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Discrimination and ordinal judgments of temporal durations at 3 months

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ABSTRACT

This study presents the first evidence that 3-month-old infants success in a timing matching task and in an ordinal timing task, when numerical information is controlled. Three-month-old infants discriminated brief temporal durations that differed by a 1:3 ratio, relying solely on temporal information. Moreover, at 3 months of age infants were able to discriminate between monotonic and non-monotonic time-based series, when numerical and temporal information were inconsistent. These findings strengthen the hypothesis that a magnitude representational system for temporal quantities is operating very early in the ontogenetic development.

Representing time allows organizing and understanding reality. Therefore, it is an essential competency for many aspects of behavior, and it is critically linked to survival. Many studies suggested that temporal processing might be unlearned, automatic, highly flexible, and independent of verbal representations (e.g., Malapani & Fairhurst, 2002; Meck & Church, 1983; Wearden, 1999).

In his pioneering experiments on the development of the concept of duration, Piaget (1937, 1946) showed that children cannot correctly estimate time before the age of 8 years, when they acquire the proper mental operations. Later on, researchers have reported an ability to make temporal judgments at an earlier age (e.g., Droit-Volet, 1998; Droit-Volet, Clément, & Fayol, 2003; Levin, 1992). These studies have demonstrated that children are able to estimate time by 3 years, and that by 5 years of age they possess adult-like representation of absolute time elapses that are independent of events (e.g., Droit-Volet, 1998). However, when in a sequence of stimuli both time and number co-varied, children between 5 and 8 years showed a higher sensitivity for number than for time (Droit-Volet et al., 2003). In this study, children were tested with a bisection task: they were instructed both to process the duration of a sequence while ignoring the number of stimuli (temporal bisection), and to process the number of stimuli while ignoring the duration (numerical bisection). Results revealed that number interferes with temporal discrimination more than time does with numerical discrimination, suggesting that number is more salient than time to children between 5 and 8 (Droit-Volet et al., 2003).

Nevertheless, it is important to notice, that by 2 years of age children start learning and producing number words and counting (Fuson, 1988, 1992). Consequently, language acquisition of number words might explain the interference between time and number estimations obtained in childhood.

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A possible way to overcome this problem is to explore temporal processing in preverbal ages, taking into account that the interference between time and number estimations obtained in childhood is not comparable with quantification processes in preverbal ages. The present study investigates the ability to process temporal information in very early infancy. To this aim, we tested whether temporal discrimination (Experiment 1) as well as temporal ordinal judgments (Experiment 2) are functional at 3 months.

1. Discrimination of temporal durations

Temporal discrimination competences in adults, children and non-human animals are similar in many ways. For example, both in monkeys and in humans, temporal discrimination obeys Weber's law, meaning that it depends on the ratio between two values not on their absolute difference. More specifically, timing behavior shows scalar variability both in human and non-human animals (e.g., Dale, Grafton, & Gibbon, 2001; Gallistel & Gelman, 1992; Gelman & Gallistel, 1978; Gibbon, Church, & Meck, 1984; Melgire et al., 2005; Wearden & Bray, 2001). However, while the nature of timing competences in animals and human adults is relatively well understood, their ontogenetic development is still unclear.

Very few studies have addressed temporal representations in preverbal human infants, showing that at 6 months of age temporal discrimination competences are functional as well (Brannon, Suanda, & Libertus, 2007; vanMarle & Wynn, 2006). In addition, data confirmed that timing abilities are ratio dependent, which is consistent with the idea that temporal representations follow a Weber's law. Using a visual habituation procedure, vanMarle and Wynn (2006) studied 6-month-old infants' discrimination of temporal durations and whether their discrimination function was characterized by Weber's Law. In that study, infants were habituated to a puppet of "Sylvester the Cat" that danced and emitted a tone for a given duration and were then tested with the same puppet dancing and sounding for the habituated duration or a novel duration. They found that 6-month-olds successfully discriminated events based on their duration and discriminate durations with a 1:2 ratio but not those with a 2:3 ratio. Brannon et al. (2007) have recently extended these findings investigating the increasing precision in temporal discriminations between 6 and 10 months of age. In their study, at 6 months infants required a 1:2 ratio in duration for successful discrimination, however, by 10 months of age infants were able to discriminate between intervals that differed by a 2:3 ratio.

In order to directly study neural activity underlying preverbal infants' temporal processing, some electrophysiological studies were conducted with infants within the first year of life. Brannon tested adults' and 10-month-old infants' timing competencies in an auditory oddball paradigm, measuring the scalp-recorded event-related electrical brain potentials (ERPs). The results demonstrated that by 10 months of age infants are able to discriminate temporal durations and that, like adults, they are differentially sensitive to durations that differ by a 1:4, 1:3, 1:2 and 2:3 (Brannon, Roussel, Meck, & Woldorff, 2004; Brannon, Libertus, Meck, & Woldorff, 2008). These data showed that 10-month-old infants obey the scalar property found in time perception in adults, children, and nonhuman animals, which is that discrimination of durations follows a Weber's law function in that the proportionate, not absolute, difference between values determines discriminability.

Altogether, evidence converges with theoretical proposals that, at least by 6 months of age, temporal durations are processed and represented by a system that yields representations that exhibit a scalar variability, obeying Weber's law (e.g., Meck & Church, 1983; Gallistel, 1990; Walsh, 2003). These results fit well with the mode-control model which maintains the existence of an inborn and biologically determined predisposition to elaborate temporal information (e.g., Gallistel, 1990; Meck & Church, 1983). The mode-control model was initially proposed by Meck and Church (1983) to account for animals' numerical competencies, and successively Gallistel and Gelman (1992) adapted it to include evidence on pre-verbal human infants' numerical abilities.

In line with these models (e.g., Meck & Church, 1983, 1984), Experiment 1 of the present study was aimed to verify whether infants show the ability to discriminate temporal durations even before 6 months of age. Crucially, previous studies have demonstrated a ratio-dependent developmental trajectory showing that 10-month-olds required a 2:3 ratio for discriminating durations, whereas 6-month-olds required a 1:2 ratio (Brannon et al., 2007; vanMarle & Wynn, 2006). Following this developmental course, it is expected that 3-month-olds required at least 1:3 ratio to succeed in discriminating temporal intervals.

2. Experiment 1

Using a visual familiarization technique (e.g., Quinn, 1994, 2004; Quinn, Adams, Kennedy, Shettler, & Wasnik, 2003; Quinn, Cummins, Kase, Martin, & Weissman, 1996), infants were assigned to two duration conditions (i.e., short and long duration), and familiarized with three different videos each showing three different puppets moving and dancing at the same time for a fixed temporal interval. In specific, in the short movie the puppets danced for 1.6 s and stayed still for 5 s, and vice versa in the long movie. Consequently, both the dancing intervals and the still intervals presented a 1:3 ratio between the long and short conditions. Then, infants were tested with two novel videos, one presenting the familiar duration (e.g., 1.6 s) and the other presenting a novel duration (e.g., 5 s). It was predicted that, as a result of familiarization, infants would recognize the familiar temporal interval, preferring to look longer the movie with a novel duration.

Fig. 1. The two frames used to create the apparent motion of Winnie puppet.

2.1. Method

2.1.1. Participants

Twenty-four 3-month-old infants (mean age = 92.62 days, *SD* = 4.53) were recruited. They were middle-class infants and 98% of them were Caucasian and 2% African. Four infants were excluded from the final sample, 2 for fussiness and 2 for technical problems. Thus, the final sample consisted of 20 infants (9 females, 11 males), randomly assigned to two different experimental conditions: long temporal duration ($n = 10$) and short temporal duration ($n = 10$). Infants were tested only if awake and in an alert state, after the parents gave their informed consent.

2.1.2. Stimuli

Using the software Adobe Flash CS3 Professional, eight digital videos were created. Each video showed a black background (40 cm high × 64 cm width; about 38° × 61°) in which appeared three identical puppets centered on the central row and each was far from the next one of 10 cm (9.5°). All the puppets were from Winnie the Pooh movie: they were Winnie, Tiger, Piglet and Rabbit. Each puppet was 10.6 cm high (about 10.1°) and a mean of 6.1 cm width (5.8°).

Duration of motion: All the three puppets danced, starting and stopping at the same time. The motion was obtained alternating a figure of one puppet with the mirror image of the same figure, so to obtain the perception of a puppet that "jumps" (Fig. 1). Two kinds of videos were created each lasted 8.6 s. In one of the videos the three puppets moved for 1.6 s and they still for 5 s (Short-Motion Duration condition; S-MD condition), in the other video the three puppets moved for 5 s and still for 1.6 s (Long-Motion Duration condition; L-MD condition) (Fig. 2).

Velocity of motion: To ensure that numerical variables did not provide any cue to the temporal discrimination, number of jumps made by the three puppets was controlled handling the velocity of jumping (=number of jumps/time). See Section 2.1.4 for more details.

At the beginning of each video a 1 s white screen and a 1 s black screen were presented. Each video was presented repeatedly and a black (1 s) and a white (1 s) screen marked the beginning of each cycle. In addition, at the onset of each cycle a different brief sound was played for triggering baby's attention to the display.

2.1.3. Apparatus

Infants were seated in a highchair 60 cm from a computer monitor resting on a stage surrounded by blue fabric. Parents were seated next to their infants and instructed to keep their eyes closed and to refrain from talking to, touching, or otherwise interacting with their infant for the duration of the experiment. A micro camera monitoring the infant's face and a video feed directly from the stimuli presentation computer were multiplexed onto a TV monitor and VCR. One experienced experimenter blind to the experimental condition recorded the infants' looking behavior while viewing the live video with the display occluded. Looking behavior was recorded by holding a button down when the infant was looking at the computer monitor and letting go when the infant looked away.

Familiar stimuli	Duration	1.6 s	1.6 s	1.6 s
	Jumps	3	5	2
	Duration	5 s	5 s	5 s
	Jumps	9	15	5
Test stimuli	Duration	5 s	5 s	5 s
	Jumps	6	6	6
	Duration	1.6 s	1.6 s	1.6 s
	Jumps	4	4	4

Fig. 2. Schematic representation of the characteristics of the stimuli presented for testing 3-month-old infants in a temporal ordinal task in Experiment 1.

2.1.4. Procedure

The infant was seated on a highchair in front of a computer monitor, on which a brief Walt Disney cartoon was projected, to attract the baby's attention to the computer screen and to make her/him at ease. The total duration of the cartoon was 41 s, but the experimenter could stop it as soon as the baby was judged ready to start the test.

Thereafter, an additional video was created, showing a zooming windmill centered on a black background as central fixation point. The zooming windmill was used to attract the infant's gaze at the start of each trial. As soon as the infant fixated the windmill-attractor the familiarization phase began. The familiarization phase implied 3 trials (Quinn, 2004), each of which terminated as soon as the infants accumulated 15 s of fixation time (e.g., Quinn, 2004). Babies that did not reach the 15-s time criterion in one or more than one of the familiarization trials were not included in the final sample. In the present experiment, all the babies reached the 15-s time criterion and none infants were excluded based on this criterion. One experienced experimenter blind to the experimental condition recorded the infants' looking behavior. As soon as the 15 s of fixation criteria was reached, the stimulus was automatically turned off and the windmill-attractors were turned on and the subsequent trial began (Fig. 3).

Whereas the duration of the overall motion was held constant among the three familiarization trials, each familiarization trial differed by the others for two aspects: (1) the identity of the puppets and (2) the velocity of their motion and consequently the number of jumps made by the puppets (Fig. 2). The three puppets in each trial of the familiarization phase made a different number of jumps but in the same temporal duration.[2] Consequently, the temporal duration of puppets' dance (1.6 s in the short duration condition, and 5 s in the long duration condition) was the only property held constant among the three familiarization trials.

Moreover the position of the fastest jumping stimulus was held constant in the center of the series; while the order of the medium and lowest jumping stimuli varied across the trials. Insofar, the only variables constant throughout the familiarization were the ratio between the velocities of jumping and the duration of the motion of the puppets.

At the end of the familiarization trials, a preference test phase started. Each infant was given four test trials, in which they were alternately presented with videos displaying 5 s jumping and 1.6 s jumping, in counterbalanced order (Fig. 2). The test stimuli presentation lasted until each stimulus had been fixated at least once, and a total of 10 s of looking had been accumulated. Each trial ended after 30 s if the 10-s criterion was not reached (see Quinn, 2004).

In the test stimuli in order to avoid that babies used velocity information to recognize short vs. long motion stimulus the velocity was held constant in the series presenting the same number of jumps: the 1.6 s-series jumped 4 times and the 5 s-series jumped 6 times (Fig. 2). Insofar, the only quantity information that infants could use to recognize the familiarized series was the duration of the jumping motion.

A second coder unaware of the stimuli presented subsequently analyzed videotapes of eye movements throughout the trials frame by frame. Inter-coder agreement was 1.00 (Cohen Kappa) for the number of orienting responses toward the stimuli and 0.92 (Pearson correlation) for total fixation time.

[2] The fastest jumping was a jump every 0.32 s. That is 5 jumps in the S-MD condition and 15 jumps in the L-MD condition. The slowest jumping was a jump every 0.9 s.; that is 2 jumps in S-MD condition and 5 jumps in S-MD condition. Then, by a 1.5-fold change the medium velocity of jumping was a jump every 0.5 s. That is 3 jumps in the S-MD stimulus and 9 jumps in the L-MD condition.

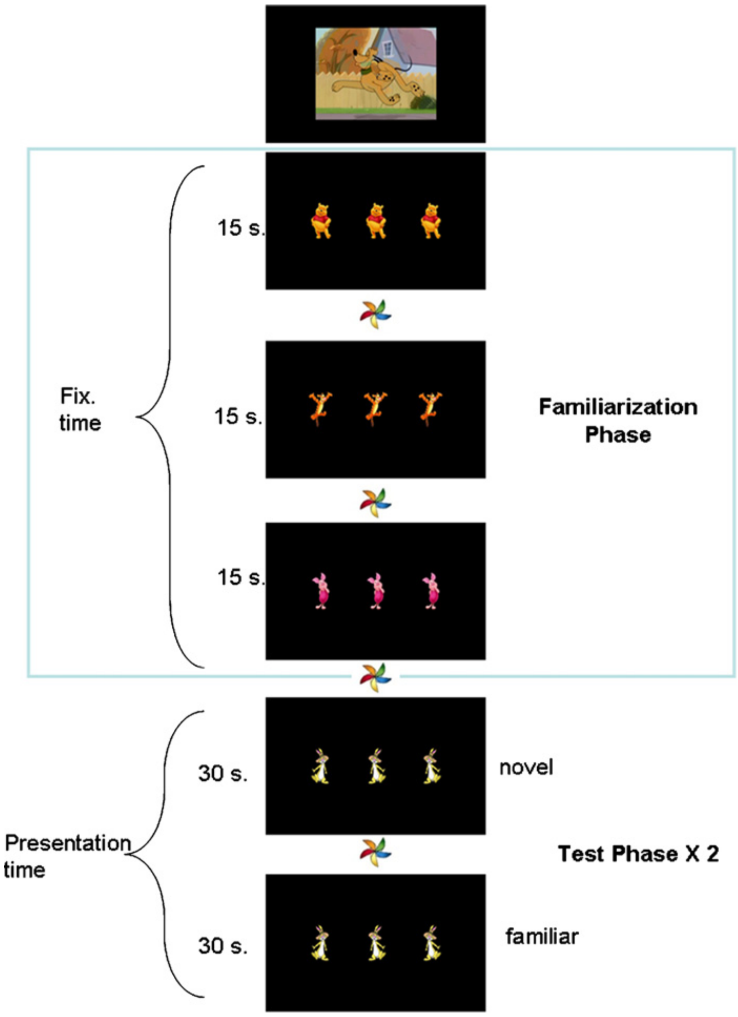

Fig. 3. Schematic representation of the stimuli and the procedure employed in the Experiments.

2.2. Results

A Kolmogorov–Smirnov test confirmed the normal distribution of the data ($z = 1.117$; $p = 0.165$, 2-tailed), allowing the employment of parametric analysis.

A preliminary repeated-measures 2 × 2 × 2 ANOVA was run on infants' total looking times in test, with Familiarization condition (long vs. short) and Test trial order (novel first vs. familiar first) as between-subjects factors and Test Stimulus (Novel vs. Familiar) as the within-subject factor. There was a main effect for Stimuli ($F(1,16) = 22.503$, $p < 0.001$). Infants looked to the stimulus with a novel temporal duration for a mean total fixation time of 39.81 s ($SD = 4.896$). The stimulus with the familiar temporal duration was fixated for a mean total fixation time of 30.57 s ($SD = 5.944$) (Fig. 4). There were neither main effects nor interactions involving the factors Familiarization condition and Test trial. Therefore, data were collapsed across these factors in the following analyses.

Mean total looking times in test were transformed in preference scores (percentage), by dividing each infant's total looking time at the stimulus with the novel temporal duration by the total looking time at both the novel and familiar stimuli, and subsequently converted into a percentage score. Hence, only scores significantly above 50% indicated a preference for the stimulus with the novel temporal interval. To determine whether the preference score for the novel stimulus was significantly different from the chance level of 50%, a one-sample t-test was applied. Preference scores for the stimulus with the novel temporal interval was significantly above chance ($M = 56.72\%$, $SD = 6.27$), $t(19) = 40.468$, $p < 0.001$, 2-tailed.

Finally, a binomial test revealed that a greater number of infants looked longer at the novel duration stimulus compared to the familiar duration stimulus (18/20; binomial test, $p = 0.5$, $p < 0.001$) (Fig. 4).

Overall, evidence showed that, by the age of 3 months, infants are able to represent temporal duration, and they can discriminate durations of events that differ at least by a 1:3 ratio. In the present experiment, number of jumps did not covary with temporal durations and did not hold a constant ratio change between durations within a series.

However, the novel test trials always involved a novel number of jumps that is outside of the range of numerical values shown in familiarization. That is, in short-duration condition infants were familiarized to 2, 3 and 5 jumps and the novel

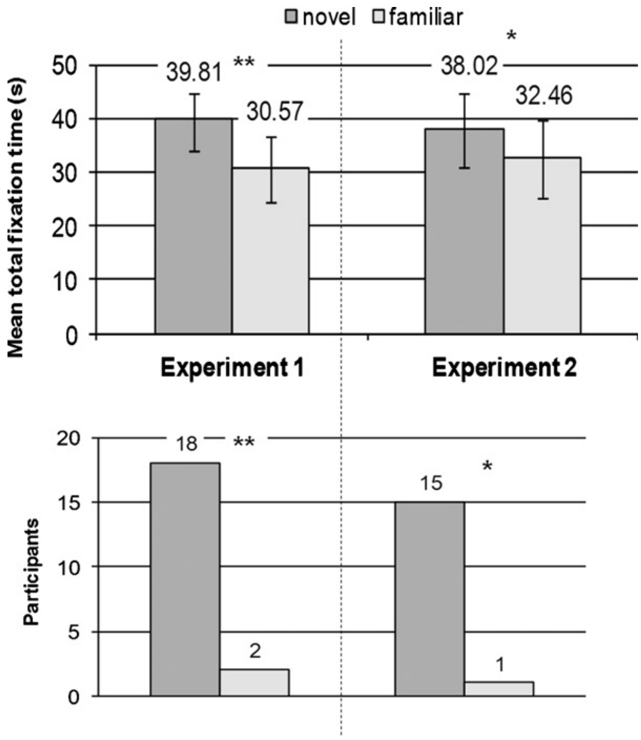

Fig. 4. (Top) Mean looking time to the novel and familiar test trials in Experiment 1 (left) and in Experiment 2 (right). Error bars indicate standard deviation (**$p < 0.001$; *$p = 0.001$). (Bottom) Participants' distribution in Experiment 1 (left) and in Experiment 2 (right). Error bars indicate standard deviation (**$p < 0.0001$; *$p = 0.001$).

stimulus presented 6 jumps; as well in the long-duration condition, infants were familiarized to 5, 9 and 15 jumps and the novel stimulus presented 4 jumps. Therefore, an alternative explanation of the results of Experiment 1 is that infants responded to the novel numerical values and not to the novel temporal duration. Nevertheless, in both the conditions the novel stimulus presented a number of jumps that differed only for 1 jump by the range presented in familiarization: 5 vs. 6 jumps in the short-duration condition and 5 vs. 4 jumps in the long-duration condition. It is unlikely that 3-month-old infants were able to discriminate a 1.2-ratio change between large numerosities, given that evidence demonstrated that they need at least a 1:2 ratio to succeed at 6 months and a 1:3 ratio at 3 days (e.g., Izard, Sann, Spelke & Streri, 2009; Xu & Spelke, 2000). It is more likely that infants perceived the novel number of jumps in the novel stimuli and the number of jumps presented by one puppet in familiarization as identical. Therefore, we retained that infants' ability to discriminate the temporal intervals can be based solely on temporal information, not on number of jumps.

3. Ordinal judgments of temporal duration

Beside the mode-control model (Meck & Church, 1983, 1984), it has been more recently proposed another model (A Theory Of Magnitude; ATOM—Walsh, 2003). Starting from neuropsychological evidence, the theory of magnitude (ATOM) claims that some commonalities between time, space, number and other magnitudes involve the parietal cortex and originate from a single developmental algorithm for *more than* and *less than* distinctions of any kind of stuff in the external world. More simply, this model suggests the existence of an analog approximate representation of quantities that applies to all magnitudes that can be experienced as "more than" or "less than": numerical quantity, space, and time. This Model is confirmed by recent evidence that 9-month-old infants are able to transfer bidirectionally a learning association across number, size and duration (Lourenco & Longo, 2010). This latter study shows that 9-month-olds transfer associative learning across magnitude dimensions. For example, if shown that larger objects were black and had stripes and that smaller objects were white and had dots, infants expected the same color-pattern mapping to hold for time. These results provide support for the existence of an early-developing and prelinguistic general magnitude system, whereby representations of magnitude information are abstracted from the specific dimensions.

In line with this model, an exhaustive study of time processing has to address others abilities in addition to discrimination competencies. An essential underlying basis of time processing is ordinal judgment, which refers to inherent *longer than* and *shorter than* relationship between temporal durations. The handful of studies that have directly addressed the development of ordinal knowledge in the first months of life suggest that infants are able to detect and elaborate *continuous* ordinal information (i.e., size of one element) at 9 months of age (e.g., Brannon, 2002; Suanda, Thompson, & Brannon, 2008), and *numerical* ordinal information at 7 months of age (e.g., Brannon, 2002; Picozzi, de Hevia, Girelli, & Macchi Cassia, 2010).

Familiar stimulus	Duration	1.6 s	5 s	15 s
	Jumps	3	10	20
Novel stimulus	Duration	1.6 s	15 s	5 s
	Jumps	3	20	10
	Duration	5 s	1.6 s	15 s
	Jumps	10	3	20

Fig. 5. Schematic representation of the characteristics of the stimuli presented for testing 3-month-old infants in a temporal ordinal task in Experiment 2, Ascending condition.

In regard to ordinal judgments of *continuous* quantities, 9-month-old infants were habituated to three-item sequences of continuous magnitudes (i.e., sizes) presented in ascending or descending order (Brannon, 2002). Following habituation, infants were tested with new continuous values where the ordinal relations were maintained or were reversed from the habituation. In other words, infants were required to recognize the familiar direction of the size-based ordinal sequence and discriminate it from a novel sequence in which the direction of ordinal relationships was inverted. Results highlighted that at 9 months of life infants are already able to detect the ordinal relationships between continuous magnitudes. A more recent study demonstrated that 9-month-old fail to abstract size or area information from a set of elements (Suanda et al., 2008). Therefore, it seems that, at this age, the ability to detect continuous ordinal relationships is limited to process continuous values of single objects, at least with size.

However, results from Experiment 1 of the present paper have shown that timing representation might occur even early than 9 months. In our study, at 3 months of age, infants were able to detect and to process temporal information: 3-month-olds succeeded in discriminating temporal durations that differed by a 1:3 ratio.

Moreover, recent studies that have indirectly investigated infants' temporal information appreciation suggest that from 3 to 4 months infants are sensitive to temporal structure in both the auditory and visual modalities, perceiving the order of 3-elements audiovisual sequences (e.g., Lewkowicz, 2000, 2008).

Starting from these studies the aim of Experiment 2 was to test whether 3-month-olds were able to recognize an ordinal series of temporal durations, differing each other according to a 1:3 ratio, when numerical variables are controlled.

4. Experiment 2

As in the previous experiment, a visual familiarization technique was employed (e.g., Quinn, 2004). Infants were randomly assigned to two familiarization conditions: *Ascending condition* and *Descending condition*. In the Ascending condition, infants were familiarized with monotonic ascending series of durations, whereas in the Descending condition infants were familiarized with monotonic descending series of durations.

In test phase infants were presented with a familiar monotonic series or with a novel non-monotonic series. It was expected that if infants are able to recognize the monotonic series, they would look longer at the non-monotonic series of durations.

4.1. Method

4.1.1. Participants

Eighteen 3-month-old infants (mean age = 88.5 days, *SD* = 5.02) were recruited. They were middle-class infants and 97% of them were Caucasian and 3% African. One infant was excluded because he did not reach 15 s-criterion in each trial of the familiarization phase and one for fussiness. Thus, the final sample consisted of 16 infants (7 females, 9 males).

Participants were randomly assigned to two different experimental conditions: ascending order ($n = 8$) and descending order ($n = 8$).

As in the previous experiment, infants were tested only if awake and in an alert state, after the parents gave their informed consent.

4.1.2. Stimuli

Twelve videos were created in the same way as the previous experiment, except for the temporal characteristics (Fig. 5). In each video three puppets were presented simultaneously and they started to move at the same time. Under the Ascending condition, the first puppet jumped for 1.6 s, the second puppet for 5 s and the third puppet for 15 s (from left to right). Vice versa under the Descending condition the first puppet jumped for 15 s, the second puppet for 5 s and the third puppet for 1.6 s (from left to right). In both the conditions the temporal durations differed by a 1:3 ratio within a video. In order to control number information, puppets within each sequence jumped with different velocity and therefore made a different number of jumps. Specifically, the number of jumps within each sequence varied across puppets by a non-constant ratio. The 1.6 s puppets jumped 3 times, the 5 s puppets for 10 times and the 15 s puppets for 20 times. Therefore, the 1:3 ratio was held constant only for duration, while it was disrupted for the number of jumps (Fig. 5).

Other four videos were created in which a non-monotonic series appeared showing the three durations in a random order from left to right. They were used as novel stimuli in test phase. Each video was presented repeatedly and at its beginning a 1 s white screen and a 1 s black screen were presented marking the beginning of each series. As in Experiment 1, at the onset of each cycle a different brief sound was played.

4.1.3. Apparatus

The apparatus was the same used in Experiment 1.

4.1.4. Procedure

As in the previous experiment after the projection of the Walt Disney cartoon and of the windmill-attractor, the familiarization phase began. Familiarization phase implied 3 trials. The three trials were similar for the duration of motion and the velocity of each puppet, but differed for the identity of the three puppets.

Infants were randomly assigned to two familiarization conditions: *Ascending condition* and *Descending condition*. In the Ascending condition, infants were familiarized with monotonic ascending series of durations, whereas in the Descending condition infants were familiarized with monotonic descending series of durations. In both conditions a total fixation time criteria of 15-s for each familiarization trial was employed (e.g., Quinn, 2004).

At the end of the familiarization trials, the preference test phase started. Each infant was presented with the ascending/descending familiar monotonic series and with a novel non-monotonic series (Fig. 5). To avoid the possibility that infants based their novelty response on the basis of the position of the puppet that stopped jumping for first (shorter-duration jump) or for last (longer-duration jump), half of the babies were presented the novel non-monotonic series that showed the longest duration in the familiar position (ascending: medium–shortest–longest; descending: longest–shortest–medium) and the other half were presented with the novel non-monotonic series that showed the shortest duration in the familiar position (ascending: shortest–longest–medium; descending: medium–longest–shortest) (Fig. 5). The order of presentation of novel stimuli and familiar stimuli were counterbalanced between subjects. The test stimuli presentation lasted until each stimulus had been fixated at least once and a total of the 10 s looking had been accumulated, or until 30 s had elapsed (e.g., Quinn, 2004).

A second coder unaware of the stimuli presented subsequently analyzed videotapes of eye movements throughout the trials frame by frame. Inter-coder agreement was 1.00 (Cohen Kappa) for the number of orienting responses toward the stimuli and 0.97 (Pearson correlation) for total fixation time.

4.2. Results

As in the previous experiment, a Kolmogorov–Smirnov test was run to test the normal distribution of the data. The analysis was not significant ($z = 0.641$; $p = 0.806$, 2-tailed), allowing the employment of parametric analysis.

Again, a repeated measures $2 \times 2 \times 2 \times 2$ analysis of variance was run on infants' total looking times in test, with Familiarization condition (ascending vs. descending), Test stimuli order presentation conditions (novel stimulus presented for first vs. familiar stimulus presented for first), Novel stimulus kind (shortest stimulus' familiar position vs. longest stimulus' familiar position) as between-subjects factors and Test Stimulus (Novel vs. Familiar) as within-subjects factor. The analysis revealed a main effect of the within-subject factor Test Stimulus (F (1,12) = 29.797; $p = 0.001$). Infants looked to the novel trials for a mean of total fixation time of 38.02 s ($SD = 6.83$) and the familiar trials for a mean total fixation time of 32.46 s ($SD = 7.07$) (Fig. 4). There were no main effect or interactions involving the factors Familiarization conditions, Test stimuli order presentation conditions and Novel stimulus kind. Therefore, data were collapsed across these factors.

As in the previous experiment, mean total looking times in test were transformed in preference scores (percentage) and preference scores for the novel stimulus were significantly above chance ($M = 54.27\%$, $SD = 3.94$), t (15) = 4.324, $p = 0.001$, 2-tailed.

A binomial test revealed that a greater number of infants looked longer at the novel stimulus compared to the familiar stimulus (15/16; binomial test, $p = 0.5$, $p = 0.001$) (Fig. 4).

Overall, collected data demonstrated that 3-month-old infants were able to recognize a monotonic series of temporal durations that differed by a 1:3 ratio when numerical variables are controlled. In the present experiment, the only constant variable that infants could abstract across the familiarization trials was the 1:3 increasing or decreasing ratio between temporal durations. Therefore, the results indicate that infants were able to detect and recognize the ordinal relations between temporal information in the familiar stimuli showing a novelty preference for the series in which the temporal ordinal relation was disrupted. In other words, infants showed the competency to learn a temporal sequence arranged in accordance to ordinal principles.

One could claim that infants based their response to the novel on the number of jumps instead of temporal information. However, if it was the case, they should abstract from each trial two different ratios (i.e., 3 vs. 10-ratio 1:3.34 and 10 vs. 20 ratio 1:2) as constant. Obviously, this process is much more demanding than the abstraction of one ratio between temporal information. In line with the general hypothesis of an economical rule in the cognitive development (e.g., Hebb, 1949), in our view it is more plausible to posit that 3-month-old infants recognized monotonic series on the basis of temporal information than on numerical information. Future research could explore this specific issue.

A second alternative interpretation of the current findings could be that infants represented the duration of the jumps of one single puppet within each sequence, and based their discriminative response on the change in the duration of the jumps of the puppet located in the familiar position within the novel sequence. In particular, infants may have focused on the shortest and/or the longest jump durations, which were, respectively, the first and the last to stop, and based their discrimination on the position of the puppet that stopped first or that still moved when the other puppets were still. The results of the ANOVA with Novel stimulus kind (shortest stimulus' familiar position vs. longest stimulus' familiar position) as between-subjects factor discarded this alternative interpretation: no main effect or interactions involving the factor Novel stimulus kind were revealed.

Altogether the results of Experiment 2 suggest that infants are able to process and represent ordinal relationships between temporal durations, at least when duration variations follow a 1:3 ratio.

5. General conclusions

The present study shows that 3-month-old infants are able to discriminate brief temporal durations that differ by a 1:3 ratio, relying solely on temporal information (Experiment 1). Moreover, at 3 months of age infants are capable to discriminate between monotonic and non-monotonic series of temporal durations when numerical variables are controlled (Experiment 2).

These results confirm and extend the findings reported by Brannon et al. (2007) and vanMarle and Wynn (2006), according to which by the first year of life infants are able to discriminate brief temporal durations. The present study has demonstrated that these competencies are present even at 3 months of age, at least with durations that present a ratio of 1:3. Altogether these lines of evidence converge, supporting the mode-control model's (e.g., Meck & Church, 1983; Gallistel, 1990) and the ATOM model's (Walsh, 2003) indicating that a magnitude representational system for temporal quantities is operating early in the ontogenetic development (Lourenco & Longo, 2010).

A relevant difference between the present study and the previous researches concerns the nature of the stimuli. In the previous studies, infants were required to represent durations of a bimodal event. The event consisted of both a visual and an auditory component. For instance in Brannon et al. (2007), the puppet opened and closed the mouth synchronized with a "moo" sound. The present study is the first that have investigated whether 3-month-olds are able to determine the durations of events within the sole *visual modality*.

Another relevant result of this study is that 3-month-old infants are able to process series of temporal durations arranged in accordance with ordinal principles. These evidence, constituting the first step in investigating ordinal competencies in early infancy, strength the ATOM model's hypothesis of an ordinal process of temporal magnitudes present early in the ontogenetic development.

However, it is relevant to stress out that our results are constrained to peculiar aspects of the stimuli and the procedure here employed. For instance, in the current study only a three-fold change was used. In order to delineate a developmental trend of ordinal knowledge in the first 6 months of age, further studies are needed to test whether 3-month-old infants succeed in the task with smaller ratios (e.g., 1:2 ratio).

In spite of these dissimilarities with the previous researches, our results fit well with data in the literature and together with them suggest that temporal discrimination increases in precision between 3 and 10 months of age. Further studies should be conducted to ask more specific questions about the nature of infants' sensitivity to duration and to investigate ordinal representation of timing in infancy.

Our findings also contribute to understanding the development of magnitude's representation in infancy. In line with Walsh's model (2003), if the same mechanism underlies infants' magnitude processing, than infants should be able to show similar competencies with numerosities or other continuous quantities. Therefore, the presence of ordinal representations of other magnitude dimensions (e.g., luminance, volume, speed) at the same age might be hypothesized. Future research addressing ordinal and cardinal discrimination of different dimensions in young infants might critically disclose whether a general magnitude system is operating from the first months of life.

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