targets is if they are able to discriminate the temporal parameters of the cues. The findings demonstrated that 6-month-old infants were able to successfully discriminate durations of 700 milliseconds from 1200 milliseconds, as seen by the percentage of correct anticipations they made when there was a predictable cue duration–target location relation relative to when it was random. In contrast to the findings with 6-month-old infants, 3-month-old infants were unable to properly discriminate the temporal durations of 700 milliseconds from 1200 milliseconds. This was observed as the 3-month-old infants failed to correctly anticipate the location of targets above chance performance even when there was a predictable cue duration–target location relation. The findings from this study suggest that the use of the VExCP can assess sensitivity to timing on the scale of hundreds of milliseconds and that this task is more viable than the violation-of-expectation paradigm for assessing the development of temporal processing.

While the current findings would seem to suggest that 3-month-old infants lack the capacity to perceive differences in time on the scale of hundreds of milliseconds, there is an alternative possibility. The temporal parameter of events used throughout Experiments 1 and 2 were 700 and 1200 milliseconds. Recent research suggests infants as young as 4 months of age optimally discriminate temporal parameters that differ by a ratio of 1:3 (Provasi, Rattat, & Droit-Volet, 2011), with this optimal ratio decreasing with increasing age (Brannon, Suanda, & Libertus, 2007). That is, the temporal parameters that are to be discriminated have previously been shown to need to differ from one another by a magnitude of three or more for infants that are younger than 4 months of age. Thus, the possibility exists that 3-month-old infants can discriminate temporal information on the scale of hundreds of milliseconds and then use that information in formulating expectations, but that the temporal parameters used in the current study did not sufficiently differ to activate the 3-month-old infants' sensitivity—the temporal parameters used in the present study differed by a ratio just under 1:2. To explore the validity of this possibility, a follow-up experiment to Experiment 2 in which the ratio is changed to better match their hypothetical sensitivity would need to be conducted. This potential study would be identical to Experiment 2 with the noticeable exception that the temporal parameters of the cues would be 500 and 2000 milliseconds. By the temporal parameters differing from one another by a factor of four, whether 3-month-old infants can discriminate and incorporate temporal information on the scale of hundreds of milliseconds into the formation of visual expectations could be assessed. If such a proposed temporal difference manipulation does not provide evidence for discrimination, then the notion that 3-month-old infants do not possess such a temporal capacity would be supported. Nevertheless, while it is worth further investigating the temporal processing capacity (or lack of) in 3-month-old infants, that 6-month-old infants, but not 3-month-old infants, were successfully able to discriminate temporal differences near a 1:2 ratio and incorporate that temporal information into their visual expectations suggests a developmental process is mediating a change in temporal sensitivity.

A plausible process to account for why performance differed among these two age groups may be related to neural development. Neurons in the pre-supplementary motor and supplementary motor areas have been linked to controlling self-initiated actions (Mushiake, Inase, & Tanji, 1991) and their temporal organization (Tanji, 2001; Shima & Tanji, 1998). Further investigation of these neurons has led to the observation that they show selective firing in the presence of the temporal, rather than the content, information of a viewed event (Mita, Mushiake, Shima, Matsuzaka, & Tanji, 2009). That these neurons exhibit temporal encoding properties is functionally important, but perhaps of equal interest may be where these structures reside anatomically. The supplementary and pre-supplementary motor areas share projections with the frontal eye fields (Gould, Cusick, Pons, & Kaas, 1986; Huerta, Krubitzer, & Kaas, 1987), and the frontal eye fields have been associated with generating anticipatory saccades (Keating, 1991; Ramkumar, Lawlor, Glaser, Wood, Phillips, Segraves, & Kording, 2016). A logical hypothesis to make, therefore, is to propose that the temporal information gathered by the neurons in the supplementary and pre-supplementary motor areas may be integrated into the process of generating anticipatory saccades from the frontal eye fields. As the brain develops with age, the sensitivity of detecting temporal information by the neurons of the supplementary and pre-supplementary motor cortex and/or the efficiency of projecting such information to the frontal eye fields may become more refined. For instance, there is structural maturation of myelin in the frontal and temporal lobes of the brain that occurs from 6 to 8 months of age (Deoni et al., 2011). The maturation of myelin may, therefore, aid the efficiency of temporal information being projected from the supplementary and pre-supplementary motor areas to the frontal eye fields as anticipatory eye movements are generated. Consequently, this framework provides a plausible anatomical explanation as to why 6-month-old, but not 3-month-old infants were able to successfully incorporate distinct events' temporal information when making anticipatory saccades.

Emergence of Discrete Time Processing

The findings from the current study may suggest a developmental transition from 3 months to 6 months of age, where sensitivity and application of detecting and discriminating temporal information on the scale of hundreds of milliseconds emerges. A potential reason for this may be explainable by Dynamic Systems Theory. Dynamic Systems Theory postulates that the emergence of developing functional capacities does not occur until it serves a function (Thelen, 2005). It is, therefore, possible that 6-month-old, but not 3-month-old infants possess the capacity to detect and discriminate differences in time on the scale of hundreds of milliseconds when formulating expectations in their environment because it facilitates the development of other cognitive processes and behaviours. One example of a functional cognitive process that requires the ability to detect and discriminate small differences among temporal events is language (de Diego-Balaguer, Martinez-Alvarez, & Pons, 2016).

Though challenging to determine the exact onset for language development, the second half of the first year of life has been considered a reasonable approximation (Kuhl, 2004). As the sensitivity for discriminating temporal durations increases with age (Brannon et al., 2007; McCormack et al., 1999), so does infants' sensitivity towards language-specific phonemic discrimination (Eimas, Siqueland, Juscyk, & Vigorito, 1971; Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992; Werker & Tees, 2002). Phonemes, which are distinct millisecond temporal events, are the basic units of sound that distinguishes words from one another in a particular language. In order to discriminate phonemes from one another, individuals must be able to detect temporal differences as small as 20 milliseconds in the vocal onset asynchronies of these produced sounds (Eimas et al., 1971). The ability to discriminate and produce phonemes, therefore, can be thought of as one of the first capacities an individual must develop before they can acquire a complete comprehension of language (Gibson & Levin, 1975). The development of language, or phonemic discrimination to be exact, can be viewed as an ability that does not become relevant to an infant until the latter half of their first year of life. From a Dynamic System Theory perspective with respect to language development, it can be postulated that the capacity to detect and discriminate small differences among temporal events and then use this information when categorizing phonemes as either relevant or not to one's language is not needed until the individual is ready to develop phonemic discrimination. If this is the case, then it can potentially explain the speculated developmental transition from 3 months to 6 months of age where the sensitivity and functional application of detecting and discriminating small differences in time emerges.

Another example of a developing behaviour that necessitates the capacity to process small parameters of time and one's ability to use this temporal information is the ability to anticipate and reach for moving objects. Emerging approximately at 5 months of age, reaching is an adaptive behaviour that allows infants to physically interact with stimuli in their environment (White, Castle, & Held, 1964). Von Hofsten, Vishton, Spelke, Feng, & Rosander, (1998) observed 6-month-old infants adapt their reaching behaviour to match the trajectory of moving objects. It can be inferred, therefore, that the infants were able to reach for moving objects because they were able to detect and use the temporal information present in the moving object's trajectory. Since reaching for moving objects does not develop until at least 6 months of age, it is possible that a reason why 3-month-old infants failed to detect and discriminate differences in time on the scale of hundreds of milliseconds is because it does not serve as a capacity necessary for the development of emerging cognitive processes and behaviours. Whereas, the capacity to detect and discriminate temporal events on the scale of hundreds of milliseconds can be inferred to facilitate 6-month-old infants' ability to reach for moving objects.

Future Directions: ADHD Research

The tasks used to understand temporal processing in adults and children have been relatively consistent. As a consequence, the performances of adults and children on certain temporal tasks (e.g., temporal generalization) have allowed researchers to directly compare the performances of each group. When studying infants, however, the tasks and measures used are typically distinct from those used on adults and children. Comparing and contrasting the findings of infant studies to those with adults and children is therefore difficult. Due to this difficulty in comparing and contrasting the findings, it is, therefore, challenging to map out the development of temporal processing. As eye movements are relatively mature in early infancy (Canfield et al., 1997), they provide the potential for conducting studies that use the same tasks and comparable behavioural measures across the developmental spectrum (see Adler & Gallego, 2014; Adler & Orprecio, 2006). As infants as young as 6 months of age were observed to complete a temporal discrimination task by use of the VExCP, the VExCP and eye movements can be used as a task and measure, respectively, to address the development of temporal processing across different age groups and in certain distinct populations. One such example would be mapping out the developmental trajectory of temporal processing in individuals that have attention deficit hyperactivity disorder (ADHD).

Research on individuals with ADHD has shown that they seem to have impairment in temporal judgements. Neural structures that have been correlated with discriminating events' temporal parameters on the scale of hundreds of milliseconds, which include the right dorsolateral and inferior prefrontal cortices, left cerebellum and right supplementary motor area (Smith, Taylor, Lidzba, & Rubia, 2003), have also been observed to be dysfunctional in individuals diagnosed with ADHD (Noreika, Falter, & Rubia, 2013). The presence of dysfunctional neural time processing mechanisms has motivated researchers to hypothesize that individuals diagnosed with ADHD have difficulty perceiving differences in time. Specifically, adults and children diagnosed with ADHD have been observed to show temporal processing deficits in discriminating temporal parameters on the scale of hundreds of milliseconds when compared to healthy controls (Valko, Schneider, Doehnert, Müller, Brandeis, Steinhausen, & Drechsler, 2010). As a result, individuals with ADHD require a greater magnitude of separation between two temporal parameters when comparing if they are the same or not, relative to individuals not diagnosed with ADHD (Yang, Chan, Zou, Jing, Mai, & Li, 2007). That said, another suggested hypothesis is that individuals with ADHD do not have trouble perceiving differences in time, rather they fail to successfully use temporal information when making time related decisions (Radonovich & Mostofsky, 2004). The VExCP could provide a methodology that could help determine the basis for the link between ADHD and impaired temporal judgements.

As previously stated, there are two hypotheses that have been suggested as to why individuals diagnosed with ADHD are impaired when making time judgements. One hypothesis suggests individuals diagnosed with ADHD have trouble discriminating (thus, perceiving) the temporal parameters of events, whereas the second hypothesis suggests individuals diagnosed with ADHD do not have an impairment in perceiving the temporal parameter of events, but rather have difficulty using temporal information when making time related decisions. A study using the VExCP as its methodology could be designed to help determine which hypothesis is more accurate when explaining the basis for individuals diagnosed with ADHD. The proposed study would consist of two populations of individuals that are either diagnosed with or without ADHD. The goal of the experiment would be to isolate an effect that one of the two hypotheses would predict, while controlling for the other effects predicted by the other hypothesis.

The proposed study would be designed to isolate for the hypothesis that individuals diagnosed with ADHD have difficulty using temporal information when making temporal judgments, while accounting for the hypothesis that individuals diagnosed with ADHD have difficulty perceiving differences in the temporal parameter of events. This experiment would involve participants having to complete a VExCP task similar to the one used in the current study. If the temporal parameters of the cues can be discriminated then participants should be able to anticipate the location of the target stimuli above chance performance when there is a predictable cue duration–target location relation, as in the predictable condition. If individuals diagnosed with ADHD have difficulty using temporal information when making time judgements, then these individuals should make correct anticipations at a rate less than the group of individuals not diagnosed with ADHD and, quite likely, anticipate at chance performance. The important part of this task, therefore, is to ensure that the temporal parameters of the cues are large enough for individuals diagnosed with ADHD to be able to detect a difference. Not only can tasks using the VExCP provide a means of examining the basis for why individuals diagnosed with ADHD have impaired temporal judgements, but can also be used to measure the presence of ADHD in young children.

Young children diagnosed with ADHD have been also observed to have impairment when discriminating temporal events on the scale of hundreds of milliseconds (Marx, Hübner, Herpertz, Berger, Reuter, Kircher, Herpertz-Dahlmann, & Konrad, 2010). As there is evidence to suggest ADHD is conferred genetically (Rhee, Waldman, Hay, & Levy, 1999; Sherman, Iacono, & McGue, 1997), parents may want to have their child examined for their risk of having ADHD as soon as possible. Since young children are typically assessed for ADHD through clinical evaluation (Pappas, 2006), it may be beneficial to have a behavioural measure that can be done to screen individuals suspected for having ADHD as well. Tasks that use the VExCP might be able to serve as an early behavioural assessment for children that are pre-verbal and do not possess fine motor control of their fingers, as their capacity to process temporal parameters and make time related decisions can be assessed. Being able to have a behavioural assessment that can potentially indicate an increased risk for ADHD in young children may lead to better and earlier diagnosis, and earlier intervention resulting in better education and preparation of these children for the years ahead of having to live with this disorder.

Future Directions: Temporal Bisection

The results from the current study also offer potential new means by which researchers could investigate the performance of infants in temporal bisection tasks. Being able to devise a temporal bisection task that can be used to measure performances in adults, children, and infants could provide direct comparisons across all age groups. Being able to compare the performance across the developmental timeline will provide information as to how the capacity to process time—particularly, how temporal parameters are distinguished from one another and categorized—typically develops. By gaining a greater understanding for how this temporal capacity develops, researchers will be able to have better information as to when and how individuals with an atypical temporal capacity delineate from typical, healthy development.

As mentioned earlier, the temporal bisection tasks were tasks that required participants to discriminate events' temporal parameters by means of pressing buttons. While button presses are a viable means of response for adults and young children, they are not for infants. The VExCP can be used as a means of assessing infants' performance on a temporal bisection task, without the requirement of a button press. An example of a possible bisection experimental design for infants with the VExCP could be one in which 6-month-old infants complete a task very similar to Experiment 1 in the current study in which a predictable cue duration–target location relation is established using two distinct standard durations (e.g., 700 and 1200 milliseconds). After a sufficient amount of trials to insure that the predictable relations have been learned, a cue can be presented for a duration that is not one of the standards, but one of intermittent length (e.g., 800, 900, 1000, or 1100 milliseconds). This creates a two-alternative forced choice test for the infant and which side they anticipate after viewing one of the intermittent cues is displayed indicates which standard duration infants perceive the intermittent cue to be most like. By forcing the infant to make a dichotomous choice of choosing the left or right side is precisely the hallmark of temporal bisection tasks. Across many participants, the experimenter can plot the percentage of anticipations to the side of the long standard duration (i.e., 1200 milliseconds) as a function of the duration of the cue that was previously displayed. Ideally, the graph would reveal a sigmoid curve as percentage of correct anticipations will increase as the duration of the cue increases. The steepness of the graph will allow researchers to not only compare the performance of 6-month-old infants to young children and adults on a temporal bisection task, but will allow researchers to examine how sensitive the decision making process of 6-month-old infants is when discriminating temporal events on the scale of hundreds of milliseconds from one another.

Conclusion

The purpose of the present study was to investigate whether infants have the capacity to process time information and use such information when interacting within their environment by forming expectations for temporally predictable events. The capacity to perceive time is important because it is a skill necessary for the functioning of many cognitive processes. As infants develop, so must their understanding of their complex environment. By being able to process temporal information and then moderate their behaviour so they can act upon such information, allows them to predict and prepare for temporally predictable events. The current study investigated this as a speculative developmental transition point was discovered between 3 and 6 months of age where 6-month-old infants possessed the capacity to detect and discriminate temporal events on the scale on hundreds of milliseconds and then use this information when formulating expectations and making anticipations to temporally predictable events. By studying infant time perception with a methodology that can be used for adult and children studies, future research can be devoted to better understanding the development of the capacity to process time across the lifespan. Being able to understand how the capacity to process temporal information develops in the typical, healthy individual will allow researchers to better understand when and why certain groups of individuals possess an atypical capacity for temporal processing.

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Appendix

Table 1

Mean Responses made by the 6-Month-Old Infants from Experiment 1

	Predictable Condition		Unpredictable Condition	
	M	SE	M	SE
Total Anticipation (%)				
Cue Duration				
700 msec	30.63	3.67	40.64	4.82
1200 msec	44.92	5.91	44.16	4.48
Correct Anticipation (%)				
Cue Duration				
700 msec	69.44	6.76	40.63	6.50
1200 msec	71.46	8.28	55.48	5.67
Reactive Latencies (msec)				
Cue Duration				
700 msec	335.38	27.42	377.88	37.73
1200 msec	281.25	16.40	358.42	39.16

Note. M = Mean. SE = Standard Error.

Table 2

Mean Responses made by the 3-Month-Old Infants from Experiment 2

	Predictable Condition		Unpredictable Condition	
	M	SE	M	SE
Total Anticipation (%)				
Cue Duration				
700 msec	40.84	6.06	35.66	4.49
1200 msec	43.17	7.44	41.90	4.69
Correct Anticipation (%)				
Cue Duration				
700 msec	55.99	10.52	52.78	10.67
1200 msec	62.65	9.51	44.44	5.26
Reactive Latencies (msec)				
Cue Duration				
700 msec	427.71	46.61	469.46	32.11
1200 msec	411.79	36.73	472.17	28.57

Note. M = Mean. SE = Standard Error.