

Langus, A., Saksida, A., Braidà, D., Martucci, R., Sala, M., & Nespòr, M. (2015). Spontaneous object and movement representations in 4-month-old human infants and albino Swiss mice. *Cognition*, 137, 63-71.

Spontaneous object and movement representations in 4-month-old human infants and albino Swiss mice

Alan Langus¹, Amanda Saksida¹, Daniela Braidà², Roberta Martucci², Mariaelvina Sala^{2,3}, Marina Nespòr¹

Affiliations

1. Language, Cognition and Development Laboratory. SISSA – International School for Advanced Studies, Via Bonomea 265, 34136 Trieste, Italy.

2. Dipartimento di Biotecnologie Mediche e Medicina Traslazionale, Università degli Studi di Milano, Italy.

3. CNR, Institute of Neuroscience, Via Vanvitelli 32, Milan, Italy.

Correspondence and requests for materials should be addressed to Alan Langus (langus@sissa.it).

Word count: 5.490

Abstract

Can young infants decompose visual events into independent representations of objects and movements? Previous studies suggest that human infants may be born with the notion of objects but there is little evidence for movement representations during the first months of life. We devised a novel Rapid Visual Recognition Procedure to test whether the nervous system is innately disposed for the conceptual decomposition of visual events. We show that 4-month-old infants can spontaneously build object and movement representations and recognize these in partially matching test events. Also albino Swiss mice that were tested on a comparable procedure could spontaneously build detailed mental representations of moving objects. Our results dissociate the ability to conceptually decompose physical events into objects and spatio-temporal relations from various types of human and non-human specific experience, and suggest that the nervous system is genetically predisposed to anticipate the representation of objects and movements in both humans and non-human species.

Keywords: object/movement representations, development, visual representations, infants, mice

1. Introduction

In order to make sense of the world we have to understand the objects that inhabit it, and how they behave. There is considerable evidence that during the first months of life human infants perceive objects as bound physical entities that move as wholes on continuous paths and continue to exist even when they disappear from sight (Aguiar & Baillargeon, 1999; Leslie & Keeble, 1987; Spelke, 1990). Adherence to some of these principles is observed also in newborn human infants (Valenza et al., 2006), primates (Natale et al., 1986; Call, 2000; Santos, 2004; Hall-Haro et al., 2008) and chicks (Regolin & Vallortigara, 1995). In human infants the notion of objects does therefore not appear to require visual, physical or even human specific experience with actual objects to emerge (Spelke et al., 1992; Baillargeon, 2002). It has therefore been suggested that a concept of objects may form part of our innate cognitive repertoire (Carey, 2011).

Could young infants' conceptually decompose physical events into constituents that go beyond simple object representations? There is some evidence that during the first year of life infants are sensitive to the spatial arrangement of objects (e.g. depth, distance, containment and support) and how this changes over time (cf. Baillargeon, 2004). Motion in particular is interesting because in many situations, it signals to infants the presence of events better than space does (Kellman, Spelke & Short, 1986; Werker, Cohen, Lloyd, Casasola, & Stager, 1998): it determines whether objects are animate or inanimate, and may be the basis for understanding the causality of events (Golinkoff, Harding, Carlson-Luden, & Sexton, 1984; Kotovsky & Baillargeon, 2000; Mandler, 2004; Wang, Kaufman & Baillargeon, 2003). It has therefore been

suggested that – at least in theory – the concept of motion and space may also belong to the pre-linguistic conceptual primitives from which infants construct their understanding of how objects in the physical world relate to each other (Mandler, 2004; Jackendoff, 1983). However, there are several gaps in experimental evidence to support the idea that during the first months of life infants conceptually decompose physical events into object and movement representations.

Young infants are clearly sensitive to object motion. However, because movement is so central to young infants' perception of objects, it has primarily been used as a tool for studying object properties (see Baillargeon, 2004). Movement thus facilitates object perception during the first months of life (Kellman, Spelke & Short, 1986; Smith, Johnson & Spelke, 2003; Werker, Cohen, Lloyd, Casasola, & Stager, 1998): young infants fail to perceive objects both if these are stationary (Kellman & Spelke, 1983), and if the infants themselves are moving relatively to a stationary object (Kellman, Gleitman, & Spelke, 1987). This suggests that object movement, and not any motion in general, may be necessary for young infants to perceive objects. Young infants could thus primarily use the information about where an object is and how its location is changing over time for guiding attention to – and keeping track of – objects in the visual field (Leslie, Xu, Tremoulet, & Scholl, 1998). Evidence from young infants cannot therefore rule out the possibility that they may not conceptually decompose physical events into independent object and movement representations, but instead represent physical events holistically (Carey, 2011; Pulverman et al. 2006).

Conceptual decomposition of physical events has only been studied in older infants. For example, 14- to 17-month old infants familiarized with a motion event of a star moving in relation to a ball, can discriminate change in the star's path (e.g. over vs. under) and manner of movement (jumping vs. spinning) (Pulverman, Sootsman, Golinkoff, & Hirsh-Pasek, 2003), an ability that has also been observed in 7-month-old infants (Pulverman & Golinkoff, 2004). However, in these discrimination tasks infants could also simply recognize overall changes in the motion event without building independent representations of event parts. Borrowing an example from color perception, the color PURPLE is made of the basic colors RED and BLUE and the color GREEN of the basic colors YELLOW and BLUE. When humans see a change from PURPLE to GREEN they perceive a holistic change in the composite colors and are incapable of seeing a change in the basic color constituents RED to YELLOW. Similarly, young infants could thus detect an overall change in motion events without being aware of which constituent (e.g. object, motion path or manner) has changed (for a discussion see Pulverman et al. 2006). Because only 14- to 17-month olds have been shown to represent the manner and path of motion independently, it is not clear whether also younger infants perceive motion events as consisting of individual constituents. Furthermore, dissociating manner and path of motion does not directly answer the more fundamental question of whether infants also represent objects and movements independently.

These gaps in our knowledge about when young infants begin to see physical events as consisting of objects, movements and space make it difficult to determine how this ability emerges from the interplay of nature and nurture. For example, because evidence for object representations pre-dates movement representations by several

months, it may be suggested that infants are born with the notion of object, but that independent movement representations emerge later in cognitive development. In fact, several studies suggest that experience could facilitate infants' abilities to represent different aspects of physical events. Visual training with occlusion events can thus strengthen infants' understanding that objects continue to exist even when they move behind an occluder and help them to predict when the object should emerge from occlusion (Johnson, Amso, & Slemmer, 2003). In addition, also physical experience with objects can facilitate infants' ability to segregate objects (Needham, 2000) as well as to understand the goal of actions (Sommerville, Woodward & Needham, 2005). Finally, learning the names of objects can help infants to categorize them (Xu, 2002; Gliga, Volein, & Csibra, 2010). Young infants begin to grasp objects with agility around 5-months of age (von Hofsten, 1991; Carey, 2009), and they appear to know some common words from 6-months of age onwards (Bergelson, & Swingley, 2012) – a developmental timeframe which roughly coincides with the age at which they appear to discriminate changes in the path and manner of visual motion events (Pulverman & Golinkoff, 2004). It is therefore important to determine whether younger infants, who have not yet acquired such experience, are capable of spontaneously decomposing visual events into independent representations of objects and their spatio-temporal relations.

2. Experiment 1: Object / Movement Representations in 4-month-old Infants

In Experiment 1, we tested 4-month-old infants' ability to spontaneously decompose moving objects into independent object and movement representations. We devised a novel Rapid Visual Recognition (RVR) procedure that presents infants with a dual

choice task between a partially matching and a novel test event, measuring the recognition of spontaneous representations in multiple interleaved trials. Infants were thus presented in each trial with a brief familiarization event of a moving object immediately followed by two simultaneously presented test events. One of these test events contained either the familiarization object (Object recognition trials) or the familiarization movement (Movement recognition trials) paired with a novel counterpart (movement or object, respectively). The other test event contained both a novel object and a novel movement. Because infants are never presented with a test event that is identical to the familiarization event – i.e. both test events contain at least one novel object or movement – it becomes impossible for infants to simply track overall changes without having first represented the object and the movement independently. We thus reasoned that if infants represent movements and objects independently, they should recognize the familiar object/movement in the partially matching test event and consequently look longer to the test event that contained both a novel object and a novel movement.

2.1. Method

2.1.1. Participants

We tested 21 infants (14 boys, 7 girls, mean age 136 days, range 107 to 157). Five infants were rejected from the analysis because less than 50% of the total possible looking-time samples were collected during the experiment. The final analysis contains the looking-behavior of 16 infants. All infants had APGAR ≥ 8 and had no known visual or auditory problems.

2.1.2. Materials

The stimuli of Experiment 1 consisted of 8 abstract two-dimensional shapes controlled for color, texture, size and other low-level visual cues (e.g. curvature vs. linearity). We did not implement depth cues (e.g. three-dimensional objects) because previous research has shown that movement of two-dimensional shapes is sufficient to trigger object representations in young infants (cf. Spelke, 1982). An object could move in 1 of the 8 different directions separated by 45° angles (from the center outward), with different movements controlled for distance from the center of the frame and the speed with which the shape moved. This resulted in 64 different videos, each video consisting of 3 repetitions of the same moving object on a black background. To make sure that the objects only moved in 1 direction, once the object reached the maximum distance from the center it disappeared and reappeared in the center. The total length of the familiarization and test events was 2400 ms (frame size 600x600 px; frame rate 60 fps) (Figure 1).

2.1.3. Procedure

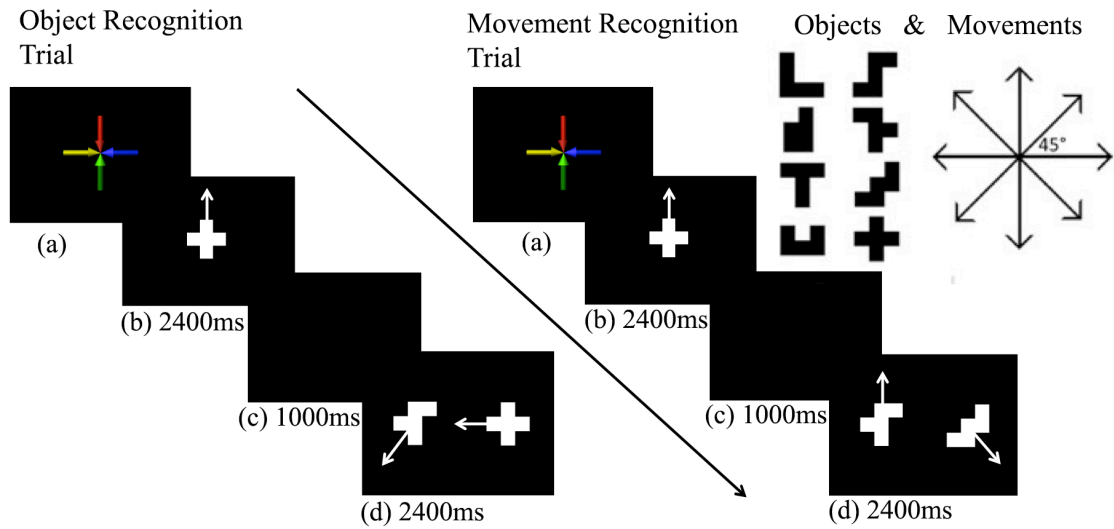


Fig. 1. Procedure and stimuli of Experiment 1.

The Rapid Visual Recognition (RVR) procedure is shown in Figure 1. Infants were presented with Object recognition (n=8) and Movement recognition (n=8) trials in random order. Each trial began with a familiarization video of a moving object (2400ms) presented centrally on the screen. The familiarization video was followed simultaneously by two test videos of two moving objects (2400ms). In the Object recognition trials one of the test videos contained the familiarization object moving in a new direction (familiar test event) and the other video contained a novel object moving in a new direction (novel test event). In the Movement recognition trials one of the test videos contained a novel object moving in the same direction as the object in the familiarization video (familiar test event), and the other test video contained a novel object with a novel movement (novel test event). The novel movements in the object recognition trials and the novel objects in the movement recognition trials were

different from each other. The sides of the familiar/novel test events were randomized across trials and the 64 different possible combinations of the 8 objects and 8 movements were equally balanced in 4 different lists across infants. The familiarization and test phases were separated by 1s long pauses. Trials were separated by central fixations and the experimenter initiated each trial when the infants' gaze was directed to the center of the screen. Infants' gaze was recorded with a TOBII T60 eye-tracker at a rate of 60 Hz. The eye-tracker was integrated into a 17-inch TFT screen. The stimuli were presented via PsyScope X software. Infants were seated on their parent's lap at about 50 cm distance from the monitor. Parents wore blocked glasses to avoid the eye-tracker collecting their gaze. This also ensured that the parents were unable to see the stimuli and influence the infant's performance. To determine whether infants' looking behavior to the two test videos in each trial differed, we delimited a region of interest that matched the size and the location of the videos on the screen (600x600 pixels for each video). Only the looks that fell within these regions of interests were counted in the measures of looking times for each of the two test videos. We measured the preference for the novel video compared to the familiar one by calculating infants' cumulative and longest fixations to each of the two test videos.

2.2. Results and Discussion

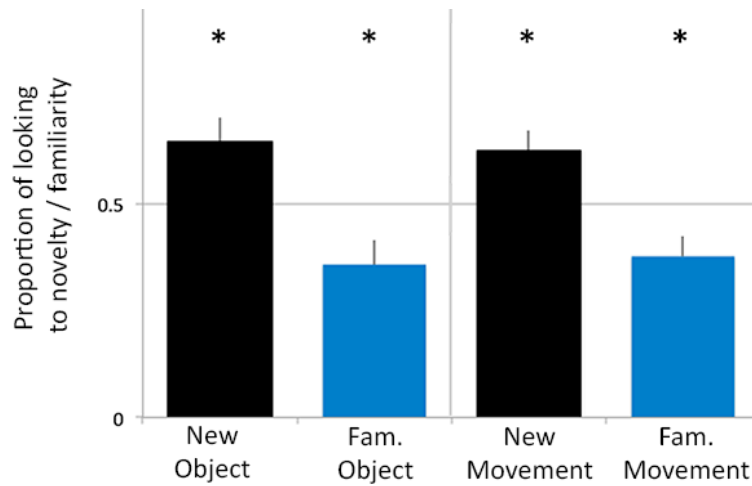


Fig. 2. Results of Experiment 1. For better comparison between experiments, cumulative looking-time to novel and familiar test events is converted into proportions of total looking-time spent looking at novel and familiar test events together. Error bars represent standard errors. (*) denotes significant differences in cumulative looking times between familiar and novel test events ($P < .05$).

The results are shown in Figure 2. We calculated the cumulative looking time infants spent looking at the novel and at the familiar test videos. A 2 x 2 Repeated Measures ANOVA with Condition (Object / Movement recognition trials) and Type of Test Event (Familiar / Novel) as within-subject factors revealed a main effect for the Type of Test Event ($F(1,15) = 9.864, P < .007$), no main effect for Condition ($F(1,15) = 3.947, P = .066$) nor an interaction between Condition and the Type of Test Event ($F(1,15) = .011, P < .998$). Pairwise comparisons of cumulative looking times to novel and to familiar test events showed that significant novelty preferences in cumulative looking-times prevailed in both object (2-tailed t -test: $t(15) = 2.145, P = .049$) as well as movement (2-tailed t -test: $t(15) = 2.300, P = .036$) recognition trials.

Additionally, we also calculated the longest looks that infants directed to novel and to familiar test events. A 2 x 2 Repeated Measures ANOVA with Condition (object recognition trials / movement recognition trials) and Type of Test Event (familiar / novel) as within subject factors revealed a main effect for the Type of Test Event ($F(1,15) = 8.857, P < .009$) no main effect for Condition ($F(1,15) = 4.134, P = .06$), nor an interaction between Condition and the Type of Test Event ($F(1,15) = .328, P = .575$). Pairwise comparisons of longest looking times to novel and to familiar test events showed that significant novelty preferences prevailed in both object (2-tailed t -test: $t(15) = 2.324, P = .035$) as well as movement (2-tailed t -test: $t(15) = 2.114, P < .049$) recognition trials. In order to determine whether infants' looking-behavior changed during the experiment we compared the cumulative looking times and longest looks to novel test items across trials. Infants' looking-behavior did not show significant increase or decrease during the course of the experiment (linear correlation between the elapsed trials and the cumulative looking time to novel items in each trial: $R^2 = .009, F(1,14) = .131, P = .723$; linear correlation between the elapsed trials and the longest look to novel items in each trial: $R^2 = .027, F(1,14) = .389, P = .543$). This suggests that infants' performance was not significantly increased through learning nor decreased due to inattentiveness during the experiment. An item based analysis of average looking time to each of the objects (one-way ANOVA: $F(7,120) = 1.606, P = .140$) and movements (one-way ANOVA: $F(7,120) = 2.125, P = .05$) with post-hoc multiple comparison using Bonferroni corrections (95% confidence level) showed no significant preferences for either individual objects or movements.

Because both test events were novel, containing at least either one new object or one new movement, these consistent novelty preferences for test videos that contained

both a novel movement and a novel object could only emerge if infants recognized the repeated familiarization objects and movements in the familiar test event.

Furthermore, because the object and the movement recognition trials were presented in an interleaved manner, infants could not have learned which element of the moving object will be repeated in any given trial nor anticipated what they had to pay attention to during the experiment. This suggests that infants spontaneously decomposed the familiarization events into independent object and movement representations. The fact that there were no quantitative differences in looking times across object and movement recognition trials shows that by 4-months of age, human infants are capable of representing objects as easily as their spatio-temporal relations.

The results of Experiment 1 also suggest that the RVR Procedure provides a more direct way of testing spontaneous representations in young infants than many other widely used looking-time paradigms. For example, habituation to visual stimuli can cause cognitive processing that is not necessarily spontaneous in nature. Switches between the novelty and the familiarity preference as a function of habituation length are one such example (Rose, Gottfried, Melloy-Carminar, & Bridger, 1982).

Additionally, repeated visual exposure may also lead infants to acquire concepts such as object continuity that under similar experimental conditions with shorter habituation remain elusive (Johnson, Amso, & Slemmer, 2003). Because the RVR Procedure only relies on a short familiarization with the moving object, it minimizes possible learning effects caused by habituation during the experiment. Instead, the brevity of the familiarization and test phases allows for the inclusion of many more trials that reduce the paradigm's sensitivity to outliers. Finally, because infants are faced with a dual choice task that presents the alternative outcomes (e.g. novel and

familiar test events) in a single trial – rather than distributing these across trials as single-choice tasks do – the RVR procedure also reduces the likelihood that infants sustain their attention on a single test event simply because there is nothing else to look at.

To what extent is this ability to build independent object and movement representations thus dependent on experience with the physical world? At some point between 3- and 4-months of age the eyes of human infants go through the physiological changes necessary for capturing their gaze with an eye-tracker. This is an age range that according to previous findings roughly corresponds to when infants begin to demonstrate the ability to smoothly follow moving objects (Hofsten & Rosander, 1997). Infants in our study are therefore among the youngest that can presently be tested with the RVR procedure whose strength lies in infants' ability to control and execute rapid eye-movements between two alternative test events. The fact that infants can spontaneously build object and movement representations immediately when they begin to actively explore the visual world suggests that the ability may not be dependent on experience. However, it is still possible that the ability emerges sometime during the first 4 months of life. While 4-month-old infants cannot yet handle objects with agility (von Hofsten, 1991; Carey, 2011), they clearly have already acquired visual, as well as some linguistic, tactile and other social experience with the world that surrounds them. The results of Experiment 1 cannot thus fully rule out the possibility that early exposure to moving objects is necessary for the conceptual decomposition of motion events.

3. Experiment 2: Object / Movement Representations in Albino Swiss Mice

In Experiment 2, we therefore aimed to determine whether independent representations of objects and movements could emerge also in the absence of human specific experience. We reasoned that if this ability is a genetically determined cognitive trait that is evolutionarily highly conserved, then it could also extend to non-human animals (Hauser, Chomsky, & Fitch, 2002; Carey, 2009; Langus et al., 2013). While object cognition has been studied in a variety of animal species and perceptual domains, and non-human primates appear to have a concept for objects that at least in part parallels that found in young infants (Santos, 2004; Natale et al., 1986), the majority of animal studies that investigate the question in lower animal species rely on the animal's ability to represent visual events through extensive training. However, in these experiments it is often difficult to disentangle whether training enables the animal to learn to perform a specific experimental task or it additionally also enforces the animal to learn a conceptual distinction that would not emerge spontaneously. It is therefore not clear whether spontaneous conceptual decomposition of visual events into independent object and movement representations is as readily found in non-human animals as we found in 4-month-old infants in Experiment 1.

In Experiment 2, we therefore tested albino Swiss mice (CD1®) with the stimuli of Experiment 1. The species is interesting because, in contrast to rats, mice do not use eye movements to explore the visual world (Stahl, 2008; van Alphen et al., 2001) and their binocular field of vision is only 30-40° (Dräger & Olsen, 1980; Wagor, Mangini & Pearlman, 1980). As opposed to animals that can direct their gaze without moving their head, mice's head orientation must thus be predictive of what it sees. This

enabled us to use a version of the classical object recognition test (Ennaceur, 2010; Ennaceur & Delacour, 1988), where moving objects were presented visually on two opposing screens. Previous experiments in the same experimental setting have shown that mice can discriminate changes in objects and movements when comparing the difference in the animals' looking behavior (determined through their head orientation) to familiar and novel test events (Braida et al., 2013). However, it remains an open question whether, as infants, also mice can conceptually decompose visual events into independent object and movement recognition trials.

3.1. Method

3.1.1. Subjects

We tested 16 adult male albino Swiss mice (CD1®) (Charles River, Italy; <http://www.criver.com/>) 5-6 month old weighing 30 g (± 3). The animals were housed individually in polycarbonate cages with food and water freely available through wire lids. The *vivarium* was 21°C with a 12h light cycle. The procedures followed the guidelines established by the Italian Council on Animal Care and were approved by the Italian Government decree No. 28/2010. All efforts were made to minimize the number of subjects used.

3.1.2. Stimuli

The Stimuli of Experiment 2 were identical to Experiment 1.

3.1.3. Procedure

Mice were tested in a 380mm x 300mm x 180mm container with two 3.5-inch screens attached to opposing walls of the testing arena. The experiment had 1 trial with half of the mice assigned to the Object and the other half to the Movement recognition trials. The animals were first habituated to the test apparatus for 10 min on day 1. On day 2, the animals were subjected to a 10-min long familiarization phase during which two identical moving objects were shown on two 3.5-inch widescreen displays. The test phase started 5 min after the end of the familiarization. Half of the animals were assigned to the object recognition condition and saw a test video containing the familiarization object combined with a novel movement on one screen (familiar test event) and a video of a novel object with a novel movement on the other screen (novel test event). The other half of the animals were assigned to the movement recognition trials and saw a video of the familiarization movement with a novel object on one screen (familiar test event) and a video of a novel object with a novel movement on the other screen (novel test event).

To eliminate specific object/movement preferences, the novel/familiar test events were assigned to the two screens in a counterbalanced manner from animal to animal. In order to guarantee that we were measuring visual preferences and not specific location preferences, mice's looking behavior was coded manually during familiarization and consequently half of the time the novel test video appeared on the preferred screen and half of the time on the dis-preferred screen. Mice's behavior in the arena was video recorded at all times from above the arena (at a rate of 30 fps)

and consequently coded frame by frame with the PsyCode software. A looking event was coded when the mouse head was oriented towards the screen. The agreement of the two independent blind coders was in perfect agreement (Cohen's kappa 0.93).

3.2. Results and Discussion

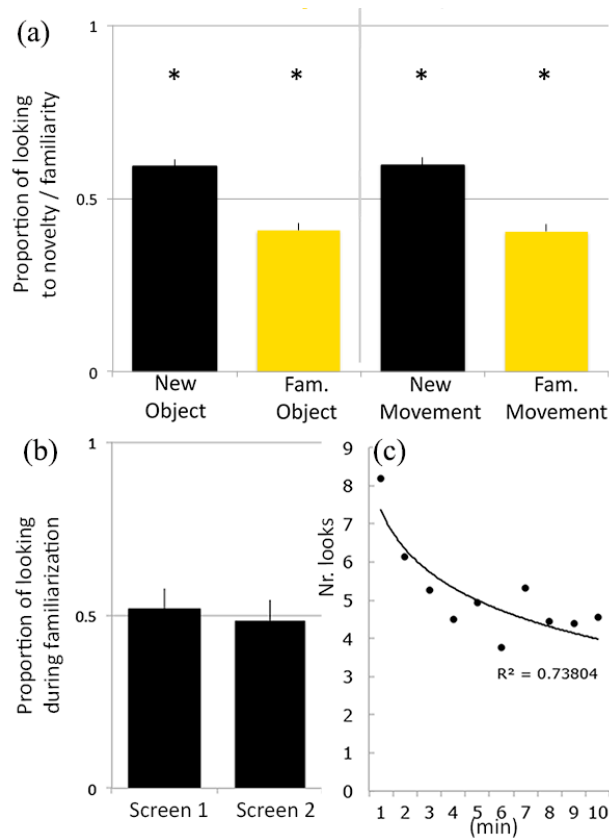


Fig. 3. Results of Experiment 2. For better comparison between experiments, looking-time to novel and familiar test events is converted into proportions of total looking-time spent looking at novel and familiar test events together. (a) The proportional differences in cumulative looking-times in object-recognition and movement recognition trials. (b) Cumulative looking-times to the two screens during the familiarization phase. (c) The average number of looks during each minute of the familiarization phase. Error bars represent standard errors. (*) denotes significant differences in looking times between familiar and novel test events ($P < .05$).

The results are shown in Figure 3. We calculated the average cumulative looking time each animal spent looking at the novel and at the familiar test videos. A 2 x 2 Repeated Measures ANOVA with Condition (Object / Movement recognition trials) as between-subject factor and Type of Test Event (Familiar / Novel) as within-subject factor revealed a main effect for the Type of Test Event ($F(1,14) = 34.410, P < .0001$), no main effect for Condition ($F(1,14) = 4.05, P = .07$), nor an interaction between Condition and the Type of Test Event ($F(1,14) = 1.041, P = .325$). Pair wise comparisons of cumulative looking times to novel and to familiar test events showed that significant novelty preferences prevailed in both object (2-tailed t -test: $t(7) = -4.679, P = .002$) as well as movement (2-tailed t -test: $t(7) = -3.578, P = .009$) recognition trials. Additionally, we also calculated the duration of longest looks that the animal directed to novel and to familiar test events. A 2 x 2 ANOVA with Condition (Object / Movement recognition trials) as between-subjects factor and Type of Test Event (Familiar / Novel) as within subject factor revealed a main effect for the Type of Test Event ($F(1,14) = 15.585, P < .001$), no main effect for Condition ($F(1,14) = 4.02, P = .11$), nor an interaction between Condition and the Type of Test Event ($F(1,14) = 0.047, P = .831$). Pair wise comparisons of longest looks to novel and to familiar test events showed that significant novelty preferences prevailed in both object (2-tailed t -test: $t(7) = -2.545, P = .038$) as well as in movement (2-tailed t -test: $t(7) = -3.245, P = .014$) recognition trials. There were no significant differences in either cumulative looking-times ($M = .51, SD = .13$: 2-tailed t -test: $t(15) = .843, P = .41$) or longest looks ($M = .49, SD = .09$: 2-tailed t -test: $t(15) = .734, P = .61$) to the two identical familiarization videos (Figure 3b). This rules out the possibility that the

preferences in the test phase emerged due to the specific locations of the screens in the arena.

The animals in our experiment were neither rewarded nor trained and they habituated to the stimuli quickly (Figure 3c). And since the stimuli are presented visually, animals cannot rely on their sense of either touch or smell to recognize the previously encountered moving objects. Mice, just like 4-month-old infants, must thus have built the object and movement representations spontaneously. Just like 4-month-old infants in Experiment 1, mice in Experiment 2 could not have discriminated overall changes between familiarization and test events. These consistent novelty preferences for test events containing both a novel object and a novel movement could only emerge if mice recognized the repeated familiarization objects and movements in one of the test events, and consequently looked longer at the other one. Compared to our previous findings that mice can discriminate changes in objects and movements in the same paradigm (Braidà et al., 2013), the present results show that mice decompose visual events into independent object and movement representations that enable the animal to recognize objects/movements in partially matching test events. The results of Experiment 2 therefore enforce the idea that looking-behavior is informative as a measure for cognitive processing also in animals for whom vision is not the primary sense to explore the world.

4. General Discussion

We explored whether 4-month-old infants and mice spontaneously decompose visual events into independent represent objects and movements. We show that both 4-

month-old infants and mice can recognize objects irrespectively of how they move and movements irrespectively of the objects that perform them. Because the familiar test events only partially matched the familiarization event, infants' and mice' performance cannot be explained by simple discrimination or change detection between the moving objects in the familiarization and test phases (for a discussion see Pulverman et al. 2006). Instead, both infants and mice had to first decompose the moving objects into independent object and movement representations and consequently recognize these in partially matching test events. Interestingly, even though objects are often considered more concrete than movements, since these unfold over time, we found no significant differences in infants' and mice's performance in object and movement recognition trials. To our knowledge this is the first experimental evidence in young infants and mice for the spontaneous conceptual decomposition of visual events into independent object and movement representations.

Our results also suggest that the representations of objects and movements can be dissociated from various types of experience that young infants have not yet mastered, and experience that mice do not have. For example, 4-months-old infants have not yet developed enough finger dexterity to handle moving objects with agility (Carey, 2011). The ability to represent movements cannot thus be learned from physical experience with moving objects (Needham, 2002; Sommerville, Woodward & Needham, 2005; Thelen et al., 2001; Elman et al., 1996). Similarly, mice have no linguistic knowledge and can thus not infer the distinction between objects and movements from words as infants have been thought to do (Xu, 2002; Gliga, Volein & Csibra, 2010). Following the same reasoning, the ability to represent objects and

movements independently cannot depend on social cues such as pointing and eye gaze, since these could facilitate object and action understanding in young infants (Hood, Willen & Driver, 1998; Woodward, & Guajardo, 2002), but not in mice. Finally, the RVR procedure presents moving objects too briefly for infants to habituate and mice were not trained or rewarded for their performance, suggesting that participants' performance was spontaneous and not learned during the experiment.

The evidence we offer thus suggests that this ability to spontaneously build independent object and movement representations must be evolutionarily old. As humans and mice diverged from a common ancestor some 75 million years ago (MGSC, 2002), this ability may extend to the whole mammalian species. In fact, the segregation of object and movement representations must be so fundamental that it emerges without human specific experience and even in an animal for which vision is not the primary sense organ. The way mice's performance parallels that of 4-month-old infants may thus suggest that the nervous system is innately geared towards conceptually decomposing visual events into object and movement representations. These independent representations may be the result of the segregation of the early visual processing in humans and other non-human animals into two visual pathways known as the ventral stream (also known as the "what pathway" responsible for object perception) and the dorsal stream (the "where pathway" responsible for spatio-temporal relations) (Mishkin & Ungerleider, 1982; Goodale & Milner, 1992; Ettlinger, 1990; Wang, Gao, & Burkhalter, 2011). Our results therefore also support the controversial idea that the nervous system does innately not only anticipate the processes required for perceiving but also for independently representing the concepts

for objects and their spatio-temporal relations, possibly in the ventral and the dorsal stream, respectively (Mahon et al., 2009).

Finally, the ease with which young infants and mice recognized objects and movements in our experiments suggests that the (Rapid) Visual Recognition Procedure may be highly sensitive for detecting cognitive processing both in young infants as well as in mice. This may mean that spontaneous representations do not only emerge for objects and movements but also for other event components such as spatial relations (distance and depth) and possibly even for object properties such as color that previous studies have often struggled to discern from infants' looking-behavior. Furthermore, as the conceptual decomposition of visual events appears to either mature very early or even to be present innately, it is also possible that infants begin to reason about physical motion events and acquire the labels for objects (i.e. nouns) and for movements (e.g. motion verbs) before previously thought. On the basis of the present study we can conclude that the basic building blocks necessary for seeing, representing and recalling the basic elements of the physical world appear to be present both in young infants and in non-human animals, they appear to be spontaneous, and do not to require human-specific experience of the world.

Acknowledgments

The research leading to these results has received funding from the European Research Council under the European Union's Seventh Framework Programme (FP7/2007-2013)/ERC grant agreement nu 269502 (PASCAL) and SISSA Young Scientist Award to A.L. We thank Jacques Mehler and Luca L. Bonatti for

discussions of this manuscript, and Marijana Sjekloca and Francesca Gandolfo for essential help with organizing the experiments and Luca Filippin for invaluable technical support.

References:

- Aguiar, A. & Baillargeon, R. (1999). 2.5-month-old infants' reasoning about when objects should and should not be occluded. *Cognitive Psychology*, 39, 116–157.
- van Alphen, A.M., Stahl, J.S., Koekkoek, S.K.E., & De Zeeuw, C.I. (2001) The dynamic characteristics of the mouse vestibulo-ocular and optokinetic response. *Brain Research*, 890, 296–305.
- Baillargeon, R. (2002). The Acquisition of Physical Knowledge in Infancy: A Summary in Eight Lessons. In U. Goswami (Ed.) “Blackwell Handbook of Childhood Cognitive Development”. Oxford, Blackwell.
- Baillargeon, R. (2004). Infants' reasoning about hidden objects: Evidence for event-general and event-specific expectations. *Developmental Science*, 7, 391-424.
- Bergelson, E., & Swingle, D. (2012). At 6 to 9 months, human infants know the meanings of many common nouns. *Proceedings of the National Academy of Sciences of the USA*, 109, 3253-3258.
- Braida, D., Donzelli, A., Martucci, R., Ponzoni, L., Pauletti, A., Langus, A., Sala, M. (2013). Mice discriminate between stationary and moving 2D shapes: application to the object recognition task to increase attention. *Behavioral Brain Research*, 242, 95-101.
- Call, J. (2000). Representing space and objects in monkeys and apes. *Cognitive Science*, 24, 397-422.

- Carey, S. (2009). *The Origin of Concepts*. New York: Oxford University Press
- Carey, S. (2011). The origin of concepts: A précis. *Behavioral and Brain Sciences*, 34, 113-167.
- Dräger, U.C. & Olsen, J. (1980). Origins of crossed and uncrossed retinal projections in pigmented and albino mice. *Journal of Comparative Neurology*, 191, 383–412.
- Elman, J.L., Bates, E.A., Johnson, M.H., Karmiloff-Smith, A., Parisi, D., & Plunkett, K. (1996). *Rethinking innateness: A connectionist perspective on development*, Cambridge: MIT Press.
- Ennaceur, A. (2010). One-trial object recognition in rat and mice: Methodological and theoretical issues. *Behavioral Brain Research*, 215, 244-254.
- Ennaceur, A. & Delacour, J. (1988). A new one-trial test for neurobiological studies of memory in rats. 1: Behavioral data. *Behavioral Brain Research*, 31, 47-59.
- Ettlinger, G. (1990). "Object vision" and "spatial vision": the neuropsychological evidence for the distinction. *Cortex*, 26, 319–41.
- Gliga, T., Volcin, A., & Csibra, G. (2010). Verbal labels modulate perceptual object processing in one-year-old infants. *Journal of Cognitive Neuroscience*, 22, 2781-2789.
- Golinkoff, R. M., Harding, C. G., Carlson-Luden, V., & Sexton, M. E. (1984). The infant's perception of causal events: The distinction between animate and inanimate objects. (Part of above symposium). In L. P. Lipsitt (Ed.), *Advances in infancy research* (Vol. 3, pp. 145-151). Norwood, NJ: Ablex.
- Goodale, M.A. & Milner, A.D. (1992). Separate visual pathways for perception and action. *Trends in Neuroscience*, 15, 20–5.

- Hall-Haro, C., Johnson, S.P., Price, T.A., Vance, J.A., & Kiorpes, L. (2008). Development of object concepts in Macaque Monkeys. *Developmental Psychology*, 50, 278-287.
- Hauser, M.D., Chomsky, N., & Fitch, T. (2002). The faculty of language: what is it, who has it, and how did it evolve? *Science*, 298, 1569-1579.
- Von Hofsten, C. (1991). Structuring of early reaching movements: a longitudinal study. *Journal of Motor Behavior*, 23, 280–292
- Von Hofsten, C. & Rosander, K. (1997). Development of smooth pursuit tracking in young infants. *Vision Research*, 37, 1799-810.
- Hood, B.M., Willen, J.D., & Driver, J. (1998). Adult's eyes trigger shifts of visual attention in human infants. *Psychological Science*, 9, 131-134.
- Jackendoff, R. (1983). *Semantics and cognition*. Cambridge: MIT Press.
- Johnson, S.P., Amso, D., & Slemmer, J.A. (2003). Development of object concepts in infancy: Evidence for early learning in an eye-tracking paradigm. *Proceedings of the National Academy of Sciences (USA)*, 100, 10568-10573.
- Kellman, P.J., Gleitman, H., & Spelke, E.S. (1987). Object and observer motion in the perception of objects by infants. *Journal of Experimental Psychology: Human Perception and Performance*, 13, 586-593.
- Kellman, P.J. & Spelke, E.S. (1983). Perception of partly occluded objects in infancy. *Cognitive Psychology*, 15, 483-524.
- Kellman, P. J., Spelke, E. S., & Short, K. R. (1986). Infant perception of object unity from translatory motion in depth and vertical translation. *Child Development*, 57, 72-86.
- Kotovskiy, L., & Baillargeon, R. (2000). Reasoning about collisions involving inert objects in 7.5-month-old infants. *Developmental Science*, 3, 344-359.

- Langus, A., Petri, J., Nespor, M., & Scharff, C. (2013). FoxP2 and deep homology in the evolution of birdsong and human language. In Botha, R. & Everaert, M. (eds.). *Emergence of Language*. Oxford University Press.
- Leslie, A. & Keeble, S. (1987). Do six-month-old infants perceive causality? *Cognition*, 25, 265–288.
- Leslie, A.M., Xu, F., Tremoulet, P.D., & Scholl, B.J. (1998). Indexing and the object concept: developing ‘what’ and ‘where’ systems. *Trends in Cognitive Science*, 2, 10-18.
- Mahon, B.Z., Anzellotti, S., Schwarzbach, J., Zampini, M., & Caramazza, A. (2009). Category-specific organization in the human brain does not require visual experience. *Neuron*, 63, 397-406.
- Mandler, J. M. (2004). *The foundations of mind: Origins of conceptual thought*. New York: Oxford University Press.
- Mascalzoni, E., Regolin, L., & Vallortigara, G. (2009). Mom’s shadow: structure-from-motion in newly hatched chicks as revealed by an imprinting procedure. *Animal Cognition*, 12, 389-400.
- Mishkin, M. & Ungerleider, L.G. (1982). Contribution of striate inputs to the visuospatial functions of parieto-preoccipital cortex in monkeys. *Behavioral Brain Research*, 6, 57-77.
- Mouse Genome Sequencing Consortium (2002) Initial sequencing and comparative analysis of the mouse genome. *Nature*, 420, 520-577.
- Natale, F., Antinucci, F., Spinozzi, G., & Poti, P. (1986). Stage 6 object concept in nonhuman primate cognition: A comparison between gorilla (*Gorilla gorilla gorilla*) and Japanese macaque (*Macaca fuscata*). *Journal of Comparative Psychology*, 100, 335-339.

- Needham, A. (2000). Improvements in object exploration skills may facilitate the development of object segregation in early infancy. *Journal of cognition and Development*, 1, 131-156.
- Pulverman, R. & Golinkoff, R. M. (2004). Seven-month-olds' attention to potential verb referents in nonlinguistic events. In A. Brugos, L. Micciulla, & C. E. Smith (Eds.), *Proceedings of the 28th Annual Boston University Conference on Language Development* (pp. 473-481). Somerville, MA: Cascadilla Press.
- Pulverman, R., Hirsh-Pasek, K., Golinkoff, R. M., Pruden, S., & Salkind, S. (2006). Conceptual foundations for verb learning: Celebrating the event. In K. Hirsh-Pasek & R. M. Golinkoff (Eds.), *Action meets word: How children learn verbs* (pp. 134-159). New York, NY: Oxford University Press.
- Pulverman, R., Sootsman, J., Golinkoff, R. M., & Hirsh-Pasek, K. (2003). Infants' non-linguistic processing of motion events: One-year-old English speakers are interested in manner and path. In E. Clark (Ed.), *Proceedings of the Stanford Child Language Research Forum*. Stanford: Center for the Study of Language and Information.
- Regolin, L. & Vallortigara, G. (1995). Perception of partly occluded objects by young chicks. *Perception and Psychophysics*, 57, 971-976.
- Rose, S.A., Gottfried, A.W., Melloy-Carminar, P., & Bridger, W.H. (1982). Familiarity and novelty preferences in infant recognition memory; Implications for information processing. *Developmental Psychology*, 18, 704-713.
- Slater, A., Morison, V., Somers, M., Mattock, A., Brown, E., & Taylor, D. (1990). Newborn and older infants' perception of partly occluded objects. *Infant Behavior & Development*, 13, 33-49.

- Spelke, E.S. (1982). Perceptual knowledge of objects in infancy. In J. Mehler, M. Garrett, & E. Walker (Eds.), *Perspectives on Mental Representation*, Hillsdale, NJ: Erlbaum.
- Spelke, E.S. (1990). Principles of object perception. *Cognitive Science*, 14, 29–56.
- Spelke, E.S., Breinlinger, K., Macomber, J. & Jacobson, K. (1992). Origins of Knowledge. *Psychological Review*, 99, 605-632.
- Santos, L. (2004). ‘Core knowledges’: a dissociation between spatiotemporal knowledge and contact-mechanics in a nonhuman primate? *Developmental Science*, 7, 167–174.
- Smith, W. C., Johnson, S. P., & Spelke, E. S. (2003). Motion and edge sensitivity in perception of object unity. *Cognitive Psychology*, 46, 31-64.
- Sommerville, J., Woodward, A.L., & Needham, A. (2005). Action experience alters 3-month-old infants’ perception of others’ actions. *Cognition*, 96, B1-B11.
- Stahl, J.S. (2008). Characteristics and Applications of Mouse Eye Movements. In Chalupa LM, Williams RW (eds.). *Eye, Retina, and Visual System of the Mouse*. (2008; 87-107) MIT Press.
- Thelen, E., Schonor, G., Sheier, C., & Smith, L.B. (2001). The dynamics of embodiment. A field theory of infant preservative reaching. *Behavioral and Brain Sciences*, 24, 1-86.
- Valenza, E., Leo, I., Gava, L., & Simion, F. (2006). Perceptual completion in newborn human infants. *Child Development*, 77, 1810-1821.
- Wagor, E., Mangini, N.J., & Pearlman, A.L. (1980). Retinotopic organization of striate and extrastriate visual cortex in the mouse. *Journal of Comparative Neurology*, 193, 187–202.

- Wang, Q., Gao, E., & Burkhalter, A. (2011). Gateways of ventral and dorsal streams in mouse visual cortex. *Journal of Neuroscience*, *31*, 1905-1918.
- Wang, S., Kaufman, L., & Baillargeon, R. (2003). Should all stationary objects move when hit? Developments in infants' causal and statistical expectations about collision events. *Infant Behavior & Development*, *26*, 529-567.
- Werker, J. F., Cohen, L. B., Lloyd, V. L., Casasola, M., & Stager, C. L. (1998). Acquisition of word-object associations by 14-month-old infants. *Developmental Psychology*, *34*, 1289-1309.
- Woodward, A.L. & Guajardo, J.J. (2002). Infants' understanding of the point gesture as an object-directed action. *Cognitive Development*, *17*, 1061-1084.
- Xu, F. (2002). The role of language in acquiring object kind concepts in infancy. *Cognition*, *85*, 223-250.