10-month Infants Visually Anticipate an Outcome Contingent on Their Own Action

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Abstract

It is known that young infants can learn to perform an action that elicits a reinforcer, and that they can visually anticipate a predictable stimulus by looking at its location before it begins. Here, in an investigation of the display of these abilities in tandem, I report that 10-month-olds anticipate a reward stimulus that they generate through their own action: 0.5 s before pushing a button to start a video reward, they increase their rate of gaze shifts to the reward location; and during periods of extinction, reward location gaze shifts correlate with bouts of button pushing. The results are consistent with the hypothesis that the infants have an expectation of the outcome of their actions: several alternative hypotheses are ruled out by yoked controls. Such an expectation may, however, be procedural, have minimal content, and is not necessarily sufficient to motivate action.

Keywords: infants; visual anticipation; expectation; action effects; goal oriented behaviour

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Since the 1960's it has been known that very young infants can learn to perform an instrumental action that results in a contingent reward (Rovee-Collier & Gekoski, 1979; Rovee-Collier, Hayne, & Colombo, 2001). For example, infants increase their sucking rate when presented with visual stimuli contingent on sucking (Siqueland & DeLucia, 1969). This method even works with newborns (DeCasper & Fifer, 1980), prompting Rochat and Striano (2000) to declare that "This remarkable instrumental learning capacity testifies to the fact that early on infants manifest a sense of themselves as an agent in the environment". However, although adults routinely expect the outcome of their actions (Hommel, Musseler, Aschersleben, & Prinz, 2001), the ability to learn to perform an action does not in itself imply expectation of the outcome. It is quite possible to perform a learnt action habitually without being motivated by a representation of the outcome. This is seen, for example, when rats that are overtrained or have lesions to the prefrontal cortex perform actions irrespective of the current outcome value (Balleine & Dickinson, 1998), or in the striking phenomenon of action learning in single-celled organisms (Armus, 2006). Furthermore, even in children and adults it is often the case that outcome expectations are not in consciousness during action performance (Bargh & Chartrand, 1999; Simpson & Riggs, 2007; Wood & Neal, 2007). In summary, observations that individuals perform rewarded actions are not proof that the individuals expect the outcome of their actions. It is therefore an open question whether or not infants do expect the outcome of their actions before they carry them out, and the purpose of this study is to address this question.

Given that children have a less developed prefrontal cortex (Diamond, 2002; Sowell, Delis, Stiles, & Jernigan, 2001), it is plausible that at least some instrumental behaviour in infants may be habitual and not accompanied by a representation of action outcome. The standard method of demonstrating an association between action and outcome in the field of animal learning is by demonstrating that an action is performed either more or less after the outcome value has been either increased or decreased (the outcome revaluation paradigm, Balleine & Dickinson, 1998; Chen & Amsell, 1980). This procedure has been tested twice with young children, who have not been found to change response rates after outcome revaluation until the age of two years (Kenward, Folke, Holmberg, Johansson, & Gredebäck, 2009; Klossek, Russell, & Dickinson, 2008). In fact, it is common to find in a variety of tasks that infants persevere in performing a previously rewarded action after changed circumstances have rendered it inappropriate (Hauser, 2003). For example, in the A not B task (reviewed by Marcovitch & Zelazo, 1999), infants several times witness an item being hidden at location A, and each time are given the opportunity to retrieve it themselves. Subsequently, when the object is instead hidden at location B, infants tend still to reach to location A. This error is attributable at least partially to a deficit in the ability to inhibit previously rewarded action (Diamond, Cruttenden, & Neiderman, 1994; Marcovitch & Zelazo, 2009), as evidenced, for example, by the fact that infants are more likely to look at the correct location than they are to reach to it (Hofstadter & Reznick, 1996).

Nevertheless, Rochat and Striano’s (2000) description of infants as agents deliberately exploiting instrumental contingencies is not without some foundation: much evidence has been put forward to argue that infants do expect outcomes instrumentally contingent on their actions, and the available evidence is often interpreted as demonstrating that even young infants behave intentionally (e.g. Biro & Hommel, 2007; but see Haith, 1998). Many arguments can be discounted because evidence is interpreted without taking into account the possibility of reinforcement learning leading to habit acquisition (e.g. Willatts, 1999), but this is sometimes controlled for. For example, 9-month-olds selectively imitate actions that they have observed to result in a rewarding outcome (Hauf & Aschersleben, 2008; Hauf, Elsner, & Aschersleben, 2004). There is, however, still a possibility that the infants may have learnt an automatic response to the stimulus through vicarious reinforcement in observational learning (Saggerson, George, & Honey, 2005).

Another approach has been to show that infants evidence frustration or surprise when an action stops working or results in an unexpected outcome (Elsner & Aschersleben, 2003; Fagen & Ohr, 1985; Lewis, Alessandri, & Sullivan, 1990). While this certainly demonstrates that a representation of an expected outcome is active at the point immediately after the action is carried out, it does not show conclusively that this representation was active before the action was carried out. This distinction is important, because an outcome expectation can only have played a role in motivating an action if the expectation was active before the action was begun.

Infants show prospective motor control – they control their posture in anticipation of the demands of their own future actions (von Hofsten, 2007). For example, prior to contracting arm muscles to pull a heavy weight, infants as young as 10-months-old contract their leg muscles to avoid loosing balance when pulling (Witherington et al., 2002). While such prospective control can be seen as a form of expectation, it is by definition not expectation of an instrumental relation. Instrumental and motor expectations differ profoundly in that (in adults at least) motor expectations are almost always unconscious (Jeannerod, 2006) and have separate neural mechanisms that can operate independently (reviewed in Kenward et al., 2009). Also well studied but not directly relevant here (except methodologically) is the phenomenon of infants' understanding of the action targets of others (e.g. Sommerville & Woodward, 2005). Although such understanding can involve anticipation (Falck-Ytter, Gredebäck, & von Hofsten, 2006), all such studies to date have involved simple actions such as grasping or displacing, rather than the utilisation of instrumental contingencies.

It is known that when infants are exposed to a predictable sequence of events, for example a particular visual stimulus in one location always followed by a second stimulus in another location, they can learn to anticipate the onset of the second stimulus by looking at its location before it occurs (Canfield & Haith, 1991). This anticipation is generally interpreted as a manifestation of an expectation that the second stimulus will occur (i.e. anticipation is a measurable behaviour, and expectation is an underlying mental process, Haith, 1994), and I refer to this method as the passive visual expectation paradigm.

In fact anticipatory gaze adjustments to ongoing events are the rule rather than the exception in infant behaviour (von Hofsten, 2007). The phenomenon is initially connected to perception of motion and emerges first in smooth pursuit eye tracking at around 2-3 months of age (von Hofsten & Rosander, 1997). From 4 months old infants anticipate the path of a temporarily occluded object – when the object disappears behind an occluder they shift gaze to the reappearing side just before the object reappears there (Johnson, Amso, & Slemmer, 2003; Nelson, 1971; von Hofsten, Kochukhova, & Rosander, 2007). If the motion is consistently perturbed behind the occluder, infants quickly learn to visually anticipate the perturbation (Kochukhova & Gredebäck, 2007). Adults visually anticipate their own and others' actions in target-oriented tasks (Land, Mennie, & Rusted, 1999; Sailer, Flanagan, & Johansson, 2005). To my knowledge, however, it has never been tested if infants visually anticipate stimuli that they themselves generate.[1]

This study describes a new method with the potential to determine if infants learn to expect the instrumental outcome of an action they perform. Such instrumental expectation is defined as the representation of an outcome that is associated with the action it is contingent on, and that is active before the action is performed. In this method, the gaze of a group of 10-month infants (the contingent group) is tracked while they push a button that immediately starts a video reward. According to the hypothesis of infant action outcome expectation, before they push the button the infants will visually anticipate the outcome by looking at the area where they expect the reward to occur. I refer to this method as the active visual expectation paradigm, complementing the already developed passive visual expectation paradigm.

An additional hypothesis, which I term the boredom hypothesis, also predicts a gaze pattern resembling anticipation. In the period before a reward is triggered, looking towards the reward location may gradually increase as the infant becomes more bored and more hopeful that the reward may begin. To address this hypothesis, a yoked control group (the control group) is included in which each infant watches a replay of the sequence of rewards that an infant in the contingent group generated by button-pushing. The boredom hypothesis predicts that in both groups reward area gaze shifting will increase with time in the period before a new reward is triggered, but the action outcome expectation hypothesis predicts an increase in reward area gaze shifting immediately before the reward in the contingent group only.

It is possible that due to factors such as increased cognitive load when actively causing stimuli compared to observing passively, expectation may not manifest itself here as visual anticipation. Expectation can also manifest itself as a faster reaction time to a stimulus (facilitation, Haith, 1994; see also Lew-Williams & Fernald, 2007). The hypothesis that infants possess action outcome expectations that lead to facilitation predicts that for events with no anticipation, reaction times will be faster for the contingent group than the control group.

In order to include a method with the potential to reveal visual indications of expectation without relying on pre-reward anticipation or fast reactions, as part of the standard procedure for the contingent group short periods of extinction are included in which button pressing no longer elicits the reward (no-reward periods). If the infants in the contingent group expect the video reward when pushing the button, although the onsets of pushing and looking may not be closely synchronised within fractions of seconds as in anticipation or facilitation, there may nevertheless be a temporal correlation between bouts of pushing and looking at the reward area.

One trivial hypothesis – the activity level hypothesis – also predicts a relation between pushing and looking in no-reward periods: both activities may be determined by activity level (an inactive infant is unlikely to do either). Because infants in the control group are exposed to a yoked video reward sequence, they are also exposed to no-reward periods. In these periods, the activity level hypothesis predicts a temporal correlation between bouts of button pushing and looking at the reward area in both groups, but the action outcome expectation hypothesis only predicts such a correlation in the contingent group. This comparison is only possible, however, if button pushing is also carried out by the control group. In order therefore to elicit such pushing, infants in the control group are provided with an auditory rather than visual reward for pushing the button, as part of the standard procedure. Button pushing always results in an auditory stimulus for the control group, even during no-reward periods.

The inclusion of an auditory reward for the control group, however, introduces a potential confound to the design because the two groups differ in more than simply whether the video reward is triggered by the participant or not. After the experiment as so far described was carried out, a second control without these auditory rewards was therefore conducted, and is presented after the original experiment.

Methods

Participants

The final sample consisted of 32 healthy 10-month infants, recruited by mail based on birth records. Infants were randomly divided into two groups of 16: the contingent group (mean age 10 months 6 days, *SD* = 5 days) and the control group (mean age 10 months 12 days, *SD* = 6 days). All infants were full term except for 1 infant in each group (both 28 days premature): these infants were not excluded because their data did not appear to differ from that of others in their groups. In addition, 4 infants were tested but not included in the final sample because of fussiness right at the start of the session (3 infants) or because they did not complete a long enough session (see below, 1 infant).

Stimuli and Apparatus

Stimuli were presented on a video screen, subtending 32° horizontally of the infant's field of view, and equipped for gaze-tracking with a Tobii 1750 corneal eye tracker (manufacturer's specifications: precision 1°, accuracy 0.5°, sampling rate 50 Hz) with special adaptations for tracking infants' eyes. Gaze data was analysed raw except for smoothing with a three-sample (60 ms) window moving-average. As the reward area is large (see below) with respect to the eye tracker specifications, the eye tracker provides a very accurate estimate of whether or not the infant is looking at the reward area. A standard 9 point infant calibration was used to ensure the tracking algorithms were tuned to individual infants' eyes (Gredebäck, Johnson, & von Hofsten, in press), in which eye-catching stimuli are displayed in 9 different locations around the screen, with each one displayed until the infant briefly fixates it.

With the corneal eye-tracking technique as implemented by Tobii, it is impossible to determine with certainty whether missing data caused by tracking loss is a result of the participant looking away from the screen or because head movements position the eyes outside of the area where tracking is possible. However, Tobii operators in our laboratory usually watch the infant during sessions, and it is our experience that the use of individual calibration and a safety car seat to restrain infants' movements ensures that a small proportion of gazes at the screen are not tracked. There is a delay of unspecified length but estimated by the manufacturer to be in the region of 100 ms for the system to re-establish tracking after it is lost if the participant looks away from the screen and then back. For a methodological review of the application of corneal eye-tracking to infants, see Gredebäck, Johnson, & von Hofsten (in press).

Also attached to the screen were audio speakers from which the video reward soundtrack and audio rewards (see below) emanated. The push-button was a red AbleNet Big Red circular switch, 125 mm in diameter, with an audible click and 3 mm travel when pushed, mounted on an adjustable arm for positioning within the infant's reach, and connected to the Tobii computer using a Phidgets 8/8/8 interface. Stimulus presentation was accomplished using Python scripting in the Blender game mode 3D environment.

The video reward stimulus was an 80 s clip of the introduction sequence of Teletubbies, a children's program aimed at 9- to 36-month-olds. The sequence consisted of dancing Teletubbies accompanied by music with sung lyrics. Each video reward presentation comprised 10 s of Teletubbies, so after 8 repetitions the video looped. The video was presented in a centrally positioned rectangle subtending 10° horizontally of the field of view, referred to as the reward area. When the video reward was not playing, the reward area was always covered by a closed 3D door, “painted” with a still image of the teletubbies (Figure 1a). The door was animated to open during the first second of the video reward (Figure 1b) and to close during the last second, so that the reward itself was revealed and concealed during the first and last second of playing. Door opening was always accompanied by a door opening sound effect, played simultaneously with the first second of the video reward soundtrack.

One second after the video reward ended a distracter stimulus always appeared (figure 1a). The distracter stimulus was always on screen outside of video reward periods (disappearing immediately at the start of video reward presentations) and was intended to prevent the infants from simply fixating the reward area throughout the session. The 1 s delay in distractor presentation after the door closed was intended to increase the salience of its reappearance. The stimulus was a rectangular still image subtending 4° horizontally of the field of view, reselected with each new presentation from a looped series of 16 pictures (e.g. human faces, cartoon fish, abstract patterns), travelling in a rectangular path with an edge always 0.5° from the screen edge and with speed 6 °/s.

An auditory reward stimulus for the control group was reselected each time from a looped series of 33 different sounds (e.g. animal sounds, cartoon style sound effects); although at the beginning of the series there was repetition intended to facilitate learning (the first sound occurred four times and the next four twice each).

Procedure

The study was approved by the ethics committee at the Research Council in the Humanities and Social Sciences and therefore in accordance with the ethical standards specified in the 1964 Declaration of Helsinki. As each family entered the lab, parents were informed about the procedure and signed a consent form. Infants were seated in a safety car seat and placed on the parent's lap. The experimenter was seated on the floor beside the parent. After calibration of the eye-tracker, the button press recording program was activated (marking the session start) and the push-button was moved into easy reach of the infant's right hand (Figure 2). The parent had been informed that it was acceptable to verbally encourage button-pressing, and to move their child's hand in any way; however they were not allowed to press the button themselves. This allowed for the possibility that parents cause their infant's hand to press the button, and this did sometimes occur initially in the session, but all included infants quickly learned to press unaided, and when this occurred the parents were instructed to leave the hand alone. The initial parental involvement was not recorded in detail because piloting had revealed that all infants, unless fussy, learned quickly and easily to press the button. There were no parental compliance problems.

The contingent group received a video reward immediately every time they pressed the button, except that additional button presses during a video reward had no effect, and there were occasional no-video-reward periods in which pressing the button had no effect. These periods, of random duration uniformly distributed between 10 and 20 s, did not occur in the first two minutes. Thereafter they occurred after random intervals uniformly distributed between 50 and 70 s. However, if at least three video rewards had not been triggered since the last no-reward period, the next no-reward period was postponed until three video rewards had been triggered within 60 s – this measure was intended to prevent extinction of button pushing. The interspersal of short no-reward periods throughout the session was expected to allow more data collection from these periods than the conventional approach of having a longer single period of extinction after the learning phase, which would probably have resulted in more rapid total extinction.

Each infant in the control group was paired with an already tested infant in the contingent group, and witnessed a replay of the same sequence of video rewards and no-video-reward periods as the paired infant had generated. Button pushing did not affect video rewards for the control group; it always produced an auditory reward, however.

Contingent sessions were not time limited. Before 20 minutes, if the infant became fussy, the parent was encouraged to console it; if successful, the session continued. After 20 minutes, the session was terminated immediately after any sign of fussiness. Control sessions lasted until the infant displayed inconsolable fussiness or until the paired contingent session ended. All disturbances during the session that were not initiated by the infant or that involved the experimenter (for example if the parent engaged the experimenter in conversation) were recorded. Sessions that did not last at least 5 minutes were excluded, because piloting suggested that infants who became fussy this quickly provided poor data even before it became necessary to terminate the session, for example because of low attention levels.

Analysis

To make maximum use of available data, while also maintaining the validity of comparisons between the groups, when presenting data graphically or analysing the groups separately, all the data from entire contingent group sessions was used, but when directly comparing the groups statistically, only events that a contingent infant and the paired control infant were both exposed to were included.

Fisher's paired comparison randomisation test (Manly, 1997) was used for all analyses (always two-tailed and with 100000 random samples) unless otherwise stated. Randomisation tests tend to be as powerful as parametric tests but are still robust under deviations from parametric assumptions (Good, 2004), hence their use here, but note that all significant results reported here are also significant with equivalent parametric tests.

Video reward anticipation

Recall that the reward area is the centrally positioned rectangle where the video reward is displayed, which subtends 10° horizontally of the screen's total 32°. To determine whether infants increased their tendency to look at the reward area prior to triggering the video reward, the rate of gaze shifts originating from anywhere outside the reward area and going into the reward area (GSR) in the 1 s period prior to the reward start (T_{-1}) was compared with the 1 s period prior to that (T_{-2}). Given that in both familiar (Land et al., 1999) and novel (Sailer et al., 2005) action tasks the vast majority of adults' anticipatory gaze shifts take place within roughly a half second of the action, and given that infant passive anticipation has also been measured to peak at around a half second prior to an event (Reznick, Chawarska, & Betts, 2000), the hypothesis of visual anticipation predicts GSR_{T-1} to be greater than GSR_{T-2}. GSR is a more sensitive measure than looking time because infants sometimes stare at the reward area throughout both periods, which dilutes looking time effects, but not GSR effects. For each infant, event specific GSR_{T-1} and GSR_{T-2} were first calculated for each reward event. For each infant, the GSR values used in analysis are the mean values of all the infant's event specific values (excepting excluded reward events, see below). To rule out alternatives to the anticipation hypothesis that also predict $GSR_{T-1} > GSR_{T-2}$, the contingent and control groups were compared for their tendency to have $GSR_{T-1} > GSR_{T-2}$ by comparing the ratio GSR_{T-1} / GSR_{T-2} between the groups.

Reward events occurring less than 2 s after the end of the previous one were of necessity excluded from this analysis, but in these cases infants were anyway likely to be looking due to the previous reward rather than in anticipation of the next reward. The first event was also excluded as no learning could yet have occurred.

Note that I did not follow the practice of counting some post-event gaze shifts as anticipatory (on the basis that there is a minimum reaction time for reactive saccades) because it is difficult to choose an appropriate minimum reaction time for anticipation (Canfield, Smith, Brezsnyak, & Snow, 1997; Rose, Feldman, Jankowski, & Caro, 2002).

No-video-reward periods

Portions of no-video-reward periods that contained disturbances (see Procedure) were excluded. Although button pushing is an instantaneous event (keeping the button held down produced no effect), a method by which button pushing bouts can be defined simplifies analysis, and any moment was therefore defined as within a pushing bout if it occurred within 1 s of a push. The mean GSR was calculated for each individual both during and outside of pushing bouts. If anticipatory gaze shifts occur, GSR during pushing bouts is predicted to be greater than GSR outside, even if gaze shifts are not closely synchronised with specific button pushes. GSR inside and outside pushing bouts in no-reward periods are therefore compared within and between groups, in the same way as GSR_{T-1} and GSR_{T-2}.

Results

Infants in both groups pushed the button frequently and over a much longer period than the minimum session length of 300 s (Table 1). Individual response rates (in both groups) began by accelerating from baseline and then reached a plateau, indicating learning had taken place. This initial acceleration was marked in both groups – for the contingent group, the mean push rate was 8 per minute (SD = 8) for the first ten pushes and 21 (SD = 13) for the second ten, $p <$

0.001, *d* = 1.02, and for the control group the mean push rate was 10 per minute (*SD* = 7 per minute) for the first ten pushes and 29 (*SD* = 23) for the second ten, $p < 0.001$, *d* = 1.06 (recall that the control group received an audio reward for button pressing). The mean proportion of session time containing disturbances was 1.5% and this did not differ between the two groups, $p = 0.960$, *d* = 0.01.

Video reward anticipation and reaction facilitation

Infants in the contingent group anticipated the reward by significantly increasing their rate of gaze shifts into the reward area (GSR) during T_{-1} before pushing the button and starting the reward, with GSR peaking 0.5 s before the video reward, whereas infants in the control group did not deviate from the baseline rate in the T_{-2} period (Table 2, Figure 3).[2] The anticipatory increase in contingent group GSR just before triggering the reward, though small compared to the reactive increase after the reward start, was quite reliable: GSR increased from T_{-2} to T_{-1} for 13 of the 16 infants, $p = 0.021$, sign test.

The latency from the reward start to the first gaze shift into the reward area, though frequently calculated in similar studies, was not as good a measure as GSR in this case, because rewards that started when the infant was already looking must be either excluded (ruling out anticipation analysis), or assigned a negative latency. Assigning negative latencies requires a carefully controlled analysis (Canfield & Haith, 1991) because there is an artefactual appearance of increased reward area gaze shifting immediately prior to the reward. This artefact occurs because even if reward area looking is completely random, looking bouts that begin just before the start of the reward will be more likely to be ongoing at the reward start, and therefore more likely to contribute to latency data. However, positive latencies can be used straightforwardly to test for facilitation, in other words if the contingent group reacted faster once the reward began;

they did not (contingent *M* = 519 ms, *SD* = 360; control *M* = 516 ms, *SD* = 348), $p = 0.876$, $d = 0.04$. Latencies greater than 1 s were excluded because the infants were probably not reacting to the reward start, but omitting the exclusion did not change the result.

Detection of anticipation was possible because constant fixation of the reward area was not a problem – outside of video rewards, while looking at the screen, infants looked at the reward area for a mean of only 55% (*SD* = 9%) of the time. This was presumably because the moving distracter captured their attention for the remaining time (it was the only stimulus displayed on the screen outside the reward area), though due to technical constraints complete records were not kept of the exact distracter position at all times.

No-video-reward periods

In the no-video-reward periods, infants in the contingent group but not infants in the control group were significantly more likely to shift gaze to the reward area during bouts of pushing than outside pushing bouts (Table 3). However, the factor by which individuals' pushing increased during bouts for the contingent group was not significantly greater than the equivalent value for the control group.

Looking away from the screen to push

The relatively weak effect of anticipatory gaze shifting compared to reactive gaze shifting (Figure 3) prompted the question of whether infants in the contingent group sometimes looked at the button to press it, which would preclude anticipation. It cannot be determined when infants were looking at the button, because only gazes at the screen are tracked, but because periods of missing data are usually caused by infants looking away from the screen, such periods are a reasonable estimate of when infants looked away, and therefore indicate when they might have glanced at the button. Infants in the contingent group looked away from the screen for at least part of the T_{-1} period for mean 80% (*SD* = 7%) of video rewards. When their gaze shifted away from the screen during this period it was usually in a downwards right direction (Figure 4), as expected if the gaze is moving towards the button (Figure 2).

There was a trend for infants in the contingent group to increase their rate of gaze shifts away from the screen before pressing the button, peaking 0.5 s before pressing, similarly to the rate of gaze shifts to the reward area (Figure 5). Unlike gaze shifts to the reward area, however, the rate of gaze shifts away from the screen in the contingent group was not significantly higher during the T_{-1} period than during the baseline T_{-2} period, $p = 0.159$, $d = 0.44$. During the T_{-1} period the contingent group shifted gaze more often to the reward area ($M = 0.44$ shifts per second, $SE = 0.06$) than away from the screen ($M = 0.29$ shifts per second, $SE = 0.03$), $p = 0.022$, $d = 0.61$.

Because of the delay of approximately 100 ms in re-establishing tracking when infants looked away from the screen and looked back, it is possible that anticipation might have been slightly underestimated, if infants sometimes looked away from the screen to locate the button before pressing it, but then shifted gaze back again immediately before pressing the button. However, for 80% (*SD* = 24%) of gaze shifts into the reward area in the T_{-1} period, the shift was preceded by looking at the screen outside the reward area, for a mean period of 747 ms (*SD* = 519 ms). This indicates that gaze tracking after looking away was usually re-established before the gaze entered the reward area, and an underestimation of anticipation cannot therefore be large. Note that control infants do not press the button at the point of reward start so there is no reason to believe that they may likewise be more likely to be missing data immediately before the reward start.

No-audio-reward Control

There is a limitation in the experimental design as so far presented which is now addressed with an additional control. The original control and contingent groups differed not only in whether or not the video reward was delivered contingently, but also in that contingent audio rewards, intended to elicit button pressing, were delivered for the control group only. This allows the theoretical possibility that the difference in gaze patterns did not reflect the presence or absence of video reward anticipation, but instead something caused by this difference in auditory stimulation.

It is not in fact normally regarded as being necessary to attempt to elicit responding in the control group in the yoked control paradigm (e.g. Alessandri, Sullivan, & Lewis, 1990). The reason this measure were taken here was that without button pressing in both groups, the group comparison of the relations between button pressing and reward area gaze shifting in no-reward periods would have been impossible. With hindsight, this particular analysis delivered unclear results, and was anyway unnecessary because of the clear results concerning gaze shifting immediately before reward starts. Because of this, and because of the problems of interpretation associated with dissimilar auditory stimulus presentation between the groups, a no-audio-reward control was run in which stimulation presentation was identical between infants in the contingent group and their yoked controls.

The method for this no-audio-reward control was identical in every respect to the previously described control, with the single exception that no auditory reward was provided for button pressing. Without exception, every analysis comparing the contingent group with the no-audio-reward control produced the same pattern of results as the original comparison between the contingent group and the original control group. Details now follow.

The final sample was of 16 healthy infants (8 female), with mean age 10 months and 7 days (*SD* = 9 days). Two additional infants were tested and excluded because they did not complete a minimum five minute session. Mean (*SD*) values of parameters describing sessions were session length: 689 s (315); *N* video reward presentations: 31 (15); *N* video reward presentations included in analysis: 18 (8); and *N* button pushes: 116 (88).

Mean (*SD*) gaze shifts per second into the reward area (GSR) for the no-audio-reward control was not different in the two one-second periods before video reward starts: GSR_{T-2} = 0.42 (0.33); GSR_{T-1} = 0.33 (0.25), $p = 0.520$, $d = 0.16$. The increase factor from T_{-2} to T_{-1} (GSR_{T-1} / GSR_{T-2}) was 0.92 (0.68). Recall that for group comparisons, data is only analysed for events to which both infants in a yoked pair were exposed. For comparison with the no-audio-reward control, the contingent group's data was therefore resampled appropriately, and the T_{-2} to T_{-1} increase factor was recalculated as 1.60 (0.94), which is greater than the value for the no-audio-reward control group, $p = 0.039$, $d = 0.60$. The same pattern of results was therefore found as in the original control group comparison.

No-audio-reward control infants did press the button an appreciable amount, despite there being no effect – evidently pressing a big red button is inherently rewarding – so a comparison of no-reward periods was also possible with the no-audio-reward control group. In no-reward periods, mean (*SD*) rates of gaze shifting to the reward area for the no-audio-reward control group were not different outside, 0.31 per s (0.14), and inside, 0.37 per s (0.19), pushing bouts, $p = 0.293$, $d = 0.30$. However, the factor of rate increase from outside to inside pushing bouts was not different between the no-audio-reward control group, 1.41 (0.98), and the (appropriately resampled) contingent group, 1.29 (0.59), $p = 0.927$, $d = 0.03$. The same pattern of results was therefore found as in the original control group comparison.

Positive latencies (less than a second) from the reward start to the first gaze shift into the reward area were not different between the no-audio-reward control group (*M* = 504 ms, *SD* = 126) and the (appropriately resampled) contingent group (M = 523, SD = 126), $p = 0.718$, $d = 0.09$. The same patterns of results were therefore found in all the comparisons between the contingent group and the no-audio-reward control group as were found in the original comparisons between the contingent group and the original control group.

General discussion

Ten-month-olds given the opportunity to trigger a video reward showed an above baseline tendency to shift gaze to the location of the reward in the 1 s period before triggering it. In two yoked control groups, the rates of gaze shifting into the reward area were constant in the period before the reward, ruling out most non-anticipation based hypotheses, such as the boredom hypothesis, as explanations for the contingent group's gaze shift increase. I argue below that, while one alternative explanation requires consideration, the most plausible explanation for this gaze pattern is that it represents anticipation generated because the infants expected the location of the outcome of button pressing before they pressed the button. When infants in the contingent group triggered the reward without a prior gaze shift, they did not have a faster reaction time than control infants who did not trigger the reward.

The peak time of reward area gaze shifting was a half-second before the video reward was triggered. This timing is consistent with data from studies of adults performing manual activities, in which the eyes tend to lead the hands by around a half-second (Land et al., 1999), and with infant data from the passive visual expectation paradigm, in which anticipation peaks approximately a half second before stimulus onset (e.g. Reznick et al., 2000). This result supports the conclusion that the reward-area gaze-shifting peak identified here represents anticipation. It is also consistent with the hypothesis that similar processes of expectation may be the cause of infant anticipation in the passive and active paradigms.

Gaze shift patterns during no-video-reward periods were ambiguous with respect to the reward anticipation hypothesis and the activity level hypothesis. On the one hand, infants in the contingent group had a greater tendency to shift gaze to the reward area during bouts of pushing than when they were not pushing, whereas infants in the control groups did not display a similar significant tendency. On the other hand, the contingent and control groups could not be separated statistically. No firm conclusions can therefore be drawn about either hypothesis on the basis of data from the no-video-reward periods.

In experiments involving the passive visual expectation paradigm, visual anticipation of a stimulus has generally been interpreted as indicating an underlying expectation or forecast of the event (Haith, 1994), not only in terms of its temporal and spatial occurrence, but also its content (Adler & Haith, 2003; Wentworth & Haith, 1992). However, although the term “expectation” might seem to imply a high-level cognitive mechanism (and has therefore generated controversy, Fagen, 1993; Gewirtz & Palàez-Nogueras, 1993; Schlinger, 1993), it has also been argued that infant visual expectation is sufficiently described as procedural, and that visual anticipation does not necessitate the existence of an explicitly declarative expectation (Reznick, 1994; Reznick et al., 2000; but see Sobel & Kirkham, 2006).

The controversy associated with the term “expectation” may be avoided if it is defined, as I have done so, to imply at the least only a simple mechanism: the representation of an outcome that has become associated with a stimulus or action that tends to precede it, and that therefore becomes activated by the representation of the preceding stimulus or action (Tarabulsy, Tessier, & Kappas, 1996). The outcome representation need not contain a detailed specification of outcome content – it might be restricted to location information. In this sense, the term "expectation" neither implies nor precludes consciousness, causal cognition or declarative knowledge. In older children and adults, declarative knowledge of action-outcome relations tends to co-occur with automatic low-level associations (Shanks, 2007), as evidenced for example by the fact that outcomes can prime the actions that are known to lead to them (Eenshuistra, Weidema, & Hommel, 2004). Whether this co-occurrence is the case in young infants, however, remains to be seen.

The data presented here do not allow conclusions to be drawn about the content or type (procedural vs. declarative) of infants' expectation. Given that infants do remember visual content (Rose, Feldman, & Jankowski, 2004), and that some aspects of their passive visual anticipation are more consistent with causal than associative learning (Sobel & Kirkham, 2006), it is plausible that the anticipation here might reflect a content-rich declarative expectation. On the other hand, it is also theoretically possible that although anticipation occurs, nothing is encoded in the expectation beyond a location. According to this content-free and procedural account, the infants would learn by reinforcement to shift gaze as a habitual response to the internal stimulus of the sensation of preparing to press the button, without expecting anything specific to occur at the gaze-shift goal.

Such a simple expectation encoding nothing but location would not suffice to motivate the button pressing action. This means that these findings have little implication for our understanding of infants' mechanisms of instrumental action selection. It is plausible that the infants in this study were pressing the button because they expected and desired the outcome, but it remains a possibility that another mechanism, such as a learned habit, was the motivation for button pressing (Kenward et al., 2009; Klossek et al., 2008). If the action selection was not motivated by outcome expectation, then the mechanisms for expectation and anticipation operating here may be very similar to in the passive visual expectation paradigm – the sensation of preparing to press the button may have functioned as an internal stimulus which prompted the expectation of the outcome.

Compared to post reward-start reactive gaze shifting, the anticipatory effect was rather small. The weakness of this effect is consistent with infant data from the passive visual expectation paradigm (for example 9-month-olds anticipate an alternating left-right sequence on only 24% of trials, Canfield et al., 1997). Here, however, there is an explanation for the weakness of the effect not applicable to studies involving passive infants. Infants frequently shifted gaze away from the screen, and in the 1 s period preceding button presses, these shifts left the screen predominantly in the direction of the button. Although looking at the button was not measured formally, this gaze shift data, coupled with the experimenter's anecdotal observation that infants frequently looked at the button to press it, allows a strong argument to be made that infants sometimes looked at the button before pressing it. There are therefore two conflicting types of anticipatory gaze shift, each peaking 0.5 s before the button press – shifting to look at the physical target of the action, and shifting to look at the location of the action's result. This problem might have been avoided by including a delay in reward presentation after button pressing. This approach was not used because even in adults, causal learning becomes harder with short delays (Shanks, Pearson, & Dickinson, 1989), and because this approach would not have allowed the study of expectation present before the action was carried out.

Before definitely concluding that the gaze shift pattern observed here represents anticipation of an expected event, one other hypothesis should be considered. If the infants have formed an association between the occurrence of the reward and the act of pushing, then they may be more likely to push whenever they (for any reason) shift gaze to the reward area, because seeing the reward area activates their representation of the reward, which in turn activates the pushing action. In this mechanism, the causal direction between the reward area looking and the pushing is reversed – the pushing occurs because of seeing the reward area, rather than vice versa. If this hypothesis completely explains the relation between gaze shifting and button pressing, without expectation also playing a role, then a unidirectional backwards outcome to action association motivates action, without the corresponding forwards action to outcome association being active. Even models of action control which place strong emphasis on automatic outcome to action associations do not make sense without the corresponding action to outcome association (Elsner & Hommel, 2001). Furthermore, it has been demonstrated that learnt associations do not take the form of two separable unidirectional associations, but of one bidirectional one (Arcediano, Escobar, & Miller, 2005).

It is therefore implausible that infants' behaviour could be caused by a backwards outcome to action association without the corresponding forwards action to outcome association (i.e. an expectation) being active. In other words, if the hypothesised mechanism of reward area looking prompting button pressing does occur, then expectation is very likely to also occur, in which case expectation is demonstrated irrespective of which mechanism is responsible for increased reward area looking prior to button pushing. Note that it is possible that the two hypotheses, of expectation leading to anticipation, and of reward area looking leading to button pushing, both play a role in explaining the data.

In conclusion, this study has provided data from a new experimental paradigm showing that before 10-month-olds carry out an instrumental action, they look at the location where the outcome will occur. This is consistent with the interpretation that an expectation of action outcome location causes the infants to visually anticipate. Learnt action need not be motivated by outcome expectation, and presence of an expectation after action performance (as demonstrated in expectation violation paradigms) does not necessitate that an expectation was present before action performance. This is therefore the first data directly supporting the hypothesis that infants have some expectation of the outcome of their actions prior to action performance.

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Footnotes

[1]There is one report of this effect in 12-month olds (Carpenter, Nagell, & Tomasello, 1998). However, presumably because this issue was not the focus of that study, no relevant methods or data were provided, so the claim must be regarded as anecdotal.

[2]For the benefit of those unfamiliar with randomisation tests, I also report a parametric General Linear Mixed Model calculated for this important comparison of GSR at T_{-2} and T_{-1}. GSR was modelled with: identity of the yoked pair (random factor); and condition, time period, and their interaction (fixed factors). Model fit was checked by inspecting diagnostic scatterplots, using standardized residuals (Grafen & Hails, 2002). The interaction between condition and time period was significant, $F(1,45) = 5.34$, $p = 0.026$, confirming the significance of the observation that the contingent group's but not the control group's GSR differs between T_{-2} and T_{-1}.

Tables

Table 1

Mean (SD) of Parameters Describing Experimental Sessions

Group	Session length (s)	*N* video reward presentations	*N* video reward presentations included in analysis	*N* button pushes
Contingent	966 (326)	44 (17)	25[a] (8)	249 (137)
Control	837 (322)	38 (16)	18 (8)	151 (91)

[a]For statistical comparison with the control group, however, only the same rewards that control infants were also exposed to are included, so *N* = 18.

Table 2

Shifting Gaze to the Reward Area in the Two One-Second Periods Before the Video Reward

Group	Gaze shifts per second into the reward area (GSR):		GSR increase factor from T_{-2} to T_{-1}
	T_{-2}	T_{-1}	
Contingent	0.35 (0.19)	0.44 (0.25)	1.46 (0.69)
Control	0.39 (0.16)	0.33 (0.12)	0.98 (0.55)

Note. Group means are displayed with standard deviations in parentheses. In the contingent group GSR_{T-1} is greater than GSR_{T-2}, $p = 0.022$, $d = 0.66$, but not in the control group, $p = 0.111$, $d = 0.43$. The increase factor, which is calculated for each individual as GSR_{T-2} / GSR_{T-1}, was greater in the contingent group, $p = 0.047$, $d = 0.53$ (see Footnote 2 for a parametric equivalent of this test).

Table 3

Shifting Gaze to the Reward Area During No-Reward Periods

Group	Gaze shifts per second into the reward area (GSR):		GSR increase factor during bouts
	Outside pushing bouts	During pushing bouts	
Contingent	0.40 (0.21)	0.52 (0.28)	1.34 (0.64)
Control	0.36 (0.10)	0.38 (0.13)	1.09 (0.35)

Note. Group means are displayed with standard deviations in parentheses. In the contingent group GSR is higher during pushing bouts than outside them, $p = 0.026$, $d = 0.59$, but not in the control group, $p = 0.520$, $d = 0.16$. However, the increase factor, which is calculated for each individual as GSR during pushing bouts / GSR outside pushing bouts, was not significantly greater than the equivalent value for the control group, $p = 0.211$, $d = 0.39$.

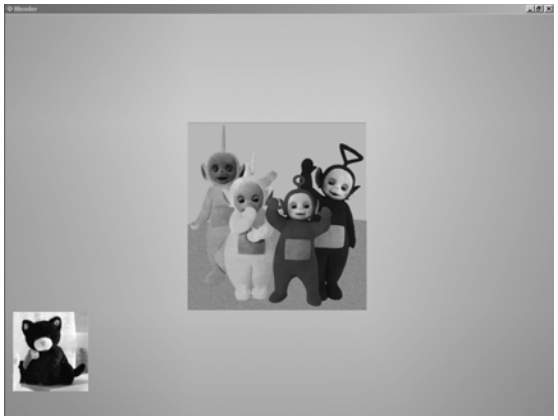
a)  b) 

Figure 1. Screenshots of stimuli, showing a) the closed door in the reward area “painted” with the Teletubbies still image, and the distracter stimulus travelling a path round the screen’s perimeter, and b) the open door revealing the playing video reward in the reward area.

Figure 2. Photograph of the experimental setup, showing an infant seated in the safety car seat on the parent's lap, hand on button, watching video reward.

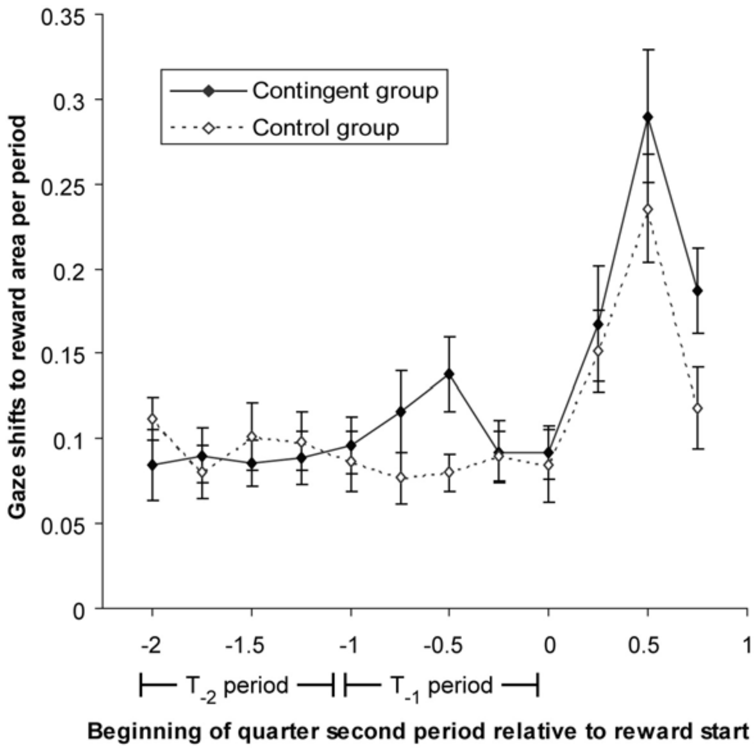


Figure 3. Numbers of gaze shifts into the reward area during quarter second periods before and after the video reward start. For the contingent group only reward starts are simultaneous with button presses. Data points and error bars represent group means (± *SE*) of individual means. *n* = 16 per group. The contingent group's peak in gaze shifting a half second prior to the reward start is significant (Table 2). Note that because periods are quarter seconds, GSR per second for any period equals the plotted value multiplied by four.

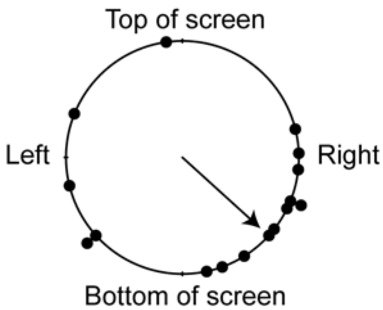


Figure 4. Contingent group screen-relative gaze travel vector when gaze left the screen in the 1 s period prior to video reward triggering (T_{-1}). Individual means (circles) and the group mean (arrow) are displayed. Note that the button was positioned to the bottom right of the screen (Figure 1). The clustering around the group mean comprises a significant deviation from a random uniform circular distribution, $\bar{R}$ = 0.455, n = 16, p = 0.034, Rayleigh test.

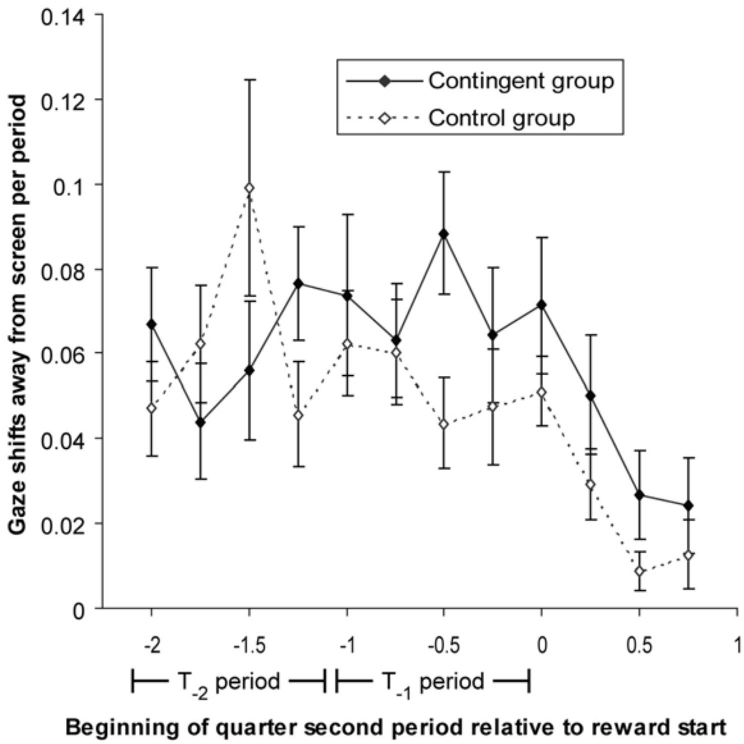


Figure 5. Numbers of gaze shifts away from the screen during quarter second periods before and after the video reward start. Data points and error bars represent group means (± *SE*) of individual means. n = 16 per group.