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FAST-TRACK REPORT

Six-month-old infants use analog magnitudes to represent duration

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Abstract

While many studies have investigated duration discrimination in human adults and in nonhuman animals, few have investigated this ability in infants. Here, we report findings that 6-month-old infants are able to discriminate brief durations, and, as with other animal species, their discrimination function is characterized by Weber's Law: proportionate difference rather than absolute difference between stimuli determined successful discrimination. Importantly, paralleling results found with nonhuman animals, the Weber function that we found for infants' discrimination of time is the same as that found for their discrimination of number. Infants discriminated durations of an audiovisual event differing by a 1:2 ratio, but not those differing by a 2:3 ratio, over a range of durations. This suggests that (a) in human as in nonhuman animals, the same mental mechanism may underlie the ability to measure duration as to represent number, and (b) we may share this mental mechanism with other animal species.

Introduction

Time is one of the fundamental dimensions along which living creatures organize and represent experience. Species from pigeons to primates can discriminate and react on the basis of duration – timing plays a role both in prewired fixed processes, such as the foraging honeybee's calculation of homeward direction based on elapsed time and solar position, and in contingent learning processes such as the pigeon's decision to peck a key according to the duration of an auditory stimulus (Gallistel, 1990). A wealth of experimental findings indicates that human adults possess duration measurement processes similar in many ways to those found in nonhuman animals, processes which are unlearned, automatic, highly flexible and ubiquitously applied (e.g. Malapani & Fairhurst, 2002; Meck & Church, 1983; Wearden, 1999). However, while the nature of these abilities in animals and adult humans is relatively well understood, their ontogenetic development is not. Few studies have investigated human infants' ability to measure time (but see Brannon, Roussel, Meck & Woldorff, 2004) and those that have focused on temporal structure (e.g. rhythm – Delany, McKenzie & Vurpillot, 1977; Trehub & Thorpe, 1989), so little is known about the extents and limits of these processes or how they develop through infancy.

We also know little about how timing in infancy relates to other cognitive processes. In nonhuman animals, strong similarities have been found between processes that determine duration, and processes that determine number. Consider the following examples: (i) the discrimination functions for time and number are identical – discriminability of both is characterized by the same Weber function; (ii) they transfer to novel stimuli equally strongly – rats trained to respond to a 6-s auditory tone will generalize to a 6-s light-flash to precisely the same extent that rats trained to respond to six auditory tones will respond to six light flashes; (iii) administration of methamphetamine causes rats to overestimate time, and to overestimate number, to exactly the same extent; (iv) experimentally, transfer effects have been obtained between time and number – rats trained to respond to a stimulus of a given duration will respond to some number as if it were that trained duration. These similarities have led researchers to propose that the same cognitive mechanism underlies animals' ability to measure duration and their ability to determine number (Gallistel, 1990; Meck & Church, 1983).

Many recent studies have documented numerical abilities in human infants (Lipton & Spelke, 2003; vanMarle & Wynn, 2006; Xu, 2003; Xu & Spelke, 2000; Xu, Spelke & Goddard, 2005), which parallel numerical capacities

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in nonhuman animals (see Gallistel, 1990; and Davis & Perusse, 1988, for review). First, animals as well as infants enumerate a wide range of entities, including objects, sounds, and events, stationary items and items in motion, items presented simultaneously and items presented sequentially. Second, there is no evident size limit on the numerical values that can be represented – experiments with rats and pigeons have found these animals can represent values at least up to 50; experiments with human infants show that they can represent values at least up to 32 (Xu *et al*., 2005). Third, discrimination of number for both infants and adults, as well as animals, follows a Weber's Law function: it is proportionate difference rather than absolute numerical difference between two values that determines how discriminable they are. Experiments show that 6-month-old infants can discriminate 4 visual items from 8, 8 from 16, and 16 from 32, but cannot discriminate 4 items from 6, 8 items from 12, or 16 items from 24 (Xu, 2003; Xu & Spelke, 2000; Xu *et al*., 2005). This same pattern is evident in the enumeration of auditory stimuli: vanMarle and Wynn (2006) found that 7-month-old infants discriminated 2 tones from 4, but not 2 from 3; and Lipton and Spelke (2003) found that 6-month-old infants discriminated 8 tones from 16, but not 8 from 12. That is, for numbers outside the subitizing range of 1–3 items (within which additional cognitive processes are believed to apply; e.g. Carey & Xu, 2001; Feigenson, Carey & Hauser, 2002; Scholl, 2001; Trick & Pylyshyn, 1994; Xu, 2003), 6- and 7-month-old infants successfully discriminate numbers of both visual and auditory items that differ by a 1:2 ratio, but not those that differ by a 2:3 ratio.

If human infants' numerical capacities have a shared basis with those present in other animal species, then we should expect to find strong similarities in infants' ability to represent number and their ability to represent time. However, because there has been relatively little work on timing processes in infancy, virtually nothing is known of the similarity, or lack of it, between these two systems in infants. The experiments reported here represent a first step towards this goal by asking (a) if 6-month-old infants can discriminate durations, in a task closely paralleling previous tasks assessing numerical discrimination in infants of this same age, (b) if infants' ability to discriminate durations is characterized by a Weber's Law function, and (c) if so, whether this discriminability function is the same as that which previous experiments – with the same age group, and using similar experimental methods and stimuli – have found to obtain for infants' number discrimination.

Our experiments were modeled after the stimuli and procedures of vanMarle and Wynn (2006). In that study, infants were habituated to sequences of auditory tones emanating from the belly of a puppet standing in the center of a display, and subsequently presented with habituated- and novel-number test sequences. In the experiments reported here, we employed the same display and puppet, the same design and procedures, and the same habituation, end-of-trial, and trial and infant exclusion criteria. Tone stimuli were generated by the same software and presented via the same hidden speaker. Thus, our experiments were designed to be maximally similar to previous experiments assessing infants' number discrimination, to allow meaningful comparison.

Experiment 1

In this experiment, we asked if 6-month-old infants can discriminate durations with a 1:2 ratio. Infants were habituated to an audiovisual event that lasted either 2 s or 4 s. They were then, in test, presented with both durations of the same event. If infants are able to recognize the test duration that is equal to the habituated one, they should look longer on test trials containing the novel event duration.

Subjects

Subjects were 16 healthy, full-term infants (seven females) with a mean age of 6 months 0 days (range 5;17 to 6;17). Twelve additional infants were excluded due to fussiness (11), and computer error (one).

Apparatus and stimuli

Infants sat in an infant seat on a table, facing a yellow display stage that could be hidden by the lowering of a black curtain. Additional black curtains surrounded the display and table, blocking the rest of the room from view. A puppet (Sylvester the Cat) could be placed in the display; a wooden dowel (not visible to infants) protruded from the back of the puppet and poked through the back wall of the stage to serve as a lever by which a hidden experimenter manipulated the puppet (see Figure 1). Events presented to infants consisted of an auditory tone coupled with visible puppet motion. A small speaker was located inside the puppet's abdomen and connected to a computer hidden behind the curtains. A hidden observer monitored infants' looking time with a separate computer. The observer could not see the display and wore headphones playing varied-length, overlapping tones that made it impossible to discern the starting point, ending point or duration of the tone presented to the infant on each trial. Inter-observer reliability for the looking time data was calculated for a randomly selected subset of the participants (six infants) by correlating the on-line observer's

Figure 1 *Experimental stage display. Infants faced a puppet placed on a display stage. A small speaker located inside the puppet generated the tone stimuli.*

looking times with those coded from the videotaped records by a second trained observer. Across these participants, inter-observer agreement was very high ($r = .96$).

A hidden experimenter generated the computer tones, and signaled the start of each trial to the observer by flashing a small light located in front of the observer. The parent or guardian and a background observer stood behind the infant, out of his or her range of vision.

The auditory stimulus tones were constructed with the Macintosh shareware program SoundEffects 0.9.2 (Ricci, 1994–5), produced by an iBook computer, and played on a PCWorks speaker system (Cambridge Soundworks Inc.). All stimulus tones were pure sine waves with a frequency of 240 hertz. While emitting the tone, the puppet also displayed a rapid vibrating or 'jiggling' motion of its head (about 1–2 cm in each direction, achieved by the experimenter shaking the wooden dowel); this was continuous and rapid so that the individual side-to-side motions were not countable.[1] This motion served two purposes: (1) to visually demarcate the beginning and end of the event, and (2) to provide an attention drawing visual component to the stimulus event (pilot testing indicated that infants found a motionless puppet either unsettling or completely uninteresting).

Procedure

Familiarization phase

Upon being brought into the experimental room and placed in the infant seat, infants received a brief introduction to the empty display: a gloved hand entered from above and patted the floor and walls of the display, then danced a toy across the stage and exited with the toy. The black curtain in front of the display was then raised and lowered three times while infants' attention was called to it. Following this, the curtain was raised to reveal the puppet sitting in the display. A gloved hand entered and touched the puppet for several seconds to allow infants to become familiar with it, and then the curtain was lowered.

Habituation phase

The curtain was raised to reveal the puppet in the display. Approximately 0.5 s later, the puppet emitted a single computer-generated tone (either 2 s or 4 s) from the speaker hidden in its belly. Simultaneously, for the duration of the tone, the puppet's head was rapidly vibrated or 'jiggled' back and forth as described above. Immediately upon cessation of the event, the experimenter signaled to the observer the start of the trial, whereupon timing of infants' looking to the now-motionless, silent puppet began. At the end of each trial, the curtain dropped to obscure the display briefly (2 s), and then rose to initiate the next trial. A trial ended when (a) after 2 or more seconds of continuous looking, the infant looked away for at least 2 continuous seconds; or (b) trial duration reached 30 s. Habituation was reached when (a) looking time on three consecutive trials (after the first three) was less than half

[1] To ensure that infants could not have used 'number of jiggles' to discriminate the novel and familiar events, the videotaped sessions were viewed offline in slow-motion (counting the number of jiggles was impossible in real-time) and 'number of jiggles' seen on every trial (habituation and test) was recorded for each infant in Experiments 1 and 3. Although the 'number of jiggles' did tend to co-vary with duration for most infants (i.e. babies generally saw about twice as many jiggles in the longer duration events than the shorter duration events), subsequent analyses determined that infants' preference for either the novel or familiar duration at test was not related to 'number of jiggles'. We tested this by first calculating two difference scores: (1) average no. of jiggles in habituation – average no. of jiggles in novel test trials, and (2) average no. of jiggles in habituation – average no. of jiggles in familiar test trials. After taking the absolute value of these difference scores, we subtracted the second from the first and took the absolute value of the result. We termed this score the Jiggle Difference and it essentially reflected the difference between the number of jiggles seen on novel and familiar test trials after taking into account how many jiggles infants saw on average during habituation. We also calculated infants' Mean LT Difference scores by subtracting their average looking time on familiar trials from their average looking time on novel trials. Finally, we correlated the Jiggle Difference score with the Mean LT Difference scores, separately for Experiments 1 and 3, to test whether the number of jiggles infants saw was related to their preference for the novel or familiar event at test. Neither correlation was significant ($r = .10$, Experiment 1; $r = .26$, Experiment 3), indicating that 'number of jiggles' could not have been driving infants' preference for the Novel event in either experiment. Note also that 'rate of jiggles' was roughly equal throughout habituation and across both types of test events, suggesting that 'rate of jiggles' was not likely a viable cue for discrimination.

the sum of the infant's looking time on the first three trials; or (b) the infant completed 14 trials without meeting criterion (a).

Test phase

Infants then received six test trials, following the same procedure as habituation trials, in which they were alternately presented with 2-s events and 4-s events, in counterbalanced order.

Results and discussion

Infants looked significantly longer at the puppet following the novel duration event. A 2 (Sex) by 2 (Order) by 2 (Habituation Condition) by 2 (Test Trial Kind) repeated measures ANOVA on infants' mean looking times at test found a significant interaction between Habituation Condition and Test Trial Kind ($F[1, 8] = 5.894$, $p < .05$).[2] Infants habituated to a 2-s event looked longer on test trials with a 4-s event ($M = 4.3$ s, SD = 3.3) than on test trials with a 2-s event ($M = 3.3$ s, SD = 1.8). Infants habituated to a 4-s event looked longer on test trials with a 2-s event ($M = 3.6$ s, SD = 4.0) than on test trials with a 4-s event ($M = 2.6$ s, SD = 1.4) (see Figure 2). Four infants (two in each habituation group) failed to meet the habituation criterion; the same pattern of looking times during the test trials obtained when they were removed from the analysis. A paired t-test comparing the remaining infants' average looking on the last three habituation trials with their average looking on the novel duration test events was marginally significant, $t(11) = 1.67$, $p = .06$, one-tailed,[3] indicating that infants dishabituated to the novel duration events at test.

These results indicate that, by the age of 6 months, infants have a means of representing duration, and they can discriminate durations of audiovisual events that differ by a ratio of 1:2, at least for durations within the 2- to 5-second range. In our next experiment, we ask if infants can discriminate durations differing by a smaller ratio within the same approximate duration range.

[2] The only other significant effect was a 4-way Sex by Order by Habituation Condition by Test Trial Kind interaction, $F(1, 8) = 12.038$, $p < .01$. Males habituated to the 4-s events in the 4, 2 trial Order group, females habituated to the 2-s event in the 4, 2 Order group, and females habituated to the 4-s event in the 2, 4 Order group looked longer on test trials with the 2-s event, while other groups looked longer on test trials with the 4-s event. As there are on average only two subjects per Sex by Condition by Order by Test Trial Kind cell, this interaction is likely spurious.

[3] Since the goal of this analysis was to examine the degree of dishabituation to the Novel test event, infants who failed to habituate were not included in the comparison in this or any other experiment.

Experiment 2

In this experiment, we asked infants to discriminate durations differing by a 2:3 ratio. Previous research indicates that infants of this age fail to discriminate numbers differing by this same ratio (Lipton & Spelke, 2003; vanMarle & Wynn, 2006; Xu, 2003; Xu & Spelke, 2000; Xu *et al.*, 2005). We hypothesized that if the same mechanism underlies infants' ability to discriminate both time and number, then they should fail to discriminate the durations in this experiment.

Subjects

Subjects were 20 healthy, full-term infants (seven females) with a mean age of 6 months 1 day (range 5;16 to 6;18). Seven additional infants were excluded due to fussiness (four), computer error (one) and disinterest (two). We tested more infants in this experiment than in Experiment 1 because we were predicting a null result and wanted to be confident that we were not simply failing to detect a small effect.

Apparatus, stimuli and procedure

Apparatus and procedure were as described in Experiment 1. Stimuli were identical in all respects except that the events were either 3 s or 4.5 s in duration. Following habituation to either the 3 s or the 4.5 s events, infants received six test trials in which the 3-s and 4.5-s events were alternately presented. Inter-observer reliability was calculated for a randomly selected subset of the participants (five infants), and again was very high ($r = .99$).

Results and discussion

Infants did not discriminate the habituated and novel durations. A 2 (Sex) by 2 (Order) by 2 (Habituation Condition) by 2 (Test Trial Kind) repeated measures ANOVA on infants' mean test looking times found no significant effects or interactions. Infants habituated to a 3-s event looked equally on test trials with a 3-s event ($M = 3.1$ s, SD = 1.2) and on test trials with a 4.5-s event ($M = 3.7$ s, SD = 1.6). Infants habituated to a 4.5-s event looked equally on test trials with a 3-s event ($M = 3.5$ s, SD = 2.3) and on test trials with a 4.5-s event ($M = 3.7$ s, SD = 2.2) (see Figure 3). Six infants (two in the 3-s habituation group) failed to meet the habituation criterion; the same pattern of looking times during the test trials obtained when they were removed from the analysis. The remaining 14 infants did not show reliable dishabituation to the novel duration test events, $t(13) = .49$, $p = .32$, one-tailed.

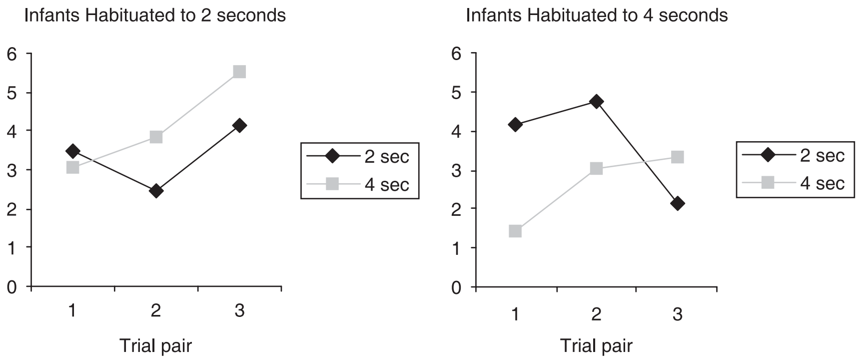

Figure 2 *Infants' mean looking times to the new and old duration in the test trials as a function of trial pair. The data for each habituation group are graphed separately and indicate that infants in both groups looked longer when presented with the novel duration compared to the habituated duration in test.*

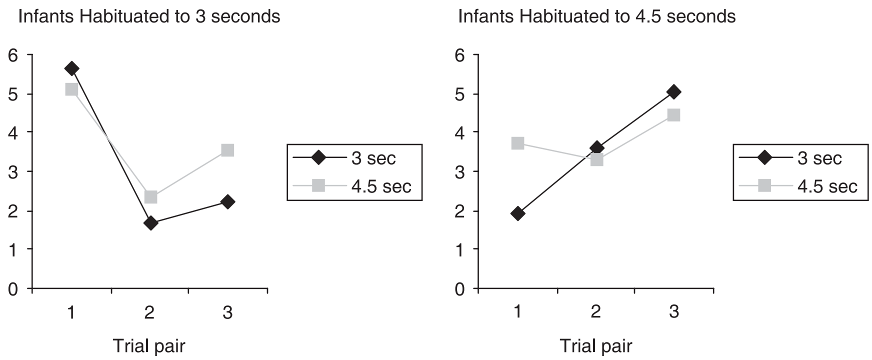

Figure 3 *Infants' mean looking times to the new and old duration in the test trials as a function of trial pair. In contrast to Experiment 1, infants here did not discriminate the novel from the habituated duration in test, regardless of habituation group.*

Results from the first two experiments show that, within the 2- to 5-second range, infants can discriminate durations differing by a ratio of 1:2, but not those differing by a ratio of 2:3. This discrimination function is similar to that shown to apply in infants' discrimination of number. However, to show that discrimination follows a true Weber's Law function, one must show that the same discrimination function applies for multiple values. Experiments 3 and 4 address this issue by asking whether 6-month-olds will show the same discrimination function – success when durations differ by a ratio of 1:2, failure when they differ by a ratio of 2:3 – for values close to one order of magnitude smaller, those within the 0.5- to 1-second range.

Experiment 3

Experiment 3 investigated infants' ability to discriminate short durations at a 1:2 ratio. Specifically, we asked if they could differentiate between events that were either 0.5 s or 1 s in duration.

Subjects

Subjects were 18 healthy, full-term infants (eight females) with a mean age of 6 months 2 days (range 5;16 to 6;12). Eight additional infants were excluded due to fussiness (seven) and disinterest (one).

Apparatus, stimuli and procedure

Apparatus and procedure were as described in Experiment 1. Stimuli were identical in all respects except that the events were either 0.5 s or 1 s in duration. Following habituation to either the 0.5-s or 1-s events, infants received six test trials alternating between the 0.5-s and 1-s events. Inter-observer reliability was calculated for a randomly selected subset of the participants (six infants), and again was very high ($r = .99$).

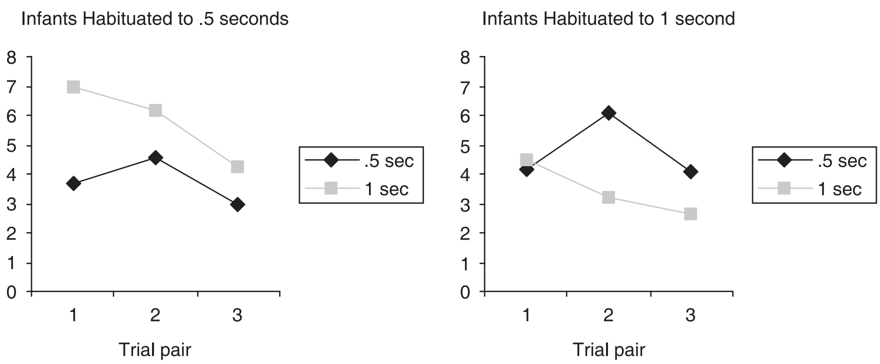

Figure 4 *Infants' mean looking times to the new and old duration in the test trials as a function of trial pair. As in Experiment 1, infants in both groups looked longer when presented with the novel duration compared to the habituated duration in test.*

Results

Infants looked significantly longer at the puppet following the novel duration. A 2 (Order) by 2 (Habituation Condition) by 2 (Test Trial Kind) repeated measures ANOVA on infants' mean test looking times revealed a significant interaction between Habituation Condition and Test Trial Kind ($F[1, 14] = 4.99$, $p < .05$). Infants habituated to a 0.5-s event looked longer on test trials with a 1-s event ($M = 5.7$ s, SD = 3.7) than on test trials with a 0.5-s event ($M = 3.8$ s, SD = 2.5). In contrast, infants habituated to a 1-s event looked longer on test trials with a 0.5-s event ($M = 4.8$ s, SD = 3.3) than on test trials with a 1-s event ($M = 3.5$ s, SD = 2.1) (see Figure 4). One infant (in the 0.5-s habituation group) failed to meet the habituation criterion; the same pattern of looking times during the test trials obtained when his data were removed from the analysis. The remaining 17 infants showed significant dishabituation to the novel duration test events, $t(16) = 2.6$, $p = .01$, one-tailed.

Experiment 4

Infants in Experiment 3 successfully discriminated short durations differing by a 1:2 ratio even though the absolute difference between them was very small. To provide clear evidence of a Weber discrimination function, it is necessary to show that infants fail to discriminate values in this same range when they differ by a 2:3 ratio. Experiment 4 addressed this by asking infants to discriminate between events that were either 0.67 s or 1 s in duration.

Subjects

Subjects were 20 healthy, full-term infants (10 females) with a mean age of 5 months 29 days (range 5;16 to 6;14). Ten additional infants were excluded due to fussiness (seven), computer error (one) and for exhibiting looking time preferences more than 2.0 SDs beyond the group mean (two). Again, since we were predicting a null result, we tested more infants in this experiment than in Experiment 3.

Apparatus, stimuli and procedure

Apparatus and procedure were as described in Experiment 1. Stimuli were identical in all respects except that the events were either 0.67 s or 1 s in duration. Following habituation to either the 0.67-s or 1-s events, infants received six test trials alternating between the 0.67-s and 1-s events. Inter-observer reliability was again calculated for a randomly selected subset of the participants (three infants), and again was very high ($r = .99$).

Results

Infants did not discriminate the habituated and novel events. A 2 (Order) by 2 (Habituation Condition) by 2 (Test Trial Kind) repeated measures ANOVA on infants' mean test looking times found no significant effects or interactions. Infants habituated to a 0.67-s event looked equally on test trials with a 0.67-s event ($M = 4.8$ s, SD = 5.2) and on test trials with a 1-s event ($M = 5.1$ s, SD = 4.2). Infants habituated to a 1-s event looked equally on test trials with a 0.67-s event ($M = 4.6$ s, SD = 2.1) and on test trials with a 1-s event ($M = 4.2$ s, SD = 1.9) (see Figure 5). Two infants (one in each habituation group) failed to meet the habituation criterion; removing their data did not affect the pattern of looking at test. The remaining 18 infants failed to dishabituate to the novel duration test events, $t(17) = .95$, $p = .18$, one-tailed.

Finally, an ANOVA on the data of all four experiments comparing mean looking time to novel and familiar durations for 1:2 ratios (Experiments 1 and 3) with those for 2:3 ratios (Experiments 2 and 4) found a marginally

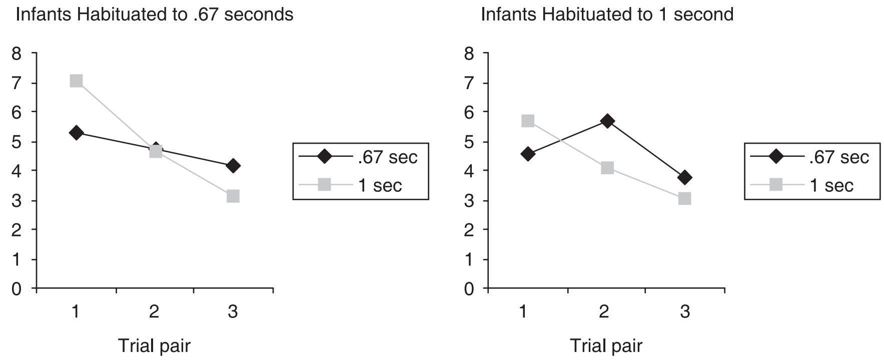

Figure 5 *Infants' mean looking times to the new and old duration in the test trials as a function of trial pair. In contrast to Experiments 1 and 3, infants here did not discriminate the novel from the habituated duration in test, regardless of habituation group.*

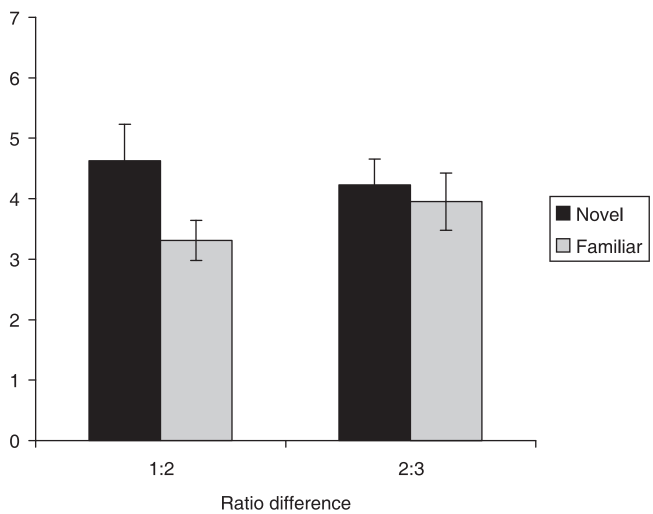

Figure 6 *Infants' mean looking times to the novel and familiar duration in the test trials as a function of Ratio. Infants discriminated events whose durations differed by a 1:2 ratio, but not a 2:3 ratio.*

significant Ratio by Trial Type interaction, $F(1, 72) = 3.224$, $p = .07$, such that infants looked longer following the novel duration events when they differed by a 1:2 ratio, but not a 2:3 ratio (see Figure 6). In addition, there was a significant main effect of Trial Type, $F(1, 72) = 13.01$, $p < .01$, such that infants overall looked reliably longer following the novel compared to the familiar test events.

General discussion

Time is one of the fundamental dimensions along which organisms interpret and understand reality. The ability to measure duration grants access to the temporal structure of experience, allowing for both the prediction of external events, and the gauging of one's own actions and internal cycles. While previous studies have investigated infants' sensitivity to related attributes, such as rhythm (e.g. Delany *et al.*, 1977; Trehub & Thorpe, 1989), none to our knowledge have directly investigated infants' ability to measure and compare durations of single events with arbitrary onsets and offsets (see Brannon *et al.*, 2004, for evidence that 10-month-old infants can discriminate inter-stimulus intervals that differ in duration). Our study constitutes a first step in investigating the nature and development of timing processes in infancy, providing a starting point from which to ask more specific questions about the extents and limits of infants' sensitivity to duration and for investigating how timing processes change and develop with age.

Our findings also contribute to another domain of inquiry: numerical cognition in infancy. If counting and timing in human infants, like nonhuman animals, are subserved by the same mechanism, then one would expect to find strong similarities between infants' counting and timing abilities. One example of such a mechanism is the accumulator model, which was originally developed to account for similarities in timing and counting processes in animals (Meck & Church, 1983). If the same type of mechanism underlies infants' numerical competence, then it follows that infants should be able to measure duration, and show similar discrimination functions for both duration and number.

Our experiments found that 6-month-old infants (a) successfully discriminated events based on their duration, and (b) discriminated durations with a 1:2 ratio, but not those with a 2:3 ratio. Moreover, infants' discrimination followed a Weber's Law function in that it was proportionate, not absolute, difference between values that determined discriminability. Infants of this age show precisely the same discrimination function for number – success with a 1:2 ratio and failure with a 2:3 ratio (Lipton

& Spelke, 2003; vanMarle & Wynn, 2006; Xu, 2003; Xu & Spelke, 2000; Xu *et al*., 2005). Our findings therefore lend support to the proposal that the same mechanism underlies both capacities in human infants.

One alternative explanation warrants discussion. Might the obtained discrimination function result from some more general property of infants' discrimination processes? That is, is this same pattern – success discriminating values differing by a 1:2 ratio, failure to discriminate values differing by a 2:3 ratio – observed in infants of this same age for other dimensions, such as length, loudness, weight or area? If so, this would undermine the argument that the similarity between infants' number and time discrimination results from a single mechanism dedicated to representing these two dimensions. Several findings argue against this alternative possibility. First, while 6.5-month-olds show surprise when a screen passes through the top 80% of the space where a box behind the screen had been seen to be located, they do not show surprise when the screen rotates through only the top 50% of the box, suggesting that they are unable to detect an apparent halving of the box's height (Baillargeon, 1991). Second, in experiments directly comparing 6-month-old infants' numerical discrimination with their ability to discriminate summed surface area, infants successfully discriminated numerical values with a 1:2 ratio, but failed to discriminate surface areas differing by this same ratio (Brannon, Abbott & Lutz, 2004). And finally, infants of 7 months successfully discriminated tempos differing by a 2:3 ratio (Pickens & Bahrick, 1995). All of these studies indicate that distinct discrimination functions obtain for distinct dimensions, lending significance to our finding that the same discrimination function holds for both time and number.

Our findings raise a number of interesting questions. First, developmental improvements have been documented in infants' ability to discriminate number. While 6-month-old infants fail to discriminate numbers differing by a 2:3 ratio, it has been shown that numbers differing by this ratio are discriminable by 9 months of age (Lipton & Spelke, 2003). If the same mechanism underlies counting and timing in infants, then we should find developmental improvements in infants' duration discrimination paralleling those found in their number discrimination. Specifically, we predict that 9-month-olds should succeed in our Experiments 2 and 4 – that is, that they should successfully discriminate durations differing by a 2:3 ratio.

Second, if human infants possess the same type of mechanism as nonhuman animals, then we should find additional similarities between infants' number and duration abilities. The present study found evidence of one similarity between infants' systems for measuring duration and number that has been found in nonhuman animals: the same discrimination function applies to both. As outlined earlier, several further similarities obtain between duration and number discrimination in nonhuman animals (Gallistel, 1990; Meck & Church, 1983). (a) Training transfers equally to novel stimuli. (b) Administration of methamphetamine causes rats to overestimate time and number to the same extent. (c) Transfer effects have been obtained between duration and number. While it will be challenging to translate some of these animal experiments into infant analogues (it would be unethical to give babies methamphetamine, for example), the predictions are clear: if it is appropriate to assume that the same mechanism subserves human infants' timing and numerical processes, further similarities should obtain. We believe that future research in these directions will further elucidate the nature of our cognitive foundations for time and number.

Acknowledgements

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