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PAPER

The cradle of causal reasoning: newborns' preference for physical causality

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Abstract

Perception of mechanical (i.e. physical) causality, in terms of a cause–effect relationship between two motion events, appears to be a powerful mechanism in our daily experience. In spite of a growing interest in the earliest causal representations, the role of experience in the origin of this sensitivity is still a matter of dispute. Here, we asked the question about the innate origin of causal perception, never tested before at birth. Three experiments were carried out to investigate sensitivity at birth to some visual spatiotemporal cues present in a launching event. Newborn babies, only a few hours old, showed that they significantly preferred a physical causality event (i.e. Michotte's Launching effect) when matched to a delay event (i.e. a delayed launching; Experiment 1) or to a non-causal event completely identical to the causal one except for the order of the displacements of the two objects involved which was swapped temporally (Experiment 3). This preference for the launching event, moreover, also depended on the continuity of the trajectory between the objects involved in the event (Experiment 2). These results support the hypothesis that the human system possesses an early available, possibly innate basic mechanism to compute causality, such a mechanism being sensitive to the additive effect of certain well-defined spatiotemporal cues present in the causal event independently of any prior visual experience.

Introduction

Imagine that you are presented with two objects, A and B, located at some distance from one another. Object A starts to move toward B at a constant speed and comes into contact with it, whereupon A remains at the point of contact and B starts moving in the same direction. You will have probably had the impression that A hit B and caused its movement, even though the objects had moved independently from one another. When presented with this type of event (known as 'launching'), most observers would report to attribute a causal role to A.

Attribution of causality (i.e. appreciation of the interaction between any two events in terms of a cause–effect relationship) has a key role in our everyday understanding of the physical world. The question of how humans come to perceive causal relationships has long been a challenge both for philosophers (Aristotle, *Physics*) and psychologists (see Sperber, Premack & Premack, 1995).

Psychological research has, on the one hand, focused on exploring higher-level cognitive processing, i.e. the dynamics of causal inferences and representations (Sperber *et al*., 1995; White, 1995), and on the other hand much critical work on causality has concentrated on the role of pure perceptual processing in determining a causal experience. Within this last perspective, Albert Michotte (1963) claimed that certain motion events (i.e. 'launching') automatically trigger a '*causal impression*' which would provide an '*original idea of cause*' (Michotte, 1963). The perception of causality in these events is fast and automatic and subjects do not have introspective access to any intermediate stages of the computation. In this sense, in a launching event a causal

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connection would be experienced as a result of what is a perceptual process, rather than a conceptually mediated inference. Michotte noted that adults perceive physical (i.e. mechanical) causality in a launching event exclusively when the parameters of motion of the two objects are consistent with a single motion transferred from the first object to the second perceptually distinct one (Michotte, 1963). Perception of physical causality, in fact, seems to be driven by a highly constrained collection of visual cues (e.g. Choi & Scholl, 2004; Choi & Scholl, 2006; Schlottmann, Ray, Mitchell & Demetriou, 2006; White, 2006), such as temporal continuity (i.e. absence of any delay) and continuity of trajectory between the motion of the two objects involved in the event. This means that perception of physical causality is impaired when a delay is interposed between the time of contact of the two objects and the moving off of the second one. Moreover, an angle of 25° between the trajectory of the second object with respect to the first one is sufficient to weaken the effect of physical causality, an effect which completely disappears with a 90° angle (Michotte, 1963).

The fact that the phenomenon of physical causality perception reflects automatic visual processing determined by highly constrained collections of visual cues and insulated to some degree from other aspects of cognition (such as higher-level causal inferences; Schlottmann & Shanks, 1992; Carey, 2009) would support its precocial ontogenetic origin. Michotte himself, in fact, though his work was based on verbal reports from adult observers, took a strong nativistic position on the origin of causal representations (for several reasons, detailed in Saxe & Carey, 2006), claiming that the perceptual mechanism for causal impressions (i.e. the '*perceptual input analyzer*') was innate and, furthermore, that the output of this mechanism was the source of all subsequently developing causal representations (Michotte, 1963).

A range of experimental data on early causal representations in infants has been contributed in recent decades (Leslie, 1986, 1988; Leslie & Keeble, 1987; Oakes & Cohen, 1990; Cohen & Oakes, 1993; Oakes, 1994; Cohen, 1998; Cohen & Amsel, 1998; Cohen, Amsel, Radford & Casasola, 1998; for data regarding perception other kinds of causality, such as social causality, see Rochat, Striano & Morgan, 2004; Schlottmann, Surian & Ray, 2009; Schlottmann, Ray & Surian, 2012). Such data have been interpreted according to two different models. Following Michotte, some authors suggest an innate, domain-specific visual module (Leslie & Keeble, 1987) that would operate '*automatically and incorrigibly upon the spatiotemporal properties of events yet producing abstract descriptions of their causal structure*' (Leslie, 1988). In contrast, other researchers suggest a domain-general and experience-dependent developmental account of the perception of causality (Oakes & Cohen, 1990; Cohen & Amsel, 1998). According to this latter view, causality between events would be perceived as a result of perceptual and cognitive development (Oakes & Cohen, 1990).

To date, the debate on the origin of causal perception still remains open. Developmental studies provided evidence confirming that preverbal infants interpret Michotte's launching events as causal starting from 6 months of age (Leslie & Keeble, 1987; Oakes & Cohen, 1990; Oakes, 1994; Cohen & Amsel, 1998). At 6 months, in fact, infants demonstrated being able to discriminate launching events from non-causal control stimuli (i.e. delayed and no-collision displays) on the basis of their causal or non-causal nature (Leslie & Keeble, 1987; Oakes, 1994; Cohen & Amsel, 1998). Moreover, further evidence of 6½-month-old infants' sensitivity to physical causality derives from data demonstrating that at this age they are able to assign distinct roles to the agent and the recipient in a launching event (whereas they fail to attribute roles for pairs of non-causal movements; Leslie & Keeble, 1987). Although there is no direct evidence of causal perception before 6 months of age, infants as young as 4 months demonstrated being able to successfully discriminate between launching and control events on the basis of their spatiotemporal parameters (Leslie, 1982; Cohen & Amsel, 1998; Cohen *et al.*, 1998), this capability being fundamental in determining adults' perception of physical causality (Michotte, 1963).

To our knowledge, the hypothesis of an experience-independent sensitivity to physical causality has never been tested under conditions of effective control for any previous experiences, though recent evidence from comparative psychology (Mascalzoni, Regolin & Vallortigara, 2010) would favour the hypothesis of an ontogenetic as well as phylogenetic precocial origin of sensitivity to physical causality. Data on 4-month-olds (Leslie, 1982; Cohen & Amsel, 1998; Cohen *et al.*, 1998), moreover, leave open the possibility that even younger infants could be sensitive to the spatiotemporal parameters specific to the launching event. In recent decades, studies focusing on the ontogenetic and phylogenetic origins of knowledge have provided evidence in favour of the existence of at least four core knowledge systems that operate from birth and enable infants to identify the entities in each domain, constraining reasoning about those entities (Carey & Spelke, 1996; Spelke & Kinzler, 2007; Carey, 2009). One of those systems, which covers object knowledge and represents inanimate objects and their mechanical interactions, has been related to the perception of physical causality (Leslie, 1984; Carey, 2009). The core system of object representations has been demonstrated to centre on some spatiotemporal principles such as cohesion (i.e. objects move as connected), continuity (i.e. objects move along connected, unobstructed path) and contact (i.e. objects do not interact at a distance) (Leslie & Keeble,1987; Spelke, 1990; Spelke & Kinzler, 2007). Recent studies support the notion that some of these principles, such as cohesion, are present at birth and allow newborns to organize their perceptual world in the absence of any postnatal experience (Valenza, Leo, Gava & Simion, 2006; Valenza & Bulf, 2011).

Parallel to the demonstration of object knowledge competencies at birth, newborns' sensitivity to several spatial and temporal features of a moving stimulus have been demonstrated: babies, for instance, are able from birth to discriminate and categorize a spatial relation, defined by the left–right spatial position of a blinking object-target with respect to a vertical landmark-bar (Gava, Valenza & Turati, 2009) as well as the order in a sequence of events (Bulf, Johnson & Valenza, 2011).

Given the presence of these capabilities at birth, it seems plausible that newborns also might possess a mechanism sensitive to the association of the well-defined spatiotemporal cues that determine causal perception in adults. For such reasons, here, by testing newborns a few hours old, we aimed at answering the question about the existence of an early available, possibly innate basic mechanism which may compute physical causality independently of any prior visual experience. Such a mechanism would be sensitive to certain well-defined spatiotemporal cues (in particular, temporal continuity and continuity of trajectory between the motion of the two objects involved in the event) which drive causal perception in adults.

Three experiments were carried out to test newborns' preference for causal (i.e. launching) and non-causal control stimuli. The temporal continuity between the motion of the two objects involved in the events (Experiment 1), the spatial continuity of the trajectories of the two objects (Experiment 2) and the temporal sequence of motion of the two objects (Experiment 3) have been manipulated to investigate the role of such cues in determining newborns' preference.

Experiment 1

In Experiment 1 we tested whether newborns are able to discriminate and manifest a preference for a launching (i.e. causal) vs. a delay (i.e. non-causal) event (Figure 1a). The launching stimulus was a typical launching event (Michotte, 1963), characterized by both spatial and temporal continuity between the motion of the two objects involved in the event, whereas the delay stimulus was characterized by temporal discontinuity. The delay event, in fact, was identical to the launching one except for the presence of a 1-s delay between the time of contact and the motion of the second object, such a delay being known to abolish any perception of causality in adult subjects (Michotte, 1963). The two events, therefore, differed in the temporal continuity/discontinuity between the movements of the two objects involved in each event. For this reason the two events required two different eye tracking movements. The launching

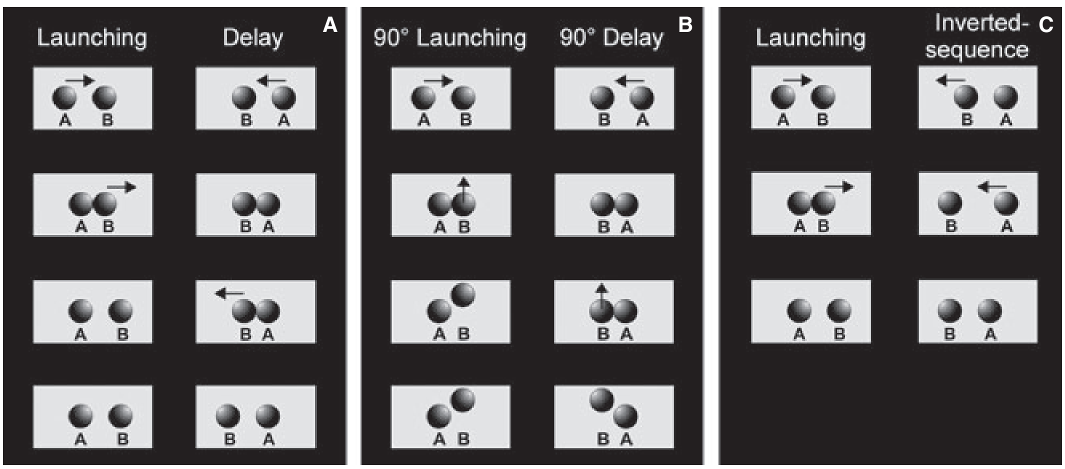

Figure 1 *Schematic representation of the events used in: a. Experiment 1 (left-most sequence: the launching event; right-most sequence: the delay event); b. Experiment 2 (left-most sequence: the 90° launching event; right-most sequence: the 90° delay event); c. Experiment 3 (left-most sequence: the launching event; right-most sequence: the inverted-sequence event). The initial left–right order of presentation was counterbalanced across subjects. The motion direction of the two events is convergent as it was in the actual stimuli presented to the newborn.*

stimulus, being characterized by temporal continuity between the motion of the two objects, required smooth tracking; in contrast, the delay stimulus, characterized by a temporal discontinuity, required interruption of eye movements (Leslie,1984).

In the absence of any sensitivity to physical causality we hypothesized that newborns would have looked longer at the delay event than at the launching one, since the delay event would better fit both newborns' preference for motion stimuli and newborns' visual tracking behaviour. In the delay stimulus, in fact, there is still 1 s of motion after cessation of motion in the launching event (i.e. due to the 1-s delay between the motion of the two objects) and this feature could trigger a preference for the delay event. Moreover, a preference for the delay event might be expected because of the peculiar features of newborns' oculo-motor system. Since newborns' tracking behaviour is not smooth but consists of a series of separate re-foveations (Johnson, 1990; Valenza *et al.*, 2006), the temporal discontinuity present in the delay event may better suit the newborns' visual tracking system, allowing the baby to reach the final position of object A in time to see the starting of motion of object B.

In contrast to these predictions, if newborns were able to perceive causality we might expect a preference for the launching event, in spite of the low-level mechanisms just described which would have favoured the delay event.

Method

Participants

Seventeen full-term newborns were selected from the maternity ward of the Pediatric Clinic of the University of Padua to participate in the study. Since the data from five newborns were discarded because they changed their state during testing, the final sample consisted of 12 newborns. Their postnatal age ranged from 8 to 71 h (mean $\pm$ SEM = 39 $\pm$ 6 h). All of them met the screening criteria of normal delivery, had a birth weight between 2800 and 4270 g, and had an Apgar score of 10 at 5 min. Newborns were tested only if awake and in an alert state, and after the parents had provided informed consent. All experimental procedures have been licensed by the Pediatric Clinic of the University of Padua.

Procedure

An infant-control preferential looking technique was used. Stimuli consisted of two computer-presented animation events, presented on an Apple LED Cinema Display (Flat Panel 30″) computer monitor (refresh rate = 60 Hz). The baby sat on an experimenter's lap at a distance of about 30 cm in front of the monitor. The experimenter holding the baby was naïve to the hypothesis being tested and the stimuli being presented, and was instructed to fix his/her gaze on a camera located on the ceiling throughout the experimental session. Plain white curtains were drawn on both sides of the newborn to prevent interference from irrelevant distractors. Above the monitor, a video camera recorded the newborns' eye movements to monitor their looking behaviour on-line and to allow off-line coding of their fixations.

At the beginning of both of the preference test trials a red disc was shown on a black background to attract the infant's gaze to the centre of the monitor. The disc grew and then shrank back continuously, from small (1.8 cm) to large (2.5 cm) in size. As soon as the newborn's gaze was properly aligned with the red disc, the sequence of trials was started by a second experimenter who watched the newborn's eyes through the video camera and pressed a key on the computer keyboard that automatically turned off the central disc and activated the onset of the stimuli. Because the stimuli were presented bilaterally on the left and the right side of the monitor (with convergent motion, from the peripheral to the central visual field) each newborn was given two paired presentations (trial 1 and trial 2) of the test stimuli in which the position of the stimuli was reversed (the initial left–right order of presentation was counterbalanced across subjects).

The experimenter recorded on-line the duration of the newborn's fixations on each stimulus by pressing two different keys depending on whether the newborn looked at the right or the left stimulus. Each trial ended when the newborn did not fixate on the display for at least 10 s.

Videotapes of the newborn's eye movements throughout the two test trials were subsequently coded off-line by a different observer unaware of the stimuli presented (it was not possible for the scorer to recognize the stimuli from the corneal reflection). The mean estimated reliability between coders was 0.849 (Pearson correlation, p = .033).

Stimuli

Stimuli consisted of two computer-presented animation events (i.e. a launching and a delay event). Each event featured two identical objects (grey discs of 3 cm in diameter) that will be called A and B hereafter.

In the launching event, object A moved towards object B, which was stationary. Immediately after contact between the two objects, object B started to move along the same direction as A, while object A became stationary (both objects moved with identical speed and covered the same distance; Figure 1a). In this sort of display adult subjects perceive object A as pushing ('launching') object B and causing its movement.

The delay event was identical to the launching event except for the presence of a 1-s delay between the time of contact and the motion of B. Both events described lasted 3.5 s (84 frames, 24 frames/s; the last static frame of the launching event was left visible for 1 s to match the 1-s delay of the delay event). Each object in the events covered a distance of 2 cm at 4 cm/s and maintained both its starting and final position for 0.5 s. At the end of the event a grey screen (identical to the background, RGB = r235, g233, b237) appeared for 0.5 s before the event was restarted. Videos were produced by looping such animations, which were saved at a resolution of 75 AVI jpeg. Each set of elements occupied an overall window 10 cm in width (20° visual angle at a viewing distance of 30 cm).

Results and discussion

When tested for their preferences for a launching vs. a delay event, newborns looked significantly longer at the launching event (average total fixation time: mean ± SEM = 47.087 ± 3.899 s) than at the delay one (mean ± SEM = 29.964 ± 4.647 s; paired-samples two-tailed *t*-test: $t_{11} = 4.486$, $p = .001$) (Figure 2). The percentage of total fixation time newborns spent looking at the launching event was (mean ± SEM) 62.874 ± 2.661% and differed significantly from chance level (one-sample two-tailed *t*-test: $t_{11} = 4.837$, $p = .001$; Figure 3, leftmost column). Ten out of 12 subjects preferred the launching event to the delay event (binomial test, $p = .039$).

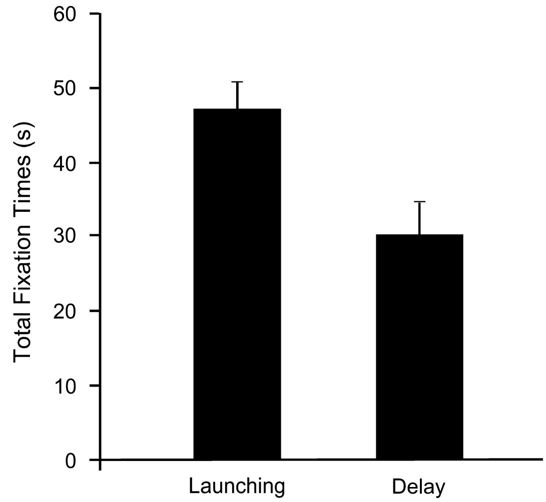

Figure 2 *Average Total Fixation Times (s) for the launching event (Mean ± SEM = 47.087 ± 3.899 s) and the delay event (Mean ± SEM = 29.964 ± 4.647 s) in Experiment 1.*

In spite of the delay event having low-level features, newborns showed a significant preference for the launching event. This preference would seem to favour the idea that naïve newborns are able to perceive physical causality in a launching event. Nevertheless, such results could be also interpreted as due to a preference for the intrinsic temporal features of the launching event (i.e. *temporal continuity* between the motion of the two objects) in the absence of any perception of physical causality. Experiment 2 was conducted to assess precisely whether newborns' preference for the launching event might be interpreted as being merely due to a preference for the perceptual cue of temporal continuity.

Experiment 2

In Experiment 2 two stimuli (called '90° launching' and '90° delay') identical in their *temporal* parameters to the launching and the delay events, respectively, used in Experiment 1 were employed. The only difference with the stimuli of Experiment 1 concerned the *spatial* parameters. Both stimuli in Experiment 2, in fact, were characterized by a *discontinuity between the trajectory of the two objects* involved in each event: after contact with A, object B started moving along a vertical path with a 90° deviation from the trajectory of A (Figure 1b). Such a 90° deviation between the trajectory of B with respect to A is sufficient to abolish any perception of causality in adult subjects (Michotte, 1963).

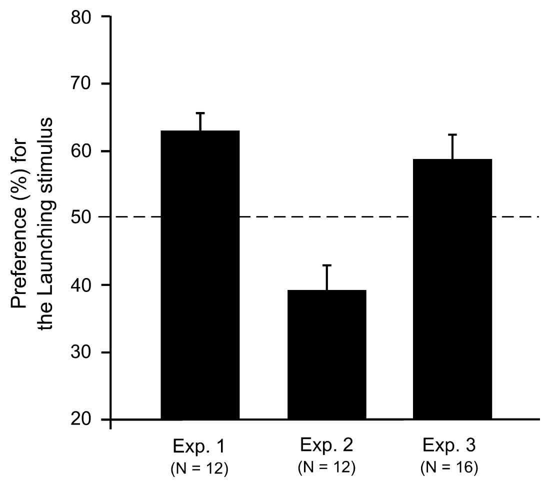

Figure 3 *Average percentage (Mean ± SEM) of preference for the launching event in the three experiments. The dotted line represents chance level. A significant preference for the launching event did emerge in Experiments 1 and 3, whereas in Experiment 2 newborns significantly preferred the 90° delay event.*

The lack of causality in both events coupled with the fact that their temporal parameters were identical to those of the events used in Experiment 1, allowed us to investigate whether newborns merely prefer a temporally continuous event (i.e. the 90° launching).

Method

Participants

A total of 17 newborns participated in the experiment from the maternity ward of the Pediatric Clinic of the University of Padua. Data from five newborns were discarded because they changed their state during testing. Therefore the final sample consisted of 12 newborns, aged (mean ± SEM) 47 ± 5 h (range: 25–76 h). Their birth weight was between 2040 and 3900 g, and they had an Apgar score of 10 at 5 min.

Procedure

The procedure was identical to that used in Experiment I. The mean estimated reliability between coders was 0.995 (Pearson correlation, $p < .0001$).

Stimuli

A 90° launching and a 90° delay event were created, those stimuli being identical to the launching and to the delay events, respectively, used in Experiment 1, except for a 90° deviation in the path travelled by object B (Figure 1b). In fact, immediately after contact in the 90° launching event (1 s after contact in the 90° delay event), object B started to move at the same speed as object A, but along a vertical path, deviating by 90° from the straight trajectory of A. Such a discontinuity in trajectory is known to abolish any impression of physical causality in adult subjects (Michotte, 1963). In both the 90° launching event and the 90° delay event, therefore, any physical causality between the movements of the two objects was disrupted. In contrast, the temporal features of the events were identical to those of the launching event and of the delay events, respectively, used in Experiment 1 (such as the distances covered by the objects, their velocities and the video features).

Results and discussion

Newborns looked significantly longer at the 90° delay event (mean ± SEM = 50.063 ± 4.061 s) than at the 90° launching one (mean ± SEM = 34.584 ± 5.412 s; paired-samples two-tailed *t*-test: $t_{11} = -2.433$, $p = .033$; Figure 4). The percentage of the total fixation time

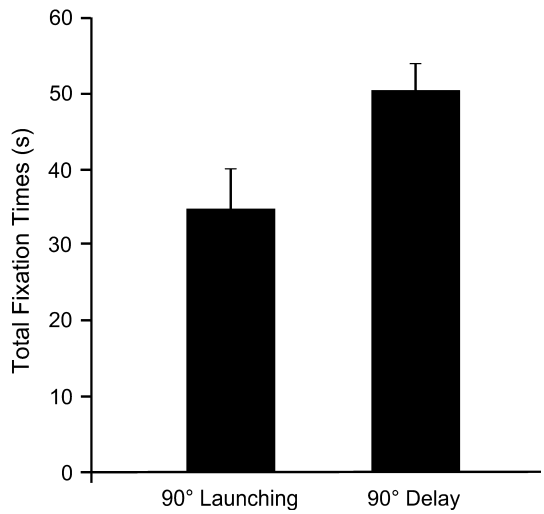

Figure 4 *Average Total Fixation Times (s) for the 90° launching event (Mean ± SEM = 34.584 ± 5.412 s) and the 90° delay event (Mean ± SEM = 50.063 ± 4.061 s) in Experiment 2.*

newborns spent looking at the 90° launching event was (mean ± SEM) 39.426 ± 3.568% and differed significantly from chance level (one-sample two-tailed *t*-test: $t_{11} = -2.964$, $p = .013$; Figure 3, central column). Finally, examination of the data for individual newborns revealed that a significant number of infants (10 out of 12) looked longer at the 90° delay event than at the 90° launching event (binomial test, $p = .039$).

Overall, data from Experiment 2 demonstrated that newborns prefer the *temporal discontinuity* of the 90° delay event to the temporal continuity of a non-causal launching (i.e. a launching with a 90° deviation of the trajectory of the second object to move). This result refutes the possibility that newborns' preference for the launching event found in Experiment 1 might have been due to a mere preference for temporal continuity *per se*. Moreover, since the only difference between the stimuli employed in Experiments 1 and 2 was in the *continuity* vs. *discontinuity of trajectory* between the motion of the two objects involved in each event, the opposite results obtained in these experiments might be exclusively due to this factor. Therefore, the spatial continuity of trajectory between the motion of the two objects appears to be crucial in determining newborns' preference.

The launching event, however, is characterized not only by temporal continuity and continuity of trajectory between the movements of the two objects, but also by a certain temporal sequence in the order of the displacements of the two objects involved in the event. In order to investigate whether newborns can discriminate the temporal sequence of motion, Experiment 3 was conducted, aiming to assess the role of the temporal sequence between the motion of the two objects in triggering newborns' preference.

Experiment 3

Newborns' spontaneous preference for a 'launching event' vs. a non-causal 'inverted-sequence' stimulus was tested. The launching event was identical to the launching used in Experiment 1. In contrast, the 'inverted-sequence' was identical to the launching one except for the order of the displacements of the two objects, which was swapped temporally: thus object B moved first and object A started its movement only after object B had stopped (Figure 1c). This event is not seen as causal by adult subjects, despite the presence of both temporal continuity and continuity of the overall trajectory as the launching event.

Method

Participants

A total of 22 newborns participated in the experiment from the maternity ward of the Pediatric Clinic of the University of Padua. Data from six newborns were discarded because of position bias ($n = 1$) or because they changed their state during testing ($n = 5$). Therefore the final sample consisted of 16 newborns, aged (mean ± SEM) 41 ± 5 h (range: 8–74 h). Their birth weight was between 2720 and 4205 g, and they had an Apgar score of 10 at 5 min.

Procedure

The procedure was identical to that used in Experiment 1. The mean estimated reliability between coders was 0.911 (Pearson correlation, $p = .012$).

Stimuli

A launching event and an inverted-sequence stimulus were employed. The launching stimulus was identical to the event used in Experiment 1. The inverted-sequence video animation was identical to the launching event except for the order of the displacements of the two objects, which was swapped temporally: thus object B moved first and object A started its movement only after object B had stopped. In this sequence any physical causality between the movements of the two objects was disrupted (no contact occurring between them), whereas distances covered by the objects, their velocities and perceptual features were identical to those of the launching effect (Figure 1c).

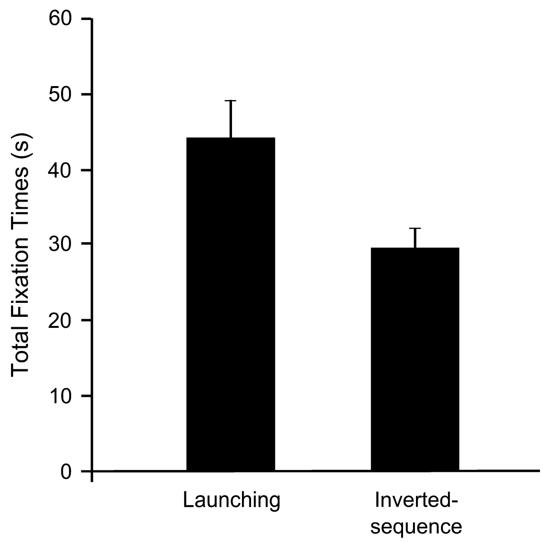

Figure 5 *Average Total Fixation Times (s) for the launching event (Mean ± SEM = 44.225 ± 4.978 s) and the inverted-sequence event (Mean ± SEM =29.711 ± 2.691s) in Experiment 3.*

Results and discussion

Newborns looked significantly longer at the launching event (mean ± SEM = 44.225 ± 4.978 s) than at the inverted-sequence stimulus (mean ± SEM = 29.711 ± 2.691 s; paired-samples two-tailed *t*-test: $t_{15} = 2.820$, $p = .013$; Figure 5). The percentage of total fixation time newborns spent looking at the launching event was (mean ± SEM) 58.880 ± 3.552% and differed significantly from chance level (one-sample two-tailed *t*-test: $t_{15} = 2.499$, $p = .025$; Figure 3, right-hand column). Finally, 12 out of 16 newborns looked longer at the launching event than at the non-causal control event (binomial test, $p = .077$, *ns*).

These data demonstrated that newborn babies are able to discriminate between two events differing only in the order of the displacement of the objects involved. Moreover, even if presented with two temporally continuous stimuli, newborns confirmed their preference for the launching event, as already shown in Experiment 1.

General discussion

The aim of the present research was to investigate the existence of an early available basic mechanism, present from birth, sensitive to certain well-defined spatiotemporal cues which determine perception of physical causality in adults. Three experiments were carried out to test whether newborns are sensitive to the temporal continuity between the motion of the two objects involved in the events (Experiment 1), the spatial continuity of the trajectories of the two objects (Experiment 2) and the temporal sequence of the displacements of the two objects (Experiment 3).

In Experiment 1 newborns demonstrated being able to discriminate between two events differing only in their temporal parameters. More importantly, newborns not only discriminate but also manifest a preference (expressed by increased looking times) for the event characterized by temporal continuity between the motion of the two objects (i.e. the launching event) when compared to an event totally identical except for the presence of a delay between the movement of object A and B (i.e. delay event). One can interpret this preference either as a preference for the launching event or as a preference for temporal continuity *per se*. To assess which hypothesis is correct, in Experiment 2 newborns were presented with the same two events as in Experiment 1 in what concerns their temporal parameters, but different with regard to the spatial parameters. More specifically, in both events of Experiment 2 the trajectory of object B was diverted by 90° with respect to the trajectory of A. In a launching stimulus this 90° deviation of the trajectory of B with respect to A is known to abolish the perception of causality (Michotte, 1963). If the results of Experiment 1 were due to a preference for temporal continuity *per se*, we would also expect a choice in favour of the temporally continuous stimulus (i.e. the '90° launching event') in Experiment 2. However, results of Experiment 2 were the opposite of those of Experiment 1: in contrast to Experiment 1, newborns preferred the 90° delay event. Since the only difference between the stimuli employed in the two experiments was in the *continuity* (Experiment 1) vs. *discontinuity* (Experiment 2) of trajectory between the motion of the two objects, we conclude that this spatial component also demonstrated being crucial in determining newborns' preference.

In Experiment 3 we tested newborns' sensitivity to the order of the displacements of the objects involved in an event. To this end a launching event (completely identical to the one used in Experiment 1) and an inverted-sequence stimulus were employed. The inverted-sequence event was identical to the launching event except for the order of the displacements of the two objects which was swapped temporally. Newborns showed that they were able to discriminate between these two events and confirmed their preference for the launching event.

To summarize, newborns manifested a preference for the launching event (Experiment 1). This preference was not a mere preference for the temporal continuity *per se*, since the same temporal continuity was not able to trigger a preference for the launching when the spatial parameters of the events were manipulated in order to destroy the continuity of trajectory between the two objects involved in the events (Experiment 2). Moreover, neither the temporal continuity nor the continuity of trajectory between the motion of the two objects *per se* can induce any preference, since the order of the movements of the two objects was revealed to be also fundamental in determining newborns' preference for the launching event (Experiment 3).

Overall, newborns seem to be sensitive to the additive effect of a set of perceptual cues (i.e. temporal continuity between the motion of the two objects involved in the event, continuity of trajectory between the motion of the two objects, and the sequence of the displacements of the two objects) which are crucial in determining perception of physical causality in adults. Human adults themselves, in fact, perceive physical causality in an event exclusively when the parameters of motion of the two objects involved are consistent with a single motion transferred from the first object to the second one (Michotte, 1963).

From this perspective, our results provide the very first demonstration of newborns' sensitivity to the same perceptual properties of a stimulus which determine perception of physical causality in adults. Moreover, we demonstrated for the first time that newborn babies are driven by such properties in expressing their visual preferences, looking longer at the stimulus consistent with both the spatial and temporal parameters of a physically causal one (i.e. the launching effect).

Our data, therefore, seem to be in favour of the existence of an innate visual mechanism sensitive to certain well-defined spatiotemporal cues which tightly correlate with adults' causal perception. Moreover, if a causal perception does exist '*in the same sense that there is perception of shapes, movements, and so on*' (Michotte, 1963, p.86), being insulated from higher-level causal inferences and representations (Michotte, 1963; Schlottmann & Shanks, 1992; Carey, 2009), such a mechanism would suffice to allow newborns to perceive causality independently of any prior visual experience.

The ability to perceive and discriminate at birth some perceptual spatiotemporal cues present in a physically causal event does not necessarily ensure the presence of any causal reasoning (i.e. causal inferences and higher-level causal representation) from birth. In this sense, the presence of a sensitivity to the additive effect of some visual spatiotemporal cues that in adults determine the perception of 'physical causality' is a sort of jumpstart to the development of causal reasoning, characterized by abstract concepts that in no way denies a role of development. The sensitivity to these perceptual spatiotemporal cues and the presence of causal perception at birth is just a first step in the investigation of the origin of causal representations.

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References

Aristotle (1980). *The physics*. Cambridge, MA: Harvard University Press.

Bulf, H., Johnson, S.P., & Valenza, E. (2011). Visual statistical learning in the newborn infant. *Cognition*, **121** (1), 127–132.

Carey, S. (2009). *The origin of concepts*. Oxford: Oxford University Press.

Carey, S., & Spelke, E. (1996). Science and core knowledge. *Philosophy of Science*, **63** (4), 515–533.

Choi, H., & Scholl, B.J. (2004). Effects of grouping and attention on the perception of causality. *Perception & Psychophysics*, **66**, 926–942.

Choi, H., & Scholl, B.J. (2006). Measuring causal perception: links to representational momentum? *Acta Psychologica*, **123**, 91–111.

Cohen, L.B. (1998). An information-processing approach to infant perception and cognition. In F. Simion & G. Butterworth (Eds.), *The development of sensory, motor, and cognitive capacities in early infancy* (pp. 277–300). Hove, East Sussex: Psychology Press.

Cohen, L.B., & Amsel, G. (1998). Precursors to infants' perception of causality. *Infant Behavior and Development*, **21**, 713–731.

Cohen, L.B., Amsel, G., Radford, M.A., & Casasola, M. (1998). The development of infant causal perception. In A. Slater (Ed.), *Perceptual development: Visual, auditory, and speech perception in infancy* (pp. 167–208). Hove, East Sussex: Psychology Press.

Cohen, L.B., & Oakes, L.M. (1993). How infants perceive a simple causal event. *Developmental Psychology*, **29**, 421–433.

Gava, L., Valenza, E., & Turati, C. (2009). Newborns' perception of left–right spatial relations. *Child Development*, **80** (6), 1797–1810.

Johnson, M. (1990). Cortical maturation and the development of visual attention in early infancy. *Journal of Cognitive Neuroscience*, **2**, 81–95.

Leslie, A.M. (1982). The perception of causality in infants. *Perception*, **11**, 173–186.

Leslie, A.M. (1984). Spatiotemporal continuity and the perception of causality in infants. *Perception*, **13**, 287–305.

Leslie, A.M. (1986). Getting development off the ground: modularity and the infant's perception of causality. In P. van Geert (Ed.), *Theory building in development* (pp. 405–437). Amsterdam: Elsevier.

Leslie, A.M. (1988). The necessity of illusion: perception and thought in infancy. In L. Weiskrantz (Ed.), *Thought without language* (pp. 185–210). Oxford: Oxford University Press.

Leslie, A.M., & Keeble, S. (1987). Do six-month-old infants perceive causality? *Cognition*, **25**, 265–288.

Mascalzoni, E., Regolin, L., & Vallortigara, G. (2010). Innate sensitivity for self-propelled causal agency in newly hatched chicks. *Proceedings of the National Academy of Sciences, USA*, **107**, 4483–4485.

Michotte, A. (1963). *The perception of causality*. New York: Basic Books.

Oakes, L.M. (1994). The development of infants' use of continuity cues in their perception of causality. *Developmental Psychology*, **30**, 869–879.

Oakes, L.M., & Cohen, L.B. (1990). Infant perception of a causal event. *Cognitive Development*, **5**, 193–207.

Rochat, P., Striano, T., & Morgan, R. (2004). Who is doing what to whom? Young infants' developing sense of social causality in animated displays. *Perception*, **33**, 355–369.

Saxe, R., & Carey, S. (2006). The perception of causality in infancy. *Acta Psychologica*, **123**, 144–165.

Schlottmann, A., Ray, E., Mitchell, A., & Demetriou, N. (2006). Perceived social and physical causality in animated motions: spontaneous reports and ratings. *Acta Psychologica*, **123**, 112–143.

Schlottmann, A., Ray, E., & Surian, L. (2012). Emerging perception of causality in action-and-reaction sequences from 4 to 6 months of age: is it domain specific? *Journal of Experimental Child Psychology*, **112** (2), 208–230.

Schlottmann, A., & Shanks, D. (1992). Evidence for a distance between judged and perceived causality. *Quarterly Journal of Experimental Psychology*, **44** (A), 321–342.

Schlottmann, A., Surian, L., & Ray, E. (2009). Causal perception of action-and-reaction sequences in 8- to 10-month-old infants. *Journal of Experimental Child Psychology*, **103**, 87–107.

Spelke, E.S. (1990). Principles of object perception. *Cognitive Science*, **14**, 29–56.

Spelke, E.S., & Kinzler, K.D. (2007). Core knowledge. *Developmental Science*, **10** (1), 89–96.

Sperber, D., Premack, D., & Premack, A. (1995). *Causal cognition: A multidisciplinary debate*. Oxford: Oxford University Press.

Valenza, E., & Bulf, H. (2011). Early development of object unity: evidence for perceptual completion in newborns. *Developmental Science*, **14** (4), 799–808.

Valenza, E., Leo, I., Gava, L., & Simion, F. (2006). Perceptual completion in newborn human infants. *Child Development*, **77**, 1810–1881.

White, P.A. (1995). *The understanding of causation and the production of action*. Hillsdale, NJ: Erlbaum.

White, P.A. (2006). The role of activity in visual impressions of causality. *Acta Psychologica*, **123**, 166–185.

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