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**ORIGINS OF SENSITIVITY
TO PHYSICAL CAUSALITY AND ANIMACY:
Evidence from newborn babies and newly-hatched chicks**

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I

General Introduction

Two central issues in cognitive science regard the exploration of humans' striking capability to perceive causal relations between objects and our capability to detect the animated "agents" acting in those events (i.e., "mechanical agents", entities capable of self-directed motion and of taking on the role of causal agent).

Regarding the attribution of causality, it appears to be a powerful mechanism for perceiving every day experiences, in such a way we may make sense of almost any aspect of the physical world. Understanding causal representations has long been a challenge both for philosophers (Aristotele, *Physics*) and psychologists (see Sperber, Premack and Premack, 1995). Psychological research has focused on exploring higher-level cognitive processing (i.e., the dynamics of causal inferences, Sperber, Premack and Premack, 1995), whilst at the same time much critical work on causality has concentrated on the role of perceptual processing (Michotte, 1963).

As regards the latter perspective, recently a growing interest in the earliest causal representations has produced a range of experimental data in developmental studies (Leslie, 1984; Leslie and Keeble, 1987; Oakes and Cohen, 1990; Cohen and Oakes, 1993; Oakes, 1994; Cohen and Amsel, 1998; Cohen, Rundell, Spellman and Cashon, 1999), such data has been used in support of two very different models of the origin of causal perception. On the one hand, Leslie and colleagues (Leslie and Keeble, 1987) suggested the existence of an innate, domain-specific visual module responsible of causal perception (Leslie, 1988). In contrast, Cohen and

colleagues supported a constructivist account. The perception of causality would be demonstrably not innate and not domain specific (Cohen and Amsel, 1998; Cohen, Chaput and Cashon, 2002): it would be a result of perceptual and cognitive development (Oakes and Cohen, 1990).

Until now, however, perception of physical causality has never been investigated in subjects under conditions in which previous experiences have been effectively controlled for (e.g., in newborn babies). Moreover, nothing is known specifically about the capability to perceive physical causality in animal species other than our own. The fact that this perception is hardly affected by higher-level beliefs or intentions (whereas it seems to depend on a highly constrained collection of visual cues; e.g. Choi and Scholl, 2004; Choi and Scholl, 2006; Schlottmann, Ray, Mitchell and Demetriou, 2006; White, 2006), nevertheless, seem to support a precocial ontogenetic (and phylogenetic) origin of such capability.

Regarding the capability to attribute “animacy” to moving objects solely on the basis of their pattern of motion (Heider and Simmel, 1944; Michotte, 1963; Schlottmann, Ray, Mitchell and Demetriou, 2006), self-propulsion seem to provide one of the most powerful cues about what makes an object “animate” (New, Cosmides and Tooby, 2007). Developmental studies have shown that infants are sensitive to this particular cue of animacy since 5 months of life, being able to distinguish between motion that has no obvious external cause, and motion caused by an external event such as a collision. (Luo and Baillargeon, 2005; Luo, Kaufman and Baillargeon, 2009). It seems possible, therefore, that human infants may be born with some precocious understanding of animacy, although the sensitivity to animacy has never been investigated in *naïve* subjects. Moreover, natural selections could have shaped the perceptual system to be particularly sensitive to cues of animacy and such capability would be shared with animal species other than our own.

Considering the lack of research about perception of physical causality and animacy by *naïve* subjects and animal species other than our own, in my

Chapter I

research I tried to examine both the ontogenetic and phylogenetic origins of such capabilities.

The first part of this thesis will be concerned with the issue of the perception of physical causality. In Chapter 2 experimental literature about such issue will be reviewed. In Chapter 3 I will describe my research about sensitivity to physical causality in both newborn babies (*Homo sapiens*; Study 1) and newly-hatched domestic chicks (*Gallus gallus*; Study 2).

The second part of my thesis will concern the origin of animacy attribution (i.e., causality in the domain of agency). The scientific literature about such matter will be reviewed (Chapter 4), and subsequently my experimental contribution about domestic chicks' susceptibility to self-propulsion as a cue to animacy will be described (Chapter 5).

Altogether, this set of investigations will contribute to verify whether the capability to perceive physical causality and animacy is already present at birth (Chapter 6), supporting the theoretical hypothesis that posits that human cognitive system is endowed with an inborn representational system for objects, agents and their relations (Carey, 2009).

II

The Perception of Causality

1. Michotte and the Launching Effect

Michotte exposed his theory about causal perception in his seminal book *La perception de la causalité* (1946/1963). In this book he reported more than 100 studies, working out in details how and when the perception of causality does and does not occur. He was mainly interested in the perceptual process of causal impression.

He firstly looked for a method to produce experimentally a genuine impression of causality and he found that the “*causal impression*” could be produced perfectly by using simple coloured shapes or even images/shadows projected onto a screen. This fact was important both theoretically and for practical experimentation. In fact, Michotte devised two brilliant new methods of stimuli presentation.

The most famous is indubitably the disc method, which needed various intricate spirals drawn on a disc in slow rotation (Fig. 1). When seen through a small slit this spirals appeared as small figures which translated back and forth.

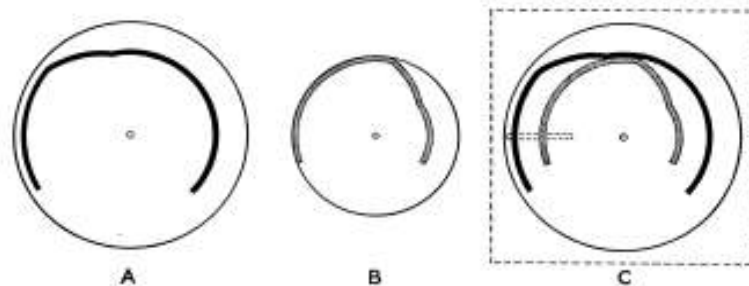


Fig. 1. Combinations of discs used in experiments on physical causality (Michotte, 1963).

Such method has proved extremely valuable for his research. In fact, it made possible to produce a large number of combinations of movements of one or more objects, such movements could be in any direction (according to the position of the slit) and took place with controlled speed, length of path and distance between objects. Moreover, with such method it was possible to produce effects that contradicted the laws of dynamics and were in contrast with rules learned by experience.

Nevertheless, the disc method suffered some limits. In fact, only rectangular objects could be used and they had to be of a small height because of the slit, which had to be small to correctly perceive the illusion of linear movement. Moreover, it was difficult to produce movements different than linear ones, the slid made a perceivable corridor and, lastly, due to the slid, the shape of the objects was not absolutely the same when they were at rest (i.e., rectangles) and when they moved (i.e. diamonds).

For such reasons a second method was employed, which involved two Kodak 2x2 in. miniature projectors (Michotte, 1963). The movement of the projectors was under the control of a single motor, operating by means of a transmission system, which allowed for different combinations of speeds (Fig. 2). The experimental conditions made by this apparatus allowed for objects of any shape and size, several different speeds, a background without limits

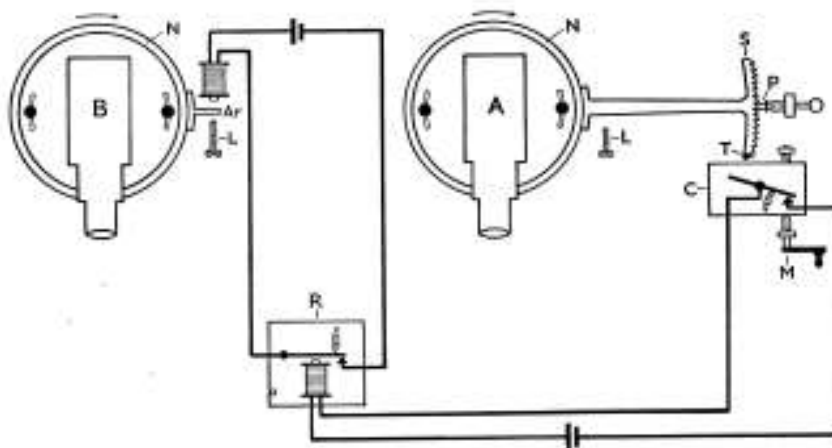


Fig. 2. System to realize the movement of the two projectors (A and B) used in experiments on physical causality (Michotte, 1963).

of size and shape. Moreover, the relative directions of the paths of the objects could be altered both by a parallel and an angular shift, the objects could be projected onto different planes and it was possible to associate a movement of the first object with a qualitative change in the second one.

In his practice, Michotte more often used the disc method, whereas the projectors method was employed for control purposes or for experiments which could not be performed in the disc way.

By employing these two methods it became possible for him to carry out several different experiments, making the causal impression appear and disappear, and linking the causal impression with other well-known perceptual phenomena. It was with such methods that Michotte created the best-known example of physical causality, the Launching Effect.

In this stimulus, one object (A) moves towards another stationary object (B) until they are adjacent. When A comes into contact with B, A stops and B starts moving in the same direction and along the same path previously taken by A (Fig. 3).

In such stimulus Michotte reported that subjects “see object A bump into object B” and “launch it”, “shove it forward, set it in motion, give it a push” (Michotte, 1963). The impression is clear: it is A which makes B moving.

Michotte reported that in such kind of stimulus the impression of causality is immediate and the production of B’s movement by A is thus directly experienced. There is no question of an interpretation: the causality perceived in the Launching Effect is a phenomenal causality.

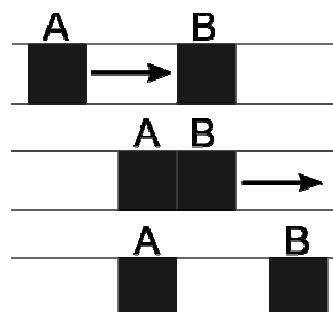


Fig. 3. The schematic sequence of a Launching Effect.

Studying the Launching Effect, Michotte intended to better understand the mechanisms concerning the perception of physical causality. For such purpose, he developed the method named "*genetic analysis*" (Michotte, 1963). Such method consisted essentially in simplifying the conditions which had been found necessary for having the causal impression in the Launching Effect, and in comparing the resultant perceptions with those given by the original stimulus. In such way he was able to trace, step by step, the genesis of the perception of causality.

He firstly noticed that the causal impression requires two objects to perform the movements, and that the two objects should be simultaneously present during each movement. The objects in fact play two roles. Firstly, they act as "*segregative agents*" for the movements: they maintain the distinction between the two movements which compose the Launching Effect, the Approach Movement (i.e. the movement played by object A) and the Withdrawal Movement (i.e. the movement played by object B). Secondly, they act as a "*centre of reference*" for their respective movements. In fact, only a part of the two movements, on either side of the point of contact between the objects, seem to be included in the Launching Effect. Michotte named such part of movement "*radius of action*" of object A and object B. Such "*radii of action*" give a certain maximum spatial limit, and consequently temporal one, to the action of the Launching Effect, and are strictly correlated to the speed of the two objects. It is in such context that each object acts as a centre of reference of the motion of the other one, "*polarizing*" its movement (in fact, it is in relation to the second object that A's movement developed, and vice versa). Hence, the objects act as "*segregative factors*" which guarantee the perception of two distinct movements (the Approach and the Withdrawal), the perception of such distinct movements being necessary to the Launching Effect.

In contrast with those "*segregative factors*" Michotte highlighted certain specific spatial, temporal and kinematic conditions necessary to perceive the Launching Effect, such conditions act as "*integrative factors*" which tend to link the movements in one whole. Regarding the Temporal aspect, it is

essential to the production of the Launching Effect that the second movement does succeed the first rapidly. In fact, a delay as short as 50 ms (such stimulus being named Delayed Launching) is sufficient to destroy any causal impression. The impression of Launching, in fact, is maintained as long as the perception is compatible with the unity of movement of a single object. The Launching Effect can appear, however, when there is a spatial gap between the final position of object A and the starting position of B, giving the impression of a *Launching-at-distance*. Even in this case, nevertheless, the Launching-at-distance is perceivable only if the gap is shorter than the radii of action, and no Launching Effect is perceived if there is a change in the trajectory of object B with respect to the trajectory of A. In fact, an angle of 25° between the two paths is sufficient to weaken the Launching Effect, which completely disappears with a 90° angle (Michotte, 1963, p. 102). Therefore, also in the case of the spatial component there is a better chance to perceive the Launching Effect when the paths of the two movements favour the perception of a simple and strong spatial unity. Finally, with regards to the kinematic aspects, there is a critical range of speeds to which the Launching Effect is restricted. When the movement of A is faster than the movement of B, and such difference is moderate, there is a strengthening of the tendency towards integration: the Launching Effect is better perceivable. If there is a high difference between the speeds of the two objects, or there is a small difference but the faster object is B, this act as a segregative factor on the movements and the Launching Effect is hardly seen. Indeed, to perceive the causal relation of the Launching Effect, spatiotemporal and kinematic conditions are required which particularly favour the integration of the two movements in a unity.

Michotte, hence, highlighted that the conditions necessary to produce the causal impression of the Launching Effect “*are apparently contradictory*” (Michotte, 1963 p. 127). The causal impression, in fact, derives from a reconciliation of opposing tendencies: a segregative tendency (i.e. the tendency exerted by the two objects) and an integrative tendency (i.e. the one exerted by the spatiotemporal and kinematic properties of the

Launching). The result of such tendencies is that in the Launching Effect two distinct events are implied, the Approach and the Withdrawal, which are characterised by a qualitative difference in their motion (due to their different polarization). Nevertheless, such events are not simply juxtaposed since “*they form an ensemble, a whole*” (Michotte, 1963 p. 129). In the Launching Effect we have no longer two distinct phases but a single event which produces the perception of an “*impact-with-launching*”. In fact, in the Launching Effect only an active form of movement is actually seen, the movement of A, which becomes dominant over the passive motion of B. The active movement of A dominates over B in virtue of both the importance of its perceptive role and its earlier position in time.

Michotte named such hierarchy between the movements of the two objects “*Hierarchy of Priority*”, and identified in it one of the most important unifying elements of the Launching Effect.

Due to its peculiar features, Michotte suggested that the Launching Effect must be considered as a perceptual Form (*Gestalt*), characterised by a specific internal structure. “*There is actual perception of causality*”, he wrote, “*in the same sense that there is perception of shapes, movements, and so on*” (Michotte, 1963, p. 86). In fact, the Launching Effect occurs when there are certain definite conditions of stimulation and reception, and it disappears as a result of appropriate modifications in the stimulus-conditions, or as a result of changes in the observer’s attitude which lead to the substitution of a different Form. Therefore, “*it is out of the question to regard the causal aspect of the launching effect as due to an ‘act of interpretation’ on our part, or to suppose that, under the influence of past experience or in some other way, we ourselves invest certain basic impression of movement with a ‘meaning’*” (Michotte, 1963, p. 86).

Michotte’s research has been important and innovative in at least two ways. He devised new methods allowing to experimentally investigate for the first time the perception of physical causality. Such new methods, moreover, allowed him to formulate his theory of causality as rooted in automatic visual

processing, in a strong contrast with all the previous philosophical theories (such as Hume's theory). Michotte himself recognized that "*if Hume had been able to carry out an experiment such as ours, there is no doubt that he would have been led to revise his views on the psychological origin of the popular idea of causality*" (Michotte, 1963, p. 256).

Since Michotte, many other investigators have extended the researches about physical causality. Researchers have explored the influence on causal perception of different spatiotemporal patterns (Kanizsa and Vicario, 1968; Schlottmann and Anderson, 1993; Choi and Scholl, 2006; Schlottmann, Ray, Mitchell and Demetriou, 2006), attention (Choi and Scholl, 2004), higher-level expectations (White, 2005) and many other factors.

The following paragraphs, however, will focus on theories about the origin of causal perception, a matter relevant to the purposes of such thesis.

2. Theories about the origin of causal perception

There is no doubt that humans represent the world in terms of a rich cause-effect texture (Carey, 2009): causal perception and reasoning are, undoubtedly, skills of great value, since understanding causal relations is what allows people to predict and control their environment (Cohen, Rundell, Spellman and Cashon, 1999).

For centuries philosophers have debated the origins of causal perception but it is only in the past several years that developmental psychologists have systematically investigated infant's perception of external causal event. There are in fact two possible questions regarding how we come to represent some connections between covariant events as causal: the epistemological question, which concerns justification and relates to the reasons for which we are justified in perceiving some events as causally connected, and the psychological question, concerning the basic cognitive structures at the basis of causal perception and representation (Saxe and Carey, 2006). Philosophers address the epistemological issue, whether cognitive scientist

focused on the psychological one. Researches about the origin of causal sensitivity, too, belong to this last perspective.

Two main different theories have been put forward regarding the origin of human capacity for causal representation. According to the Rationalist Theory, the capacity for causal perception and representation may be innate. According to the Constructivist Theory, instead, there may be no innate representation of cause, and causal notions would be constructed from experience. Such theories are going to be precisely described in the following paragraphs.

2.1. The Rationalist Theories

2.1.1. Michotte and the “perceptual input analyzer”

Regarding the origin of causal perception, Michotte (1963) firstly set off the extreme empiricist approach he attributed to Hume¹: *“the idea of causality (in the sense of necessary connexion) is derived [...], according to Hume, from the regularity in the succession of phenomena; it is based entirely on anticipation, on the expectation that when one event occurs, another event, which ordinarily follows it, will do so again”* (Michotte, 1963, p. 7).

Michotte thought that the empiricists’ reduction of causal perception to the spatiotemporal and phenomenal features of the event could be a reasonable epistemological response (*“from the evidence, the conclusion seemed inevitable that we never can [...] discover anything in the unfolding of natural events except their simple succession. [...] Indeed the truth of Hume’s claim is obvious [...]”*; Michotte, 1963, p. 8), but not a psychological one. In fact, *“even though this mode of observation was the most suitable to give an*

¹ Commentators highlighted that Michotte’s interpretation of Hume’s theory is not correct. Hume, in fact, thought that a “causal sense”, such as moral and aesthetic judgments, was innate and projected onto the world by the mind.

accurate account of physical facts, it had the result of splitting the phenomenal world into pieces and making the most interesting psychological facts disappear" (Michotte, 1963, p. 8).

The thesis which he put forward was in total disagreement with the traditional empiricist one previously described. He wrote: *"I expressed the opinion that certain physical events give an immediate causal impression, and that one can 'see' an object act on another object, produce in it certain changes, and modify it in one way or another"* (Michotte, 1963, p. 15). This is the case, for instance, of the Launching Effect, in which the motions of the two objects have parameters consistent with a single motion transferred from one object to the other. Since causality perceived in this display is fast, automatic and not influenced by subject's explicit causal beliefs, Michotte noticed that it seems to be a pure perceptual process rather than a conceptual inference. For such reason, Michotte proposed a specific perceptual mechanism (named *"perceptual input analyzer"*) at the basis of the perception of causality, such mechanism receives specific visual inputs (i.e. with certain spatiotemporal parameters) and transforms them into an *"immediate causal impression"* (Michotte, 1963). This mechanism would be modular in a way anticipating Fodor (1983): fast, automatic, data driven from limited and specific input, and encapsulated from explicit knowledge (Saxe and Carey, 2006).

For such reasons, Michotte considered the capability to perceive causality as innate: the perceptual input analyzer would allow to perceive the physical causality laying in some perceptual displays (such as the Launching Event) and would be the developmental source of any other causal representation. Michotte noticed, in fact, that *"there are many cases where a causal interpretation must be the result of an elaboration, by means of reflection, on the data of experience"* (Michotte, 1963, p. 257). This would be the case of the *"pure qualitative causality"*, such as the causality perceived in the case of *"the lighting of an electric lamp when someone presses down the switch"* (Michotte, 1963, p. 258): *"it is clear that we apply the idea of causality to these cases quite spontaneously, and apparently without any reflection or*

reasoning” (Michotte, 1963, p. 258). Nevertheless, “*since causality is not ‘given’ in these cases, the idea of it cannot be derived directly from the ‘experiences’ in question. Thus the claim that causality is intervening must rest on an inference, an inference which itself presupposes the existence of an original idea of cause*” (Michotte, 1963, p. 257).

This “*original idea of cause*” would be right the result of the activity of the perceptual input analyzer, which would give rise to the ontogenetically primary causal concept: the representation of mechanical causality. Therefore, Michotte concludes “*that the causal impression in the strict sense [i.e., the mechanical causality based on the perceptual input analyzer] forms the basis on which the clearly defined idea of cause is founded, and that, once acquired, this idea can be applied without further consideration to the case of immanent activity [i.e., voluntary actions and qualitative causality] as a result of the qualitative likeness between the phenomena*” (Michotte, 1963, p. 271).

According to Michotte, therefore, an innate module (i.e., the “*perceptual input analyzer*”) would give rise to the original perception of mechanical causality, from which all the other types of causal perceptions and inferences arise.

2.1.2. de Biran, White and the “actions haptically perceived”

Obviously the one by Michotte is not the only possible rationalist theory: other authors posited innate representation of cause, one of such authors is represented by the philosopher Maine de Biran. De Biran posits the origin of causal perception on the capacity of act upon objects: “*a being who has never made an effort would not in fact have any idea of power, or, as a result, any idea of efficient cause*” (quoted in Michotte, 1963, p. 11). The original idea of cause, therefore, derives from self-generated motion and the concept of internally generated causal power which gives rise to the sensation of physical effort (described in Michotte, 1963).

A modern version of de Biran's theory is the one by White (1988, 2006a, 2006b). As previously done by Michotte, White noticed a striking feature of the Launching Effect and other causal displays, such feature is that the most relevant role is played by object A, whereas nothing is said by the subjects about the role of B (White, 2006a-b). From a descriptive point of view of the Launching Effect, for instance, B could be perceived having a role both in its own motion as well as in A's stopping. In fact, the post collision motion of B is determined by B's mass and speed as well as by A's. Moreover, B contributes to A's stopping, but none perceives it at all. "*These two inaccuracies,*", he wrote, "*failing to perceive or underestimating the contribution of B's dynamical properties to its own post-collision motion, and failing to perceive the contribution of B's dynamical properties to A's post-collision motion, are two versions of what I have called the causal asymmetry*" (White, 2006b, p. 168). White noticed that the common feature between the objects usually perceived as causal (in several displays such as Launching or Pulling displays) is that they are always *active* first, whereas the objects not perceived as causal are *inactive* at first: "*perceptually, the only candidates for causes are objects that appear to be doing something, i.e., objects that have kinetic energy*" (White, 2006b, p. 170).

Obviously, such argument regarding the activity of the object implied in the causal interaction is valid only for the perceived causality, since in higher cognition causal judgment implies more than a merely mechanical analysis (allowing for the detection of several kinds of causes such as intentions, states of mind, etc...). In fact, there are several steps in causal sensitivity, starting from the pure perception of a causal fact till a higher cognitive reasoning about complex causal relations.

Nevertheless, White posits a single origin for all these degrees of sensitivity to causality, such origin consists in the "*personal experiences of actions on objects haptically perceived*" (White, 2006b, p. 171): "*The development of causal understanding proceeds by spreading out from this point of origin, carrying with it the conceptual fundamentals of causal understanding and applying them to successively more diverse things*"

(White, 2006b, p. 171). These experiences would give rise to representations of actions stored in memory (i.e., “schemas”), such representations are subsequently recruited to perceptually disambiguate visual causal stimuli by a “*schema matching*” process.

Postulating the origin of causal understanding in experienced actions, moreover, allows to account for the existence of causal asymmetry. By our own actions upon objects, in fact, we become aware of the transmission of force inherent in mechanical causal relations: “*This is what we experience when we act on objects: not the covariation between our actions and their results, but the actual transfer of energy from ourselves onto the object. This is the core of our causal understanding*” (White, 2006b, p. 172). In this transmission we always play the role of cause and that of the active object. It is from this asymmetric experience that the perceived causal asymmetry would originate (White, 2006b).

White posits the “*schema matching*” at the basis of our sensitivity to causality. Such schemas could be activated by our own actions or by seeing the actions of others upon objects: “*the schema supplies the experience of producing the effect as part of the perceptual interpretation of the stimulus information*” (White, 2006b, p. 175).

White’s schema matching account is obviously extremely different to Michotte’s theory in the matter regarding the origin of causal perception. Michotte posits at the basis of causal perception an innate mechanism, whereas White’s “*schemas are acquired from experience*” (White, 2006b, p. 176). Nevertheless, White himself is considered a rationalist (Carey, 2009), since he believed that “*there may be a fundamental innate competence, concerned with the capacity to acquire schemas and use them in interpreting perceptual input*”, although “*the particular schemas that are involved in visual causal impressions are acquired, not innate*” (White, 2006b, p. 176-177).

2.1.3. The statistical account of the perception of causality

A third, recent, rationalist approach posits at the basis of causal perception the capacity of statistical inference.

Several modern cognitive scientists espouse this approach (Cheng and Novick, 1990; Dickinson and Shanks, 1995; Pearl, 2000; Tenenbaum and Griffiths, 2001; Gopnik, Glymour, Sobel, Schultz, Kushnir and Danks, 2004), based on a probabilistic notion of causal dependence. For such theories causal interactions are identified through a cognitive mechanism which detects covariation between events and conditional dependence data. A description of the principles by which causal reasoning proceeds had been established, for instance, in the Causal Bayes Nets (CBN) account of causality (Pearl, 2000), such theory describes the structure of dependence between events as a collection of assumptions about causal dependence. Unlike postulated by Michotte and de Biran, according to the CBN theory the perception and attribution of causality is not restricted to a single, specific domain: any pair of experiences can be reciprocally associated and connected in a causal relation, provided that such experiences meet the constraint of covariation. The capability to detect causal relations, moreover, would be innate since it is based on the innate resource of the CBN principles² (Gopnik, Glymour, Sobel, Schultz, Kushnir and Danks, 2004).

2.1.4. Leslie's nativist theory

Concerning nativist theories derived by experimental researches in developmental psychology, the most prominent is the one by Leslie and colleagues (Leslie, 1984; Leslie and Keeble, 1987; Leslie, 1988).

² In a recent paper, however, an alternative hypothesis on the origin of causal perception is discussed. The CBN principles, guiding causal understanding in humans, would give rise to a domain-general intuitive theory of causality, learned from experience out of more primitive representations (Goodman, Baker and Tenenbaum, 2009).

During early 80s, Leslie and collaborators conducted several experiments to investigate month-old infants sensitivity to physical causality perceivable in the Launching Effect. A first question was whether infants can distinguish the sub-movements involved in a direct launching, rather than perceive it as a single motion. To investigate infants' perception of the structure of direct Launching, Leslie's idea was to use reversal: if direct Launching is perceived as an event with a peculiar internal structure (i.e., having a specific temporal order between its sub-movements), reversing the event (i.e., playing it backwards) should change such perceived structure (Leslie, 1984).

In a first research (Leslie, 1984) he conducted three experiments employing an habituation/dishabituation technique³.

In the Experiment 1, 6 ½-month-old infants were divided into four groups. A first group (which will be named G1a in this text) was habituated to a film of a red brick colliding with a green one, such display gave rise to the perception of a direct launching (i.e., Launching Effect) in adult subjects. After the habituation criterion was reached, infants were presented with the same film simply run backwards through the projector: in this show the green brick was colliding with the red one. A control group (G1b), instead, were habituated to a film featuring the red brick only, moving across the screen along the same distance covered by both bricks in the direct launching film. In such case, too, the same film was projected backwards at test. Both groups saw a spatial reversal of the habituation stimulus, whereas only the experimental group saw a reversal of the temporal order of the two sub-movements featured in the launching. As hypothesized by Leslie, the first group (G1a) dishabituated more than the control one (G1b), such bigger dishabituation being regarded as due to the capability to detect the inversion

³ The prototypical example of habituation/dishabituation paradigm consists in repeatedly present one visual stimulus until an infant's looking time reaches to some criterion level, such as 50% of the infant's initial looking time. Novel and familiar test stimuli are then presented to see if the infant looks longer at (i.e., recovers to) the novel one. Doing so indicates the infant can differentiate between the novel and familiar stimuli, even though initially the infant may not have had a "natural" preference for one over the other (Cohen and Cashon, 2003).

of the temporal order in the reversed launching stimulus⁴ (Leslie, 1984). The design of Experiments 2 and 3, moreover, allowed infants' perception of the physical characteristics of the events to be contrasted with their perception of causality. If infants would be able to perceive causality, subjects habituated to a "direct launching" would dishabituated to a "delayed plus no-collision event" more than infants habituated to a "delayed launching" and then tested with a "no-collision event".

Leslie's results supported such causality prediction. Moreover, Leslie demonstrated a gradient of infants' attentional recovery: infants seemed to represent the degree of spatiotemporal continuity between the two movements and to use such information to judge the causality of each display (Leslie, 1984). Therefore, Leslie's results showed evidence of a response simultaneously based on causality and on independent spatiotemporal features. For such reason, Leslie proposed a one-dimensional "*spatio-temporal continuity gradient*" incorporating both types of responses (Leslie, 1984).

The results just described had been further confirmed in a later research by Leslie and Keeble (1987), in which infants were habituated either to a causal (i.e., Launching Effect) or to a non-causal event (i.e., Delayed Launching) and then tested for their attentional recovery with the same stimulus but reversed (i.e., projected backwards). Data showed that infants previously habituated to the causal event had a higher dishabituation at test. Infants, therefore, were less interested in the reversal of a non-causal event in which agency roles remained constant than in the reversal of a causal event in which the roles of agent and patient were exchanged. These findings were regarded as providing evidence that infants as young as 7 months are

⁴ These results, moreover, could not be simply due to the presence of two different colours in the stimulus employed with group 1a, regarding the launching event as a single motion. In fact, two further groups were tested: group G1c was habituated to a film featuring the red brick moving across the screen and changing its colour into green halfway across, group G1d was habituated to a direct launching identical to the one used for group 1a. Both groups were then tested with the same direct launching (not reversed). Infants showed a higher dishabituation in group G1c than in group G1d, showing to be able to distinguish between a direct launching and the motion of a single object simply changing its colour (Leslie, 1984).

able to distinguish a causal from a non-causal event and to discriminate between the roles played by the objects involved in the event (Leslie and Keeble, 1987).

Starting from these experimental evidences, Leslie treads in Michotte's footsteps and postulates the existence of a precocial visual mechanism that operates "*automatically and incorrigibly upon the spatiotemporal properties of events yet producing abstract descriptions of their causal structure*" (Leslie 1988, pp 186-187). According to Leslie, such mechanism would work at three levels of analysis (illustrated in Fig. 4). At a first level, the system would compute and orthogonally represent the spatial and temporal relations between the sub-movements of the event; at a second level such relations would be summed to produce a re-description of the event in terms of

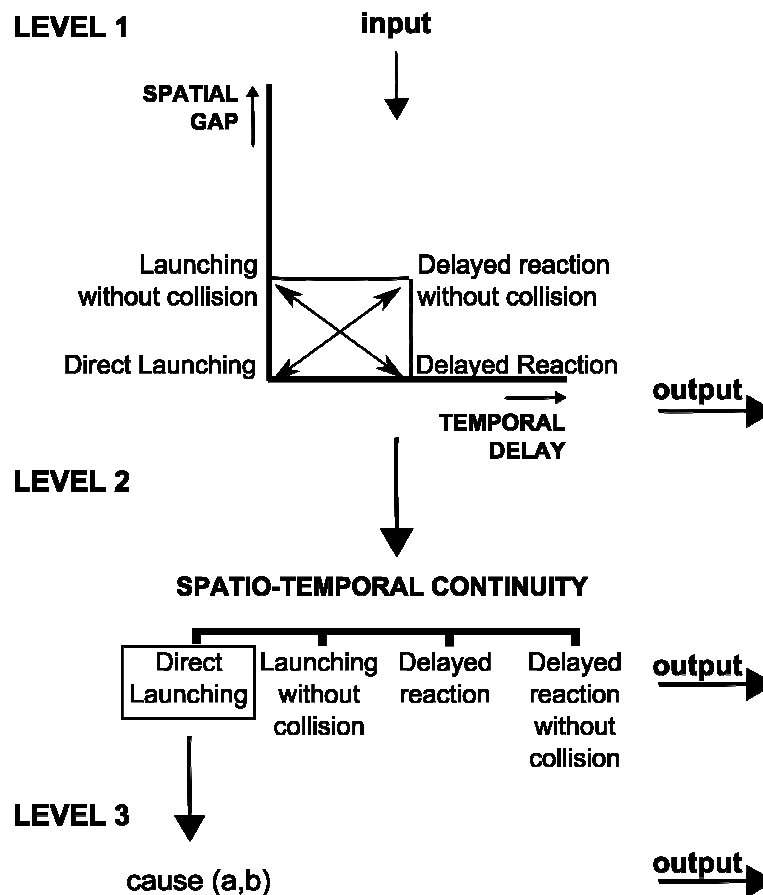


Fig. 4. Leslie's working hypothesis about causal perception (modified from Leslie and Keeble, 1987).

spatiotemporal continuity, such continuity would allow for an attribution of causal roles and a description of causal structure at level three. The output of such mechanism would subsequently be further processed by the visual system or transferred to central cognitive processes (Leslie and Keeble, 1987).

This visual mechanisms would be already effective from birth and would operate throughout life. It would consist in an “*automatic starting engine for encyclopaedic knowledge*” (Leslie, 1988, p. 194): “*it can provide a conceptual identification of input from the environment, in terms of cause and effect, in exactly the right format for inferential processes, and do this even in the absence of past experience. This is perfect for a mechanism whose job is to help produce development*” (Leslie, 1988, p. 194). The function of such mechanism would be, in fact, to create common sense theories about physical world. This visual mechanism would consist in a modular device which automatically provides elaboration upon the right inputs, “*distinguishing causal connected events from those which merely co-vary or are coincidental*” (Leslie, 1988, p. 194).

According to Leslie, therefore, causal understanding originates in a low level visual module, such module being also responsible of adults’ perception of physical causality: there should be no development of this type of perception, regardless of age and stage of cognitive development. The modular nature of such mechanism would be confirmed by its fixed, automatic and mechanical occurrence, which is not influenced at all by higher-level cognitive processes (Leslie and Keeble, 1987). Causality would be automatically perceived by infants as a function of the spatial and temporal features of the events themselves.

2.1.5. To summarize: about rationalist theories

All the rationalist theories postulate an innate or at least very precocial origin for the capability to perceive causality.

All such theories, however, differ in what are considered to be the most basic inputs used to identify causal interactions in the world (i.e., inputs from which the full concept of causality is successively generalized or derived). According to Michotte, the ontogenetically primary causal concept is the representation of mechanical causality (i.e., the detection of a transmission of power between two objects in motion) as detect in the Launching Effect (Michotte, 1963); according to de Biran and White, the source of human concept of cause is the capability to effect changes in the environment (i.e., the experienced agency; White, 2006a and b); the statistical approach posits the privileged input in the representation of conditional probabilities between events; finally, according to Leslie and colleagues, specific visual inputs would exist upon which operates an innate visual module (Leslie and Keeble, 1987).

2.2. The Constructivist Theory

Recent experimental data have cast doubt on a nativist view of causal perception, giving rise to a number of questions about what modularity would mean in this specific context (Cohen and Amsel, 1998).

An alternative explanation for the origin of infant causal perception, therefore, has been put forward, such explanation considers causal perception as developing during the first year of life (Cohen and Amsel, 1998). The most prominent theory about the development of sensitivity to causal perception is the “Information Processing View”, by Cohen and colleagues (Cohen, Chaput and Cashon, 2002).

According to such theory infants' visual information processing changes systematically with development. Initially, infants may attend to simple features of objects, such as shape, colour, and type of motion. At a further stage, they may process the relations among those features, and attend to the object itself as a unitary entity. Finally, infants may begin to learn about relationships among objects and actions, and integrate them into an event. Since "cause and effect" is one of such relationships among objects, the perception of causality would be developed across the first year of life. Such developmental trend is shown in a lot of fields, the developmental trajectory being always the same whereas the particular ages differ as a function of the type of task (Cohen, Chaput and Cashon, 2002).

This "Information Processing View" makes two distinctly different predictions than Leslie's modular view (1988).

Firstly, such developmental framework allows to predict that infants tested with identical events at different ages would attend to different aspects of such events. At a first stage infants would be able to detect only the specific features of the objects involved in a causal event and the specific spatiotemporal features of their movements (i.e. how the objects move, whether or not there is a contact, the presence of a delay, etc). Only in a further stage of development, infants could process the event as a whole in terms of the type of relationship between the objects. It would be at such stage that they would be able to perceive the event as causal/non-causal, and that the Launching Effect "*should take on a special 'causal' status*" (Cohen and Oakes, 1993). The perception of independent spatial and temporal features, hence, would be a developmental precursor to later causal perception (Cohen, 1998; Oakes and Cohen, 1994). Therefore, a decrease over development in responding to independent spatiotemporal features and an increase in responding to causality would be expected.

The other different prediction than Leslie's model relates to the "*infants incorporation of the specific objects present in the events*" (Cohen and Oakes, 1993). According to the Modularity View, the types of objects involved in the causal event would be irrelevant for the causal percept (Michotte,

1963; Leslie, 1988). In fact, Michotte himself (1963) reported experiments in which adult subjects perceived physical causality even in a launching event featuring two moving shadows. From this perspective, the only relevant factors to perceive the causality in a Launching Event are that the objects exhibit spatial and temporal contiguity and that continuity of motion exists between the movements of the two objects. Cohen and collaborators, on the contrary, would suggest that the specific objects involved in the event *are* important for infants. Such importance lies in the fact that infants are perceiving a relationship between two specific objects: causality is perceived not as a general property but as a specific relationship between the two actors involved in the specific event. Spatial and temporal features of the event trigger the perception of object A as a causal agent and object B as a recipient of the causal relation (Cohen and Oakes, 1993).

Experimental data have been collected to support the prediction of the Constructivist Model.

Regarding the first prediction (i.e. the presence over development of a decrease in responding to spatiotemporal features and an increase in responding to causality), Cohen and Amsel in 1998 conducted a research similar to the one by Leslie (1984), with the aim to explore whether infants' causal perception is innate or does develop during the first months of life (Cohen and Amsel, 1998). Three groups of infants of different ages (4, 5 ½, 6 ¼ months of life) were tested with an habituation/dishabituation paradigm. The stimuli consisted in three video animation featuring two circles (i.e. a red circle and a green one). In a first, causal, animation, the two objects were involved in a "Direct Launching" event. In such stimulus one circle moved from off one side of the screen, toward the second, stationary, circle. Immediately after the contact between the two objects, the first circle remained stationary in the centre of the screen and the second one moved off in the opposite direction from the approach of the first circle. The other two animations were identical to the previous one except for a spatial gap (i.e. "No-Collision" event) or a temporal delay (i.e. "Delayed Launching" event) present at the moment of contact. Such gap and delay, hence,

destroyed respectively the spatial and temporal continuity of the events, which were perceived by adult subjects as non-causal events. During habituation, infants were presented repeatedly with a single event (either “Direct Launching”, “No-collision” or “Delayed Launching”), till they reached the criterion. After the habituation they received one test trial with each of the three events (“Direct Launching”, “No-collision” and “Delayed Launching”).

The crucial set of analysis compared infants’ fixation times to the causal and non-causal stimuli in the test phase of the experiment. The crucial question was whether infants who had been habituated to a non-causal event dishabituated more to the causal test event than to the other non-causal event.

According to Leslie’s modular view, infants of each age would have dishabituated more to the causal than to the other non-causal event, being able to perceive the causal relationship between objects from the very early months of life. According to the constructivist theory, instead, a progression in the pattern of dishabituation would be expected for infants of different ages. Younger infants would dishabituate to the spatiotemporal features of the stimuli, showing the same pattern of dishabituation to both the causal and non-causal test events. Older infants, on the contrary, would be expected to be able to perceive the causal relationship between the objects and to dishabituate more to the test event which differentiate for such “causal” feature from the habituation one.

Regardless of the habituation stimulus (i.e. causal/non-causal) the 4-month-old infants looked longer at the causal event during the test, a result which seems to be in favour of a preference for continuous motion. At 5 ½ months, infants who were habituated to the causal event still looked longer at the causal test event than at either the of the non-causal test events. Both results from 4 and 5 ½-month-old infants are exactly the opposite of what the modular view would predict in an habituation paradigm. Data about 6 ¼-month-old infants, on the contrary, showed that infants habituated to the causal event looked longer at both the non-causal events at test, whereas

infants habituated to a non-causal event looked longer to the causal event than to the novel non-causal stimulus at test (Cohen and Amsel, 1998).

The authors highlighted that such results seem to be in favour of the presence of a developmental component in causal perception. In fact, it seems that infants respond primarily in terms of continuous motion at 4 months of age, in terms of spatial and temporal features at an intermediate age, and finally in terms of causality at 6 months of life. This developmental process seems to be characterised by a part-to-whole sequence, whereby infants first respond to the spatial and temporal components of the events and then combine these components to create an higher-level-concept of causality (Chaput and Cohen, 2001).

Starting from such data and from data collected in other researches (Oakes and Cohen, 1990; Cohen and Oakes, 1993; Oakes, 1994), Cohen and colleagues proposed a detailed Information Processing Approach to cognitive development (Cohen and Cashon, 2001), summarized by the following principles (Cohen, Chaput and Cashon, 2002):

- Infants are endowed with an innate information-processing system;
- Such information-processing system is hierarchical: infants form higher units from lower units;
- Still-higher units are formed by higher units;
- There is a bias to initiate processing at the highest level available;
- If an information overload occurs and higher units are not available, lower-level units are utilised;
- This learning system applies throughout development and across domains.

Such view of infants' cognitive development postulates a continuous interplay between a set of domain-general learning mechanisms and environmental experiences. The hierarchical progression of infants' development (as in Piagetian theory; e.g. Piaget, 1952) implies a bottom-up constructivist process of knowledge, such process can account for empirical findings in many different domains (Cohen, Chaput and Cashon, 2002).

Moreover, this bottom-up Information Processing Approach has been embodied by the authors in a computational model named CLA (i.e. Constructivist Learning Architecture; Cohen, Chaput and Cashon, 2002), which integrates the Piagetian constructivist theory with the basic principles of neuroscience. Such computational model has been successfully applied to the development of causal understanding in infants (Cohen, Chaput and Cashon, 2002). Fig. 5 provides a schematic overview of the different layers of the model. At the bottom there are the two input vectors, which capture both the spatial information (i.e., the Position Vector) of the two objects involved in a causal Launching Event, and the temporal information (i.e., the Movement Vector) of the event. These input vectors, hence, code the features of the event that have been demonstrated to be perceivable even by young infants (Cohen and Amsel, 1998). At a further level, a Movement Layer and a Position Layer receive the projection of the two vectors and represents the different positions and speeds separately over the course of the entire event. Finally, the top layer receives inputs from both the Movement and Position Layers and represents the event as a whole.

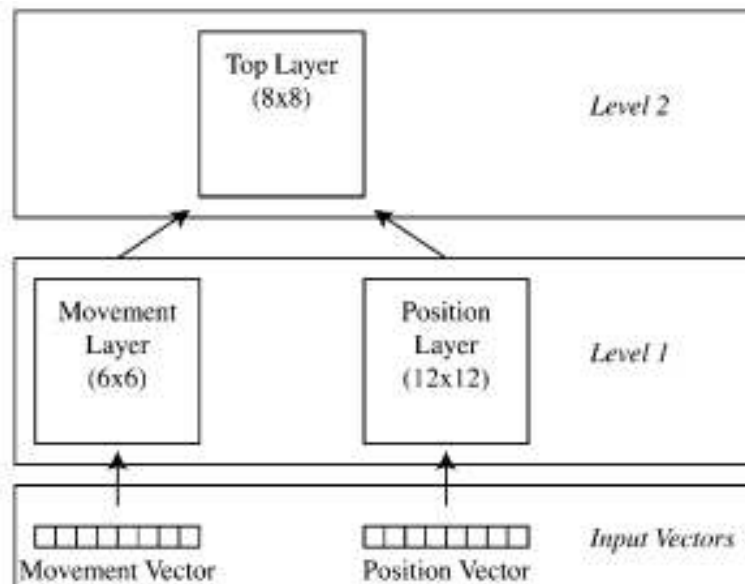


Fig. 5. A schematic of the CLA model of infants' development of causal understanding (from Cohen, Chaput and Cashon, 2002).

After training employing a causal stimulus (i.e., Direct Launching Event) and three non-causal stimuli (i.e., Delay Event, Gap Event, Delay + Gap Event), the CLA has demonstrated to be able to distinguish between causal and non-causal events. Moreover, such model seems to represent the events along a continuum of degrees of causality, ranging from non-causal to very causal events, such continuum reproduces accurately the results obtained by both Leslie and colleagues (Leslie, 1984; Leslie and Keeble, 1987) and Cohen and colleagues (Cohen and Oakes, 1993; Cohen and Amsel, 1998) on infant studies.

The authors pointed out that “*CLA is not tabula rasa*” (Chaput and Cohen, 2001). It possesses innate attributes consisting in the information processing principles. Unlike a modularist view, however, these innate attributes are domain-general: CLA possesses innate processes rather than specific innate knowledge. Moreover, the developed causal model depends strongly from the frequencies of the experienced events (Chaput and Cohen, 2001).

3. Status of the research on causal perception

The debate between rationalist and constructivist researchers is hard to resolve and up to date both theories still enjoy favours. On the one hand Leslie and colleagues assume an innate, domain-specific visual module at the basis of causal perception, such module produces abstract description of the causal structure of an event by its spatiotemporal properties. On the other hand, according to Cohen and colleagues causal perception is demonstrably learnt by experience: there is not an innate module and causal perception is not based onto a domain-specific ability. “*Infants come to perceive the causal nature of events as a result of their general perceptual development*” (Oakes and Cohen, 1990, p. 193).

Recently research in comparative psychology have started to investigate non-humans' susceptibility to causality.

In the following paragraphs both developmental and comparative researches on causal knowledge will be described.

3.1. Evidence of early perception of physical causality in infants

As the previous paragraphs disclosed, a growing interest in the earliest causal representations has recently led to a range of experimental data in developmental studies, precisely with the aim to provide more definitive answers to the origin of such capability.

Up to date, there are some convincing evidences that month-old infants are able to respond to causality, but such capability seems to appear gradually during the first months of life and to be related to the type of stimuli employed. Moreover, two kinds of evidence have to be provided to demonstrate that infants perceive an event as causal. Firstly, infants have to be sensitive to spatial and temporal continuity of an event, those features being fundamental in determining adults' perception of physical causality (Michotte, 1963); secondly, infants' representation of the stimulus have to go beyond the mere spatiotemporal analysis: infants' categorization of stimuli has to be based on whether they are causal or not.

The widespread method to obtain the first type of evidence consists in habituating infants to a launching event and subsequently showing them either more launching events or events in which there is a temporal delay or a spatial gap. Employing this type of paradigm, it was demonstrated that infants as young as 4 months successfully discriminate between events on the basis of their spatiotemporal continuity (Leslie, 1982; Cohen, Amsel, Redford and Casasola, 1998). Nevertheless such results do not demonstrate that 4-month-old infants are sensitive to physical causality itself (Cohen and Amsel, 1998).

In fact, the capability to classify events featuring two objects in motion as causal or non-causal seems to arise at about 6 ½ months of life (Leslie and Keeble, 1987; Oakes, 1994; Cohen and Amsel, 1998). At this age infants

demonstrated to be able to discriminate launching events from non-causal control stimuli (i.e., delayed launching and no-collision displays). For infants as well as for adults, in fact, equal spatiotemporal differences between events are not identically salient in the case of such differences being responsible for a causal impression in one of these events (Cohen and Amsel, 1998). Moreover, a further evidence of 6 ½-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 and Keeble, 1987).

Six-month-old infants, however, are able to perceive physical causality in a launching effect only when such event involves simple objects that move along smooth horizontal trajectories. Starting from 10 months of life, instead, infants demonstrated to be sensitive to physical causality also in presence of launching events that involve the movement of complex wheeled objects (Oakes and Cohen, 1990) or that involve objects moving along dissimilar rolling trajectories (Oakes, 1994).

Infants' perception of complex causal sequences (i.e., causal chains of three steps), moreover, seems to develop from 10 to 15 months of age (Cohen and Oakes, 1993). When the first object of a complex event is replaced, in fact, ten-month-olds dishabituate regardless of whether such object is involved in a causal (i.e., direct launching) or in a non-causal event (Cohen, Rundell, Spellman and Cashon, 1999). At 15 months of age, instead, infants show higher looking times if the replaced object is the one playing the role of cause, in spite of its ordinal position in the causal sequence⁵. 15-month-olds infants, therefore, are able to perceive three-steps causal chains and seem to be particularly attuned to the object playing the role of causal agent (Cohen, Rundell, Spellman and Cashon, 1999).

⁵ The ordinal position depends on the type of event. In direct launching the causal agent is the first object in motion, in a three-step delayed launching (i.e., a launching featuring three objects), instead, the causal agent is the second object in motion (i.e., the one whose motion will determine the movement of the third object).

Importantly, the findings so far described are not dependent from a specific type of stimuli, since simple computer-generated shapes (Oakes, 1994; Cohen and Amsel, 1998), videotaped movement of objects (Leslie and Keeble, 1987) or complex real toys (Oakes and Cohen, 1990; Cohen and Oakes, 1993) have been successfully used.

3.2. Perception of physical causality in non-human animals

The debate concerning the nature of causal knowledge has been recently extended to researches on animal species other than our own. Although the topic was indirectly dealt with by Köhler (1925/1976), it is only in the last three decades that causal understanding in non-human animals has been explicitly investigated (Sperberg, Premack and Premack, 1995; Visalberghi and Limongelli, 1996).

As for studies on human infants, investigating non-human animals' susceptibility to causality is not an easy task, since it is hard to isolate causal knowledge from other types of cognitive processes (Visalberghi and Tomasello, 1998).

Focusing on physical causality, most of the researches on non-human subjects have observed individuals as they attempt to solve physical problems by devising active behavioural strategies (i.e., tool using; Visalberghi and Tomasello, 1998). The assumption at the basis of such researches was that certain behavioural strategies seem to indicate causal understanding whereas others do not. The basic goal is usually to determine exactly what kinds of experience subjects have had with a particular kind of tool, to distinguish trial-and-error learning from a pure causal insight (Tomasello and Call, 1997). In fact, the use of tools could be simply the result of object manipulation or the outcome of a "*systematic relating of the object being manipulated (the tool) in relation to another (the goal)*" (Tomasello and Call, 1997).

Although a wide variety of non-human animals have been demonstrated to successfully use tools in several contexts (Emery and Clayton, 2009), species are not equal in the understanding of the causality involved in the tasks. Using tool, in fact, could be either the outcome of an associative learning or the outcome of a high-level causal understanding. In the first case, the low-level account, cause and effect are linked through exposure to their contiguity; in the high-level cognitive model, instead, the task is solved through an understanding of the underlying causal structure between the tool and the goal reached.

The benchmark test for causal cognition in non-human animals is indubitably the trap-tube task (Visalberghi and Limongelli, 1994), in which an animal have to insert a tool into a horizontal tube to extract a food reward, such tube has a “trap” along it, in which food can fall if pulled or pushed in the trap direction. In the traditional configuration (Fig. 6.a) a single trap is used, with the food located either next to the trap or in the centre of the tube. A control procedure is then provided (Fig. 6.b), in which the tube is upside-down so that the trap is no longer functional.

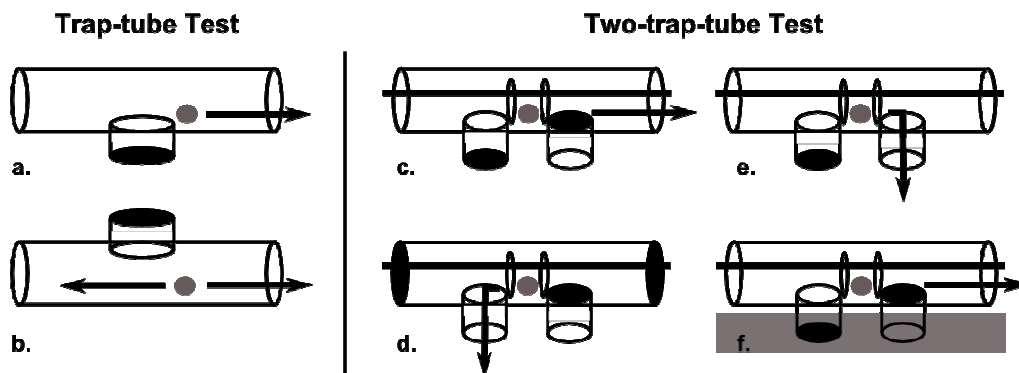


Fig. 6. Drawings of various trap-tube problems: a. the original trap-tube, b. the control trap-tube, c.-f. two-trap-tube apparatus, with the stick-tool already inserted into the tube. Each tube has one or two “traps” along its length, each having different solutions depending upon the position of horizontal black discs at the top or bottom of these traps. The arrows show the path the food will take on a successful trial (modified from Emery and Clayton, 2009).

If a subject who has learned to avoid the trap in the standard tube continues to move the tool so as to avoid the trap even in the control tube (i.e., when the trap is non functional), it is regarded to have failed to understand the causal structure of the task: such subject's behaviour would be led by a mere association between its specific successful behaviour and the food reward. If the subject, instead, inserts the tool randomly from either side of the upside-down trap-tube, it is regarded to have understood that the trap is no longer functional.

A further version of the standard trap-tube task, moreover, has been developed by Clayton and colleagues to test causal reasoning in non-tool-users (Seed, Tebbich, Emery and Clayton, 2006). It consists in a two-trap tube, with a tool already inserted in it, such tool has two discs attached in the centre, with the food placed between them. Several versions of the two-trap tube have been developed, to test for causal reasoning without recourse to alternative associative explanations (see Fig. 6.c-f.).

Several species of primates and birds have been tested employing the trap-tube task or modified versions of it (i.e., the trap-table task, Fujita, Kuroshima and Asai, 2003), such species are the tufted capuchin monkey (*Cebus apella*; Visalberghi and Limongelli, 1994; Fujita, Kuroshima and Asai, 2003), the chimpanzee (*Pan troglodytes*; Limongelli, Boysen and Visalberghi, 1995; Seed, Call, Emery and Clayton, 2009), the bonobo (*Pan paniscus*; Helme, Call, Clayton and Emery, 2006), the tamarin (*Saguinus Oedipus*; Santos, Pearson, Spaepen, Tsao and Hauser, 2006), the woodpecker finch (*Camarhynchus pallidus*; Tebbich and Bshari, 2004), and the rook (*Corvus frugilegus*; Seed, Tebbich, Emery and Clayton, 2006; Helme, Clayton and Emery, 2006; Tebbich, Seed, Emery and Clayton, 2007; Taylor, Hunt, Medina and Gray, 2009). High differences in performances have been recorded both between and within species, with some individuals performing distinctly better than others of the same species (see Taylor, Hunt, Medina and Gray, 2009 for a review). At least a rook (Seed, Tebbich, Emery and Clayton, 2006) and two chimpanzees (Seed, Call, Emery and Clayton, 2009),

moreover, showed not only to solve the basic task but also to succeed in transferring the learned knowledge to novel configurations.

Even for succeeding animals, however, there is no conclusive evidence that they used causal knowledge rather than associative learning to solve complex physical tasks requiring tools (Emery and Clayton, 2009).

Researches so far described, however, focused on a type of physical causality very different from the one studied by Michotte, which implied a perceptive rather than cognitive elaboration. Kummer, in 1995, posited a continuum in non-human animals' knowledge of causal connection between events (Kummer, 1995). Two forms of causal connections would be at the extremes of such continuum: the "*weak causal knowledge*", the result of mere associative learning, depending on experiences with many repetitions of two events in close spatial and temporal contiguity; and the "*strong causal knowledge*", which would be based on "*a rapid a priori interpretation of how events may be related to one another and so does not depend on a large number of repetitions*" (Visalberghi and Tomasello, 1998). Strong causal knowledge, moreover, may be based on evolved programs which allow a specific type of connections between events, such programs could be either innate or the results of some learning mechanisms. This last type of knowledge, therefore, would be the one at the basis of the immediate perception of physical causality aroused by the Launching Effect.

Up to date, just two researches have been developed to test non-human animals' susceptibility to physical causality in more perceptive terms.

The first research is by O'Connell and Dunbar with bonobos (*Pan paniscus*) and chimpanzees (*Pan troglodytes*, O'Connell and Dunbar, 2005). In this study subjects were tested with an habituation/dishabituation paradigm similar to the one employed by Leslie and collaborators to test for causal perception in young infants (Leslie, 1984; Leslie and Keeble, 1987). Since primates are demonstrated to quickly recognize the meaning of social cues whereas they often fail with non social cues, a social version of Leslie's colliding stimuli have been provided to chimpanzees. Three videos have been developed, with a "contact" (i.e., congruent) and a "no-contact" (i.e.,

incongruent) version for each one. The first video showed a 2-step causal interaction: a hand reached a banana which was lying on a table (“contact” version: the hand grasped the banana and both moved out of sight; “no-contact” version: before grasping the fruit rises from the table and follows the hand out of sight without any contact). In the second video a 3-step causal interaction was showed: a human (H1) eating a banana was pushed by a second one (H2) and robbed of his fruit (“contact” version: H2 pushes H1 and takes the banana; “no-contact” version: H1 falls without any contact by H2 and the banana moves by itself over to H2 who starts to eat it). The third video was a piece of a natural history film on hunting behaviour in the wild, played forward (“contact” version) or backwards (“no-contact” version). Subjects were divided into two groups. In group 1 chimpanzees were habituated to the “contact” version of one of the films and then tested with the “no-contact” version of the same film; vice versa for group 2. The salient comparison regarded the attentional recovery of group 2 vs that of group 1. The authors’ hypothesis was that, if animals were responding simply to changes, at test there should be no differences in looking times between groups. Subjects, however, showed higher dishabituation in group 1 than group 2. Authors regarded such difference as in favour of apes’ capability to perceive causality: subjects which had seen the plausible version first (i.e., group 1, which saw the “contact” version during habituation) would have detect the causal relation laying between the events of such film, finding at test the “no-contact” version causally incongruous (O’Connell and Dunbar, 2005). Of course this is not the only plausible explanation for the results, and further studies are required to clarify such results.

The other research investigating non-humans’ sensitivity to perceptual causality was the one by Young and colleagues with pigeons (*Columba livia*; Young, Beckmann and Wasserman, 2006). This is the only research employing Michottean stimuli of the same kind previously used with adult humans and infants (Michotte, 1963; Leslie and Keeble, 1987). Such stimuli consisted, in fact, in four videos featuring two squared-shaped objects involved in a Direct Launching (video 1), a Distal Launching (i.e., a launching

without contact, video 2), a Delayed Launching (video 3), and a Distal and Delayed Launching (video 4). The four animations, therefore, represented two classes: causal interaction (Direct Launching) and non-causal interaction (Distal Launching, Delayed Launching, Distal and Delayed Launching). Subjects were trained to discriminate one type of stimulus from the other three using a go/no-go task: each pigeon was reinforced for pecking at one type of animation (i.e., either Direct Launching or Distal and Delayed Launching) but not at the other three. The hypothesis was that if pigeons were able to discriminate causal interactions, those subjects which were trained to peck at the Direct Launching (i.e., the causal interaction) should find the discrimination task with the other three animations (i.e., the non-causal ones) easier than pigeons trained at the Distal and Delayed animation, which had to discriminate the non-causal target stimulus from other types of both causal and non-causal stimuli (Young, Beckmann and Wasserman, 2006). Results, however, showed that both discriminations were hard for the pigeons to master: pigeons showed considerable difficulty at learning to discriminate between stimuli which appear quite distinct to humans. During the test, in fact, pigeons often attended to subtle features which were other than the causally relevant ones. The authors suggested several reasons to account for such data: the stimuli could have been too much artificial for the pigeons or the subjects would be more attuned to contingency rather than contiguity as a cue to causation (Young, Beckmann and Wasserman, 2006).

From the researches so far described, however, it appeared that no definite data have been collected which allow to put forward a final model about the perception of causality in non-human animals.

3.3. Open issues

The research reviewed so far seems to provide evidence that preverbal infants interpret Michotte's Lanching Events as causal since 6 months of life, whereas no evidence for representations of causality was obtained before this age. As pointed out by Susan Carey, however, regarding the origin and the mechanisms responsible for such capability, "*the fact that there is no evidence for representations of causality before this [6-months] age cannot be taken as evidence, in itself, that there is no innate concept cause*" (Carey, 2009). In spite of quite strong evidence against Michotte's hypothesis of an innate *domain-specific* module for causality (see previous §§ for more details), in fact, it seems to be very likely that "*representations with the content cause may be innate*", even though at the same time part of "*a central conceptual system*" which may integrate information from different sources of evidence (i.e., direct perception of mechanical causality by one's own efficacy in the environment; contingency; Carey, 2009).

Since the presence of some form of development seems not to exclude the possibility of an innate or at least very precocial origin of such capability, it might be extremely clarifying to investigate the perception of causality in subjects under conditions of effective control for previous experiences (i.e., newborn babies).

Moreover, as it seems plausible that identifying causal relations ought to be fundamental for the survival of several species, it might be interesting to investigate non-humans species for their sensitivity to physical causality. This would allow both for a direct comparison of different species' precocial capability and for sketching out the filogenetic origin of causal perception.

In the following section we aimed at clarifying both the ontogenetic and filogenetic origin of causal perception by looking at newborn babies and newly-hatched domestic chickens.

III

Experimental Research: Early sensitivity to Physical Causality

Starting from the evidence previously described and for the lack of research on *naïve* subjects, the purpose of this thesis was to investigate the sensitivity to physical causality from a comparative perspective, employing both newborn babies and newly-hatched domestic chicks (*Gallus gallus*) as experimental subjects. Moreover, I aimed at providing more definitive answer to the issue regarding a possible precocial ontogenetic and phylogenetic origin of the sensitivity to physical causality.

Regarding newborns' capability, despite their poor visual acuity, investigators of the earliest beginning of cognition have come to recognize that newborns possess very sophisticated attentive (Valenza, Simion and Umiltà, 1995; Farroni, Simion, Umiltà and Dalla Barba, 1999) and perceptual abilities (Macchi Cassia, Simion, Milani and Umiltà, 2002; Valenza and Bulf, 2007; Simion, Regolin and Bulf, 2008) which allow them to process and represent several kinds of information. Employing newborn babies, moreover, offers the advantage of studying almost *naïve* subjects and to look for their precocial (or at least innate) capabilities.

As far as the domestic chicken is concerned, moreover, this species revealed to be an ideal model in the study of perception and cognition in a comparative perspective. It is a highly visual and precocial species, shown to be capable of perceiving shapes defined by motion information alone, much as humans can (e.g. Vallortigara, Regolin and Marconato, 2005; Mascialoni, Regolin and Vallortigara, 2009). Moreover, it hatches with a brain ready to learn critical information for survival and investigating visual perception ability in chicks has the advantage of using filial imprinting as a tool for these

studies. Filial imprinting is the process whereby young birds of a precocial species learn to recognize the first conspicuous object seen after hatching (Lorenz, 1935; Bateson, 1966). During the period of exposure to the visual stimulus the chick rapidly forms a memory of its features and develops a strong attachment to it. Usually, the natural imprinting stimulus is the mother hen, but artificial objects proved to be equally successful in triggering imprinting, with moving stimuli preferred over stationary ones. So, learning through imprinting proved to be a more ecological technique than the traditional conditioning procedures to investigate perceptual and cognitive phenomena in precocial birds species (see, for instance, Regolin and Vallortigara, 1995). Finally, the chick offers some other advantages, like the possibility to fully control any environmental stimulation, *in ovo* and post-hatching, and the existence of a good knowledge of its anatomy and physiology.

In this thesis newborn babies and newly-hatched domestic chickens have been tested for their spontaneous preference for either a causal or a non-causal video animation.

If subjects can perceive the physical causality involved in the Launching Event (as adult humans do), they would be expected to look longer at the causal rather than at the non-causal stimulus at test, showing to be interested in the peculiar feature of physical causality.

Study 1:

Preference for physical causality in newborn babies

The present study was aimed at investigating whether newborns are sensitive to physical causality involved in a typical Launching Effect. Three experiments were conducted, all employing an infant-control preferential looking technique which allowed for the testing of newborns' spontaneous preferences for a causal vs a non-causal stimulus by measuring the duration of their fixations on the stimuli.

In each experiment newborns were presented with two video animations featuring two identical objects (i.e., gray discs). Those objects were set in motion and in Experiment 1 and 2 they gave rise to either a causal or a non-causal interaction (a Launching Effect vs an Inverted-Sequence animation in Experiment 1; a Launching Effect vs a Delay animation in Experiment 2). In the third experiment, instead, two non-causal animations were used, to check for the presence of a preference for the mere spatiotemporal parameters of the Launching event.

1. General Methods

Participants

Full term newborns were selected to participate in the study from the maternity ward of the Pediatric Clinic of the University of Padua. A total of 56 newborns participated in the experiments. 16 newborns were discarded because of position bias (during the test phases they looked >80% in one same direction; n = 1) or because they changed their state during testing (n = 15), therefore the final sample consisted of 40 newborns. Their postnatal age

ranged from 8 to 76 h (mean \pm SEM = 42 \pm 3 h). All of them met the screening criteria of normal delivery (good health, with no visual, neurological or other disorders), had a birth weight between 4270 and 2040 g, and had an Apgar score between 9 and 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 Responsible Office of the Pediatric Department of the University of Padua.

Stimuli and Experimental Setting

An infant-control preferential looking technique was used in all the three experiments.

Stimuli consisted of two computer presented animation sequences, each sequence featuring two identical objects (i.e., gray discs of 3 cm in diameter), which will be called A and B thereafter.

The animations were presented on a 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 behavior on-line and to allow off-line coding of their fixations.

Procedure

At the beginning of both preference test phases a red disc was shown in the centre of the monitor, on a black background, to attract the infant's gaze.

The disc grows and then shrinks back continuously, from small (1.8 cm) to large (2.5 cm) 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 on the left and the right side of the monitor, each newborn was given two paired presentations of the test stimuli in which the position of the stimuli was swapped (the initial left-right order of presentation was counterbalanced across subjects). Each trial ended when a total of at least 30 sec of looking to the two stimuli had been accumulated.

The experimenter recorded the duration of the newborns' fixations on each stimulus by pressing two different keys depending on whether the newborn looked at the right or left position. Moreover, videotapes of the newborn's eye movements throughout the test phase were subsequently coded frame by frame by a second coder unaware of the stimuli presented (it was not possible for the scorer to recognize the stimuli from the corneal reflection).

Data Analysis

The number of fixations and the total looking time to each testing stimulus were recorded for each participants, to subsequently calculate the average number of fixations and the average looking time to each stimulus. To investigate whether one of the two stimuli was preferred over the other, two paired-sample two-tailed *t*-tests were performed both on infants' average looking fixation time and on the number of fixations toward the two stimuli.

To determine whether fixation times toward the launching stimulus significantly differed from chance level (50%), moreover, fixation times were transformed into a preference score (percentage). Each infant's looking time at the Launching Stimulus during the two test phases was divided by the total looking time to both test stimuli over the two presentations, and subsequently

converted into a percentage score. Hence, the preference score values ranged from 100 (full choice for the Launching stimulus) to 0 (full choice for the control stimulus). Fifty per cent represented chance level. To determine whether the preference score was significantly different from the chance level a one-sample *t*-test was applied.

2. Experiment I

Newborns' spontaneous preference for a Launching stimulus vs a non-causal Inverted-Sequence stimulus was tested.

Two computer-presented animation sequences were created, each sequence featuring two identical objects. The Launching video animation had the usual spatiotemporal features of a Launching Effect (Michotte, 1963). The non-causal Inverted-Sequence animation was identical to the Launching one except for the fact that the order of the displacement of the two objects was swapped temporally: In this sequence any physical causality between the movements of the two objects was disrupted whereas distances travelled and perceptual features of the two discs were identical to those of the Launching stimulus.

Participants

A total of 22 1- to 3-day-old newborns participated in the experiment. 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. Their postnatal age ranged from 8 to 74 h (mean \pm SEM = 41 ± 5 h), their birth weight was between 4205 and 2720 g, and they had an Apgar score between 9 and 10 at 5 min.

Test Stimuli

Two computer presented animation sequences were created, each sequence featuring two identical objects, which will be called A and B thereafter (objects were gray discs of 3 cm in diameter).

In the Launching video animation, 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 (Fig. 7, left-most sequence). In this sort of display adult subjects perceive object A as pushing (technically “launching”) object B, hence causing its movement.

The Inverted-Sequence animation (Fig. 7, right-most sequence) was identical to the launching one except for the fact that, maintaining the same starting positions, the order of the displacement of the two objects was swapped temporally: thus B moved first and A started its movement only after B had stopped. In this sequence any physical causality between the movements of the two objects was disrupted (no contact occurred between A

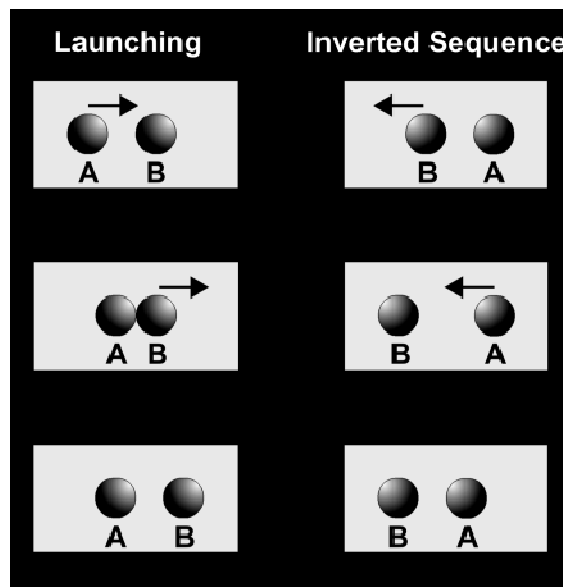


Fig. 7. Schematic representation of the animation sequences used in Experiment I. Left-most sequence: the Launching Effect; right-most sequence: the Inverted-Sequence animation (the initial left-right order of presentation was counterbalanced across subjects).

and B), whereas distances travelled and perceptual features of the two objects were identical to those of the launching effect.

Both animations were presented to the newborn with objects moving in a convergent way, from the peripheral to the central visual field. Both events described lasted 2.5 sec (60 frames; 24 frames/sec). Videos were produced by looping such animations, which was saved with 75 quality AVI jpeg. Each object in the animations covered a distance of 2 cm at 4cm/sec and maintained both its starting and final position for half a second. At the end of the sequence a gray screen (identical to the background, RGB = r235, g233, b 237) appeared for half a second before the animations restarted. Each set of elements occupied an overall window of 10 cm of width (20° of the visual angle at a viewing distance of 30 cm).

Results

The average number of fixations toward the Launching was (mean \pm SEM) 11.25 ± 1.16) whereas it was (mean \pm SEM) 9.75 ± 0.91 for the Inverted-Sequence stimulus (paired-samples two-tailed t -test: $t_{15} = 1.168$, n.s.).

The average total fixation time⁶ was (mean \pm SEM) 44.225 ± 4.978 sec for the Launching Stimulus and (mean \pm SEM) 29.711 ± 2.691 sec for the non-causal Inverted-Sequence stimulus. Newborns demonstrated to look significantly longer to the Launching Stimulus than to the non-causal one (paired-samples two-tailed t -test: $t_{15} = 2.820$, $p = 0.013$). The percentage of total fixation time newborns spent looking at the launching stimulus was (mean \pm SEM) $58.88 \pm 3.55\%$ and differed significantly from chance level (one-sample two-tailed t -test: $t_{15} = 2.499$, $p = 0.025$; Fig. 13).

Finally, examination of the data for individual infants revealed that 12 out of 16 looked longer at the Launching Effect than to the Inverted-Sequence stimulus (binomial test, n.s.).

⁶ The inter coder agreement for total fixation time was 0.911 (Pearson correlation, $p = 0.012$).

No significant preference emerged when considering the number of fixations at the Launching and the number of newborns which looked longer to this stimulus; nevertheless, the index of preference for the Launching stimulus seems to suggest the presence of a spontaneous visual preference for a causal over a non-causal motion stimulus in newborn babies.

3. Experiment II

Results of Experiment 1 favour the idea that *naïve* newborns show a preference for the causal sequence (i.e. the Launching Effect) over the non-causal interaction between objects. Nevertheless, those results could be due to a preference for the specific low-level spatiotemporal features of the Launching Event rather than to a preference for the Causality *per se*.

In fact, the control animation sequence of Experiment 1 differed from the Launching one for two main features:

1. Absence of a contact between the discs involved in the animation,
2. Spatial discontinuity between the motion of object A and B,
3. Object B, which moved first, was also nearest to the fixation point (in fact both animations were presented to the newborn with objects moving in a convergent way, from the peripheral to the central visual field, see methods for more details on how the stimuli were presented to the newborn).

Trying to face those criticisms, in the second experiment newborns' spontaneous preferences for a Launching Effect vs a non-causal Delay stimulus were tested.

Participants

A total of 17 1- to 3-day-old newborns participated in the experiment. Five newborns were discarded because they changed their state during testing. The final sample consisted of 12 newborns with a postnatal age ranging from

8 to 71 h (mean \pm SEM = 39 ± 6 h). Their birth weight was between 4270 and 2800 g and their Apgar score was 10 at 5 min.

Test Stimuli

A Launching stimulus (identical to the one used in Experiment 1) and a Delay stimulus were employed at test.

The Delay video animation was identical to the Launching one except for the presence of a 1 sec-delay between the time of contact and the motion of B (Fig. 8, right-most sequence). In adult subjects the presence of a delay is known to abolish any impression of physical causality: object B appears in this case as being self-propelled and moving independently from object A. Due to the 1 sec-delay this animation sequence lasted 3.5 sec (84 frames; 24 frames/sec), 1 sec more than the Launching one used in Experiment 1.

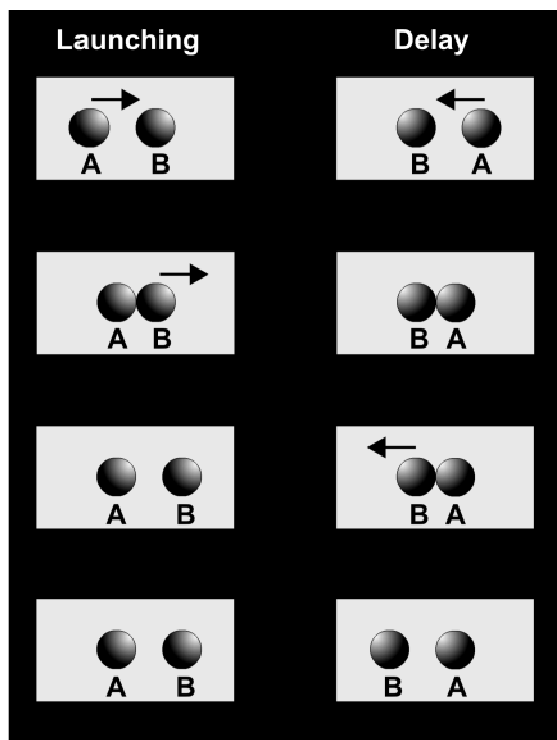


Fig. 8. Schematic representation of the animation sequences used in Experiment II. Left-most sequence: the Launching Effect; right-most sequence: the Delay animation (the initial left-right order of presentation was counterbalanced across subjects).

For this reason, the Launching animation was modified by leaving visible for 1 sec its last static frame. The distances covered by the objects and their velocities, the video features and the experimental setting were identical to the ones described for the previous experiment.

Delay and Launching stimuli were selected as they were comparable for what concerns contact between object A and B, and spatial continuity of the motion. Moreover, the first object to move was in both cases the farthest away from the fixation point.

Obviously, the animations employed in this experiment differed from one another in the features necessary to obtain a causal vs a non-causal stimulus.

Although the total amount of motion was identical for both stimuli (4 cm covered by the discs and 1 sec of motion in each animation), the Delay animation differed from the Launching for three main points:

- the temporal discontinuity of motion (due to the 1 sec-delay between the time of contact and the motion of B),
- the extended time of contact between object A and B, which was 1 sec longer than the same contact in the Launching animation,
- motion of object B in the control (Delay) animation continues for 1 sec after cessation of any movement in the Launching animation (Fig. 8).

Nevertheless, all these differences should favour the preference of the control animation. It is well known that the tracking behaviour of a moving object in newborn babies is characterized by the so called “smooth pursuit saccades” (Kremenitzer, Vaughan, Kurtzberg, and Dowling, 1979), which consist in tracking eye movements slower than the usual saccades. For this reason, the temporal discontinuity and the extended contact time present in the Delay animation seem to better suit the newborns’ visual tracking system, allowing the baby to reach the final position of object A in time to see the motion of object B. Moreover, the longer duration of motion in the Delay stimulus could have affected the fixation times by attracting the newborns’ attention to the Delay animation.

Results

The average number of fixations toward the Launching Stimulus (mean \pm SEM = 13.92 \pm 1.35) was significantly different from that toward the Delay stimulus (mean \pm SEM = 9.58 \pm 1.23; paired-samples two-tailed *t*-test: t_{11} = 4.083, p = 0.002). Moreover, newborns looked significantly longer to the Launching stimulus (average total fixation time: mean \pm SEM = 47.087 \pm 3.899 sec) than to the Delay stimulus (mean \pm SEM = 29.964 \pm 4.647 sec; paired-samples two-tailed *t*-test: t_{11} = 4.486, p = 0.001)⁷.

The percentage of total fixation time newborns spent looking at the launching stimulus was (mean \pm SEM) 62.87 \pm 2.66% and differed significantly from chance level (one-sample two-tailed *t*-test: t_{11} = 4.837, p = 0.001; Fig. 13). Ten out of 12 subjects preferred the Launching stimulus to the Delay stimulus (binomial test, p = 0.039).

All the variables considered (i.e., the number of fixations toward the Launching, the average total fixation times toward the Launching, and the number of newborns who looked longer to such stimulus) support the idea that *naïve* newborns have a preference for a causal stimulus (i.e. the Launching Effect).

4. Experiment III

Results from both the previous experiments seem to favour the idea that *naïve* newborns prefer to look at a causal (i.e., the Launching Effect) rather than to a non-causal stimulus. Nevertheless, such pattern of results could be due to a preference for the spatiotemporal features of the Launching stimulus rather than for its implicit physical causality.

For such reason, in Experiment 3 a “90° Launching” and a “90° Delay” stimuli were employed. Those stimuli are both perceived as non-causal by

⁷ The mean estimated reliability between coders was 0.849 (Pearson correlation, p = 0.033).

adult humans. Nevertheless, they are identical in their spatiotemporal parameters with respect to the Launching and Delay stimuli used in Experiment 2, allowing for a direct measure of newborns' preferences for such characteristic spatiotemporal features.

Participants

A total of seventeen 1- to 3-day-old newborns participated in the experiment. Five newborns were discarded because they changed their state during testing. Therefore the final sample consisted of 12 newborns, aged (mean \pm SEM) 47 ± 5 h (range: 25–76 h). Their birth weight was between 3900 and 2040 g, and they had an Apgar score of 10 at 5 min.

Test Stimuli

The “90° Launching” stimulus and the “90° Delay” stimulus were identical, respectively, to the Launching and to the Delay video animations used in Experiment 2, except for a 90° deviation in the path travelled by object B (Fig. 9).

In fact, immediately after contact in the “90° Launching” stimulus whereas 1 sec after contact in the “90° Delay” stimulus, object B started to move at the same speed of object A, but along a vertical path, deviated by 90° from the straight trajectory of A. Such kind of deviation of trajectory is known to weaken or even abolish any impression of physical causality (Michotte, 1963, experiment 34; Kerzel, Bekkering, Wohlschläger and Prinz, 2000).

In both the “90° Launching” stimulus and the “90° Delay” stimulus, hence, any physical causality between the movements of the two objects is disrupted, whereas the distances covered by the objects and their velocities, the video features and the experimental setting were identical to those of the Launching and of the Delay stimuli used in Experiment 2.

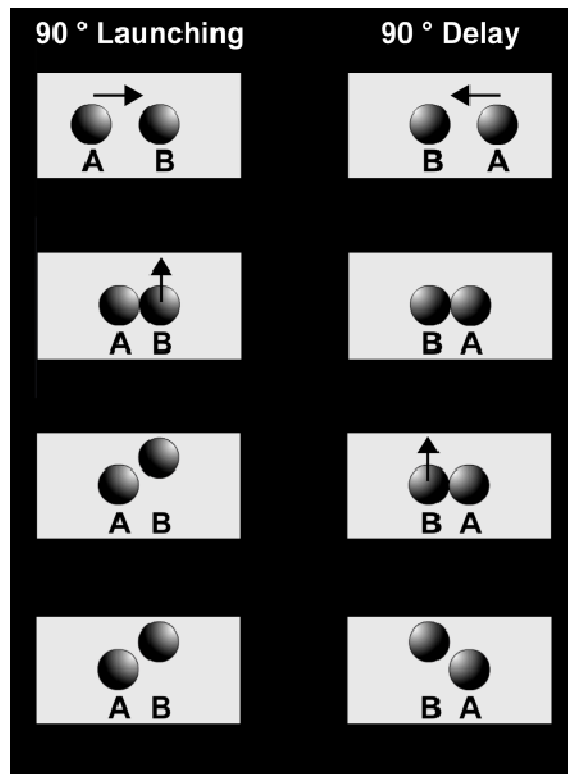


Fig. 9. Schematic representation of the animation sequences used in Experiment III. Left-most sequence: the “90° Launching” stimulus; right-most sequence: the “90° Delay” stimulus (the initial left-right order of presentation was counterbalanced across subjects).

Results

The average number of fixations toward the “90° Launching” stimulus was (mean \pm SEM) 13.00 ± 1.49 , whereas it was (mean \pm SEM) 15.83 ± 0.95 for the “90° Delay” stimulus (paired-samples two-tailed t -test: $t_{11} = -1.671$, n.s.).

The average total fixation time⁸ for the “90° Launching” stimulus was (mean \pm SEM) 34.584 ± 5.412 sec and (mean \pm SEM) 50.063 ± 4.061 sec for the “90° Delay” stimulus. Newborns demonstrated to look significantly longer to the “90° Delay” stimulus than to the “90° Launching” one (paired-samples two-tailed t -test: $t_{11} = -2.433$, $p = 0.033$).

The percentage of total fixation time newborns spent looking at the “90° Launching” stimulus was (mean \pm SEM) $39.43 \pm 3.57\%$ and differed

⁸ The mean estimated reliability between coders 0.995 (Pearson correlation, $p = 0.000$).

significantly from chance level (one-sample two-tailed t test: $t_{11} = -2.964$, $p = 0.013$; Fig. 13).

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” stimulus than to the “90° Launching” stimulus (binomial test, $p = 0.039$).

Although the number of fixations toward the “90° Launching” was not significantly different from the number of fixations toward the “90° Delay”, overall the results of Experiment 3 show that newborns prefer to look longer at the “90° Delay” stimulus. This means that newborns prefer the spatiotemporal parameters of the Delay stimulus rather than those of the Launching one when in the absence of any physical causality in both the animations used at test. At present, no explanation can be put forward for this evidence (but for some considerations relevant to this issue see page 49).

Therefore, these results confirm the hypothesis that the choice expressed for the Launching stimulus in the previous experiments was precisely due to a preference for the physical causality itself.

Study 2: Spontaneous preference in newly-hatched domestic chicks

As previously pointed out reviewing the literature, just few research studied the perception of physical causality by non-human animals, and only two research focused on a Michottean causality (O'Connell and Dunbar, 2005; Young, Beckmann and Wasserman, 2006).

The present research was aimed at investigating whether visually *naïve* domestic chickens are sensitive to the physical causality experienced in the Launching Effect.

To this purpose, two experiments were conducted, taking advantage of a spontaneous preference task. In each experiment chicks were asked to freely choose between two video animations featuring two identical objects which gave rise to a causal (i.e., Launching Effect) vs a non-causal stimulus (i.e., a Delay stimulus in Experiment 1, a Passing stimulus⁹ in Experiment 2).

A preference for either stimulus would be the very first convincing evidence of animals' capability to discriminate between the two testing stimuli. Due to the similarity of the paradigm employed, moreover, the results of such experiments would be directly comparable with the results obtained with newborn babies.

⁹ i.e., a moving object going past in front of a stationary one.

1. General Methods

Subjects

A total of 191 Hybro domestic chicks (*Gallus gallus*) were tested, 54 birds were discarded because they did not perform any choice during the test. Therefore, the final sample consisted of 137 subjects. All chicks came from eggs hatched in our laboratory under controlled conditions. Fertilized eggs at the 14th day of incubation were delivered weekly to our laboratory from a local commercial hatchery (Agricola Berica, Montegalda, Vicenza - Italy). On arrival, eggs were placed in an incubator MG 70/100 (45 x 58 x 43 cm, 100 eggs capacity) until day 19 of incubation. Temperature was constantly monitored and maintained at 37.5°C; a hygrometer was used to control the humidity in the incubator, maintaining it at 55-60%, standard conditions for optimal incubation.

From day 19 to day 21, eggs were placed into a hatchery (60 x 65 x 66 cm) with the same temperature as the incubator, but lower humidity, an ideal condition for hatching. The incubator, the hatchery and the hatching room were all kept thoroughly dark until day 21 (the hatching day), to prevent the embryos and the newborn chicks any visual experience before testing. This is a standard procedure in this type of experiments (see Vallortigara, Regolin and Marconato, 2005) because light exposure of the eggs in the last phase of incubation has been shown to affect chicks' neural development and behaviour (see Rogers and Bolden 1991; Rogers, Zucca and Vallortigara, 2004); in fact a variable amount (from 6% to 10%) of the light cast on the egg penetrates through the egg-shell, the membranes and the embryo's eyelid, selectively stimulating the eye which is directly facing the egg shell (i.e. the right eye, while the left eye is screened by the chick's body; Rogers 1990).

Stimuli and Apparatus

The test stimuli consisted in two computer presented animation sequences featuring two square-shaped objects of the same size (width=3 cm, height=2 cm) and colour (RGB = r51, g153, b255, with alpha =100%).

Animation sequences were generated by “Flash® 8” software. Videos were produced by looping a 60-frames/sec animation, and saved with 75 quality AVI jpeg. Stimuli were presented on a Samsung syncMaster 931BF (LCD 19”) screen.

The test apparatus consisted of a white-plywood runway (71 x 20 x 30 cm), virtually subdivided in a central (15 cm long) and two side areas (28 cm long; Fig. 10), with two computer screens, projecting the testing stimuli, placed at the opposite ends of it.

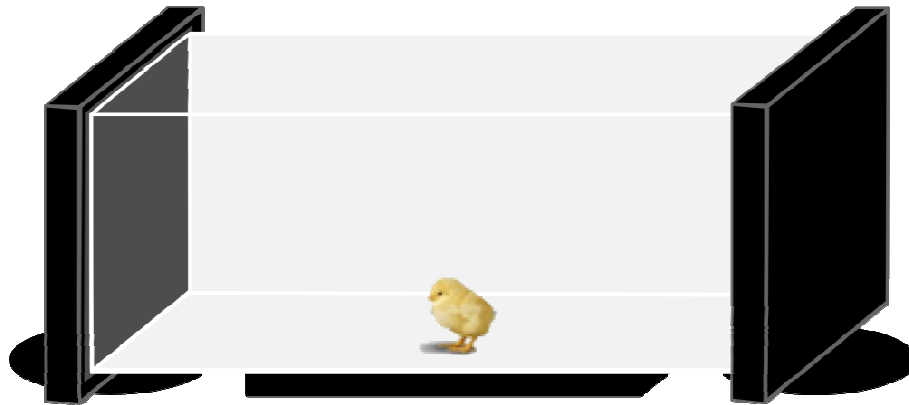


Fig. 10. The test apparatus.

Procedure

On Day 2 of life, in the early morning, chicks were singly taken from the dark hatchery in a closed cardboard box and carried to the experimental room (located nearby the imprinting room, and kept at 29-30° C and humidity of 68%). Each chick was placed in the central area of the test apparatus (i.e., facing one of the two white side walls), so that its spontaneous preference for either animations could be assessed. The chicks' position at the starting point

(i.e., the wall it was facing), as well as the position of the two stimuli (i.e., the end side of projection), was balanced across animals.

Chicks' behaviour was observed for a total of 6 consecutive minutes. Permanence of the chick in the mid compartment was assumed to indicate no choice, whereas movement of the chick to one of the end-side compartments was regarded as a preference for the animation sequence presented at that end.

Data Analysis

Time (sec) spent by the chick in each of the three areas was scored on-line by an experimenter blind to the purposes of the research. A preference score (percentage) was subsequently computed: The time spent near the causal stimulus was divided by the total amount of time spent in both side areas and then converted into a percentage score. The preference score values, hence, ranged from 100 (full choice for the Launching stimulus) to 0 (full choice for the non-causal control stimulus). Fifty per cent represented chance level.

To determine whether the preference score was significantly different from the chance level a one-sample (two-tailed) *t*-test was applied (SPSS statistical package).

2. Experiment I

Chicks' sensitivity to physical causality was investigated by testing their spontaneous preferences for a Launching stimulus vs a non-causal Delay stimulus.

Naïve newborn chicks were required to choose between two video animations featuring two squared shapes, such shapes being involved either in a Launching Effect or in a Delay interaction.

Subjects

A total of 68 newly-hatched domestic chicks were tested. Seven chicks were discarded because they did not choose any stimulus, therefore 61 subjects (28 males and 33 females) were included in the analysis.

Test Stimuli

Two computer presented animation sequences were created, each sequence featuring two identical square-shaped objects which will be named A and B thereafter (squares were chosen rather than ovals to maximize the area of contact between the two objects when colliding).

In the Launching video animation object A moved towards object B which remained stationary. Immediately after contact B started to move along the same direction, at the same speed and covering the same distance as A, whereas object A became stationary (Fig. 11.a). As described in previous paragraphs, in this display adult humans perceive object A as “launching” B and causing its movement.

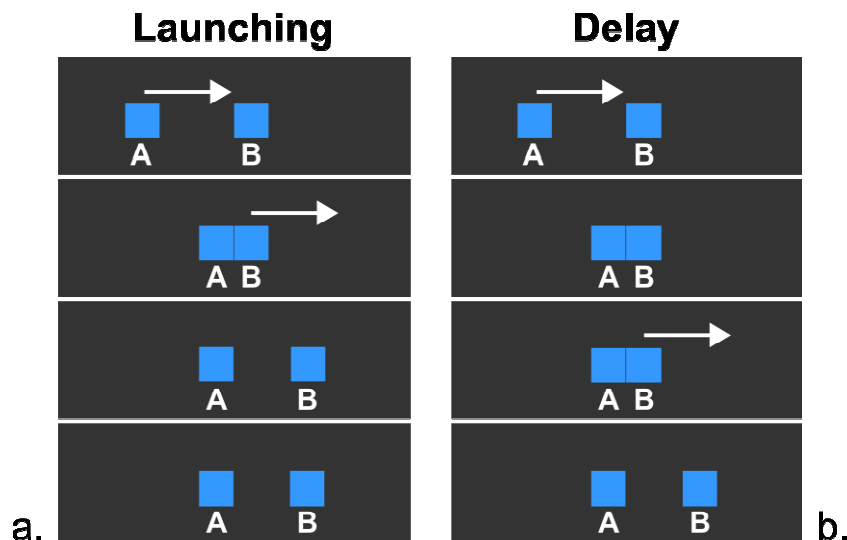


Fig. 11. Schematic representation of the animation sequences used in Experiment 1: a. the Launching stimulus; b. the Delay stimulus (the left-right position of presentation was counterbalanced across subjects).

The Delay video animation was identical to the Launching one except for the presence of a 2 sec-delay between the time of contact and the motion of object B (Fig. 11.b). Due to the 2 sec-delay this animation would last 2 sec more than the Launching stimulus. For this reason, the Launching animation was modified by leaving visible its last static frame for 2 sec. Therefore, both animations lasted 7 sec (420 frames; 60frames/sec). Each object in the animation covered a distance of 8 cm at 8cm/sec.

At the end of the sequence a gray screen (identical to the background, RGB = r51, g51, b51) appeared for 1 sec before the animation restarted.

Results

A one-sample (two-tailed) *t*-test applied at the preference score for the Launching animation vs chance level (50%) did not reveal any significant choice (mean \pm SEM = 48.574 \pm 3.886; one-sample *t*-test: $t_{60} = -0.367$, $p = 0.715$; Fig. 14).

Results of Experiment 1 did not show any spontaneous preference for either test stimuli.

3. Experiment II

Results of Experiment 1 provide evidence for the absence of a preference for either causal or non-causal displays in the domestic chicken. Nevertheless, results could be due also to the peculiar spatiotemporal features of the stimuli employed in this experiment.

As previously analyzed in Study 1 (Experiment 2), in fact, the Delay stimulus differed from the Launching one for several points:

- the extended time of contact between object A and B (which was 2 sec longer than the one in the Launching stimulus)

- the overall movement of the display (which continued for 2 sec after cessation of any movement in the Launching)
- the temporal discontinuity of motion of the delay stimulus due to the prolonged contact between A and B.

For such reasons, in Experiment 2 *naïve* chicks' spontaneous preference for a Launching stimulus vs a non-causal Passing stimulus was investigated.

Subjects

A total of 123 newly-hatched domestic chicks were tested. 47 were discarded because they did not choose any stimulus, therefore 76 subjects (42 males and 34 females) were included in the analysis.

Test Stimuli

The stimuli consisted into two computer presented animation sequences featuring two identical square-shaped objects, as in Experiment 1.

The Launching video animation was identical to the one used in the previous experiment (except for its length, since it did not maintain its final frame for 2 sec; Fig. 12.a).

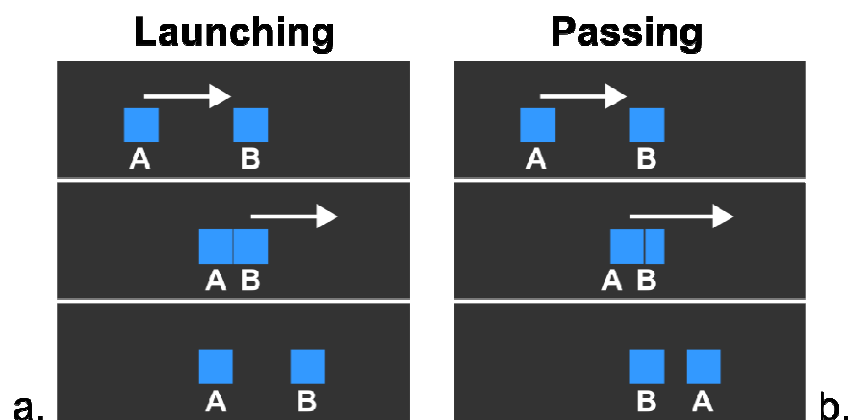


Fig. 12. Schematic representation of the animation sequences used in Experiment 2: a. the Launching stimulus; b. the Passing stimulus (the left-right position of each presentation was counterbalanced across subjects).

The first frame of the Passing video animation was identical to the one of the Launching display (Fig. 12.b). The first object to move (A) moved towards the stationary object (B), passed in front of it and reached the final position occupied by B at the end of the Launching sequence. In this animation no physical causality was implied but the spatiotemporal continuity typical of the Launching stimulus was preserved.

Each object in the Launching animation covered a distance of 8 cm at 8cm/sec, whereas object A in the Passing stimulus covered a distance of 17 cm at 8,5cm/sec and maintained both its starting and final position for 1 sec.

At the end of the sequence a gray screen (identical to the background, RGB = r51, g51, b51) appeared for 1 sec before the animation restarted. Both animations lasted 5 sec (300 frames; 60frames/sec).

Results

A one-sample (two-tailed) *t*-test applied at the preference score for the Launching animation vs chance level (50%) did not reveal any significant choice (mean \pm SEM = 48.382 \pm 3.338; one-sample *t*-test $t_{75}=-0.485$, $p=0.629$; Fig. 14).

These results revealed that *naïve* chicks do not exhibit any spontaneous preference for a Launching video animation vs a Passing one, approaching similarly the two test stimuli.

Discussion

The present research built on previous findings that infants interpret Michotte's Launching Events as causal starting since at least six months of life (Leslie and Keeble, 1987; Oakes, 1994; Cohen and Amsel, 1998), and that some non-human species successfully use physical causality to obtain a reinforce in a tool-using task (Visalberghi and Limongelli, 1994; Limongelli, Boysen and Visalberghi, 1995; Fujita, Kuroshima and Asai, 2003; Helme, Clayton and Emery, 2006; Tebbich, Seed, Emery and Clayton, 2007; Seed, Call, Emery and Clayton, 2009; see Taylor, Hunt, Medina and Gray, 2009 and Emery and Clayton, 2009 for a review).

This research aimed to extend those findings in at least two ways:

- It examined for the first time the spontaneous preference of newborn subjects, whose previous experience were completely absent (in the case of domestic chickens) or at least reduced to a minimum (as for day-old newborn babies);
- It would hopefully allow for a direct comparison between preferences expressed by both newborn babies and *naïve* non-human subjects (i.e., domestic chicks).

In Study 1 newborn babies were tested for their preference for either a causal (i.e., Launching stimulus) or a non-causal (i.e., Inverted-Sequence stimulus in Experiment 1, Delay stimulus in Experiment 2) video animation.

Results revealed that newborns prefer the Launching effect (a choice which persists with both the non-causal stimuli used at test in the two experiments; Fig. 13). Such preference was not due to a mere choice for the spatiotemporal features of the Launching animation, since a preference for the spatiotemporal parameters of the Delay did emerge when newborns were

presented with a stimulus having such parameters and a stimulus having the features of a Launching-without-causality (Experiment 3).

Newborn babies, hence, demonstrated to distinguish a causal from a non-causal stimulus and to prefer the causal one. It seem, therefore, that humans are susceptible to the physical causality of a Launching event from the very early hours of life.

In Study 2 the preference of newly-hatched domestic chicks for physical causality was investigated. Two experiments were conducted, in each experiment chicks were asked to freely choose between a causal (i.e., Launching Effect) and a non-causal video animation (i.e., a Delay stimulus in Experiment 1, a Passing stimulus in Experiment 2).

Data did not reveal any significant preference in either experiment (Fig. 14).

On the ground that not significant results should be interpreted with caution, those data could be read in several ways:

1. newly-hatched domestic chicks could lack the capability to perceive physical causality in a Michottean Launching Event;
2. newly-hatched domestic chicks are sensitive to physical causality present in the Launching stimulus but they could have no preferences for causal vs non-causal stimuli;
3. newly-hatched domestic chicks could be sensitive to physical causality present in the Launching stimulus but the type of stimuli and/or the specific paradigm employed failed to highlight it.

Obviously, the present research does not allow to disambiguate between such alternatives (a further research is required to check for those possibilities).

The present research, to conclude, succeeded in extending previous findings in the case of the newborn babies: it demonstrated for the first time newborns' sensitivity to physical causality and highlighted the precocious origin of such capability in the human species.

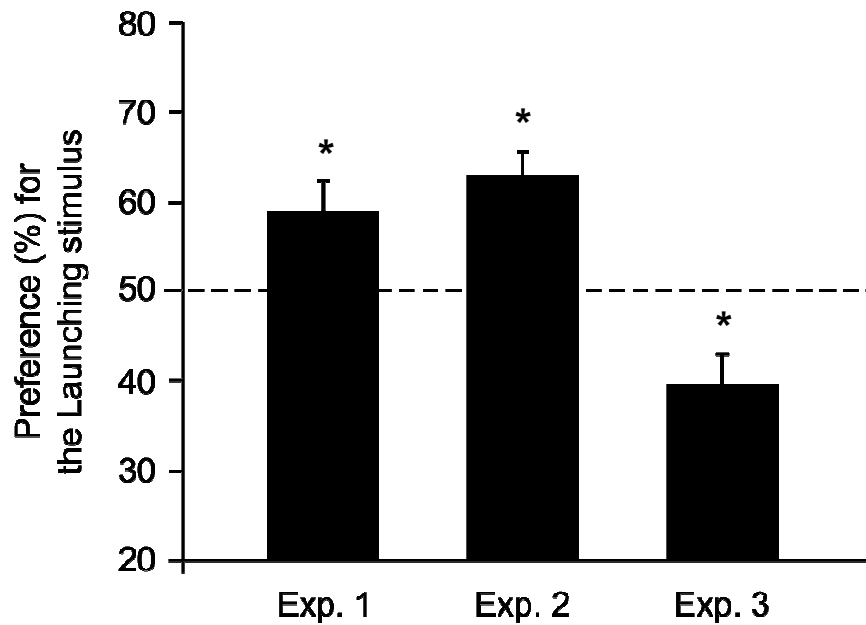


Fig. 13. Overall results on newborn babies. Average percentage (Mean \pm SEM) of total fixation time newborns spent looking at the Launching stimulus in the three experiments. The dotted line represents chance level. A significant preference for the Launching stimulus did emerge in Experiment 1 and 2, whereas in Experiment 3 newborns looked significantly longer to the “90° Delay” stimulus.

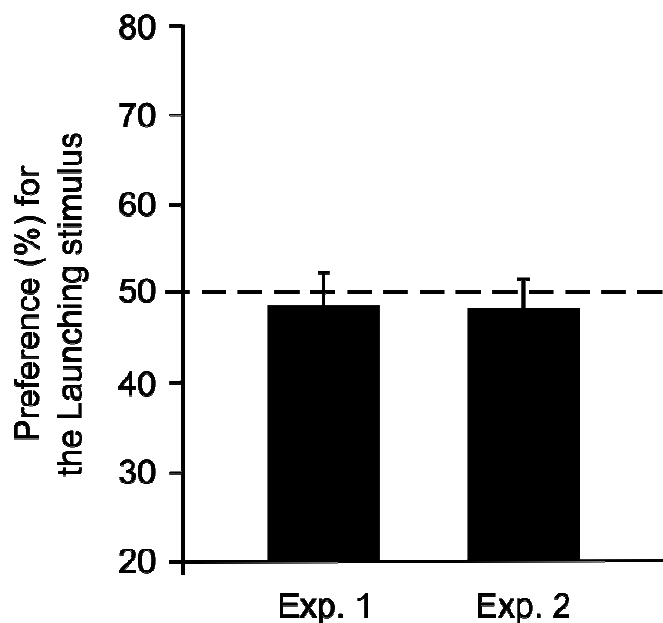


Fig. 14. Overall results on domestic chicks. Average percentage (Mean \pm SEM) of time spent by the chicks near the Launching stimulus in the two experiments. The dotted line represents chance level. *Naïve* chicks did not exhibit any spontaneous preference for either stimulus.

Chapter III

IV

Agency, Animacy and Self-Propelled motion

In the previous chapters we faced the possibility that humans and other animal species (e.g., the domestic chick) may possess a precocious system for the detection of *physical* relations between object (i.e., physical causality). The second half of this thesis, however, will focus on the origin of knowledge about *social* objects (i.e., animate beings), in both the *physical* and *psychological* domain.

Humans' striking ability to attribute intentions and motivations to agents, even when these consist in simple geometric figures in motion, is widely demonstrated. The first experimental observations about such phenomena date back to 1944, when the psychologists Fritz Heider and Mary-Ann Simmel devised an animation involving three simple geometric shapes (i.e., a big triangle, a small one and a little circle) that move with different spatiotemporal features (speed, acceleration) within and around a rectangle. All subjects (i.e., adult humans) described the events in terms of intentional action and social interaction: they reported to see the big triangle as trying to hurt, entrain or chase the little circle and the little circle as trying to escape from the triangle (Fig. 15, Heider and Simmel, 1944). Furthermore, *naïve* observers do not only perceive these shapes as "alive": particular personal traits, beliefs, intentions and emotions are often attributed to them as if they

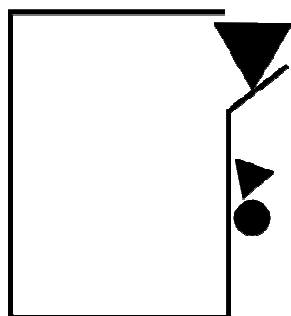


Fig. 15. Schematic representation of a static frame from the classic Heider-and-Simmel animation: abstract geometric shapes moving around and inside of a rectangle (modified from Heider and Simmel, 1944).

were animate beings (Heider and Simmel, 1944; Kanizsa and Vicario, 1968; Heberlein and Adolphs, 2004). These anthropomorphic interpretations of the events were automatic and remarkably consistent from one subject to another: although subjects were aware of being merely observing an animation, they nevertheless could not help seeing these events in terms of intentional actions performed by animate agents.

Since Heider and Simmel's work, several researches have tried to reveal which are the features that characterize an object as an agent. In this context, "agency" has been conceptualised at different levels (Carey, 2009). The first and basic level is the "mechanical agency" (i.e., the so called "animacy"), which implies the objects being capable of self-propelled motion, of acting as a mechanical cause and of resisting forces acting upon it. This aspect of agency obviously interacts with the representations of physical causality described in Chapter 2, since an animate agent is capable to play the role of causal agent in an interaction or to resist to a physical contact by another object (Leslie, 1994; Carey, 2009). The concept of "mechanical agency", therefore, belongs to the domain of *naïve* physics, and thus it seems to lie outside the psychological domain of intentions and mental states (Leslie, 1994; Csibra, Gergely, Bíró, Koos and Brockbank, 1999). The second type of agency concerns our explanations for specific actions. The behaviour of animate objects, in fact, is very precociously interpreted in terms of goals and motivational states. Such animate objects, therefore, would be regarded as "intentional agents", capable to attend to and perceive other objects and to set themselves a goal (i.e., to "*desire a state of affair*", Carey, 2009). It is obvious from features previously described that an intentional agent does not coincide with an animate agent: animacy can be attributed to an object in spite of the lack of intentionality in its acts. A further and more complex level of agency attribution (i.e., the "mentalist agency") is occasionally distinguished from the intentional one, although not all researchers accept such distinction. Mentalistic agency would entail the possession of mental states such as desires and beliefs, a type of

unobservable constructs having a specific relationship with the world, being *directed to the world* and *having content* (Johnson, 2000)¹⁰.

Starting from experimental evidences demonstrating infants' bias to pay attention to specific features belonging to animate beings (such as biological pattern of motion, Bertenthal, 1993, Simion, Regolin and Bulf, 2008, and the appearance of faces, eyes and gaze, Morton and Johnson, 1991, Farroni, Csibra, Simion and Johnson, 2002, Farroni, Johnson, Menon, Zulian, Faraguna and Csibra, 2005), a mechanism is supposed to exist which precociously biases humans towards relevant social stimuli, allowing us to attribute agency to other entities.

Up to date several features have been demonstrated to be relevant cues for agency attribution by human infants, such as goal-directed behaviour, rationality, variability of behaviour, reactivity to social contingencies and self-propulsion. Nevertheless, both the relations between such cues and their weight in triggering different types of agency attribution (i.e., mechanical, intentional, mentalistic agency) are not yet clearly defined.

In the next paragraphs the literature about the role of different cues in agency attribution will be reviewed, mainly focusing on the role of self-propelled motion, as this is the cue which has been investigated in our research on domestic chickens.

1. Goal-directedness and Rationality as cues for Intentional Agency

In the last two decades several developmental researches have been conducted in order to point out which features of an object act as salient cues allowing for agency attribution. Most of these studies investigated whether

¹⁰ The reason advanced for the frequent lack of distinction between mentalistic and intentional agency is usually that it is hard to make a clear-cut distinction between a goal-directed behaviour and the possession of desires.

infants would attend selectively to aspects of an action which are related to a goal-directed behaviour and whether such goal-directed behaviour would lead to agency attribution.

Amanda Woodward and her colleagues first provided convergent evidences that young infants represent actions as goal-directed (Woodward, 1998) by employing an habituation/dishabituation paradigm. Five-month-old infants were habituated to a hand moving across a stage and grasping¹¹ one of two objects placed at the opposite sides of the stage. At test, the position of the two objects was reversed and one of two events was shown. In the first event (i.e., “novel path”) the hand took a novel path to grasp the same object as before, which was actually in a different position; in the second event (i.e., “novel goal”) the hand took the same path as before but grasped the novel object (which was actually placed in the position occupied by the target object during the habituation phase; Fig. 16). The habituation event, hence, could be described along two dimensions: the spatiotemporal one, which regarded the specific path followed by the grasping hand, and the goal-dimension, which regarded the specific target the hand grasped (i.e., such second dimension being the one implied in the attribution of intentional agency to the hand). At test, each event preserved only one of those dimensions. Since infants are known to look longer at an event that they perceive as novel, longer looking times to one test event over the other would demonstrate that the dimension encoded in the habituation phase was the one which changed in such test event.

Data showed longer looking times for the “novel goal” event, a result in line with the hypothesis that infants had represented the original habituation action in terms of goal-directed behaviour (Woodward, 1998).

¹¹ It has been demonstrated that infants understand some aspects of the mechanics of grasping: 3–4-month-old infants know that an object is adequately supported when grasped by a hand, but not when the hand releases it (Needham and Baillargeon, 1993; Baillargeon, 1995). By 5 ½ months of life, moreover, infants are sensitive to some of the constraints which determine an actor’s ability to retrieve an object (they show surprise, for instance, when an actor retrieves an object without removing a barrier placed between the hand and the object (Baillargeon, Graber, DeVos and Black, 1990).

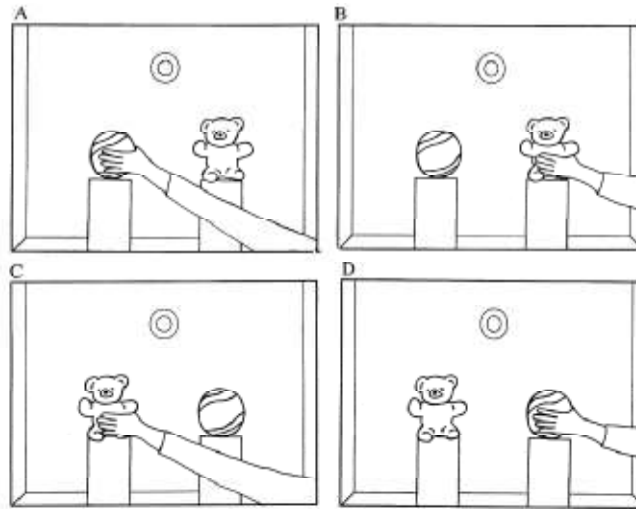


Fig. 16. Events used by Woodward in her researches on infants. Infants were habituated to either event A or B and then presented with C or D at test. In case of habituation to A, C would be the “novel goal-same path” event, D would be the “same goal-novel path” event; viceversa in case of habituation to B (from Woodward, 1998).

Several control conditions ruled out the possibility that subjects were merely representing the spatial relation between the hand and the target, demonstrating that infants dishabituated to the “novel goal” event (rather than to the “novel path”) only when the action was performed by a hand and can be interpreted as goal-directed¹².

This and other researches (see Carey, 2009 for a review), hence, demonstrated that infants are sensitive to the goal-directedness feature of a behaviour.

Besides the goal-directed behaviour in itself, nevertheless, a crucial cue to intentional agency attribution seems to be the “*principle of rational action*” as defined by Gergely and Csibra: such principle “*states that an action can be explained by a goal state if, and only if, it is seen as the most justifiable*

¹² In a first control condition the hand was replaced with a stick having a multifingered sponge at the end. In a second control condition the arm and the hand were replaced by a rod with a flat occluder and in a third control condition a rod with a pincer was used. In all these conditions the spatial relation at the end of each habituation trial was the same as in the hand-grasping condition: the grasping object was in contact with the target. Results showed longer looking times for the “old goal-novel path” event (rather than for the “novel goal-old path”) in control 1 and 3, whereas no differences between test events were found in control 2 (Woodward, 1998).

action towards that goal state that is available within the constraints of reality” (Csibra and Gergely, 1998).

In an early study by Gergely, Csibra and colleagues (Gergely, Nádasdy, Csibra and Biro, 1995) evidences were provided that 12-month-old-infants can interpret the behaviour of computer animated shapes as goal-directed *rational* actions (comparably to adult subjects; Heider and Simmel, 1944). In this research infants were habituated to an event in which a small disc repeatedly approached and contact a large disc by “jumping over” a rectangular obstacle separating them (Fig. 17). Adult subjects interpreted this jump as a justifiable action (i.e., required by the contextual constraints) performed by the small disc to reach its goal (i.e., that of contacting the big disc). At test the rectangular obstacle was removed and infants were shown either the familiar “jumping approach” or a novel action (i.e., a “straight-line approach”). Since the obstacle had been removed, the “straight-line approach” might have been perceived as the more rational one in terms of goal-directed behaviour (i.e., it was the shortest and most rational path to be covered by the small disc to approach the big one) but completely novel for its spatial component. The “jumping approach”, on the contrary, would have been “irrational” at a goal-directedness analysis but the same as the habituation one from the spatial point of view.

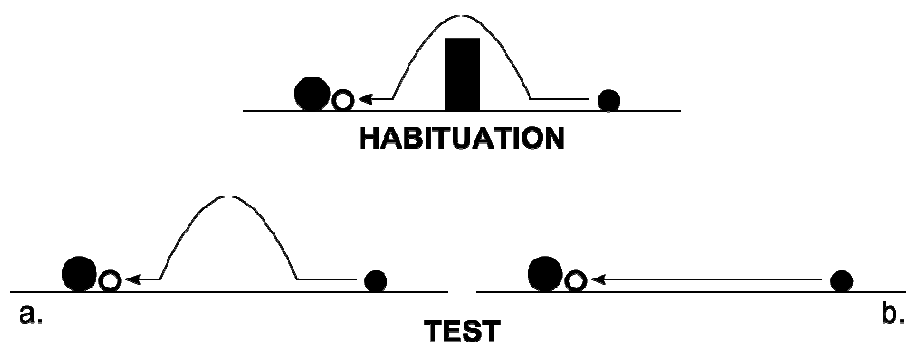


Fig. 17. Schematic depiction of habituation and test events (a. the “jumping approach” event, b. the “straight-line approach” event) in Gergely, Nádasdy, Csibra and Bíró, 1995.

Data on infants showed at test higher looking times for the “jumping approach” rather than for the “straight-line approach” and this result was replicated with 9-month-old infants in a subsequent research (Csibra, Gergely, Bíró, Koos and Brockbank, 1999)¹³. These data showed that infants had judged the appropriateness of the perceived movement in respect to the goal rather than the mere perceptual familiarity with the spatial trajectory. This seems to indicate that as early as 9 months of age infants can take advantage of a *naïve* psychological structure which allows them to interpret the behaviour of objects in terms of goal-directedness and rationality (such an interpretation being independent from the detection of human-like features, since the “actors” in these research had neither faces nor biological motion; Gergely, Nádasdy, Csibra and Bíró, 1995; Csibra, Gergely, Bíró, Koos and Brockbank, 1999).

Taken together, the Gergely, Csibra and Woodward studies suggest that infants represent some actions as goal-directed by 6 months of age, demonstrating to be capable of goal-attribution even to animated geometric shapes which do not possess facial or body features (Gergely, Nádasdy, Csibra and Bíró, 1995; Woodward, 1998; Csibra, Gergely, Bíró, Koos and Brockbank, 1999). Infants, moreover, have been demonstrated to perceive an event in terms of goal-directedness even when the goal of a certain behaviour is not visible and has to be inferred from the rest of the event (Csibra, Bíró, Koos and Gergely, 2003; Wagner and Carey, 2005).

It’s obvious, however, that the capability to detect goal-directedness in a behaviour does not necessarily entail in itself the capability to attribute intentional agency to the actor of such behaviour.

¹³ Further control studies were conducted to verify whether this results were indeed ascribable to the infants’ interpretation of the habituation event. In the control experiments the habituation events were identical to the previous one except for the position of the “obstacle”, which was placed not in between the two balls but behind the moving one. In this display the “jumping approach” performed by the small disc maintained its spatial features but lost its instrumental meaning. The test events were the same of the main experiment. Data did not show any significant difference in infants’ looking times to the “jumping approach” and “straight-line approach” at test, supporting the statement that their performance was due to their interpretation of the habituation stimulus in terms of goal-directed behavior (main experiment) or mere spatial features (control experiments) (Gergely, Nádasdy, Csibra and Bíró, 1995; Csibra, Gergely, Bíró, Koos and Brockbank, 1999).

Gergely, Csibra and their colleagues, for instance, put forward a representational system at the basis of infants' perceptions of goal-directed actions which does not entail agency attribution (Gergely and Csibra, 1997). They supposed that when looking at certain stimuli (such as the ones used in the experiments previously described) infants adopt a Teleological Stance (i.e., a bias rather than an explicit inferential system); this would be “a *tendency to construe events in accord with a certain formal structure*” (Csibra, 2003). This bias would imply an interpretational schema (Fig. 18) which establishes a teleological explanatory relation among three relevant aspects of the reality: if and only if the observed behaviour is an *efficient* action (i.e., which gives rise to a certain end-state within the given physical context), a well formed teleological interpretation¹⁴ of the event is created. Nevertheless, by applying the Teleological Stance infants *do not* necessarily need to attribute intentional mental states to the actors in order to perceive behaviours in terms of goal-directedness (Csibra and Gergely, 1998; Csibra, 2003; Gergely and Csibra, 2003): to attribute intentionality to the actor is not a necessary implication of the Teleological Stance.

Gergely and Csibra, in fact, theorized the existence of a further representational system, the Intentional Stance, which allows for the attribution of intentions and mental states to the actors involved in the perceived events (Csibra, 2003).

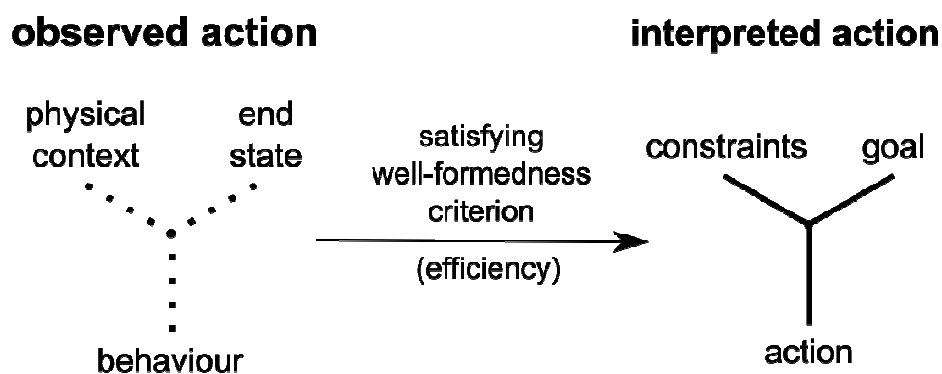


Fig. 18. The three-part structure of the Teleological Stance (Csibra, 2003).

¹⁴ In the teleological interpretation the perceived behaviour becomes a *rational* action toward a goal satisfying specific constraints (Csibra, 2003).

Gergely and Csibra's Teleological Stance satisfactorily accounts for experimental evidences about infants' capability to detect a goal-directed behaviour. Nevertheless, according to such theory the perceived goal-directed behaviour in itself is not explicitly predicated of an agent: infants would see an action as goal-directed without any attribution of agency to the actor (Csibra, 2003).

On the contrary, in a series of recent studies, evidences have been found that infants are concerned with agency attribution on the basis of the detection of a goal-directed behaviour.

In a research by Saxe, Tenenbaum and Carey (2005), for instance, 10- and 12- month-old infants were habituated to a figure flowing in from offstage over a screen and landing on the other side of the stage¹⁵ (the screen had different heights so that different paths but the same ending position were experienced by infants). After habituation, a hand appeared either from the side of the stage where the flying figure had come in or from the side where it had landed. For half of the infants the flying figure was a beans-bag whereas for the other half of the subjects it was a puppet with eyes and legs. The crucial experimental manipulation, however, was a familiarization period before habituation in which infants were acquainted with the nature of the flying object (i.e., inanimate in the case of the beans-bag, animate in the case of the puppet). Data showed a different pattern of results depending on the employed flying figure: in the case of the beans-bag infants looked longer at the test event in which the hand appeared from the side where the bag had landed¹⁶, whereas, in the case of the puppet, infants did not differentiate the two sides and showed in both cases longer looking time for the puppet than they had shown for the beans-bag (Saxe, Tenenbaum and Carey, 2005). Thus, it seems that infants interpreted the puppet itself as the source of its own goal-directed behaviour: this result demonstrate that infants do assign goals to particular agents.

¹⁵ It was a real-life rendering of the event in Experiment 2 of Csibra, Gergely, Bíró, Koos and Brockbank, 1999.

¹⁶ Such difference disappeared if the hand was substituted by a "non-agent" (i.e., a train).

Another line of investigation led to the same conclusion. When habituated to a goal-directed behaviour acted by a certain object toward another (e.g., object A chasing object B), in fact, 9-month-old infants demonstrated to dishabituate to the reversal of this action (e.g., to object B chasing object A) in which the roles of the two actors had been swapped (Schlottmann and Surian, 1999; Rochat, Striano and Morgan, 2004). These pattern of results, hence, demonstrates that infants assign distinct roles to distinct actors in a goal-directed action.

Overall, the reviewed researches demonstrate that by 6 months of life infants are capable of spontaneously represent an action as goal-directed (Woodward, 1998; Kamewari, Kato, Kanda, Ishiguro and Hiraki, 2005), such representation being possible also for actions performed by geometric shapes (i.e., shapes without any human-like features) (Gergely, Nádasdy, Csibra and Bíró, 1995; Csibra, Gergely, Bíró, Koos and Brockbank, 1999; Luo and Baillargeon, 2005), even when the goal of a certain behaviour is not visible and has to be inferred from the rest of the event (Csibra, Bíró, Koos and Gergely, 2003; Wagner and Carey, 2005).

Moreover, infants do not merely detect goal-directed behaviours (in terms of a teleological interpretation of the perceived event) but they also attribute Intentional Agency on the basis of such goal-directedness feature to both human-like actors and geometric shapes (Schlottmann and Surian, 1999; Rochat, Striano and Morgan, 2004; Saxe, Tenenbaum and Carey, 2005). Goal-directed behaviour and the principle of rationality, hence, have been demonstrated to be relevant cues employed for Intentional Agency attribution (Carey, 2009).

2. Self-propulsion as a cue for Intentional Agency

Motion features are known to be a salient cue in identifying objects and in classifying them into different categories. Strictly regarding self-propulsion, different theoretical models have focused on its role in agency attribution. In one of the most prominent theory (Leslie, 1994, 1995) self-propelled motion would be detected by the first component of a hierarchically organized system and would be interpreted in terms of the physical notion of “force”, giving rise to the attribution of mechanical agency (i.e., an agent having an internal source of energy) to the object which self-propulsion belongs to. The self-propelled nature of motion, however, would not suffice to provide an attribution of Intentional Agency, which would require goal-directed behaviour and other perceptual features besides it.

This theoretical hypothesis according which self-propelled motion would play a role in triggering intentional agency attribution but would not be either necessary nor sufficient, has been corroborated by many experimental evidences.

Up to date, in fact, it is well attested that self-propelled motion acts as a cue to Intentional Agency attribution.

In a research by Luo and Baillargeon (2005), for instance, 5-month-old infants were familiarized with a box approaching one of two target objects. Two test trials followed, in which the locations of the two target object were swapped (as described for Woodward, 1998): in one of the trials the box moved along the same direction as before but towards the new target object (“new goal” condition) whereas in the other trial it moved towards the same target but along a different direction (“new direction” condition). Goal attribution was assessed by measuring whether infants’ attention recovered when the target changes (“new goal” condition). When the box apparently travelled under its own momentum towards a certain target, infants attributed a target-specific preference to the box (i.e., they showed higher attentional recovery for the “new goal” event than for the “new direction” one), but they

did not so when the box might have been driven by external force¹⁷. This suggests that 5-month-old infants may attribute goals to inanimate unfamiliar objects on the basis of the property of self-motion. These results suggested that self-propelled motion provides a salient cue for infants to identify Intentional Agents in a teleological (i.e., goal-directed) context (Luo and Baillargeon, 2005).

Nevertheless, self-propelled motion is demonstrated to be neither a necessary nor a sufficient cue for Intentional Agency attribution (see Bíró, Csibra and Gergely, 2007 for evidences on 9- and 12-month-old infants). It is now recognized, in fact, that self-propulsion is usually overridden by other cues of agency, such as “variability of behaviour” (i.e. the capability to adjust behaviour in a manner relevant to be interpreted as making a choice) and reactivity to social contingencies.

With reference to the prominence of the variability of behaviour, this was recently investigated in a study by Csibra (2008). In this research 6 ½-month-old infants were habituated to a 3D video animation in which a box reached a target object by making a detour around an obstacle placed between them. Two conditions were created. In the Single Route condition the box always approached the target the same way (i.e., to the right from the viewer’s point of view) whereas in the Variable Route condition the box approached the target by either two ways (i.e., left and right) in alternated presentation¹⁸. After habituation criterion was reached, two test events were presented in which the obstacle was removed. In a first test event the box repeated one of the two routes it took during habituation (“detour test event”), in the other event the box went straight to the target (“straight path event”). Results showed longer looking times for the “detour path event” in the “variable route” condition only. These data suggest that 6 ½-month-old infants do *not*

¹⁷ When the box had an handle which extended outside the scene and so it might have been driven by external forces, in fact, infants did not show any significant difference in their attentional recovery for the two test events (Luo and Baillargeon, 2005).

¹⁸ A control group was presented with two habituation events which were the same as described above except that the obstacle was placed next to the far wall of the room and not in the way of the box (Csibra, 2008).

interpret a box moving on a single route around an obstacle toward a target as an Intentional Agent having goal-directed behaviour. Thus, it seems that self-propelled motion in itself does not allow for the attribution of Intentional Agency in the absence of some degrees of variability in behaviour (Csibra, 2008).

The relevance of both variability of behaviour and reactivity to social contingencies was investigated in a series of experiments by Susan Johnson and her colleagues (Shimizu and Johnson, 2004; Johnson, Shimizu and Ok, 2007), employing a task similar to that of Luo and Baillargeon (2005). Twelve-month-old infants were habituated to an oval-shaped “blob” covered with bright fibre which approached and stopped near one (i.e., object A) of two objects placed at the opposite sides of the back wall of the apparatus. At test the location of those two objects was swapped. In one of the two test event the blob was shown to approach object A (“new location” event) whereas in the other test trial it approached object B (“new goal” event). The crucial manipulation regarded the orientation or “reactivity” of the blob before both habituation and test trials. When the blob appeared with its front-to-back axis already aligned with the target object it was going to approach, infants looked about equally at both test events: they did not seem to perceive the blob as an intentional agent, in spite of the self-propelled nature of its motion. Longer looking times for the “new goal” test event (in respect to the “new location” event), however, have been obtained in two key conditions: 1) when at the beginning of each event the blob faced a position midway between both objects and subsequently turned toward the target one before approaching it; 2) when the blob took part in a “conversation” with the experimenter¹⁹ before approaching the target (Shimizu and Johnson, 2004; Johnson, Shimizu and Ok, 2007)²⁰.

¹⁹ The experimenter spoke in English to the blob, which answered with a series of varying beeps (Shimizu and Johnson, 2004).

²⁰ Converging evidences have been obtained in 14- to 15-month-old infants using a “gaze following” paradigm: infants shifted their attention and gaze toward the orientation of the actor except when the actor lacked contingently interactive behaviour (Johnson, Bolz, Carter, Mandsanger, Teichner and Zettler, 2008).

The upshot of these studies, therefore, is that for an Intentional Agency attribution to occur (in terms of goal-directed behaviour), the unfamiliar actor involved in the events has to show *both* self-propulsion *and at least one other cue* of agency, such as the capability to vary its behaviour (in a manner that is relevant to be interpreted as making a choice; Johnson, Shimizu and Ok, 2007) or to react to social contingency (Johnson, Slaughter and Carey, 1998; Shimizu and Johnson, 2004; Johnson, Bolz, Carter, Mandsanger, Teichner and Zettler, 2008).

Although probably providing some contribution, self-propulsion is certainly not the primary cue for the attribution of Intentional Agency in its primary domain of goal-directed behaviour.

3. The role of Self-propelled motion in Animacy attributions

From a *naïve* view, self-propelled motion seems to provide one of the most powerful cues about what makes an object “animate”, i.e. a type of object distinct from one that can be put into motion only as a result of physical contact.

This idea dates back to at least Aristotle (*Physics*) and it has been incorporated into developmental psychology doctrine. Several researchers focused on the origin of the Animate-Inanimate distinction, investigating infants’ ability to relate different types of motion with different kinds of objects (see Rakison and Poulin-Dubois, 2001 for a review): the majority of the theorists regarded the physical principles related to the motion of entities as a crucial cue for infants’ earliest distinction between animate and inanimate objects. In fact, the most obvious feature that distinguishes animate from inanimate subjects seems to be the ability to move, or self-propelled motion, as opposed to motion caused by an external force. In Leslie’s theory of agency (Leslie, 1994, 1995) the self-propelled origin of motion is interpreted in terms of the physical notion of “force”. It would be detected by the first

component of a hierarchically organized system giving rise to the attribution of mechanical agency (i.e., animacy, an agent having an internal source of energy) to the object which it belongs to²¹. For Leslie as well as for other authors (Premack, 1990; Baron-Cohen, 1994; Rakison and Poulin-Dubois, 2001²²), hence, self-propelled motion is a salient cue to trigger attribution of animacy.

In spite of some common principles²³ which underlie infants' reasoning about both inanimate and animate entities, in fact, some specific principles for the animate beings seem to exist, one of those principles being exactly self-propelled motion (Spelke, Philips and Woodward, 1995). An analysis of the literature, however, reveals a relative absence of studies on infants' ability to discriminate self-propelled from caused motion.

A relevant part of the research initially tended to focus on infants' ability to relate self-propelled nature of motion with different kinds of objects. In a research by Woodward and colleagues (Woodward, Philips and Spelke, 1993), for instance, 7-month-old infants' expectations about inert and self-propelled objects have been investigated. Subjects were habituated to a video featuring two actors. At the beginning of the video a large occluder was present in the centre of the monitor, with one of the "actors" (i.e., named B) partially visible at the right edge of it, whereas the other actor (i.e., A) was not present. Few seconds later, A entered the stage from the left and moved

²¹ The detection of self-propulsion, however, is not sufficient to provide an attribution of intentional agency, which requires goal-directed behaviour besides it.

²² According to Rakison and Poulin-Dubois the animate/inanimate distinction in infancy would be rooted in at least 5 features, with the self-propelled nature of motion as foremost cue. Those cues are: the onset of motion (A: self-propelled vs I: caused motion), the line of trajectory (A: irregular vs I: smooth), the form of causal action (A: at a distance vs I: from contact), the pattern of interaction (A: contingent vs I: non-contingent), the type of causal role (A: agent vs I: recipient). In addition to these motion-related features, those authors believe that certain psychological attributes need to be subsequently included: the purpose of action and the influence of mental states (Rakison and Poulin-Dubois, 2001).

²³ Such principles are Cohesion (i.e., the fact that physical objects "*move as connected bounded wholes*"), Continuity (i.e., the fact that physical objects "*move on connected unobstructed paths*") and Gravity (i.e., the fact that physical objects "*rest and move on supporting surfaces*") (Spelke, Philips and Woodward, 1995).

toward the right, disappearing behind the occluder. After a proper interval²⁴ B moved to the right and disappeared at the right side of the monitor. After habituation criterion was reached, the occluder was removed and infants were shown two test events totally identical to each other except for what happened during the previously occluded portion of the actors' trajectory. In the "contact test event" A collided with B, whereas in the "no-contact test event" A stopped before contacting B. Infants were assigned either to an inert or self-propelled condition which differed for the type of actors involved: in the "inert condition" they consisted in two human-sized blocks differing in their perceptual features (i.e., shape, pattern, colour) whereas in the "self-propelled condition" a man and a woman were employed to perform the event. Data showed higher dishabituation for the "no-contact test event" in the "inert condition", whereas no differences had been recorded between the looking times assigned to the two test events in the "self-propelled condition" (Woodward, Philips and Spelke, 1993). These results demonstrated infants' knowledge that inert objects can be set into motion only after contact with another object and that humans are self-propelled entities which can move by their own momentum (Woodward, Philips and Spelke, 1993; Luo, Kaufman and Baillargeon, 2009).

The possibility to generalize those findings, however, is questionable. People, in fact, are not only prototypical self-propelled entities, but they are also the animate objects with which infants have the most experience. It might be, thus, that they attribute certain properties such as self-propulsion to people than to animate objects in general (Rakison and Poulin-Dubois, 2001). In this sense the research by Woodward and colleagues might not investigate infants' sensitivity to self-propulsion as an animacy cue but rather self-propulsion as a human-being cue. Nevertheless, those results indisputably provide evidence in favour of an infants' early sensitivity to self-

²⁴ An interval allowing for the perception of contact causality (i.e., a Launching Event) by adult humans.

propulsion itself²⁵, this sensitivity having been confirmed by further research (such as those by Kosugi, Ishida and Fujita, 2003 and by Saxe, Tzelnic and Carey, 2006; 2007).

Recently, Luo, Kaufman and Baillargeon (2009) extended those findings investigating 5- to 6 ½ -month-old infants' expectations about physical events after receiving evidence that the object involved in the events was either inert or self-propelled. Objects identical in shape, colour, dimension and all their features were employed in all the events, to control for possible confounds (Luo, Kaufman and Baillargeon, 2009). Results showed that infants were surprised if the inert but not the self-propelled object: reversed its direction of motion, remained stationary when hit, remained stable when released in midair.

Those results demonstrate that by the 5th month of age infants are capable to perceive the self-propelled nature of a movement. Moreover, they seem to hold different expectations for physical events involving inert or self-propelled objects when such events involve the possess of an internal source of energy by the object itself²⁶. Those results, hence, can be readily explained if we assume that infants are capable to reason about self-propelled objects, even though in an extremely *naïve* manner.

4. Status of the art and open issues

Literature reviewed in the previous paragraphs has demonstrated that humans are exquisitely attuned to several cues belonging to living entities, such cues regarding mostly some motion features (i.e., goal-directedness, rationality, variability to contingencies and self-propulsion) and allowing for an

²⁵ In terms of Leslie's "Internal-Energy Hypothesis", according to which a self-propelled object would be endowed with "*an internal source of energy*" which it would use directly to control its own motions or indirectly (i.e., by applying a force) to control the motion of other objects (Leslie, 1994, 1995).

²⁶ When the event violates common properties of physical objects (such as cohesion or permanence), instead, infants were surprised both if the object involved was inert and when it was self-propelled (Luo, Kaufman and Baillargeon, 2009).

attribution of mechanical/intentional agency. It has been highlighted that it is not even necessary to be presented with an organism-shaped body to detect such cues, since they are easily perceivable from the motion of simple geometric figures (Heider and Simmel, 1944; Gergely, Nádasdy, Csibra and Bíró, 1995; Csibra, Gergely, Bíró, Koos and Brockbank, 1999; Luo and Baillargeon, 2005).

Regarding specifically those motion cues which allow for animacy attribution, in the last decade research has enormously grown (Johnson, 2000; Scholl and Tremoulet, 2000; Rakison and Poulin-Dubois, 2001; for a review see Gelman and Opfer, 2002), even demonstrating that sensitivity to motion-cues of animacy are widespread across cultures (see Morris and Peng, 1994) and subtended by some specific brain regions (Castelli, Happé, Frith and Frith, 2000; Blakemore, Boyer, Pachot-Clouard, Meltzoff, Segebarth and Decety, 2003). The role of self-propulsion has been widely demonstrated, giving evidence that infants are sensitive to this particular cue of animacy since 5 months of life, being able to distinguish between motion that has no obvious external cause, and motion caused by an external event such as a collision.

Regarding the ontogenetic origin of the capability for animacy attribution, therefore, it seems possible that human infants may be born with some innate understanding of animacy and that their perceptual system may be designed so that animate entities are inherently appealing (i.e., with perceptual features drawing infants' attention to them). Nevertheless, the current state of the research cannot exclude the possibility that experience during the first five months of life may have shaped infants' responses towards animate objects.

A further open issue, moreover, regards the phylogenetic origin of animacy attribution. The fact that humans' attributions of animacy are largely automatic (Scholl and Tremoulet, 2000) seems to suggest that natural selections could have shaped the perceptual system to be particularly sensitive to cues of animacy. If this would be the case, such capability might be shared with animal species other than our own.

To the best of our knowledge only one research does exist which investigated non-human primates in their capability to attribute animacy on the basis of self-propelled motion of objects (Hauser, 1998) ²⁷. In this research cotton-top tamarins (*Saguinus oedipus oedipus*) were tested for their expectation about an object's potential capacity to change its spatial location. Seven different objects were used as stimuli, each belonging to one of three category: 1. self-propelled, moving and living; 2. self-propelled, moving, non living; 3. inert, moved by an external agent, non living. In a familiarization trial subjects were provided with experience of the objects and the events to be used at test. Test apparatus consisted in a box composed of two communicating chambers. At test subjects firstly saw an object placed in one chamber and then both chambers were momentarily occluded from the subject's view. The occluder was then removed revealing the test object in either the same or the opposite chamber. Subjects' looking times were not affected by the test object emerging in the novel chamber if such object belonged to the 1st category, whereas subjects showed surprise if the object belonged to the 2nd or 3rd category. Self-propelled motion seems not to be enough to explain subjects' responses: the living/non living feature, in fact, seems to better account for the tamarins' performance (Hauser, 1998).

From such research, therefore, it remains unclear what role self-propelled motion plays in forming an expectation about an object's potential capacity to change its spatial location.

Being the tamarins employed in Hauser's research adults, moreover, results may also be confounded by the animals' past experiences.

Therefore, further research on *naïve* non-human subjects should be conducted to better understand both the filogenetic origin of animacy attribution and the role played by experience in shaping such capability.

²⁷ There is also little behavioral evidence investigating agency attributions in terms of goal-directed action by non-human species, such studies always employed non-human social primates as experimental subjects (chimpanzees, Uller and Nichols, 2000, retracted in Uller, 2001; Uller, 2004; rhesus monkeys, Wood, Glynn and Hauser, 2008).

V

Experimental Research: Sensitivity to self-propelled motion in the domestic chick

In this second half of my thesis I was concerned with self-produced motion as a pure animacy cue (i.e., with causal-agency and the presence of an internal force of action; Leslie and Keeble, 1987).

As reviewed in the previous section, literature on non-human primates did not clarify as to what role self-propelled motion plays in forming an expectation about an object's potential capacity to change its spatial location (Hauser, 1998). Hauser's study, moreover, employed adult animals and was not aimed at testing for the role of past experiences, such issue can be definitively addressed only with controlled-rearing experiments on newborn subjects.

On this grounds, in the present experimental research two issues will be addressed:

- First, does the basic distinction between objects that are and that are not self-propelled also hold true in non-human animal species?
- Second, does such a distinction emerge as a result of experience or is it rather part of a natural predisposition?

We employed a methodology and a model species which allowed us to circumvent the potential drawback of previous research. We took advantage of the phenomenon of filial imprinting, a learning process by which the young of some animal species learns the characteristics of an object - usually a

social partner – when exposed to it for a short time soon after hatching (Horn, 2004). The newly-hatched domestic chicken (*Gallus gallus*) was used as animal model (Andrew, 1991; Rogers, 1993; Suge and McCabe, 2004) since it is a precocial species which allows for the rigorous control of sensory experiences.

The domestic chicks, moreover, hatches prone to imprint onto the most salient stimulus present in their visual field, and it is well attested that motion is one of the most relevant features of a potential imprinting stimulus (Vallortigara, Regolin and Marconato, 2005). For such reason, self-propulsion may be detected as a relevant cue triggering the imprinting process in such species.

In the following paragraphs I am going to describe the experiments designed in order to understand specifically the role of self-propulsion as a cue to animacy.

Four experiments were conducted to test whether chicks are susceptible to self-propulsion as a cue to animacy. Newly-hatched chicks were exposed to video animation sequences picturing two objects of different colour to which motion could be attributed either a causal-agentive role (the object appeared as self-propelled) or a receptive role (i.e. the object appeared as moved by an external force). After exposure, chicks were tested for their spontaneous preference between the two objects.

1. General Methods

Subjects

Subjects were domestic chicks (*Gallus gallus*) coming from eggs hatched in our laboratory under controlled conditions.

As described for the previous research (Study 2), fertilized eggs were obtained from a local commercial hatchery (Agricola Berica, Montegalda, Vicenza - Italy). On arrival, eggs were placed in an incubator MG 70/100 (45 x 58 x 43 cm, 100 eggs capacity) until Day 19 of incubation. Temperature was maintained at 37.5°C and humidity was maintained at 55-60%, providing standard conditions for optimal incubation. Then, from day 19 to day 21, eggs were placed into a hatchery (60 x 65 x 66 cm) with the same temperature as the incubator, but lower humidity, an ideal condition for hatching. The incubator, the hatchery and the hatching room were all kept thoroughly dark until day 21 (the hatching day), to prevent the embryos and the newborn chicks any visual experience before testing (see Rogers 1990; Rogers and Bolden 1991; Rogers, Zucca and Vallortigara, 2004; Vallortigara, Regolin and Marconato, 2005).

A total of 626 domestic chicks were tested, 189 chicks were discarded because they did not perform any choice during the test. Therefore, the final sample consisted of 437 subjects.

Exposure Stimuli and Apparatus

Exposure stimuli consisted of computer presented animation sequences featuring two oval objects of the same size (width=3.5 cm, height=2.5 cm) but of different colour (red: RGB = r255, g0, b0, with alpha =100%; purple: RGB = r255, g0, b255, with alpha =100%). Some chicks (n=222) were exposed to A-red and B-purple, the remaining chicks (n= 215) to A-purple and B-red. Animation sequences were generated by “Flash® 8” software. Each object in the animation covered a distance of 6.5 cm at 4.3 cm/sec and maintained

both its starting and final position for 2 sec and could be perceived as either self-propelled or passive.

At the end of the sequence a black screen appeared for 1 sec before the animation restarted. Videos were produced by looping a 60-frames/sec animation, and saved with 75 quality AVI. Stimuli were presented on a Samsung syncMaster 931BF (LCD 19") screen.

The exposure apparatus consisted of a set of 8 clear-fronted plywood-boxes (10 x 10 cm), each housing one chick. The exposure animation was shown on a computer screen placed 40 cm away, with the centre of the stimulus coaxial to the centre of the exposure apparatus, to guarantee an appropriate view to all of the chicks. The computer screen was placed at the end of a black-plastic tunnel, to prevent chicks from seeing any other visual stimulus. Apart from the light arising from the monitor, the room was maintained in complete darkness.

Test Stimuli and Apparatus

The test apparatus consisted of the same white-plywood runway (75 x 20 x 30 cm) employed for the previous research (Study 2, Fig. 10), with the testing stimuli presented at its opposite ends.

Two different pairs of test stimuli were employed. The first pair (i.e., type 1; Fig.19.a) consisted of two animations, each reproducing either object A or B continuously moving back and forth (moving 1.5 cm in either direction) on a black background. Although chicks saw the stimuli when they were already set in motion (thus preventing a possible cue to self-propelling) the moving back could perhaps be seen as self-propelled rather than as physical bouncing (though the latter was the impression reported by human observers).

If both objects are perceived as being self-propelled at test, one could

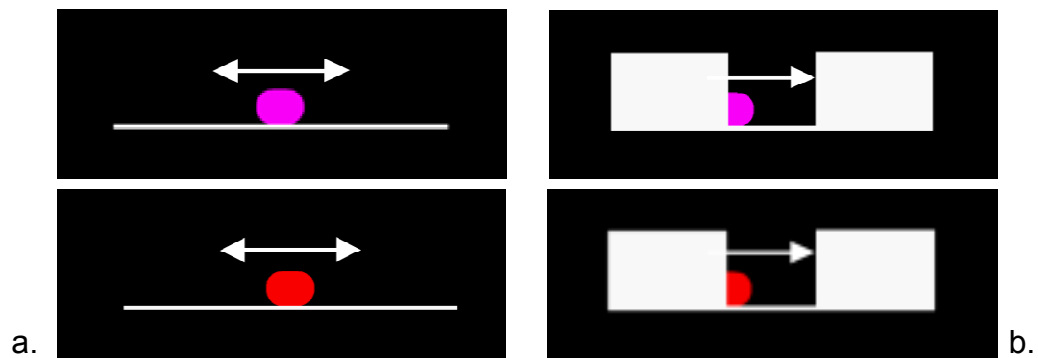


Fig. 19. Schematic representation of the test stimuli: a. test stimuli of type 1, which consisted in object A and B continuously moving back and forth on a black background; b. test stimuli of type 2, representing object A and B appearing and disappearing from behind partitions (the direction of motion was coherent with the one experienced in the exposure phase).

wonder which of the two effects underlies the possible chicks' preference: a choice for the object whose motion in the exposure animation had been perceived as self-propelled or aversion to the object that behaves in a novel manner -- i.e., whose motion changes from passive (during exposure) to self-propelled (during the test; it could be that chicks are equally attracted by to the two objects during the exposure session, but they subsequently avoid the object that changes its motion at test).

In either case, there would be evidence for sensitivity to self-propelled motion. However, since it is only the first interpretation that shows that chicks preferentially imprint onto self-propelled objects, another pair of test stimuli was used (i.e., type 2; Fig. 19.b), in which the objects appeared and disappeared from behind two side partitions (spaced 6.5 cm apart). In this stimulus pair, object A (or B) moved along one direction, i.e. the same one experienced by the chick during exposure. Using these partitions the nature of the motion (self propelled vs not self propelled) of the two objects remains undetermined and any preference for either object would be due to the role they played in the imprinting animation sequence.

The animation sequences were produced by looping a 60-frames/sec animation, and saved with 75 quality AVI, presented on a Samsung syncMaster 931BF (LCD 19") screen in a completely dark room.

Procedure

On Day 1 of life, in the early morning, chicks were taken from the dark hatchery and placed individually in each exposure box where they were showed the exposure stimulus. After ca. 90 min of continuous exposure, each chick was taken from its box and placed in the central area of the test apparatus, which was subdivided virtually into a middle (15 cm long) and two side areas (each one 28 cm long), with the two computer screens placed at its opposite ends. The chicks' position at the starting point (i.e., the wall it was facing), as well as the position of the two stimuli (i.e., the end side of projection), was balanced across animals. Chicks' behaviour was observed for a total of 6 consecutive minutes. Permanence of the chick in the mid compartment was assumed to indicate no choice, whereas movement of the chick to one of the end-side compartments was regarded as a preference for the object presented at that end.

Data Analysis

Time (sec) spent by the chick in each of the two side areas was scored on-line by an experimenter blind to the purposes of the research. A preference score (percentage) was subsequently computed: The time spent near the stimulus which moved first was divided by the total amount of time spent in both side areas and then converted into a percentage score. The preference score values, hence, ranged from 100 (full choice for the first stimulus to move) to 0 (full choice for the second stimulus to move). Fifty per cent represented chance level.

Data were analysed by analysis of variance (ANOVA) with Type of Stimuli (type1 vs type2) as a between-subjects factor and the index of preference (%) as dependent variable. To determine whether the preference score was significantly different from chance level a one-sample (two-tailed) *t*-test was applied (SPSS statistical package).

2. Experiment I

Chicks were exposed to a Launching Effect featuring two oval-shaped objects of different colour to which motion could be attributed either a causal-agentive role (i.e., the object appeared as self-propelled) or a receptive role (i.e. the object appeared as moved by an external force). After exposure, chicks were tested for their spontaneous preference between the two objects.

If chicks would be able to distinguish between the source of motion of the objects (i.e., self-propelled/passive) interacting in the exposure stimulus, the hypothesis was that they would have chosen to approach the object that they had perceived as self-propelled²⁸.

Subjects

A total of 160 newly-hatched domestic chicks were tested. Fifty-eight subjects were discarded because they did not choose any stimulus, therefore 102 subjects (49 males and 53 females) were included in the analysis.

Exposure Stimulus

Exposure stimulus consisted in a video animation featuring two oval objects performing the classical example of Michotte's perceived physical causality (Michotte, 1963), i.e. the Launching Effect. In the animation sequence one object (A) moved towards a second, stationary, object (B). Immediately after contact, object B started to move along the same direction as A, while object A became stationary. Object B moved with identical speed and covered the same distance which had been travelled by object A (Fig. 20).

²⁸ Since it is well attested that they orient preferentially towards the most adequate imprinting stimulus, and motion seems to be a highly relevant feature of such object.

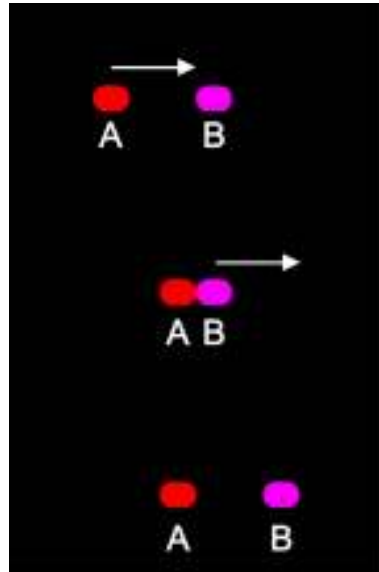


Fig. 20. Schematic representation of the animation sequence used during exposure in Experiment 1, the classical Launching Effect.

In this sort of display adult humans (Michotte, 1963) perceive object A as being a “self-propelled agent” launching object B and causing its movement, whereas B appears as inert and passive.

Test Stimuli

Both pairs of test stimuli were used in this experiment. A first group of subjects (n=77) were tested with the first type of stimuli (i.e., object A and B continuously moving back and forth on a black background) whereas the remaining chicks (n=25) were tested with the other type of stimuli (i.e., objects appearing and disappearing from behind two side partitions, moving along only one direction).

Results

An analysis of variance (ANOVA) with Type of Stimuli (type1 vs type2) as between subjects factors and the index of preference (%) for the first stimulus to move (i.e., object A) as dependent variable did not show any significant

effect (Test Stimuli: $F_{(1,100)} = 0.995$, $p = 0.321$). As a consequence, data were collapsed across this factor.

A one-sample (two-tailed) t -test applied at the preference score for the first stimulus to move vs chance level (50%) revealed a significant choice for such stimulus (mean \pm SEM = 60.700 ± 3.294 , one-sample two-tailed t -test $t_{101} = 3.248$ $p = 0.002$; Fig. 24).

Therefore, from such data chicks seemed to show a clear preference for object A, the self-propelled object playing the agentive role during the exposure phase.

3. Experiment II

Nevertheless, results of Experiment 1 could be due to a mere preference for the first object to move (i.e., object A) rather than to a choice for the object which had been perceived as self-propelled.

To check whether the perceived self-propulsion was crucial for the results obtained in Experiment 1, therefore, in Experiment 2 the order of the displacements of the two objects was swapped temporally.

In this new animation sequence (named Inverted-Sequence stimulus) any physical causality between the movements of the two objects was disrupted (no contact between A and B) and both objects would thus appear as self-propelled. Nevertheless, a sequence in the motion of the two objects was maintained, allowing for the expression of a possible preference for the first object to move.

Subjects

One-hundred and seventy-six newly-hatched domestic chicks were tested in this experiment. Thirty-nine were subsequently discarded because they did

not express any choice during test, therefore 137 subjects (61 males and 76 females) were included in the analysis.

Exposure Stimulus

The exposure stimulus (i.e., Inverted-Sequence stimulus) consisted in a video animation identical to the Launching used in Experiment 1, except for the sequence of movements which was inverted: thus object B moved first and object A started its movement only after object B had stopped (Fig. 21). In this sequence any causality between the movements of the two object was disrupted, whereas spatiotemporal and perceptual features of the sequence were identical to the those of the Launching effect. Therefore, both A and B appeared as being self-propelled to an adult human.

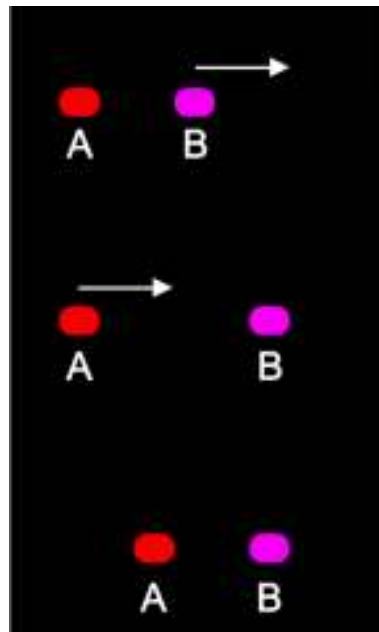


Fig. 21. Schematic representation of the animation sequence used during exposure in Experiment 2, the Inverted-Sequence stimulus.

Test Stimuli

Both pairs of test stimuli were used: 80 subjects were tested with the first type of stimuli (type1) whereas the remaining chicks (n=57) were tested with the other type of stimuli (type2).

Results

Data were analysed with an ANOVA considering Type of Stimuli (type1 vs type2) as between subjects factors and the index of preference (%) for the first stimulus to move (i.e., object B) as dependent variable. The ANOVA did not show any significant effect (Test Stimuli: $F_{(1,135)} = 0.901$, $p = 0.344$) therefore data were collapsed across this factor.

Overall, at test chicks did not express a significant choice for either stimulus (mean \pm SEM = 44.999 ± 3.103 , one-sample two-tailed t -test $t_{136} = -1.611$ $p = 0.109$; Fig. 24).

Results of Experiment 1 could not, therefore, be due to a preference for the stimulus that moved first in the animation, since no preference for stimulus B (which moved first) was apparent in Experiment 2.

4. Experiment III

Given that in Experiment 2 any physical contact between A and B was removed, we wondered whether chicks' preferences in Experiment 1 could be accounted for in terms of which object applied physical contact over the other object, which perhaps may have acted as a cue of "animacy". To determine this, in Experiment 3 chicks were exposed onto a non-causal physical animation.

Subjects

One-hundred and eighty-nine newly-hatched domestic chicks were tested: Sixty-six did not express any choice during test and were subsequently discarded whereas 123 subjects (64 males and 59 females) were included in the analysis.

Exposure Stimulus

The stimulus sequence was identical to the Launching effect used in Experiment 1 except for the presence of a 3 sec-delay between the time of contact and the motion of B (Fig. 22). As previously described, in human subjects the presence of a delay is known to abolish any impression of physical causality (Michotte, 1963; Schlottmann, Ray, Mitchell and Demetriou, 2006): object B appeared in this case as being self-propelled as was object A.

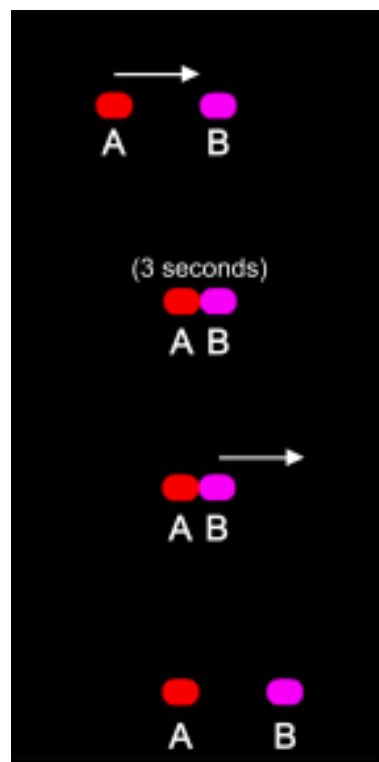


Fig. 22. Schematic representation of the animation sequence used during exposure in Experiment 3, the Delay stimulus.

Test Stimuli

Both pairs of test stimuli were used. Eighty-two subjects were tested with the first type of stimuli and forty-one with the second type of stimuli.

Results

An analysis of variance (ANOVA) with Type of Stimuli (type1 vs type2) as between subjects factors and the index of preference (%) for the first stimulus to move (i.e., object A) as dependent variable did not show any significant effect (Test Stimuli: $F_{(1,121)} = 1.573$, $p = 0.212$), therefore data were collapsed across this factor.

At test, chicks did not exhibit any preference for either stimulus (mean \pm SEM = 51.002 ± 3.298 , one-sample two-tailed t -test $t_{122} = 0.304$ $p = 0.762$; Fig. 24).

Results of Experiment 1 could not, therefore, be due to a preference for the stimulus that “applied physical contact” over the other object, since no preference for stimulus A appeared in Experiment 3.

5. Experiment IV

From the results of the previous experiments it remained unclear whether the results of Experiment 1 were due to a preference for the self-propelled stimulus or to a preference for the object which was the “cause” of the motion sequence. For such reason in the fourth and last experiment chicks were exposed onto a causal animation which did not provide any cue about the nature of the motion of the objects implied.

Subjects

A total of 101 domestic chicks were tested. Twenty-six subjects were discarded because they did not choose any stimulus, therefore 75 subjects (40 males and 35 females) were included in the analysis.

Exposure Stimulus

Chicks were exposed to a video animation identical to the one used in Experiment 1 (i.e., Launching Effect) except for the presence of two opaque screens, one of which occluded the object at the beginning and one at the end of the motion sequence (such stimulus being named Occluded-Launching; Fig. 23).

In this way no cues were available about the self/not-self propelled nature of object A, although it continued to be perceivable as the cause of motion of object B.

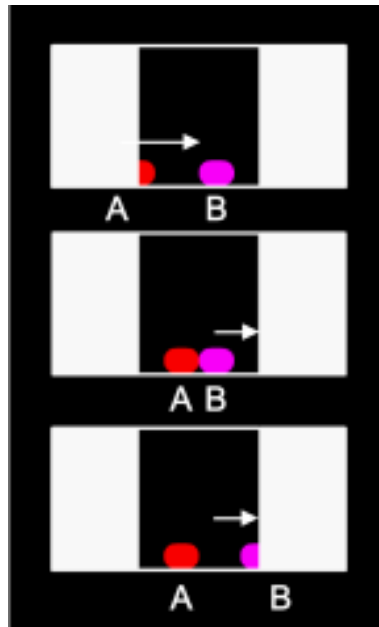


Fig. 23. Schematic representation of the animation sequence used during exposure in Experiment 4, the Occluded-Launching stimulus. Note that for reasons of comprehension (and differently from Fig. 20-22) the top and bottom images do not represent the first and the last frame of the video.

Test Stimuli

Only stimuli with occluded trajectories were used (type 2), since the first three experiments did not reveal any statistically significant effect of the type of test stimuli employed.

Results

At test, chicks did not show any significant preference for either object (mean \pm SEM = 45.796 \pm 4.330, one-sample two-tailed t -test $t_{74} = -0.971$ $p = 0.335$; Fig. 24).

Therefore, chicks did not show any preference for an object which played the role of “causal-agent” if no cues about the nature of the motion of such object had been provided.

6. Overall analysis and discussion

An analysis of variance (ANOVA) with Experiment (1-4) and Type of Stimuli (type1 vs type2) as between subject factors, and the index of preference (%) for the first stimulus to move as dependent variable revealed a significant heterogeneity between chicks' preferences in the four experiments ($F_{3,430} = 4,511$ $p = 0.004$; Fig. 24). No other significant main effect (Type of Stimuli: $F_{1,430} = 3,248$ $p = 0.072$) or interaction (Experiment \times Type of Stimuli: $F_{2,430} = 0.046$ $p = 0.955$) were observed. The heterogeneity was due to preferences expressed by the chicks in Experiment 1: when excluding this experiment, the ANOVA did not show any significant heterogeneity between the remaining three experiments ($F_{2,330} = 1.678$ $p = 0.188$). Preferences in Experiment 1 were significantly different from those observed in Experiment 2 ($t_{237} = 3.425$ $p = 0.001$), Experiment 3 ($t_{223} = 2.062$ $p = 0.040$), and Experiment 4 ($t_{175} = 2.790$ $p = 0.006$).

The results of the four experiments showed that the first vs second stimulus to move during the exposure phase were immaterial with respect to the chicks' subsequent preference at test. Only when one of the two objects appeared as being self-propelled and the other did not (Experiment 1), did a preference emerge, as a choice for the self-propelled stimulus. Physical contact, which was not accompanied by physical causation (Experiment 3), or physical causation without any cue about the nature of the motion of "the causal object" (Experiment 4), sufficed to abolish any preference, showing that physical contact in itself, when both objects appeared as being self-propelled, or causation in itself, when no cue was given about the nature of "the causal object" (self/not-self propelled), were not capable of producing any preference.

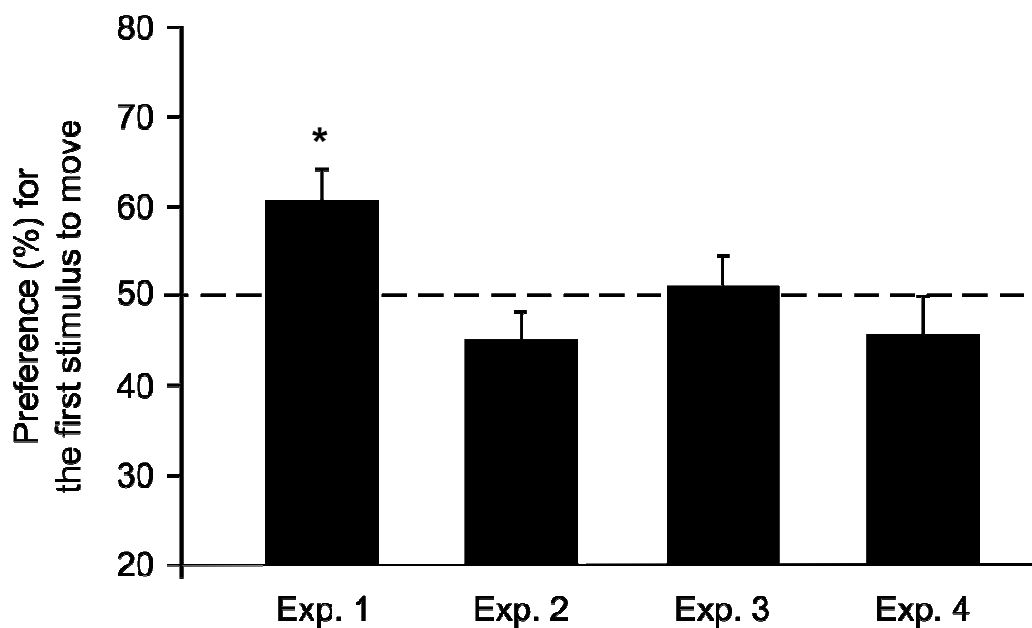


Fig. 24. Overall results. Average percentage of time (Mean \pm SEM) spent by the chicks near the first stimulus to move. The dotted line represents chance level.

VI

General Discussion

1. Overview of the present research

Humans' striking ability to attribute causal relations and "animacy" (i.e. the capability of an object to have self-produced motion and of being a causal-agent) to moving objects solely on the basis of their pattern of motion is well attested (Heider and Simmel, 1944; Michotte, 1963; Schlottmann, Ray, Mitchell and Demetriou, 2006).

Sensitivity to physical causality has been demonstrated since 6-7 months of life in human infants (Leslie, 1984; Leslie and Keeble, 1987; Oakes, 1994; Cohen and Amsel, 1998) and some non-human species were successfully demonstrated to use physical causality to obtain a longed-for reinforcement (Visalberghi and Limongelli, 1994; Limongelli, Boysen and Visalberghi, 1995; Fujita, Kuroshima and Asai, 2003; Helme, Clayton and Emery, 2006; Tebbich, Seed, Emery and Clayton, 2007; Seed, Call, Emery and Clayton, 2009). Regarding animacy attribution, self-propelled motion seems to provide one of the most powerful cues about what makes an object "animate" (Aristotle, *Physics*; New, Cosmides and Tooby, 2007). Nevertheless, just few research focused on its role as a cue to animacy (see Luo, Kaufman and Baillargeon, 2009) and from previous findings it remains unclear as to what role self-propelled motion plays as an animacy cue for non-human animals (Hauser, 1998).

On the grounds of such literature, the experimental work included in the present thesis aimed at investigating both the filogenetic and ontogenetic origin of causal perception and animacy attribution, employing newborn

babies and newly-hatched domestic chicks (*Gallus gallus*) as experimental subjects.

1.1. Early sensitivity to physical causality

In the first part of this thesis the capability to perceive physical causality has been investigated in *naïve* subjects.

This research aimed to extend the previous findings in at least two ways: by examining for the first time the spontaneous preference of subjects with absent or at least very limited visual experience, and by directly comparing such preferences in two different species. For such reasons spontaneous preference for a causal vs a non-causal stimulus was tested both in newborns babies and newly-hatched domestic chicks.

Regarding newborn babies (Study 1) three experiments were conducted, all employing an infant-control preferential looking technique.

In Experiment 1 newborns' spontaneous preference for a causal stimulus (i.e., Launching) vs a non-causal control stimulus was investigated. The non-causal stimulus (i.e., Inverted-Sequence) was identical to the causal one except for the fact that the order of the displacement of the two featured objects was swapped temporally. Results revealed a preference by newborn babies to look longer at the Launching stimulus. This preference persisted also when the causal stimulus (i.e., Launching stimulus) and the non-causal one (i.e., Delay stimulus) were matched for two crucial features which differed in the previous experiment: the presence of a contact between the objects involved in the animation and the sequence of the movements being coherent with the direction of motion (Experiment 2). Such preference, moreover, was not due to a mere choice for the spatiotemporal features of the Launching animation, since a choice for the spatiotemporal parameters of the Delay did emerge when newborns were presented with a Delay stimulus

vs a stimulus having the features of a Launching-without-causality (i.e., “90° Launching stimulus”, Experiment 3).

Overall, the results revealed that newborn babies prefer a causal (i.e. Launching) vs a non-causal stimulus (Experiments 1 and 2). An event with the same spatiotemporal features of the Launching one but lacking physical causality (Experiment 3) did not trigger any preference in newborn babies. Therefore, it seems that sensitivity to physical causality is present from birth in our species. Testing newborn babies, in fact, allowed us to exclude the role of a learning mechanisms in the emergence of such sensitivity.

The specific types of stimuli employed in this study, moreover, suggest that newborns’ sensitivity to physical causality might be the outcome of an innate capability to perceive causality *per se*. If such sensitivity would be the result of a mechanism to detect mere covariations between events (as supposed by the CBN model, see Chapter 2), in fact, the same pattern of preference might have been found in both Experiments 2 and 3 (since the same covariations exist in both the “Launching” and the “90° Launching stimulus”).

The present study, to conclude, succeeded in demonstrating for the first time newborns’ sensitivity to physical causality and their capability to perceive causal features since the very first hours of life.

Study 2 of this thesis dealt with sensitivity to physical causality in the domestic chick. Newly-hatched domestic chicks were tested for their spontaneous preference for physical causality. Subjects were asked to freely choose between a causal (i.e., Launching Effect) and a non-causal video animation (i.e., a Delay stimulus in Experiment 1, a Passing stimulus in Experiment 2). No significant preferences for either stimuli was revealed.

The non significant results obtained in Study 2 do not allow for a conclusive interpretation of data on domestic chicks. Those data, in fact, could be due to several different reasons: 1) to chicks’ incapability to perceive physical causality, or 2) to the absence of preference for causal features in such species, or 3) to an improper procedure to test chicks about

such matter. It would be interesting to check for those possibilities with an alternative paradigm in a further research.

1.2. Sensitivity to self-propelled motion in the domestic chick

Four experiments were conducted to test whether newly-hatched visually *naïve* domestic chicks are sensitive to self-propulsion as a cue to animacy. In those experiments chicks were exposed to a video animation sequence picturing two objects in motion, such motion could be attributed to either a causal agentive role (i.e., the object appeared as self-propelled) or a receptive role (i.e., the object appeared as moved by an external force). After exposure, subjects were tested for their spontaneous preference between the two objects. If they would be able to detect self-propulsion as a cue to animacy attribution, at test chicks would have chosen the object which had been perceived as self-propelled during exposure.

In Experiment 1, chicks were exposed to two objects performing a typical Launching Effect: In this sort of display adult humans perceive a first object as a “self-propelled causal agent” pushing the second one and causing its movement. When tested for their preferences for those objects, chicks showed a clear preference for the self-propelled object which played the causal-agentive role during the exposure phase. Those results, moreover, were not due to a preference for the stimulus that moved first in the animation, since no preference did emerge for either stimulus if no physical causality was involved and both objects appeared as self-propelled (Experiment 2). Chicks’ preferences, moreover, could not be accounted for either in terms of which object applied physical contact over the other or in terms of which object was the “cause” of the motion sequence, since chicks did not show any significant choice after having been exposed to a Delay stimulus (Experiment 3) or to an Occluded-Launching stimulus (Experiment 4) in which both objects appeared self-propelled.

Therefore, only when one of the two objects appeared as being self-propelled and the other did not, did a preference emerge, as a choice for the self-propelled stimulus (Experiment 1). Physical contact which was not accompanied by physical causation (when both objects appeared as being self-propelled; Experiment 3), or physical causation without any cue about the nature (self/not-self propelled) of the motion of “the causal object” (Experiment 4), sufficed to abolish any preference.

Since all subjects came from a dark incubator and hatchery, they had not had any chance to visually experience the movement of an animate being before the exposure phase. During this phase, moreover, the total amount of exposure to both objects was the same. Therefore, the preference for the self-propelled object found in Experiment 1 cannot be accounted for in terms of any specific learning.

The results thus demonstrate that newly-hatched chicks show an innate sensitivity to differentiate and prefer a self-propelled causal agent as a target for imprinting. These data, in fact, clearly demonstrated chicks' innate sensitivity to self-propulsion as a crucial cue to animacy (i.e., mechanical agency). Since subjects consistently preferred the object acting as a causal self-propelled agent, moreover, the results seem even to suggest that chicks are able to perceive contact causality (even if causality presented without any cue of self-propulsion did not suffice to trigger any preference; Experiment 4).

At least two aspects, hence, seem to be innately represented by the chicks as a cue to animacy: self propulsion and contact causality. Chicks' sensitivity to those features may be sufficient to adaptively constrain the early commitment of such precocial species as to what to pay attention to, i.e. to imprint on.

Starting from such results, it would be interesting to determine whether chicks are also innately endowed with a sensitivity to other movement properties, such as efficiency of goal approach and rationality, that are cues to intentional agency in human subjects (Carey, 2009).

2. Conclusive remarks

Overall, the results of the present research demonstrate that newborn babies are born with an innate bias towards causality (i.e., at least in its physical component) and that newly-hatched chicks possess an innate sensitivity to differentiate and prefer a self-propelled causal-agent as a target for imprinting. Findings from this thesis, therefore, are compatible with the idea that many vertebrate species, including humans, have a primitive bias to attend toward, or preferentially process, sensory information about other living entities (Carey, 2009), both in terms of causal relations between them and in terms of animacy attributions.

Up to date, it has been attested that since few months of life infants are able not only to recognize a goal-directed action, but also to attribute mental states to simple geometric shapes in motion, interpreting future actions of an actor on the basis of previously witnessed behaviour in another context and assessing individuals on the basis of their actions towards others (Kuhlmeier, Wynn and Bloom, 2003; Hamlin, Wynn and Bloom, 2007). It would be interesting to investigate these capabilities in *naïve* subjects of different species (e.g., newborn babies and newly-hatched domestic chicks), to attest the ontogetetic and filogenetic origin of such abilities.

The possibility of performing controlled-rearing studies with animals and the generality of the underlying basic mechanisms in different species (Carey, 2009), moreover, could open the door to direct investigation of the neural and genetic bases of those capabilities.

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